

DATA COLLECTION AND ANALYSES PERTINENT TO EPA'S
DEVELOPMENT OF GUIDELINES FOR PROCUREMENT OF HIGHWAY CONSTRUCTION
PRODUCTS CONTAINING RECOVERED MATERIAL

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Volume II
Technical Data and Appendices

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PREFACE

This report was prepared as a joint venture with Franklin Associates, Ltd. of Prairie Village, Kansas, and Valley Forge Laboratories, Inc., of Devon, Pennsylvania. Franklin Associates was prime contractor on the project. The study was performed for the U.S. Environmental Protection Agency, Office of Solid Waste, under Contract No. 68-01-6014.

This report has been separated into two volumes because of its size. Volume One is the "Issues and Technical Survey." Volume Two is "Technical Data and Appendices." It contains the full technical reports authored by Valley Forge Laboratories, as well as appendices which contain support documentation for the entire report.

This project relied heavily on interviewing people knowledgeable about the procurement process, and about the issues relevant to this project. We are indebted to the numerous people who contributed to this project. They include people in state, local, and Federal government service, suppliers of highway construction material, contractors, trade associations, and others. Special recognition is made to the American Association of State Highway Transportation Officials (AASHTO) who put forth substantial effort to secure information for this project.

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Part I

POWER PLANT ASH

INTRODUCTION

The residual materials collected from the burning of coal at electric utility plants are referred to as power plant ash. These materials are produced in two forms: fly ash and bottom ash. Fly ash is the fine-grained dusty material from the combustion of ground or powdered coal that is recovered from boiler flue gases by means of electrostatic or mechanical collection systems. Bottom ash is the granular material which, after coal combustion, collects in the ash hopper at the base of the boiler unit.

The relative amounts of fly ash and bottom ash produced at a particular power plant location are determined mainly by the design of the boiler units. However, as a general rule, 70 percent or more of all power plant ash is fly ash. Although fly ash and bottom ash are collected separately, at many power plants these materials are mixed together for storage or disposal.

FLY ASH

Production and Handling

The production of fly ash has increased tremendously over the past 15 years as more coal-burning power plants come on line and ash collection methods improve. Ash collection and utilization statistics compiled by the National Ash Association show that fly ash production has tripled between 1966, the first year the association began collecting data, and 1979. In 1966, 17.1 million tons of fly ash was collected, while in 1979, the most recent year that statistics are available, a total of 57.5 million tons of fly ash was collected (Reference I-1) as shown in Table I-1.

Fly ash is currently being produced at a total of 380 coal-burning power plants located in 39 states. The locations of all existing coal-fired power plants in the United States are shown in Figure I-1. Estimated quantities of total ash produced in 1978 in each state are shown in Figure I-2. These quantities were determined based on 1978 consumption of coal by electric utility companies in each state, as shown in Table I-2. No attempt was made to further determine amounts of fly ash produced in each state because the respective quantities of fly ash and bottom ash at each plant vary depending on plant design, operation, and other factors. From Figure I-2, it is evident that half of all ash which is now being generated in the United States is found in the six largest ash-producing states (Ohio, Pennsylvania, Illinois, Indiana, Kentucky, and West Virginia).

Table I-1

PRODUCTION OF POWER PLANT ASH IN
THE UNITED STATES SINCE 1970
(Millions of tons)

<u>Year</u>	<u>Fly Ash</u>	<u>Bottom Ash</u>	<u>Boiler Slag</u>	<u>Total Ash</u>
1970	26.5	9.9	2.8	39.2
1971	27.8	10.1	5.0	42.9
1972	31.8	10.7	3.8	46.3
1973	34.6	10.8	3.9	49.3
1974	40.4	14.3	4.8	59.5
1975	42.3	13.1	4.6	60.0
1976	42.8	14.3	4.8	61.9
1977	48.5	14.1	5.2	67.8
1978	48.3	14.7	5.1	68.1
1979	57.5	12.5	5.2	75.2

Note: In 1978, a total of 8.4 million tons of fly ash was utilized, representing 17.4 percent of the 48.3 million tons of fly ash produced. This is the highest percentage of ash utilization in any one year so far. Replacement of portland cement in concrete mixes is the largest single use of fly ash.

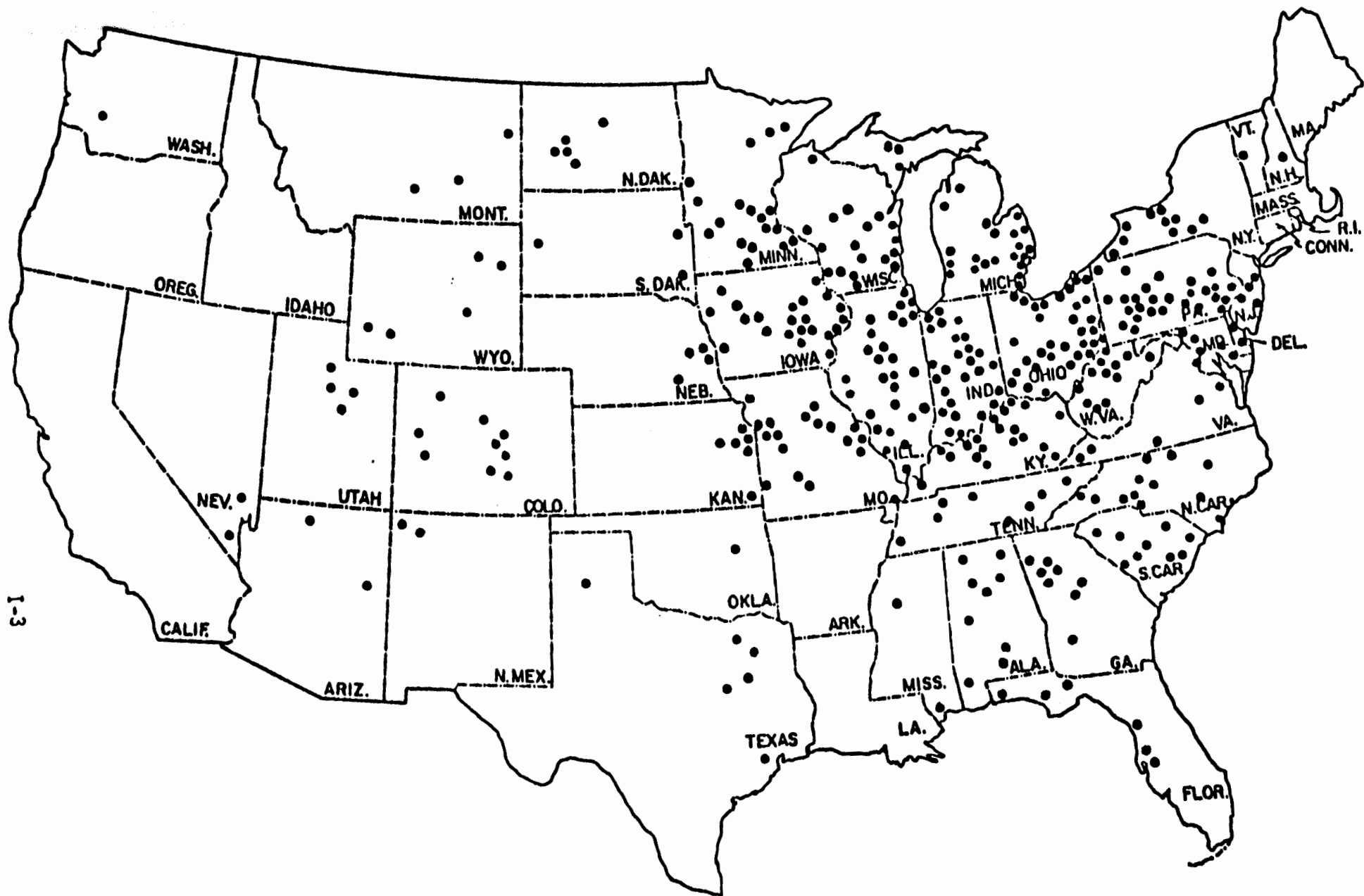


Figure I-1. Locations of power plant ash.

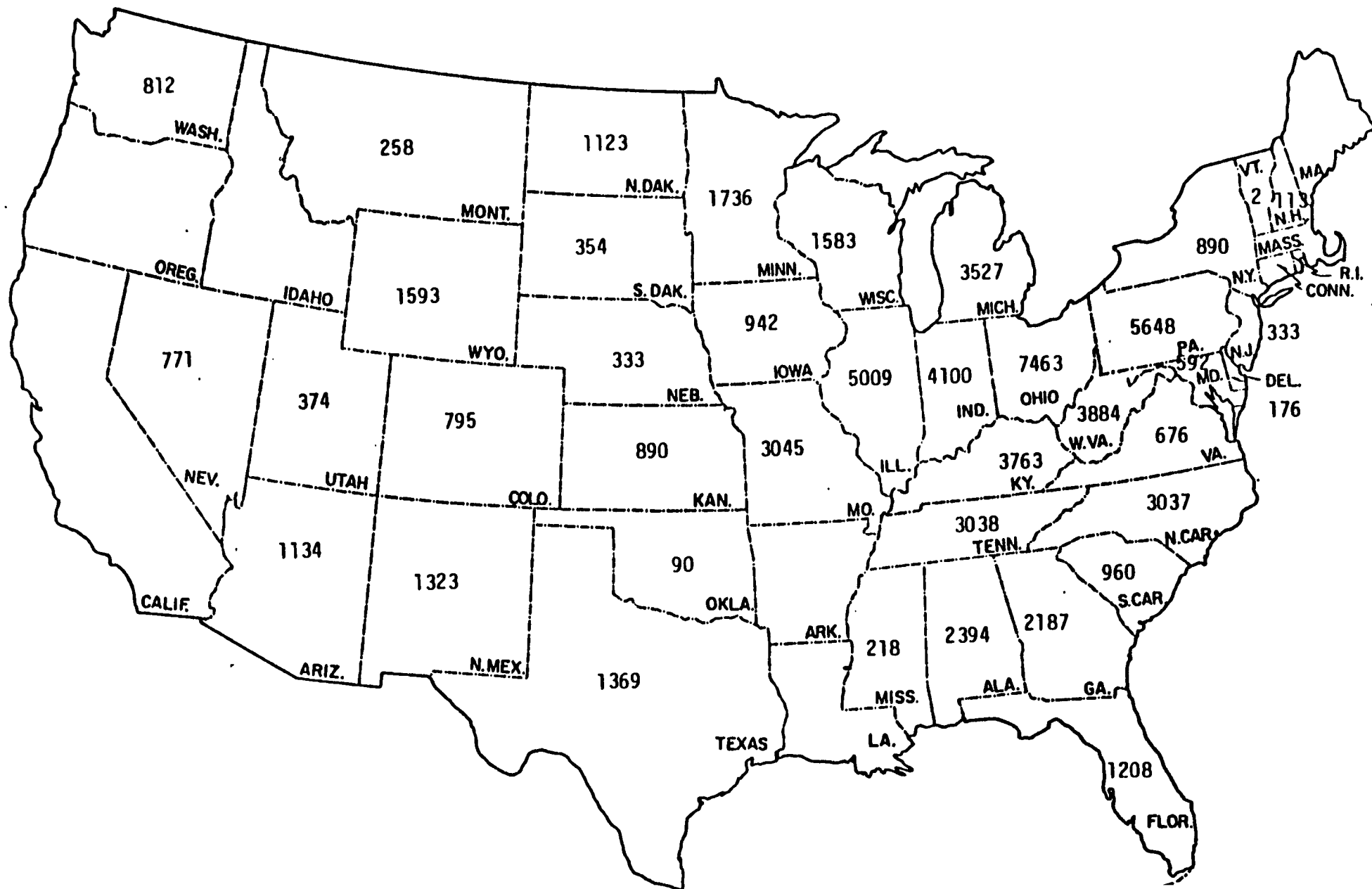


Table I-2

QUANTITIES OF UTILITY COAL BURNED AND TOTAL ASH PRODUCED IN 1978 BY STATE

(Thousands of tons)

	<u>State</u>	<u>Number of Plants</u>	<u>Utility Coal Burned</u>	<u>Total Ash Produced</u>		<u>State</u>	<u>Number of Plants</u>	<u>Utility Coal Burned</u>	<u>Total Ash Produced</u>
1.	Alabama	9	17,100	2,394	21.	New Jersey	4	2,220	311
2.	Arizona	2	7,560	1,058	22.	New Mexico	2	8,820	1,235
3.	Colorado	9	5,680	795	23.	New York	10	6,350	890
4.	Delaware	2	1,170	162	24.	North Carolina	13	21,690	3,037
5.	Florida	6	8,630	1,208	25.	North Dakota	5	8,020	1,123
6.	Georgia	8	15,620	2,187	26.	Ohio	32	53,310	7,463
7.	Illinois	27	35,780	5,009	27.	Oklahoma	1	600	84
8.	Indiana	26	29,280	4,100	28.	Pennsylvania	27	40,340	5,648
9.	Iowa	22	6,730	942	29.	South Carolina	9	6,860	960
10.	Kansas	6	6,350	890	30.	South Dakota	3	2,360	330
11.	Kentucky	19	26,880	3,763	31.	Tennessee	8	21,700	3,038
12.	Maryland	5	4,230	592	32.	Texas	6	9,780	1,369
13.	Michigan	24	25,190	3,527	33.	Utah	4	2,490	349
14.	Minnesota	18	12,400	1,736	34.	Vermont	1	10	2
15.	Mississippi	2	1,450	203	35.	Virginia	6	4,830	676
16.	Missouri	18	21,750	3,045	36.	Washington	1	5,410	757
17.	Montana	3	1,720	241	37.	West Virginia	12	27,740	3,884
18.	Nebraska	4	2,220	311	38.	Wisconsin	18	11,310	1,583
19.	Nevada	2	5,140	719	39.	Wyoming	5	11,380	1,593
20.	New Hampshire	1	750	105					
						TOTAL	380	480,850	67,319

Note: Fly ash (fly ash and bottom ash) quantities determined by assuming 14 percent ash content for all utility coal burned.

According to the most recently published figures, a total of 255 new coal-fired power plants are expected to come on line in the United States by 1987. Of this total, 164 plants are expected to be completed by 1985. These 164 plants will be built in 36 states, including 4 states (Arkansas, California, Louisiana, and Oregon) that do not presently have any coal-fired plants (Reference I-2). Based on projected new plant construction and planned conversions from oil to coal, it is estimated that the total amount of fly ash that will be generated in 1985 will be 90 million tons (Reference I-3).

Not all fly ash is the same. The quantity and quality of fly ash is influenced by the source of the coal burned, the basic design of the coal-fired boiler, and the means used to collect the fly ash. Most of the coal mined and burned in the United States is bituminous coal, but ashes from anthracite coal tend to have higher carbon content, while ashes from lignite and sub-bituminous coals have a much higher percentage of calcium oxide. The physical and chemical characteristics of fly ash are discussed in greater detail in the following section of this report.

There are three basic types of coal-burning boilers: stoker-fired, cyclone-fired, and pulverized coal-fired units. Stoker-fired units generally produce a comparatively coarse fly ash, the amount varying depending on whether the stoker is a traveling grate or spreader type. With cyclone or slagging boilers, from 0 to 65 percent of the fly ash is released into the flue gases and collected. Most of the fly ash produced in cyclone units melts and is collected with the bottom ash as a slag at the base of the furnace. In pulverized coal-fired units, finely ground coal is burned in suspension, causing the fly ash to enter the stream of flue gases for eventual removal either by mechanical collectors or electrostatic precipitators (Reference I-4).

After collection, the quality of fly ash is further influenced by the techniques used at the power plant for ash handling and storage. To some extent, ash handling and storage techniques are related to power plant design, but are also influenced by utility practice and available land. Basically, ash handling and storage is accomplished either by wet or dry methods. At least 50 percent of all ash currently produced is handled dry. Dry methods involve short-term storage of fresh ash from the precipitator in hoppers or long-term storage of the dry ash in silos. Dry ash can be discharged through gates or pneumatically into transport vehicles.

Wet handling of fly ash involves adding a certain quantity of water to the fly ash, which puts it in either a conditioned or ponded form. Conditioned fly ash results from the addition of small amounts of water (20 percent or less by weight) sufficient to prevent dusting of the fly ash and enable it to be stockpiled in large quantities. Ponded fly ash results from the addition of large amounts of water to produce a slurry and enable transport of the ash by pipeline to settling ponds or lagoons. At many power plants, fly ash and bottom ash are collected and disposed of together in the same lagoon, although a power plant may employ more than one means of ash collection and storage (Reference I-5).

Physical and Chemical Properties

Not only are there differences in the fly ash from different coal sources and power plants, but there is also a certain amount of variability in the ash from a single power plant. Normally, fly ash is gray in color, although the color can range from cream to light tan, through various shades of gray, to dark brown and nearly black. The cream color is usually indicative of high calcium oxide content. The tan color is usually attributed to the presence of iron oxide, while the darker colors are most often associated with an increasing presence of carbon.

Fly ash is composed of fine particles that are predominantly spherical in shape, solid or hollow, and of a glassy or amorphous nature. The carbon content in ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes, as shown in Figure I-3, lies essentially within the range of a silt (Reference I-6). Particle sizes for glassy spheres in bituminous fly ash vary from 10 to 300 microns (Reference I-7). In general, lignite and sub-bituminous coal fly ashes are coarser than bituminous coal fly ashes.

The specific gravity of fly ash usually ranges from 2.1 to 2.6, while Blaine fineness values vary from 1,700 cm^2/gm for fly ashes from mechanical collectors to 6,400 cm^2/gm for fly ashes from electrostatic precipitators. As a general rule, fly ash from mechanical collectors is normally coarser than fly ash from electrostatic precipitators. The water soluble content for bituminous fly ash is from 1 to 7 percent. The leachate from most fly ashes is alkaline with a pH ranging from 6.2 to 11.5. Compacted dry densities of fly ash are generally from 70 to 95 pounds per cubic foot, with the lower densities often attributable to higher carbon content (Reference I-8).

Chemically, the principal components of bituminous coal fly ash are silica, alumina, iron oxide, lime, and magnesia, with varying amounts of carbon, as measured by loss on ignition. Figure I-4 shows the range of chemical constituents found in typical bituminous coal fly ashes (Reference I-9). The composition of fly ashes from the western (lignite and sub-bituminous) coals, or fly ashes produced from limestone or dolomite injection processes, are often significantly different from bituminous fly ashes. Lignite and sub-bituminous fly ashes are characterized by higher concentrations of calcium and magnesium oxide and reduced percentages of silica and iron oxide, as well as a lower carbon content. Modified fly ash from limestone and dolomite injection processes, as expected, have significantly higher lime and magnesia content. The western and the modified fly ashes also have a much higher water soluble content than bituminous fly ashes (Reference I-10).

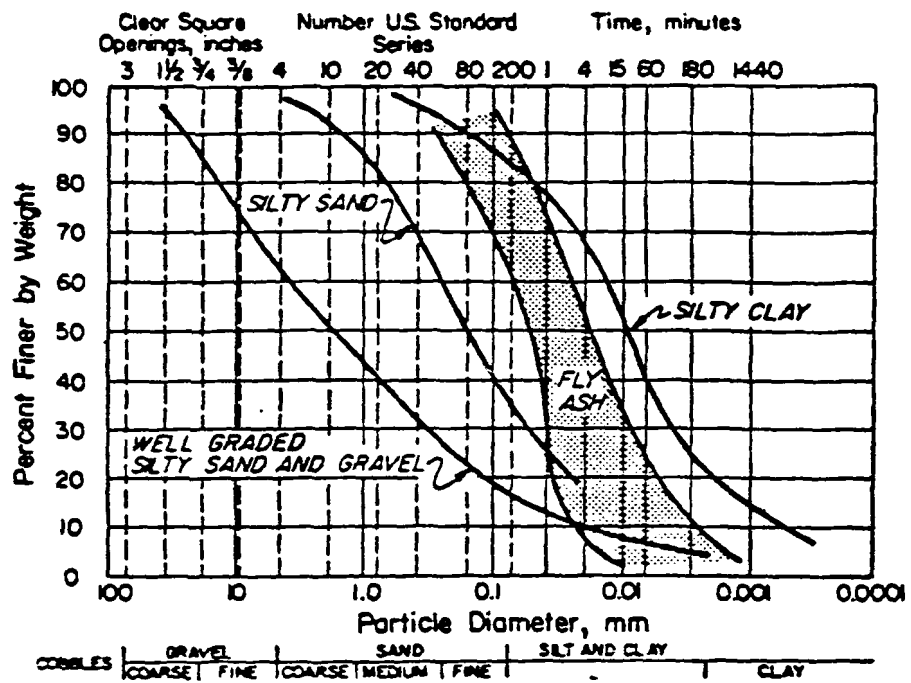


Figure I-3. Particle size distribution of fly ash.

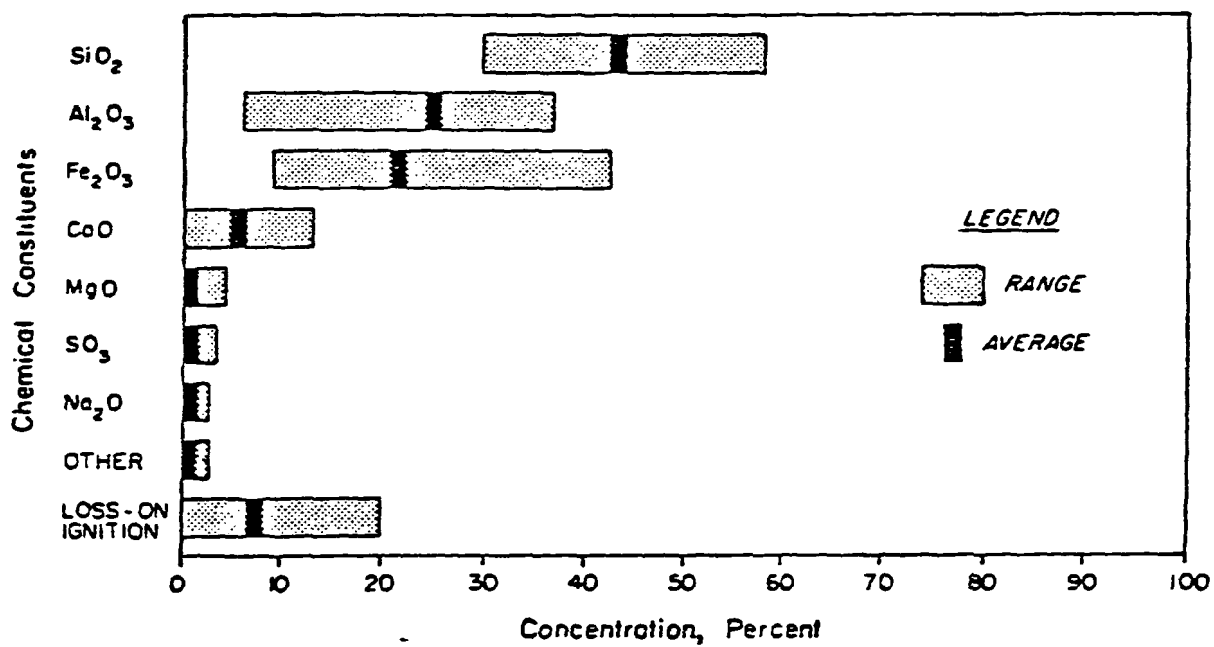


Figure I-4. Chemical composition of bituminous coal fly ash.

Table I-3 compares the normal range of chemical composition of bituminous coal fly ash with that of lignite and sub-bituminous coal fly ashes. From this table, it is evident that lignite and sub-bituminous coal fly ashes have much higher free lime content and lower loss on ignition characteristics than fly ashes from bituminous coals (Reference I-11).

Although the use of fly ash in portland cement concrete is not being considered in this report, classification of fly ash for this purpose may be of some use in identifying basic chemical differences between fly ashes from different types of coal. There are three different classifications of fly ash, according to ASTM C618-80, "Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete," which is included in the Appendix of this report. These classifications are defined in the specification as follows:

1. Class N - raw or calcined natural pozzolans that comply with the applicable requirements for the class, such as some diatomaceous earths, opaline cherts and shales; tuffs and volcanic ashes or pumices, any of which may or may not be processed by calcination; and various material requiring calcination to induce satisfactory properties, such as some clays and shales.
2. Class F - fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class. This class of fly ash has pozzolanic properties, which will be explained later in this report.
3. Class C - fly ash normally produced from lignite and sub-bituminous coal that meets the applicable requirements for this class. In addition to having pozzolanic properties, Class C fly ash also has some cementitious properties. Some Class C fly ashes may contain lime contents higher than 10 percent.

The chemical requirements for these three classes of fly ash are presented in ASTM C618 as follows:

<u>Chemical Composition</u>	<u>Mineral Admixture Class</u>		
	<u>N</u>	<u>F</u>	<u>C</u>
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ - min., %	70.0	70.0	50.0
Sulfur trioxide (SO ₃) - max., %	4.0	5.0	5.0
Moisture content - max., %	3.0	3.0	3.0
Loss on ignition - max., %	10.0	12.0	6.0

Table I-3

NORMAL RANGE OF CHEMICAL COMPOSITION OF
FLY ASHES FROM DIFFERENT TYPES OF COALS

	<u>Bituminous</u>	<u>Sub-bituminous</u>	<u>Lignite</u>
SiO ₂	20 to 60	40 to 60	15 to 45
Al ₂ O ₃	5 to 35	20 to 30	10 to 25
Fe ₂ O ₃	10 to 40	4 to 10	4 to 15
CaO	1 to 20	5 to 25	15 to 35
MgO	0 to 5	1 to 6	3 to 10
SO ₃	0 to 4	0 to 2	0 to 10
Na ₂ O	0 to 4	0 to 2	0 to 6
L.O.I. (Loss on Ignition)	0 to 20	0 to 3	0 to 5

In terms of quality control for use in highway construction, the most significant fly ash properties are fineness, as measured by the -325 mesh sieve, and loss on ignition. Also of importance are the specific gravity and surface area, although the latter is no longer part of ASTM C618. Table I-4 summarizes these physical properties for a number of bituminous and western coal fly ash samples.

Utilization of Fly Ash in Highway Construction

Over the years, fly ash has proven an extremely useful material. Its principal use at the present time is a partial replacement for portland cement in the production of concrete and concrete block. Fly ash has also been used in substantial quantities as a highway construction material. Its main applications have been as a road fill material, as a stabilization agent for highway and parking lot base courses, and as a filler in asphalt paving mixes.

Table I-4

PHYSICAL PROPERTIES OF FLY ASH FROM DIFFERENT SOURCES

Plant Source:	Ft. Martin	Albright	Hatfield's Ferry	Hawthorn	Meramec	Leland Olds	Four Corners	Big Brown	Mohave	Hoot Lake	J.E. Corette
Location:	Maidsville, W. Va.	Albright, W. Va.	Masontown, Pa.	Kansas City, Mo.	St. Louis, Mo.	Stanton, N.D.	Fruitland, N.M.	Fairfield, Tx.	Laughlin, Ne.	Fergus Falls Mn.	Billings, Mt.
Ash Type:	Bituminous	Bituminous	Bituminous	Bituminous	Bituminous	Lignite	Sub-bit.	Lignite	Sub-bit.	Lignite	Sub-bit.
<u>Physical Properties</u>											
Ignition Loss (%)	1.2	2.0	3.1	2.6	2.6	0.3	0.2	0.4	0.7	1.9	0.5
Specific Gravity	2.39	2.12	2.34	2.57	2.43	2.77	1.67	2.44	2.24	2.58	2.48
Percent Retained #325 Mesh Sieve	15.9	18.9	12.0	20.8	15.2	27.7	44.9	19.2	10.0	12.7	11.2
Surface Area (cm ² /cm ³)	2,404	1,980	2,456	2,470	3,701	2,606	1,777	2,101	9,115	6,435	7,802

This section of the report discusses in detail the quantities of fly ash used in these applications, the properties of fly ash that make it suitable for each use, technical factors associated with such uses, and the performance of selected highway projects in which fly ash has been used in these applications.

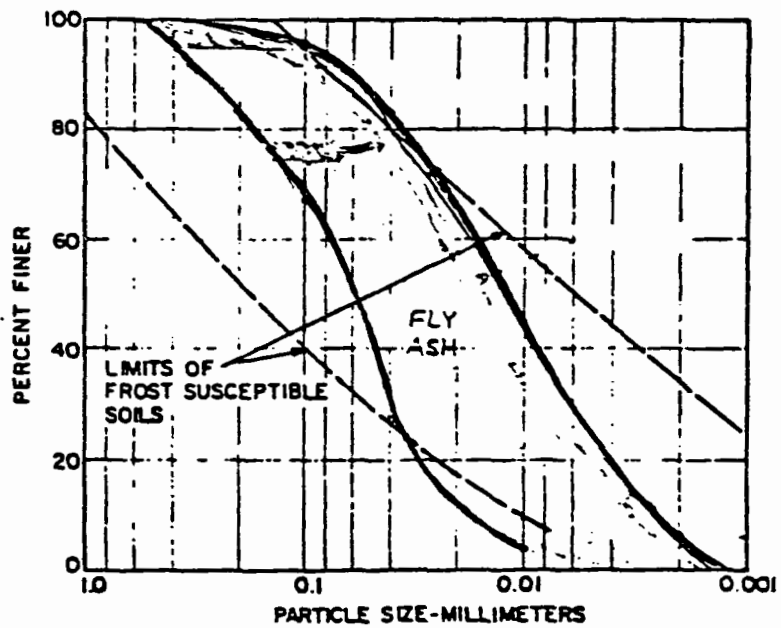
Structural Fill and Backfill. The earliest documented use of fly ash as a structural fill material occurred in Great Britain during the late 1950s. After repeated field trials, the use of fly ash, or pulverized fuel ash, as it is known in England, has become more or less standard practice on British highway projects. Over the years, a number of other European countries (such as France, Germany, Poland) have also begun utilizing significant portions of their fly ash in the construction of roadway fills and embankments.

In the United States, however, there has to date been very limited use of fly ash for highway fill material, despite the comparatively large quantities of fly ash that exist in many parts of this country. This is probably due in large part to the lack of familiarity many highway engineers possess concerning fly ash and some of its unique engineering properties.

Engineering Properties of Fly Ash as Fill Material.

Frost Susceptibility. As noted previously, fly ash is predominantly a silt-size non-plastic material. As such, its particle size distribution falls essentially within normally recognized limits for frost-susceptible soils, as shown in Figure I-5 (Reference I-12). This apparent frost susceptibility of fly ash may be one of the principal reasons why most highway engineers in the United States are reluctant to use fly ash as a fill material. However, this objection can be overcome by restricting the use of fly ash in embankments to depths below that normally expected for frost penetration and covering the fly ash with non-frost susceptible soil. Alternatively, fly ash within the frost penetration zone can be stabilized with either lime or cement to inhibit the effects of damaging frost action.

Despite the fact that fly ash falls within the grain size of a frost-susceptible material, particle size distribution alone is not a fully reliable indicator of frost susceptibility. Other factors such as pore size, permeability, and mineralogy also influence the response of a material to frost. Although no frost susceptibility criteria have been established in the United States, the Road Research Laboratory in England has developed a test method to evaluate frost susceptibility. The test method involves subjecting a compacted 6-inch high specimen to freezing temperatures which simulate actual field conditions. The test is run over a 250-hour time period and then the total amount of frost heave of the specimen is measured.



The following criteria have been adopted by the Road Research Laboratory for the frost susceptibility test:

1. Materials considered to be essentially non-frost susceptible exhibit a heave of 0.5 inches or less.
2. Marginally frost susceptible materials heave between 0.5 and 0.7 inches.
3. Frost susceptible materials heave 0.7 inches or more (Reference I-13).

Results of frost heave tests performed on a number of fly ash samples by the Road Research Laboratory have shown that some fine-grained fly ashes have performed satisfactorily with respect to their frost-heave characteristics, despite the fact that their particle size distribution is indicative of frost susceptibility. However, the fact remains that some fine-grained fly ashes are frost susceptible and that testing of a particular source of fly ash prior to its intended use is the only reliable way to identify the extent of frost susceptibility. A copy of the Road Research Laboratories' Frost Susceptibility test method is included in the Appendix of this report.

In summary, the possible frost susceptibility of compacted fly ash for use as borrow or embankment fill material is not as serious a problem as most engineers are led to believe. In the first place, the depth of frost penetration varies with geographical location and is not a major consideration in some ash-producing regions of the United States. Secondly, the resistance of fly ash to frost heaving can be substantially increased by the addition of cement or lime in moderate amounts (5 to 15 percent by weight). Such stabilization increases the tensile strength of the compacted ash, providing added resistance to heave pressure from ice lenses, and reduces fly ash permeability, allowing less water to penetrate the ash for later frost formation. Finally, objections to the use of fly ash as compacted fill within the frost depth can be overcome simply by substituting a non-frost susceptible soil for fly ash within the frost zone. In Great Britain, for example, the use of frost susceptible materials is not allowed within 450 mm (approximately 18 inches) of the road surface (Reference I-14).

Moisture-Density Characteristics. One of the most important considerations of a material to be used in a fill or embankment is proper compaction. Fly ash is somewhat of a unique engineering material in terms of its compaction characteristics. In dry form, fly ash is cohesionless and is generally considered a dusty nuisance. When saturated, it becomes an unmanageable mess. But, as with most fine-grained soils, it can be easily handled and compacted at more intermediate moisture contents, and does exhibit some cohesion. Conditioned fly ash tailgated over the slope of an embankment can have a dry density as low as 40 to 50 pounds per cubic foot. However, when it has been well compacted at an optimum moisture content (usually between 18 and 30 percent), the dry unit weight of fly ash may be in excess of 85 pounds per cubic foot.

The objective of any compacted fill is to achieve the highest practical densification at a reasonable cost. In this respect, fly ash offers some distinct advantages compared to conventional soils, insofar as it possesses a lower compacted density, thereby reducing the applied loading and resultant settlement to the supporting subgrade and allowing for greater usage of an equivalent amount of fly ash.

The compaction characteristics of a fill material are defined by the results of moisture-density tests performed in the laboratory using standardized testing methods. The two moisture-density tests used by American engineers are the standard and modified proctor test methods. Both tests involve the compaction of material into a standard size steel mold 4 inches (10.16 cm) in diameter by 4.6 inches (11.68 cm) high. The standard proctor test (ASTM D698 or AASHTO T-99) involves the compaction in three equal layers using a 5.5 pound (2.5 kg) hammer and a drop of 12 inches, with a total of 25 blows for each layer. The modified proctor test (ASTM D1557 or AASHTO T-180) also involves compaction in three equal layers with a total of 25 blows for each layer, but specifies the use of a 10 pound (4.5 kg) hammer and a drop of 18 inches.

A copy of each test method is included in the Appendix. For each test method, material is compacted at different moisture contents and the dry density is determined. For most materials, there is a level of moisture, termed the optimum moisture content, at which the compacted dry density achieves a maximum value. At moisture levels above or below the optimum, the dry density is reduced.

Because of the basic differences in the composition and properties of different fly ashes, there may be considerable variation in the moisture-density characteristics of fly ashes from different power plants, or even different samples of fly ash from the same power plant. Such variations are attributable to changes in compactive effort and the behavior of fly ash to compaction at different moisture levels. Consequently, both laboratory and field compaction tests are recommended for use of any fly ash source as fill material in order to define the anticipated range of moisture contents and dry density values.

Since fly ash may be delivered to the field over a wide range of moisture (depending upon whether it has been handled in a dry, conditioned, or ponded state), it is necessary to determine the practical range of density values which are associated with such levels of moisture.

Dry fly ash should be conditioned to within 4 percent of optimum moisture content prior to being delivered to the job site. Conditioned fly ash that has been stockpiled may exhibit considerable variability in moisture content, depending on its relative location within the stockpile. Ponded ash should have a moisture content as close as possible to optimum following excavation from the lagoon, especially since ponded fly ash has a characteristically flat moisture-density curve (Reference I-15).

Figure I-6 shows a range of modified Proctor moisture-density curves developed from a National Ash Association study of engineering properties of seven western Pennsylvania bituminous coal fly ashes for use as structural fill materials (Reference I-16). Each ash sample had a different particle size distribution and specific gravity. From this figure, it can be seen that the maximum density of compacted fly ash varied from 89.0 pounds per cubic foot at an optimum moisture content of 19 percent to a low of 76.7 pounds per cubic foot at an optimum moisture content of 29 percent. Further study of Figure I-6 shows that compaction characteristics are not directly related to specific gravity, since the fly ash with the highest maximum dry density in this study also had the lowest specific gravity.

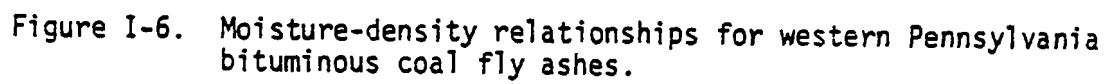
The use of the modified Proctor compaction curves in Figure I-6 serve to establish approximate limits of a compaction envelope for fly ash. The area within the compaction envelope defines ranges of achievable density at corresponding unit weights for a modified Proctor compactive effort, which is attainable in the field using modern compaction equipment. Such information is of practical value in the field since it is not always possible to adjust the moisture content of delivered fly ash at the job site. Using such a compaction envelope enables an engineer to control the method of placement and compaction of fly ash in the field to achieve more uniform density results and achieve a desired percentage of the maximum compacted density value.

Figure I-7 shows modified Proctor moisture-density curves for four samples of Michigan fly ash. The maximum dry density values for these samples ranged from 74 to 96 pounds per cubic foot, while optimum moisture contents varied from 18 to 32 percent (Reference I-17).

Shear Strength. Development of shear strength is an essential characteristic of embankment and fill materials. The shear strength of a material is determined by means of the undrained triaxial compression test (ASTM D2850 or AASHTO T-234-74). Shear strength tests conducted on freshly compacted fly ash samples show that fly ash derives most of its shear strength from internal friction (Reference I-18).

The shear strength of fly ash is affected by the density and moisture content of the test sample. Remolded triaxial test specimens may be prepared at any predetermined density and moisture content and, if required, may also be soaked prior to testing. Undrained shear strength has been found to decrease significantly in fly ash samples compacted on the wet side of optimum moisture content (Reference I-19), or to less than maximum dry density.

Generally, it is not practical nor possible to compact a material to 100 percent of its maximum dry density in the field. In most cases, a minimum compaction of 90 to 95 percent is specified as a more realistic compaction limit in the field. According to the FHWA Fly Ash Users Manual, recommended reductions in the laboratory test values for shear strength, apparent cohesion, and angle of internal friction with associated reductions in compacted density of fly ash are as follows:



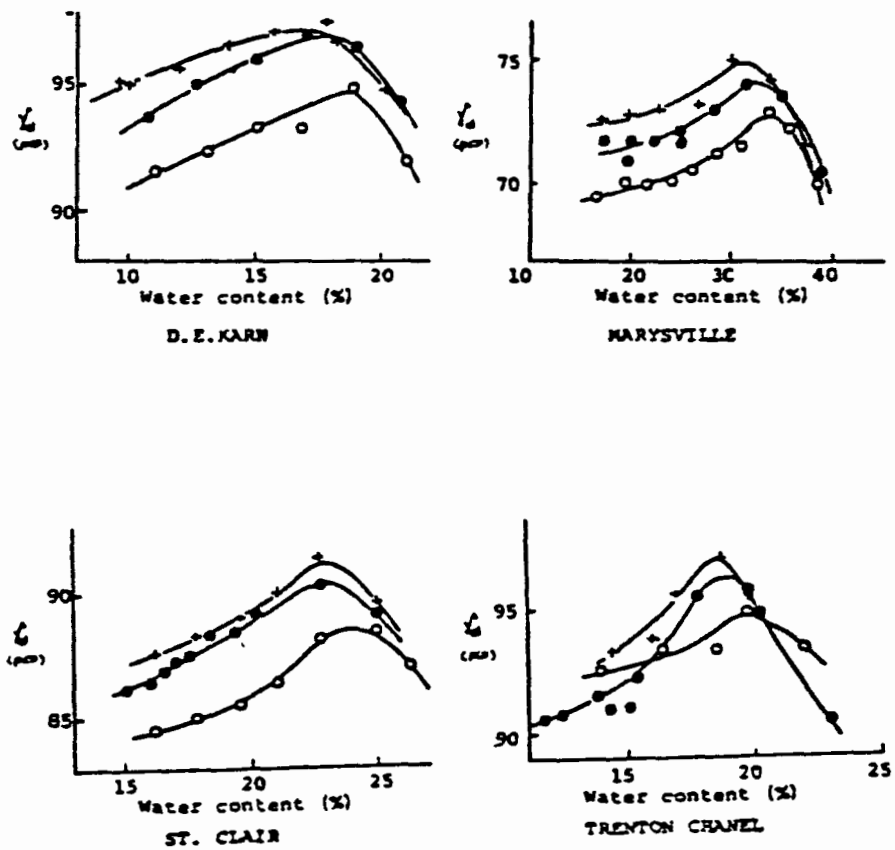


Figure I-7. Moisture-density relationships for Michigan bituminous coal fly ashes.

Percentage of Maximum Dry Density	Percentage of Value at Maximum Density		
	Shear Strength	Unit Cohesion	Angle of Internal Friction
85	60	70	80
90	75	70	80
95	90 to 95	70	80

One distinct advantage of using fly ash as a fill or embankment material is its self-hardening or age-hardening ability. The age-hardening of fly ash can best be correlated with the amount of free lime present in the ash. Most self-hardening fly ashes contain at least 4 to 6 percent free lime. Fly ashes that have been ponded prior to compaction exhibit much less age-hardening than conditioned fly ashes. This is probably because the water used to convey ash to the lagoon results in agglomerations, uneven distribution of internal moisture, and largely dissipates the chemical reactions responsible for age-hardening of fly ash.

Not all fly ashes possess age-hardening properties. Most eastern coal fly ash is not self-hardening, while western coal fly ash is. But even in those fly ashes with little or no age-hardening, there is still an apparent cohesion due to capillary forces produced by pore water (Reference I-20). However, this apparent cohesion can be destroyed either by saturation or complete drying. Fly ashes possessing self-hardening properties develop a cohesion resulting from the cementing action which occurs between the fly ash particles and which increases with age (Reference I-21).

The shear strength and compressive strength characteristics of compacted fly ashes have been found to increase over time, particularly if the fly ash is self-hardening. Table I-5 presents data from British fly ashes used as compacted fill, which clearly shows cohesion and compressive strengths which double or triple within a three month period (Reference I-22).

In the case of western fly ashes, high free lime contents often necessitate that such ashes be conditioned and stockpiled for a period of time prior to use to reduce their reactivity. Nevertheless, such reactive fly ashes, even after conditioning and stockpiling, may exhibit age-hardening properties.

Compressibility. An embankment or fill material should possess low compressibility in order to minimize roadway settlements or differential settlements between structures and adjacent approaches and to maintain to the maximum extent possible a smooth riding surface. Available data reported to date show that settlements within fly ash embankments, either with or without age-hardening properties, have been within acceptable limits and have provided satisfactory performance.

Table I-5

DEVELOPMENT OF SHEAR AND COMPRESSIVE
STRENGTH CHARACTERISTICS OF COMPACTED
FLY ASH OVER TIME

Age (Days)	Source of Fly Ash								
	Barony			Braehead			Portobello		
	Unit Cohesion	Friction Angle	Compressive Strength	Unit Cohesion	Friction Angle	Compressive Strength	Unit Cohesion	Friction Angle	Compressive Strength
1	11	38	45	9	34	34	13	35	50
7	29	41	127	29	39	122	17	41	75
28	32	42	144	32	41	140	20	43	92
91	38	42	171	35	42	157	22	43	101
182	40	42	180	39	41	171	24	43	111
371	42	42	189	43	40	185	25	43	115
749	51	45	246	45	39	189	25	46	124
1,230 (3.4 years)	79	41	346	70	40	300	29	44.5	138

Note: All ash sources are located in Great Britain. Data initially reported by Sutherland, H. B. (Reference 22). Unit cohesion and compressive strength data are experienced in pounds per square inch.

The compressibility of fly ashes with no self-hardening characteristics is basically similar to the compressibility of a typical cohesive soil. The compressibility of a material is determined by means of a laboratory consolidation test (ASTM D2435), wherein a sample (2-inch diameter by at least 0.5 inch high) is subjected to a series of incremental pressures and the change in height of the sample is measured after full consolidation at each loading. The void ratio of the sample is then determined at each pressure. The slope of the resultant curves is called the compression index and is a measure of the compressibility of the material. A copy of the ASTM consolidation test method may be found in the Appendix.

Figure I-8 shows that consolidation occurs more rapidly in compacted fly ashes than in clay soils because fly ash has a greater permeability than clay. Although a number of factors affect the compressibility of fly ashes which do not self-harden, the predominant factor in determining the overall compressibility of such ashes is the initial compacted density (Reference I-23).

For fly ashes with self-hardening properties, the time-dependent phenomena of age-hardening can reduce the time rate of consolidation, as well as the magnitude of the compressibility. The results of a study of the compressibility of compacted fly ashes with age-hardening properties show that the overall magnitude of settlements in these materials is less than that which would occur in ordinary soils and is a function of the hardening characteristics of the ash material and the age at which loading is applied to the compacted material. This study also indicates that partly saturated fly ashes, regardless of whether or not they are self-hardening, tend to be less compressible than fully saturated samples (Reference I-24).

Permeability and Leaching Characteristics. The permeability of fly ash which has been compacted to its maximum dry density in accordance with the standard Proctor method (ASTM D698 or AASHTO T99-74) has been found to range from 4×10^{-10} cm per second to 5×10^{-7} cm per second (Reference I-24). These values were determined by means of the falling head permeability test, described in U.S. Army Corps of Engineers Manual 110-2-1906, Appendix 7, Section 4, which is included in the Appendix.

Despite air void ratios ranging from 8 to 14 percent, these values represent relatively low permeability rates, comparable to those of a clay or silty clay soil (Reference I-25). The permeability of a compacted fly ash embankment material is a function of the degree of compaction, the extent of age-hardening of the fly ash, and the grain size distribution of the material.

ASTM Subcommittee E-38.06.05 task group on process wastes had developed a Recommended Practice for Use of Process Waste in Structural Fill. This recommended practice describes the physical characteristics of and procedures for the use of certain process wastes (inorganic by-

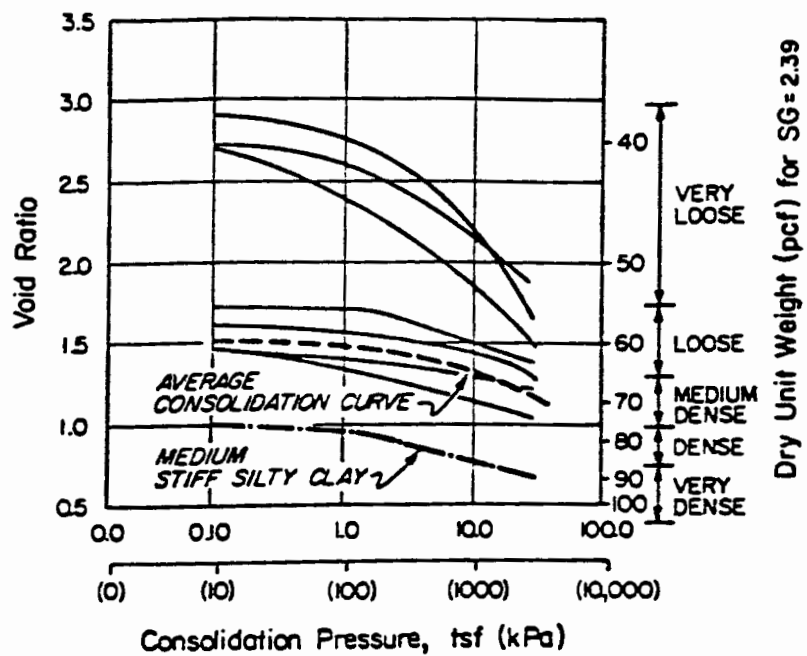


Figure I-8. Comparison of consolidation rates of fly ash and silty clay soil.

products such as coal combustion wastes, including fly ash) in structural fill and similar applications. This practice also describes structural and engineering properties of such in-place materials related to structural integrity and protection of ground and surface water, as well as test procedures to be used in determining these properties.

The Recommended Practice has a special provisions section dealing with handling leachate from process wastes where leachate concentrations exceed certain levels. The Special Provisions of the Recommended Practice, which is found in the Appendix, are:

- Materials having an in-place permeability of greater than 1×10^{-5} cm/sec. should have an appropriate underdrain and permeate collection and disposal system.
- Materials having an in-place permeability of 1×10^{-5} cm/sec. or lower do not require permeate collection systems.

These provisions apply only to process wastes having leachate concentrations in excess of 100 times Drinking Water Standards.

The criteria for the Drinking Water Standards and the testing procedures used in producing and analyzing the leachate for comparison with these criteria are discussed in the following paragraphs.

In order to simulate leachate production, laboratory techniques have been developed to combine water and waste materials such as ash for a specific contact period and degree of agitation, separate the ash and water, and then analyze the water for the presence of trace elements.

An extraction procedure (EP) was developed by the U.S. Environmental Protection Agency (EPA) as a means of generating leachate from a particular material so that the leachate could be analyzed for toxicity as defined by the hazardous waste regulations of the Resource Conservation and Recovery Act (RCRA). A waste material is considered hazardous if the extract from the EP has a concentration of any substance listed in The National Interim Primary Drinking Water Standards that is greater than or equal to one hundred times that standard. The following inorganic chemicals and permissible concentrations are listed in the Drinking Water Standards:

<u>Contaminant</u>	<u>Drinking Water Level (mg/l. or ppm)</u>
Arsenic	0.05
Barium	1.00
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05

The basic steps involved in the EPA extraction procedure are detailed in the hazardous waste guidelines and regulations that were first published in the December 18, 1978 issue of The Federal Register and recently updated in the May 19, 1980 issue of The Federal Register. A copy of the updated extraction procedure is included in the Appendix. The extraction procedures involves the following:

- A minimum 100 gram sample of the waste material is separated in liquid and solid phases by means of a filter or a centrifuge.
- The liquid portion is refrigerated between 1° and 5° Centigrade (34° to 41° Fahrenheit) until the analysis is performed.
- The solid portion must be ground so that it will pass through a 3/8 inch (9.55 mm) sieve.
- The solid portion of the sample, after grinding, is added to 16 times its own weight of deionized water. The solution is adjusted to a pH of 5 and the mixture is agitated for 24 hours, using an approved shake or extractor apparatus. During the 24-hour agitation period, the solution must be maintained at a pH of 5 by adding 8.5N acetic acid and the sample temperature must be kept between 20° and 40° Centigrade (68° to 104° Fahrenheit).
- After the 24-hour extraction procedure is completed, the sample is again filtered to separate the liquid and solid phases. The second liquid phase is diluted with more deionized water and mixed with the original liquid phase which has been refrigerated.
- The liquid extract is then analyzed for the substances listed in the Primary Drinking Water Standards. Appropriate methods for analyzing the leachate generated by the extraction procedure are listed in "Methods for Chemical Analysis of Water and Wastes," published by the U.S. Environmental Protection Agency (Reference I-26).

A collaborative interlaboratory testing program was performed during 1979 under the joint sponsorship of the U.S. Department of Energy's Laramie Energy Technology Center and the American Society for Testing and Materials (ASTM). A total of 18 laboratories participated in the testing program. Nineteen fossil energy materials were tested, including various fly ashes, bottom ash, boiler slag, and other combustion by-products. Each material was tested using three different extraction procedures, including the Environmental Protection Agency's procedure, although not all materials were tested by each laboratory.

Table I-6 presents a summary of the test results for those laboratories participating in leachate extraction testing of fly ash samples using the EPA extraction procedure. A total of five fly ash samples were analyzed--three bituminous coal fly ashes, one lignite, and one sub-bituminous coal fly ash. There were a total of 39 extraction tests performed, each involving analysis of concentrations for eight different inorganic chemicals, or a total of 312 separate analyses.

From Table I-6, it can be seen that from the total of 312 analyses, there were 29 test values which exceeded 10 times drinking water standards, but only one in excess of 100 times drinking water standards. This involved the selenium concentration tested by one of the 16 laboratories analyzing bituminous coal fly ash sample number 1. Leachate concentrations exceeding 10 times drinking water standards included 13 selenium analyses, 9 arsenic, 3 cadmium, 2 chromium, 1 mercury, and 1 lead. Bituminous coal fly ash sample number 3 had no test values in excess of ten times drinking water standards (Reference I-27).

Although more extensive leachate testing of coal combustion by-products will be conducted in the future, the preceding test results, while performed on a small number of samples, indicate that fly ashes, when used in an embankment or fill situation, do not typically leach hazardous concentrations of inorganic chemicals. Further discussion of the environmental impacts of fly ash use is presented in Volume One of this report.

Actual field experience with fly ash embankments to date has shown that very little water has been observed to percolate through such embankments. This is probably due not only to the comparatively low permeability of compacted fly ash, but also to the gradual cementing action resulting from self-hardening of the ash.

Because of relative impermeability and alkalinity, the danger of pollution to underlying ground water or to surface waters in the vicinity of a fly ash embankment is minimal, particularly if the entry of surface water is well controlled and the fly ash is capped with an envelope of natural soil. As noted earlier, the permeability of compacted fly ash can also be substantially reduced by chemical stabilization with lime or portland cement. Another advantage of low permeability is that construction operations are not adversely affected by inclement weather.

Because of the relatively low permeability of compacted fly ash, unprotected side slopes are subject to a high degree of runoff. Therefore, side slope protection in the form of natural soil and topsoil covering with vegetation, or at the very least a bituminous seal coating, is required to prevent erosion.

Table I-6

SUMMARY OF LABORATORY TEST RESULTS FROM
LEACHATE EXTRACTION ANALYSES OF FLY ASH SAMPLES

<u>Sample Description</u>	<u>Power Company</u>	<u>Plant Location</u>	<u>No. of Tests by Labs</u>	<u>Total Values Exceeding 10 x DWS</u>	<u>Elements Exceeding 10 x DWS</u>	<u>Total Values Exceeding 100 x DWS</u>
1. Bituminous Coal Fly Ash No. 1 (From 2% sulfur coal)	Pennsylvania Electric Company	Keystone Station Shelocta, Pa.	16	17	8 Se 7 As 1 Pb 1 Hg	1 (Se)
2. Bituminous Coal Fly Ash No. 2 (From 4% sulfur coal)	Ohio Power Company	Kammer Plant Captina, W. Va.	5	7	3 Cd 2 Cr 1 As 1 Se	-
3. Bituminous Coal Fly Ash No. 3 (From 2% sulfur coal)	Monongahela Power Company	Harrison Station Haywood, W. Va.	7	-	-	-
4. Lignite Coal Fly Ash (From less than 1% sulfur coal)	Minnkota Power	Milton Young Plant Center, N.D.	7	4	3 Se 1 As	-
5. Sub-bituminous Coal Fly Ash (From less than 1% sulfur coal)	Commonwealth Edison Company	Waukeegan Plant Waukeegan, Ill.	4	1	1 Se	-
TOTAL			39	29	6 out of 8 possible elements	1

Capillary Action. Water has been observed to rise by capillary action in some compacted conditioned fly ash embankments. Capillarity can cause saturation and resultant instability in embankments or fills less than 2 feet (0.6 meters) in thickness. The phenomenon of capillary rise is not reduced or materially affected by self-hardening or the increase in shear strength of the compacted fly ash over time. An effective means of preventing capillary rise in fly ash embankments and fills is the placement of a drainage layer of full-draining granular material at the base of the embankment to a height of at least 18 inches above the ground water level (Reference I-28). The ASTM Recommended Practice for Use of Process Waste in Structural Fill notes that such material should be placed a minimum of 5 feet above the historical high water table.

Slope Stability. An average slope of two horizontal to one vertical should provide a minimum safety factor against sliding based on an effective internal friction angle of 33° and zero cohesion. This is felt to be a conservative estimate of the safety factor of a fly ash slope because the beneficial effects of apparent cohesion and age-hardening of the fly ash were not included in the analysis (Reference I-29).

Handling Characteristics. The moisture content of fly ash brought to the field for use as a fill or embankment material can present certain difficulties above and beyond those normally encountered in placement and compaction of conventional soils. First, the handling of dry or silo stored ash creates in many cases a severe dusting problem when the material is dumped and spread, especially on hot, windy days. The following precautions are advised to minimize the dusting problem:

1. Wet the material with water to bring its moisture content up to the optimum range.
2. Have a water truck with a spray bar attachment available for additional wetting of the surface after placement and rolling.
3. Keep traffic off the surface of the fill after rolling unless placing an additional layer.
4. Seal the exposed surface at the end of each day's work.

When stockpiles of conditioned or ponded ash are used, lumps of hardened ash are sometimes encountered. These must be broken up by construction equipment prior to using the ash for embankment or fill purposes. The effects of lensing (the formation of small, shallower, transverse shear cracks) and crusting of the surface can be avoided by using discing or tilling equipment to agitate the loose lift and the surface of the preceding compacted lift (Reference I-30).

One of the principal advantages of using fly ash as a fill material is that, unlike conventional soils, fly ash can be placed throughout the winter months. Table I-7 presents a comparison of the advantages and disadvantages of fly ash embankments with those of conventional soils.

Table I-7

COMPARISON OF FLY ASH EMBANKMENTS
WITH CONVENTIONAL SOILS

ADVANTAGES OF FLY ASH

Lighter compacted unit weight, resulting in lower settlements and ability to place fill on soft or marginal ground.

Self-hardening properties for many fly ashes ultimately result in higher cohesion and shear strength than most conventional soils.

Low compressibility when properly compacted with negligible resultant settlement.

Fly ash can be placed throughout the winter because it does not freeze like conventional soils.

DISADVANTAGES OF FLY ASH

Most fly ashes are frost susceptible, requiring either chemical stabilization or substitution with suitable natural soils in frost prone areas.

Sensitivity to moisture, necessitating that compaction be done very close to, and preferably below, optimum moisture content.

Subject to capillary action, requiring underlayment with a drainage layer of granular material directly above the ground water table. Some clay and soil borrow materials also are subject to capillary action.

Subject to dust generation during placement.

Examples of Fly Ash Utilization in Highway Embankment Construction. There are numerous examples of the use of fly ash in the construction of highway fills or embankments throughout the United Kingdom. A few of the more outstanding projects are cited herein to dramatize the advantages of fly ash, or pulverized fuel ash, use for embankment purposes.

Motorway M.5 - Bristol and Somerset, England. A section of motorway M.5 two miles in length was constructed on a highly compressible alluvium layer up to 40 feet thick. Embankment heights of up to 7 feet were built along the main road with interchange road fills up to 20 feet high. The embankments were constructed of pulverized fuel ash because of the relatively light unit weight of the ash in comparison to locally available borrow material. In addition, potential settlement problems at 14 bridges and 2 interchanges were alleviated by using the lighter ash over the compressible alluvium subgrade. When sufficient amounts of ash could not be obtained from the nearest generating station, over 1 million tons of additional ash was transported to the job site from another power station 80 miles away by rail so that the unique properties of the ash could continue to be utilized (Reference I-31).

Alexandria By-Pass - Dumbarton, Scotland. The construction of the Alexandria By-Pass included a bridge over the River Leven with very high approach embankments due to clearance requirements for navigational purposes. The use of a lightweight fill material was warranted because of poor subsoil, in this case a saturated silt. Construction of the facility in two stages involved placement of nearly 670,000 cubic yards of pulverized fuel ash in the embankments, which reached a maximum height of 39 feet. Two years after completion of the project, the total settlement of the embankment was only 10 inches, which is considered quite satisfactory (Reference I-31).

Clophill By-Pass, Motorway A.6 - Bedfordshire, England. During 1975, approximately 20,000 cubic yards of pulverized fuel ash was used to construct an 8-foot high roadway embankment over a 16 foot thick layer of highly compressible peat on a section of the A.6 Motorway. In addition, the ground water table in the area was essentially at ground surface, making it almost impossible to operate construction equipment. In order to minimize settlements, pulverized fuel ash was used for construction of the embankment. The total settlement of the embankment is 6 inches, which is less than the predicted settlement (Reference I-31).

Despite numerous projects utilizing fly ash as fill material for construction of highways in Europe, only five documented instances of such use in the United States have been determined from available literature. Three projects are described in this report.

U.S. Route 250 - Fairmont, West Virginia. Approximately 5,000 tons of fly ash were utilized in the repair of an embankment along a section of U.S. Route 250 in Fairmont, West Virginia. The repair work resulted from a slide failure caused by poor drainage. The slide mass was removed, sub-surface drainage installed, and the slide material that had been removed was replaced with fly ash. The embankment had an average height of 25 feet with 1-1/2 to 1 side slopes.

Fly ash was hauled to the site in open trucks with no dusting problems during hauling or placement. The ash was tailgated and spread in 9-inch thick lifts and compacted by a rubber-tired vibratory roller to a density of 97 percent or more of Standard Proctor (ASTM D698 or AASHTO T-99) density values. Upon completion of compaction operations, the exposed surface of the fly ash embankment was sealed with a coat of hand-sprayed road tar (Reference I-32).

Melvin E. Amstutz Expressway - Waukegan, Illinois. The Melvin E. Amstutz project (Federal Aid Route 437, Section 8) in Lake County, Illinois involved the construction of a fill embankment for a four-lane divided highway with a 42-foot wide median between Grand and Greenwood Avenues in Waukegan, Illinois, some 40 miles north of Chicago. This is probably the most outstanding example of fly ash use in highway embankment construction thus far in the United States.

A total of 246,000 cubic yards of embankment material were required for this job. Fly ash was selected as an alternate because a nearby Commonwealth Edison power plant offered an available source of material at a potential cost savings. Alternate bids indicated that construction of a fly ash embankment would result in a savings of approximately \$62,000 compared to an earth embankment (Reference I-33).

Prior to placement of the fly ash, unsuitable in-place soils were removed and replaced with granular fill to a height of 2 feet above the ground water table. The average height of the fly ash embankment was 3.5 feet, although 18 to 20 foot embankments were built in ramp areas. The fly ash embankment was covered by 8 feet of earth fill on the outside slopes and by 2 feet of earth fill in the median areas.

Fly ash was trucked to the site either from stockpiles located outside the power plant or from closed storage silos and placed in 6 inch layers. Each layer was compacted by means of a 10-ton vibratory single steel drum roller to densities in excess of 85 percent of the maximum dry density at optimum moisture levels of 25 percent.

The contractor added water where necessary to obtain the desired density. Side slopes of 2 to 1 were maintained and are performing satisfactorily.

The fly ash placed in this embankment is stronger than most natural soils because of its age-hardening characteristics. The material was workable and stable with excellent compaction characteristics, provided the proper construction methods and equipment are utilized. The use of fly ash enabled work to proceed under wet conditions when it might not have been possible to work with conventional soils. Moreover, the lighter weight fly ash was found to be advantageous in bridging over weak subsoils (Reference I-33).

Route 7 and 148 - Powhatan Point, Ohio. Nearly 6,000 tons of fly ash from the Burger Station of Ohio Edison Company were used as back-fill material around a concrete bridge over a railroad at the intersection of state routes 7 and 148 in Powhatan Point, Belmont County, Ohio, which is located in the southeastern part of the state. The conditioned ash was placed between the Fall of 1979 and March of 1980.

At its deepest point, the ash embankment is 27 feet high and extends longitudinally about 80 feet. The material was compacted in 12 inch lifts except near the top, where 6 inch lifts were used. Compaction operations were monitored by a field representative of the Ohio Department of Transportation, who verified that all layers of fly ash were compacted to at least 95 percent of Standard Proctor density. Prior to placement of the compacted ash fill, the surfaces of the bridge abutment were coated with an asphalt preparation. In addition, a base of steel mill slag was placed and overlain with a celanese filter cloth.

According to the contractor on the project, the amount of ash used on the project worked out closer in planned quantity than any other material he had ever used and did not demonstrate the shrinkage one normally expects with dirt or gravel. He also felt that there was no way he could have achieved the same degree of compaction with an earthen fill in that situation without a lot of hand tamping.

Throughout the winter construction period, there was no shutdown time while placing the fly ash embankment. Whenever the ash began to dry out, the contractor simply ordered a load of wet ash, which he blended with the dry ash and corrected the problem. However, the contractor did feel that he would not recommend ash placement in temperatures below 30 degrees Fahrenheit simply because he had experienced problems getting the ash out of the truck bed at those temperatures.

Exposed slopes were capped with a soil cover. Rail traffic was maintained at all times during construction of the embankment. Little or no settlement has been observed in the fill since the sub-base and wearing surface was placed and the road was opened to traffic in the Spring of 1980 (Reference I-34).

Overall Technical Assessment. It is evident from the review of available literature pertaining to fly ash use as an embankment or structural fill material that fly ash is unquestionably suitable for such use and, in addition, provides certain unique and beneficial properties when utilized in such applications. Of particular advantage is the relatively low density of the material combined with substantial shearing strength and long-term strength gaining characteristics. Moreover, compacted fly ash has a low permeability, particularly if it is self-hardening, and indications thus far are that the material does not leach potentially hazardous concentrations of inorganic chemicals.

Prospective users of fly ash must be aware of the potential for frost susceptibility of this material. Furthermore, the placement of fly ash in a fill or embankment must be accomplished above the anticipated high water table and the material must be underlain by a drainage blanket or open-graded granular material. Precautions must be made to keep the fly ash sufficiently moist while spreading and compacting in order to avoid excessive dusting and all exposed sloping surfaces of the fly ash must be covered with soil to protect against erosion.

In spite of the preceding precautions, an objective engineering assessment of the use of fly ash for embankment and structural fill purposes leads to the conclusion that this material is well suited for such purposes. Indeed, fly ash has been used extensively and successfully as highway fill and backfill material throughout much of Great Britain for many years and its excellent performance in many British highway projects has been repeatedly documented. In those few instances where fly ash has been used as highway fill material in the United States, its record of performance has also been outstanding.

During April 1980, a questionnaire was circulated to all state highway departments by The American Association of State Highway and Transportation Officials (AASHTO). The questionnaire requested information on uses, extent, performance, and attitudes related to different recovered materials in highway construction in each state. Results of this questionnaire indicate that a total of 8 states have made, or are making, use of fly ash in an embankment or structural fill. These states are Arizona, Illinois, Minnesota, New York, Ohio, West Virginia, Wisconsin, and Wyoming. All of these states rated the material's performance in this application as either acceptable, good, or excellent. Each of these states plans to make further routine use of fly ash as an embankment or structural fill material, except that Minnesota feels that more field study should be made in connection with such use.

Aside from lack of knowledge about the usefulness of fly ash and some of its unique characteristics, perhaps the biggest obstacle to more widespread use as highway fill material in this country is logistics. Most highway construction projects are designed so that there is practically a balance between cuts and fills and as little borrow material as possible is required. Except for those occasional situations where a large stockpile of ash may be located relatively close to a highway project, in most instances, the use of excavated earth from the project site will be more convenient, available, and economical. Moreover, there will most likely be less future opportunities to utilize fly ash as a highway embankment or fill material because fewer new highway facilities will be constructed compared to reconstruction, widening, and resurfacing of existing facilities.

For these reasons, development of procurement guidelines for the use of fly ash as a structural fill do not appear to be warranted. However, further efforts should be made to educate highway engineers, road-building contractors, and other interested parties concerning the advantages offered by fly ash in the construction of fills and embankments so that, when opportunities to make use of this material do arise in the future, fly ash will receive favorable consideration and not be discriminated against because it is unlike soil. The relative economics and logistics of each site-specific situation should be the determining factors in deciding whether fly ash use as highway fill material is most suitable and advantageous for a particular project.

Lime-Fly Ash-Aggregate Bases and Sub-Bases

One of the most successful and promising applications for the use of fly ash in highway construction is in lime-fly ash aggregate (LFA) base or sub-base mixtures. These mixtures are blends of commercial lime, fly ash, and mineral aggregates, combined with water in the proper proportions and compacted to form a dense, stable mass. Mixtures of lime, fly ash, and aggregate and in some cases additional portland cement are often referred to as pozzolanic pavements. These mixtures may also involve substitution of kiln dusts in place of lime or cement, which is discussed in another section of the report.

Description of Pozzolanic Reaction. A pozzolan is defined as a siliceous or aluminous and siliceous material which is in itself chemically inert, and possesses little or no cementitious value, but, when in a finely divided form and in the presence of water, will react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Reference I-35). The term pozzolan is derived from the Latin word "pozzuolana," which referred to a volcanic ash found near the town of Pozzuoli, Italy, where the mixing of volcanic ash with a crude lime was first discovered in 350 B.C. and used as a matrix for Roman building materials.

The most commonly available pozzolan in use in the United States at this time is fly ash. Because of basic variations in coals from different sources, along with design differences in coal-fired boilers, not all fly ashes are the same. While there are differences in fly ashes from one plant to another, day to day variations in the fly ash from a single plant are usually quite predictable, provided plant operation and coal source remain constant. It should also be pointed out that fluctuations in the chemical composition of fly ash are far less critical for use in LFA base materials than in portland cement concrete.

To determine whether a particular source of fly ash is suitable for use in a pozzolanic pavement, the pozzolanic reactivity of the fly ash must be determined in accordance with the procedures outlined in ASTM C593, "Standard Specification for Fly Ash as a Pozzolan for Use with Lime," a copy of which is included in the Appendix of this report.

Although it is not necessary to understand the mechanisms by which cementitious compounds are formed in the pozzolanic reaction, some awareness of the basic chemistry involved is useful. It should be recognized that the chemistry of pozzolanic reactions, which is closely related to cement chemistry, is an extremely complex subject which has been extensively researched for many years.

Essentially, what occurs in a pozzolanic reaction is that calcium from the lime and silica from the pozzolan (normally fly ash) react in the presence of water to form a gelatinous calcium-silicate compound, which provides a cementitious binder for the aggregate particles in the mix. The pozzolanic reaction is time and temperature dependent, so that different compounds may be in varying stages of formation, depending on the length of time the reaction has been progressing or the temperature conditions to which the component materials have been exposed.

In cases where dolomitic limes are used, the presence of magnesium in these limes will cause other cementitious compounds to be produced, generally at a slower rate and over a longer period of time than the calcium-silicate compounds, thus resulting in an even more complicated reaction mechanism. Analysis of aged pozzolanic products has also indicated the formation of crystalline compounds at later stages of the reaction. The chemical interaction of calcium ions on the surface of the silica, along with later crystalline growth, are both involved in the pozzolanic reaction (Reference I-36).

Most western (lignite and sub-bituminous) coal fly ashes contain higher concentrations of free lime (CaO) and sulfate (SO₃), resulting in the formation of other cementitious reaction products such as ettringite (calcium sulfo-aluminates). Such reactions are related to portland cement chemistry and offer opportunities to use higher fly ash dosages in LFA mixtures (Reference I-37).

History of Lime-Fly Ash-Aggregate Base. The initial discovery of a pozzolanic reaction between fly ash and lime and its subsequent use in the stabilization of fine-grained soils was made by Jules E. Havelin and Frank Kahn, engineers from the Special Tests Branch of the Philadelphia Electric Company during the mid-1940s. This discovery subsequently became the basis for three patents on the stabilization of soils using lime-fly ash reactions. Copies of these patents are included in the Appendix of this report.

As a followup to this work, Dr. L. John Minnick of the G. and W. H. Corson Lime Company, under the sponsorship of Philadelphia Electric Company, began research on the use of lime-fly ash pozzolanic reactions with aggregates and soil-aggregate mixtures. Much of this early lime-fly ash-aggregate work in the laboratory was performed during the late 1940s and early 1950s at the University of Pennsylvania under the direct supervision of Richard H. Miller of the Civil Engineering Department.

The earliest known field installation involving the use of lime-fly ash-aggregate as a base course material was in November of 1950 on a temporary by-pass road along the New Jersey Turnpike in Swedesboro, New Jersey. The test section was several hundred feet long and involved the blending of fly ash and boiler slag on a 1:3 ratio with a 3 percent lime content. The materials were mixed in place and compacted. The road base remained in very good condition and provided excellent performance for two years, at which time the new construction was completed and the by-pass was removed.

Three more experimental projects using LFA were placed in 1951, one each in Pennsylvania, New Jersey, and Maryland. Later samples were extracted from each of these locations and compressive strengths were found to range from 2,090 to 4,315 psi (Reference I-38). On the basis of these and other early successful installations, a patent was granted for lime-fly ash-aggregate mixtures in road base construction. A copy of the original patent for lime-fly ash-aggregate compositions (marketed under the trade name of Poz-O-Pac) can be found in the Appendix of this report.

With the issuance of a patent for "Poz-O-Pac," and the establishment of a licensee arrangement for the production of the material, pozzolanic base materials were eventually produced and placed in construction projects in at least a dozen states. The most frequent use of LFA materials has been in the states of Illinois, Ohio, and Pennsylvania. A later section of this report will focus on the extent of LFA base course use in several of these states.

Recently, the "Poz-O-Pac" patents have expired, although there are still a number of pozzolan producers in many of these states that continue to sell pozzolanic base course materials. Throughout the years, it is estimated that approximately 25 to 30 million tons of LFA or pozzolanic base course materials have been produced and placed in the United States.

Table I-8 presents estimated quantities of pozzolanic base course materials produced on an annual basis in the United States since 1970. For comparison purposes, annual production figures from the Chicago area are also included in this table. Table I-8 clearly shows that for the past ten years the Chicago area has produced approximately 80 percent of the LFA base course materials used in the country. Since 1956, it has been estimated that over 12 million tons of LFA base materials have been produced in the Chicago area (Reference I-39).

Also evident from this table is the steadily declining production of these materials. To some extent, this decline can be attributed to drastic reductions in state highway construction programs occasioned by inflation and declining gas tax revenues in key fly ash producing states, such as Ohio and Pennsylvania.

Table I-8

ESTIMATED ANNUAL PRODUCTION OF
LIME-FLY ASH-AGGREGATE BASE MATERIAL
IN THE UNITED STATES
(Thousand tons)

<u>Year</u>	<u>Total LFA Production</u>	<u>LFA Production In Chicago Area</u>	<u>Percent - Production In Chicago</u>
1970		660	
1971		1,010	
1972		490	
1973	1,050	660	62.9
1974	778	660	84.8
1975	610	500	82.0
1976	801	680	84.9
1977	736	630	85.6
1978	755	650	86.1
1979	<u>738</u>	<u>600</u>	<u>81.3</u>
TOTAL		6,540	

NOTE: Poz-O-Pac patents expired in 1979.

SOURCE: I U Conversion System, Inc., Horsham, Pennsylvania
and American Fly Ash Company, Chicago, Illinois

There is, however, potential for a considerable increase in the amount of fly ash which could be used for pozzolanic base course construction in many states because of the economic and environmental benefits to be derived from using such materials.

Materials and Mixture Proportions. The key to successful pavement performance with lime-fly ash-aggregate (LFA) mixtures is good mix design and sound construction techniques. The quality of the principal constituents of these mixtures must also be assured in order to design an acceptable mix.

Lime. The term lime, when used in reference to LFA mixtures, can include various chemical and physical forms of quicklime, hydrated lime, or hydraulic lime. The most commonly used forms of lime in LFA mixtures have been monohydrated high calcium and dolomitic hydrated limes. However, in recent years, increasing demand for lime products, plus the escalating cost of lime production, have resulted in localized lime shortages or the periodic unavailability of commercial lime for use in the LFA base market. To alleviate such shortages, certain lime producers, such as Marblehead Lime Company in the Chicago area, have combined lime stack dust with their regular hydrated lime, with additions of the stack dust being as high as 80 percent, and marketed this product under the name "polyhydrate." This is considered an acceptable source of lime where it is available in the State of Illinois (Reference I-40).

In other states, such as Ohio, the shortage of lime in some areas has become so severe that there is not a sufficient quantity of lime to blend with stack dust for polyhydrate. Consequently, stack dusts from lime and cement kilns are presently being evaluated as an alternative source to lime. A more detailed discussion of the potential for utilization of lime and cement kiln dusts in road base compositions is presented in another section of this report.

Fly Ash. Quality requirements for the use of fly ash and other pozzolans with lime in plastic mortars and non-plastic mixtures are contained in ASTM C593-76a, "Standard Specification for Fly Ash and Other Pozzolans for Use with Lime." To be considered acceptable for use in LFA mixtures, fly ash must meet the following physical requirements:

Water soluble fraction, maximum percent	10.0
Fineness, amount retained when wet sieved:	
No. 30 (.60 mm) sieve, max. percent	2.0
No. 200 (.075 mm) sieve, max. percent	30.0
Lime-pozzolan strength, or minimum compressive strength, psi:*	
Plastic mixes	
At 7 days, $130 \pm 3^\circ\text{F.}$ ($54 \pm 2^\circ\text{C.}$)	600
After additional 21 days, $73 \pm 3^\circ\text{F.}$ ($23 \pm 2^\circ\text{C.}$)	600
Non-Plastic Mixes	
At 7 days, $100 \pm 3^\circ\text{F.}$ ($38 \pm 2^\circ\text{C.}$)	400

* psi indicates pounds per square inch.

In addition to the above requirements, many state and Federal transportation agencies also specify that the fly ash have a minimum loss on ignition value of 10 percent when determined in accordance with the procedures of ASTM C311. Although ASTM C593 has set no limit on the loss on ignition value for a pozzolan when used with lime, such a provision would be very desirable.

The Illinois Department of Transportation requires that the moisture content of dampened pozzolan shall not exceed 35 percent. The Ohio Department of Transportation specifications do not require that fly ash meet the criteria of Section 7 of ASTM C593 for plastic mixes. The Pennsylvania Department of Transportation specifications require only that pozzolan comply with ASTM C593. In addition, the Federal Aviation Administration (FAA) does not require that the water-soluble fraction of the fly ash be determined, and states that the requirements of ASTM C593 may be waived if it can be demonstrated that a mix of comparable quality and reliability can be produced with lime and/or fly ash that do not meet specified quality criteria (Reference I-41).

The pozzolanic reactivity or lime-pozzolan strength of fly ash is the best indicator of its ability to form cementitious compounds in LFA mixtures. The pozzolanic reactivity of fly ashes is dependent on the following factors:

1. Fineness--the larger the percentage passing the -325 mesh sieve, the greater the surface area and pozzolanic reactivity.
2. Silica and alumina content--the higher the silica, or the silica and alumina, the more reactive the fly ash.
3. Loss on ignition and carbon content--the lower the loss on ignition, the higher the pozzolanic reactivity of the fly ash.
4. Alkali content--the higher the alkali content, the more reactive the fly ash. (Reference I-7).

Aggregates. Since the major proportion of an LFA mixture is composed of aggregate, the quality of the final product is dependent to a large extent on the aggregate used. A wide variety of aggregate types and gradations have been used successfully in LFA compositions. These include crushed stones, sands, gravels, bottom ash, boiler slag, and several types of ferrous slags. Whatever the type and source of aggregate used, the gradation of the aggregate should be such that, when mixed with lime, fly ash, and water, the resultant mixture is mechanically stable and capable of being densely compacted in the field. Furthermore, any aggregate used in LFA base mixtures should consist of hard, durable particles and be free from any deleterious chemicals or organic substances that could interfere with the desired pozzolanic reactions within the mixture.

In general, aggregates with a relatively high percentage of fines (-200 mesh sieve) tend to produce mixtures with somewhat greater durability than the more coarse graded aggregates, although LFA mixtures containing coarser aggregate gradations have usually been more mechanically stable and may possess higher strengths at an earlier age. Over time, however, LFA mixtures containing fine graded aggregates ultimately develop strengths equal to or in excess of mixtures with coarser aggregates. In assessing the relative suitability of different aggregates for use in LFA mixtures, it must be recognized that ultimate strength development appears to be more dependent on the lime-fly ash matrix than on the aggregate (Reference I-42). However, the key to good performance is the use of a well-graded aggregate.

Most, if not all, state and Federal transportation agencies that specify LFA mixtures also specify the quality requirements and range of acceptable gradations for aggregates to be used in such mixtures. Table I-9 compares the gradation and other physical requirements of aggregates for use in LFA mixtures in the states of Illinois, Ohio, and Pennsylvania, as well as the Federal Aviation Administration. From Table I-9, it can be seen that there are basic similarities in these aggregate specification requirements.

Mix Proportions. The relative proportions of each constituent (lime, fly ash, and aggregate) used in LFA mixtures may vary, depending on the materials used and the design criteria to be satisfied. Generally, lime and fly ash contents are designated as a percentage by dry weight of the total mixtures, not including water (Reference I-43). Acceptable mixtures have been used in which the lime content has been as low as 2 percent or as high as 8 percent. Fly ash contents have been found to range from a low of 8 percent to as high as 36 percent. Typically, LFA mixtures contain from 2-1/2 to 4 percent lime and from 10 to 25 percent fly ash. In some cases, small quantities (from 0.5 to 1.5 percent) of Type I portland cement have also been added to LFA mixtures in order to accelerate the initial strength gain of the mix (Reference I-44).

For mix design purposes, LFA mix proportions are developed by determining the lime to fly ash ratio and the lime plus fly ash content. The ratio of lime to fly ash is important because it affects the quality of the matrix in the mix. Lime to fly ash ratios generally are in the range of from 1:10 to 1:2 with ratios of 1:3 to 1:5 being most common. Lime content is established by trial batch procedures to provide for desired strength and durability characteristics of the mix. Factors that tend to increase the amount of lime required are increased aggregate fines (-200 mesh sieve), higher plasticity index of the aggregate particles passing the -40 mesh sieve, and fly ash with a relatively high pozzolanic reactivity.

Table I-9

**AGGREGATE SPECIFICATION REQUIREMENTS FOR LIME-FLY ASH-AGGREGATE
BASE COURSE MIXTURES USED BY VARIOUS STATE
TRANSPORTATION AGENCIES AND THE FEDERAL AVIATION ADMINISTRATION**

AGGREGATE GRADATION REQUIREMENTS
(Percent Passing)

<u>Sieve Size</u>	<u>Illinois</u>	<u>Ohio</u>	<u>Pennsylvania</u>		<u>FAA*</u>
2" (50.0mm)	---	100	100	100	100
1-1/2" (38.1mm)	100	---	---	---	---
1" (25.0mm)	90-100	75-100	---	---	75-100
3/4" (19.0mm)	---	---	52-100	70-100	---
1/2" (12.5mm)	60-100	50-85	---	---	50-85
3/8" (9.5mm)	---	---	36-70	58-100	---
#4 (4.75mm)	40-70	35-60	24-50	45-80	35-60
#8 (2.36mm)	---	15-45	---	---	15-45
#16 (1.18mm)	---	10-35	10-30	25-50	10-35
#40 (0.425mm)	0-25	---	---	---	---
#50 (0.300mm)	---	3-18	---	---	3-18
#100 (0.150mm)	---	---	15 max	6-20	---
#200 (0.074mm)	0-10	1-7	0-10	---	1-12
	(Gravel)				
	0-15				
	(Crushed stone or slag)				

*Gradation for LFA material used in Toledo Airport Project.

OTHER TYPICAL AGGREGATE REQUIREMENTS

<u>Property</u>	<u>Illinois</u>	<u>Ohio</u>	<u>Pennsylvania</u>	<u>FAA</u>
Sodium Sulfate Soundness	25% max.	15% max.	20% max.	12% max.
Los Angeles Abrasion	45% max.	----	55% max.	----
Liquid Limit	----	----	25 max.	25 max.
Plasticity Index	9 max.	----	6 max.	6 max.

The ratio of the lime plus fly ash to the aggregate determines the amount of the matrix which is available to fill the void spaces between aggregate particles. The matrix helps to produce a mix of optimum density and maximize the contact between the cementitious matrix and the aggregate particles. Normally, lime plus fly ash contents in LFA mixtures range from 12 to 30 percent. However, fine graded aggregates generally require a higher percentage of lime plus fly ash to provide satisfactory strength development than well graded aggregates. Also, aggregates with an angular particle shape and rough surface texture require larger quantities of lime plus fly ash than aggregates with rounded and smooth particles (Reference I-45).

The state of Illinois has recently adopted a mix design procedure for lime-fly ash-aggregate compositions as part of its laboratory evaluation program for approval of such mixtures. A copy of this mix design procedure is included in the Appendix.

Moisture Content. Lime-fly ash-aggregate base course mixtures are mixed with water at an optimum moisture content to assure a mix of moist, nonplastic consistency that can be compacted in the field to a maximum density by means of conventional spreading and rolling equipment. The optimum moisture content of a particular LFA mixture is determined in the laboratory by the moisture-density test procedures such as outlined in ASTM C593.

Most state and Federal transportation agencies specify some form of modified compactive effort (10 pound hammer, 18 inch drop) as part of their moisture-density test procedures for LFA mixtures. Pennsylvania is a notable exception, since the PennDOT specification requires a standard compactive effort (5.5 pound hammer, 12 inch drop) to determine the moisture-density relationship of LFA mixtures.

The following table compares the moisture-density test procedures used by the states of Illinois, Ohio, and Pennsylvania, as well as the Federal Aviation Administration, in determining the optimum moisture content for LFA.

MOISTURE-DENSITY TEST PROCEDURES
USED FOR LIME-FLY ASH-AGGREGATE MIXTURES
IN VARIOUS STATES

<u>Name of Agency</u>	<u>Procedure</u>	<u>Hammer Weight (lbs.)</u>	<u>Hammer Drop (inches)</u>	<u>Number of Layers</u>	<u>Number of Blows/ Layer</u>
Illinois DOT	ASTM C593	10	18	3	25
Ohio DOT	ASTM C593	10	18	3	25
Pennsylvania DOT	PTM 106	5.5	12	3	25
Federal Aviation Administration	FAAT611	10	18	5	25

Engineering Properties. Knowledge of the engineering properties of lime-fly ash-aggregate mixtures is important with respect to mix proportioning and pavement structural analysis. The most important of these properties are strength and durability. The properties of LFA mixtures are affected by the characteristics of the lime and/or ash, mix proportions, compacted density, and the curing conditions (time, temperature, and moisture) to which the materials are exposed.

This report discusses significant engineering properties of these mixtures. Since most, if not all, of these properties vary for a given mixture depending on curing conditions, it is necessary to define the curing conditions when reporting data.

Compressive Strength. The most widely used criterion for the acceptability of a pozzolanic base material is the compressive strength test. As a general rule, the higher the compressive strength, within limits, the better is the quality of the stabilized material, provided excessive early strengths are not developed. LFA base materials have the unusual characteristic of developing compressive strength over an extended period of time, depending also on temperature conditions.

The compressive strength development of LFA compositions is most frequently determined in the laboratory by means of the curing procedures outlined in ASTM C593 (7 days at 100°F or 38°C). Typical well-designed LFA mixtures generally develop compressive strengths ranging from 500 to 1,200 psi under these curing conditions. Use of a lignite or sub-bituminous fly ash, which has a relatively high calcium content, may even result in higher 7-day strength values. A minimum compressive strength value of 400 psi is specified in the ASTM C593 procedure.

Actual compressive strength development of LFA base course materials in the field is time and temperature dependent. As the temperature increases, the rate of strength gain also increases. Below 40°F, the pozzolanic reaction, virtually ceases and the mixture does not gain strength. However, once temperatures exceed 40°F, the reaction again continues. In this way, LFA compositions in the field, although they gain no strength during the winter, continue to increase in compressive strength at other times of the year for a long, indefinite period. Compressive strengths in excess of 4,000 psi have been recorded for core specimens taken from LFA base course mixes after several years in the field.

Figure I-9 shows the compressive strength development of a typical LFA base course mixture placed in the Chicago area. This figure shows that approximately half of the strength of this mixture was developed prior to the first winter. During the second and third years, additional strength gains were reported during the summer months as temperatures increased. After the third year, the mix exhibited a compressive strength of approximately 2,000 psi (Reference I-45), although it does not yet appear to have reached its ultimate strength.

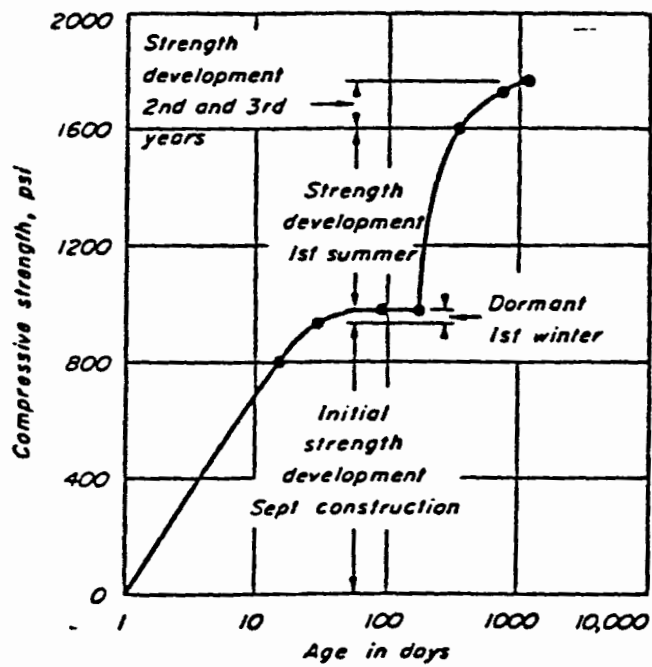


Figure I-9. Compressive strength development of a lime-fly ash-aggregate mixture in the Chicago area.

It should be noted that the compressive strengths of LFA mixtures produced in the Chicago area are generally higher than the strength of comparable mixtures produced elsewhere. The principal reason for this is that most coal-fired power plants in the Chicago area burn sub-bituminous coal, which results in a more reactive fly ash than that of eastern bituminous coals.

Flexural Strength. Many engineers believe that measurement of the flexural strength of LFA mixtures may be a better indicator of the effective strength of the material than compressive strength. Although flexural strength can be determined directly from tests, most agencies estimate the flexural strength of LFA mixtures by taking a ratio of the material's compressive strength. The ratio of flexural strength to compressive strength for most LFA mixtures is between 0.18 to 0.25. An average value of 20 percent of compressive strength is considered to be a fairly accurate estimate of the flexural strength of LFA mixtures (Reference I-47).

Modulus of Elasticity. The modulus of elasticity is a measure of the stiffness or bending resistance of a material. Theoretically, the modulus of elasticity is the ratio of the change in stress divided by the change in strain for a given stress increment.

For materials such as pozzolanic base mixtures, the relationship between stress and strain is not linear and, therefore, it is not possible to determine a constant value for the modulus of elasticity. Moreover, the modulus is different depending on whether it is derived from compressive or flexural testing procedures. Since the flexural modulus is recommended for use in pavement design calculations, and since this value is lower than the compressive modulus, the modulus of elasticity is based on the flexural modulus. For LFA mixtures, the modulus of elasticity is in the range of 1.5×10^6 psi to 2.5×10^6 psi (Reference I-48).

California Bearing Ratio. The California bearing ratio (CBR) test (ASTM D1833) is often used as a way of measuring the comparative strength of soils used as a subgrade for highway and airfield pavements. Because of the high strength of LFA mixtures compared to conventional soils, it is difficult to obtain meaningful values from CBR tests performed on these mixtures. In fact, CBR values of several hundred are not unusual when testing cured LFA specimens. The CBR test is much more applicable for evaluating the improvement in soil bearing characteristics when treating the soil with lime and fly ash (Reference I-49).

Autogenous Healing. One of the most unique characteristics of LFA base course compositions is their inherent ability to heal or re-ment cracks within the material by means of a self-generating mechanism. This phenomenon is referred to as autogenous healing and results from the continuing pozzolanic reaction between the lime and the fly ash in LFA mixtures.

Laboratory tests and field observations have confirmed that autogenous healing does occur and that cracking of LFA mixtures in the field can be corrected to a significant extent. The degree to which autogenous healing occurs depends on the age at which cracking occurs, the degree of contact of the fractured surfaces, curing conditions, the strength of the pozzolanic reaction, and available moisture. Because of the autogenous healing, LFA mixtures are not as susceptible to deterioration under repeated wheel loadings as other materials which do not possess this property. In addition, autogenous healing enables LFA base materials to be more resilient and better able to resist attack from the elements (Reference I-50).

Fatigue Properties. All engineering materials are subject to failure caused by progressive fracture under repeated loading. The flexural fatigue properties of LFA base course materials are important in pavement design analysis. A study of these fatigue properties was made at the University of Illinois by applying loads on beam specimens of LFA materials on a continuous basis at the rate of 450 load applications per minute. Figure I-10 summarizes the results of these tests and relates the number of load applications to failure with the ratio of applied stress to the modulus of rupture of the material.

In analyzing fatigue properties of LFA mixtures, the relationship of strength gain with time must also be recognized. The flexural strength of LFA mixtures, like the compressive strength, increases with time, while the stress level (ratio of applied stress to the modulus of rupture) decreases. Therefore, as the time required to accumulate the number of load applications to failure increases, the actual number of load applications needed for failure also becomes greater. If the gain in strength of the LFA material is sufficiently rapid, or if the applied stress is small, the material may never fail in fatigue (Reference I-51).

Because of the autogenous healing, LFA mixtures are even less susceptible to fatigue failure than other conventional paving materials. This was confirmed by tests conducted on pozzolanic base course materials at the University of Illinois Pavement Test Track Facility. During these tests, it was discovered that if the pozzolanic materials did not fail under the action of repeated loads after only a few load applications, then fatigue failure was not attained during the remainder of the testing program (Reference I-52).

Dimensional Stability. The main causes of volume changes in LFA base materials are variations in moisture, temperature changes, and frost action. For most LFA materials, the first two factors are of greater significance than frost action with respect to dimensional stability.

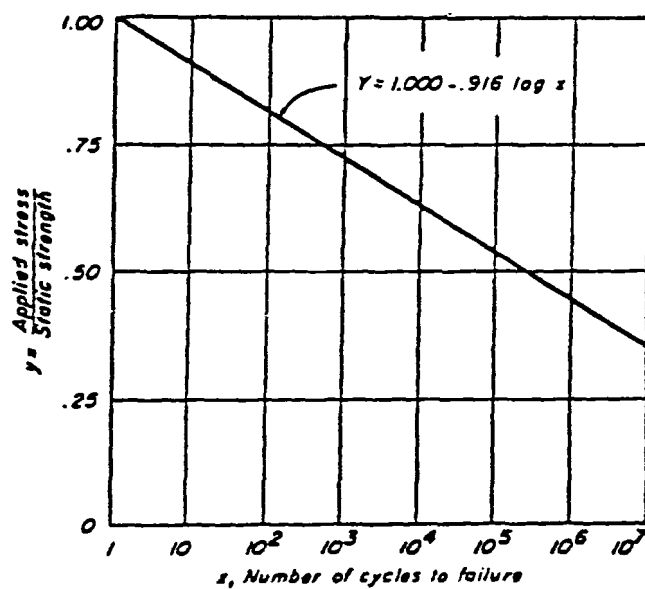


Figure I-10. Flexural fatigue behavior of lime-fly ash-aggregate material.

The change in volume caused by temperature change is expressed as the coefficient of thermal expansion. It is expressed in terms of inches per inch per degree Fahrenheit. Miller and Couturier investigated the thermal expansion for these compositions ranged from approximately 5 to 7 x 10⁻⁶ inches per °F. These values are comparable to those of concrete at the same moisture content. Moreover, the coefficient of thermal expansion increased with the dry density of the mix. Larger percentages of lime and fly ash also tended to increase the coefficient of thermal expansion for LFA mixtures (Reference I-53).

There is no published information on moisture-related volume changes in LFA mixtures. However, it is known from field experience that LFA mixtures exhibit drying shrinkage tendencies (Reference I-54). This is particularly evident when LFA mixtures attain high early strengths and then are exposed to lower temperatures and internal moisture reductions.

Durability. The durability of LFA mixtures is the single property which most affects its performance in the field. Durability refers to the ability of a material to maintain its structural integrity under the in-service environmental conditions to which it is exposed. Cyclic freezing and thawing is the major durability factor that must be considered when evaluating LFA mixtures.

The extent to which an LFA base material will be exposed to cyclic freeze-thaw action is influenced by geographic location, variability in climate, location of the LFA material within the pavement structure, and the design characteristics of the pavement. The major concern of producers and users of LFA mixtures is that the material be durable enough to withstand the effects of the first winter of cyclic freezing and thawing.

During the early development and use of LFA mixtures, the durability of pozzolanic materials was evaluated by a freeze-thaw test patterned after an existing procedure that had been developed for evaluating the hardening of soil-cement compositions (ASTM D658). Essentially, the freeze-thaw test procedure for LFA mixtures involved making triplicate cured specimens, exposing them to 12 cycles of freezing and thawing (24 hours of freezing at -10°F and 23 hours of thawing at 73°F), wire brushing each specimen 25 times after each cycle, and recording the loss in weight after brushing. This freeze-thaw test procedure was incorporated into ASTM C593 and the acceptance criteria required a maximum 14 percent weight loss after 12 freeze-thaw cycles.

Over the years, a substantial amount of laboratory test data was collected which correlated compressive strength development for many different LFA compositions with performance in the ASTM C593 wire brush freeze-thaw test. With few exceptions, these data clearly established the fact that compacted LFA mixtures which were cured in the laboratory for 7 days at 100°F and which developed average compressive strengths in excess of 400 psi were able to pass the freeze-thaw test with less than the maximum allowable 14 percent weight loss. As a result, a minimum compressive strength requirement of 400 psi after 7 days curing at 100°F was introduced into the ASTM C593 specification.

The principal objections to the ASTM C593 wire brush freeze-thaw test procedure were:

1. The 24-hour freeze cycle at -10°F and the 23-hour thaw cycle at 73°F were not truly representative of actual freeze-thaw conditions which LFA materials were exposed to in the field.
2. A total of 12 cycles of freezing and thawing may or may not be indicative of the actual number of freeze-thaw cycles to which a road base material will be exposed during a typical winter.
3. The use of a wire brush to administer 25 strokes across the exposed face of the cylindrical test specimen after each freeze-thaw cycle seemed an arbitrary and unnecessarily severe measure of the LFA material's ability to withstand freezing and thawing.

A stabilized base materials durability study, funded by the Federal Highway Administration (FHWA) and the Illinois Department of Transportation (IDOT), was undertaken at the University of Illinois in 1972 to evaluate these objections. Some of the findings of this comprehensive investigation are:

1. A standard Illinois freeze-thaw cycle was developed for use in durability testing of stabilized materials. This standard cycle is shown in Figure I-11, which also shows that pavement temperatures within a base course can vary by as much as 3°F , depending on pavement design (Reference I-55).
2. An automatic programmable freeze-thaw curing cabinet was built to provide for exposing LFA test specimens to any desired range and variation of temperature.
3. A heat transfer model was developed to compute actual pavement temperatures at different locations within an LFA base in relation to air temperature and pavement layer thicknesses.
4. A vacuum saturation test procedure was found to correlate very well with the compressive strength of LFA road base test specimens after 5 and 10 standard Illinois freeze-thaw cycles in the programmable curing cabinet (Reference I-56).

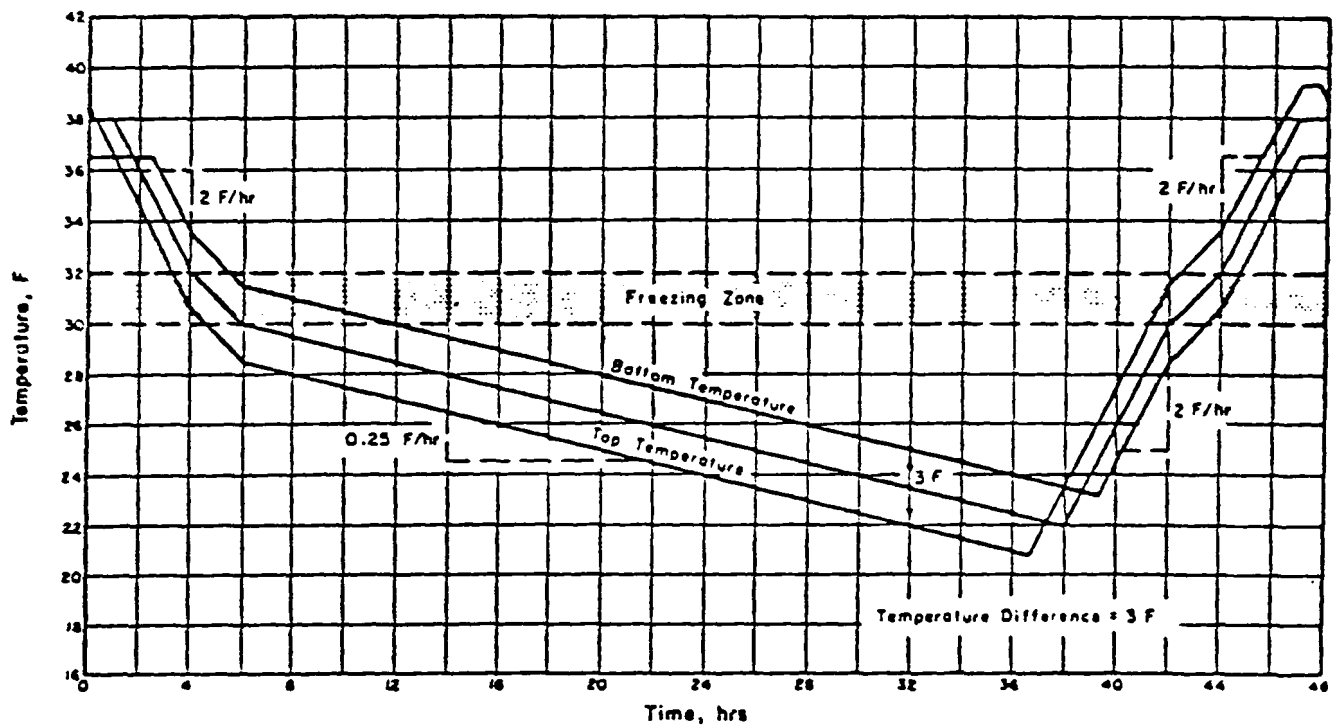


Figure I-11. Standard freeze-thaw cycle for Illinois.

Based on the findings of these studies, ASTM Committee C7.07 in 1976 revised ASTM C593 to replace the freeze-thaw test with the vacuum saturation test procedure, with the additional stipulation that the minimum acceptable compressive strength after vacuum saturation must be 400 psi. The vacuum saturation test procedure is described in ASTM C593-76 and found in the Appendix.

Permeability. LFA mixtures containing normal hydrated lime have an initial permeability in the range of 3.5×10^{-5} centimeters per second, as measured by the falling head permeability tests. This initial permeability decreases rapidly over the first several days of curing, approaching 3.5×10^{-6} cm/sec after 5 days of curing and 2.5×10^{-6} cm/sec after 13 days of curing. It has been reported that a special LFA blend containing high-early strength additives was evaluated in the laboratory by the Corson Lime Company in 1971 and found to have a permeability of 7×10^{-8} cm/sec after 7 days of curing (Reference I-57).

Although these data are somewhat sketchy, they are illustrative of the low permeability of LFA base materials and the fact that the permeability of the material continues to decrease over time as the pozzolanic reaction takes place. The permeability of LFA base is especially low when compared to that of crushed stone base and is also considerably lower than bituminous base.

LFA Pavement Thickness Design Considerations. The thickness design of pavements with LFA (or LCFA) base course mixtures is based on the structural layer equivalency concepts developed from the AASHTO Road Test, as well as recognized structural design methods. In those states where a considerable amount of experience and performance history is available for LFA base materials, such as Illinois, Ohio, and Pennsylvania, the equivalency approach is used and is quite adequate for pavement design. A total of 34 states make use of structural layer coefficients in pavement design (Reference I-58). In other states where experience and familiarity with the materials is not as extensive, a more rigorous approach using theoretical pavement design analysis is used.

AASHTO Structural Equivalency Method. The AASHTO Road Test sponsored by the American Association of State Highway Officials, was conducted in Ottawa, Illinois between 1958 and 1960 and involved the testing of six specially constructed roadway loops using either rigid or flexible pavement. The flexible pavements were underlain with either crushed stone, gravel, cement-treated base, or bituminous-treated base. No lime-fly ash-aggregate base was used in the AASHTO Road Test. During the 25-month test period, over 1.1 million total vehicle axle loads were applied to the test pavements and bridges.

One of the objectives of the AASHTO Road Test was to determine the relationships between the number of repetitions of different axle loadings and configurations with the performance of different types of pavement and different thicknesses of bases and sub-bases. A serviceability rating system on a scale of 0 to 5 was developed and correlated with axle loadings and pavement characteristics such as pavement profile, rutting, cracking, and patching. By means of mathematical models and regression analysis, pavement performance was related to axle loadings and an empirical structural number was developed for layered flexible pavement systems (Reference I-59).

A more comprehensive discussion of the findings of the AASHTO Road Test and the theory involved in development of the findings of the AASHTO Road Test and the theory involved in development of pavement performance equations may be found in Report 5 of the AASHTO Road Test (Reference I-60).

The structural number, which relates pavement layer thickness to pavement performance is given by the following equation:

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3$$

where

SN = structural number or structural capacity of the pavement

D_1 , D_2 , and D_3 are the thicknesses of the surface base, and sub-base, respectively.

a_1 , a_2 , and a_3 are the equivalency values or structural coefficients for each layer.

The structural number for a flexible pavement is a function of the anticipated traffic loading, subgrade, and environmental conditions, and required performance level. Nomographs have been developed to relate these factors and determine the required structural number for a given set of conditions. The value of the structural number (SN) generally ranges from 1.0 to 6.0. The design methodology for pavement systems based on the structural equivalency method developed from the AASHTO Road Test is contained in the AASHTO Interim Guide for Pavement Structures (Reference I-67).

The acronym AASHTO refers to the same organization, which is now known as the American Association of State Highway and Transportation Officials. At present, 32 states make use of the AASHTO Interim Guide, either in their entirety or with some modification.

The fundamental premise for selection of values for structural coefficients a_1 , a_2 , and a_3 is that there is a ratio of thicknesses between different materials such that pavements constructed in a similar manner will have identical performance records. However, this assumption is not necessarily valid under all conditions (Reference I-62).

From the AASHTO Road Test, the following structural coefficients were determined:

a_1	Bituminous concrete wearing surface	0.44
a_2	Bituminous stabilized base	0.30-0.35
a_2	Portland cement stabilized base	0.30-0.35
a_3	Crushed stone base	0.13-0.14
a_3	Gravel sub-base	0.11

Since the AASHTO Road Test did not evaluate the performance of pozzolanic base course materials, the University of Illinois, which had begun its research on LFA materials in 1956, undertook a pavement test track study in 1960. This test track study, sponsored by the National Lime Association, involved a comparison of the performance of crushed stone and LFA bases. A circular test tract, with a 16' centerline diameter, was housed in a 40 by 60 foot quonset-type building on the University's campus. Dynamic wheel loadings were applied to the test track by two rubber tired wheels mounted on a rotating loading frame. The test track was also equipped with water level control, provisions for varying the loading and speed of the wheel frame, and electronic deflection gauges mounted in the test pavement.

In all, a total of six test sets were run, three for each base type. Each test set comprised six separate pavement sections. Crushed stone base thicknesses were varied from 4 to 12 inches. Pozzolanic base sections were varied from 4 to 6 inches. Various surface materials, including chip seal coat and asphaltic concrete, were used. The number of dynamic wheel load applications generally ranged from 100,000 to 400,000 for crushed stone bases to in excess of 1 million for pozzolanic bases.

Based on the comparative performance of pozzolanic and crushed stone base materials from the University of Illinois Test Track Study, and using a structural coefficient of 0.14 for the crushed stone base, Ahlberg and Barenberg (Reference I-62) recommended the following structural coefficients for pozzolanic base materials, assuming adequate cured strength at time of loading:

<u>Quality</u>	<u>Compressive Strength, psi (7 days @ 100°F)</u>	<u>Recommended Structural Coefficient</u>
High	Greater than 1,000	$a_2 = 0.34$
Average	650 to 1,000	$a_2 = 0.28$
Low	400 to 650	$a_2 = 0.20$

Pozzolan base course materials have been used to a greater extent in Illinois, Ohio, and Pennsylvania than in any of the other states. Each of these three states makes use of structural coefficients in the design of layered flexible pavements. However, because of differences in environments, traffic, and construction practices from one state to another, each state establishes layer coefficients applicable to its own practices and based on its own experience. The structural coefficients for LFA base course mixtures in each of these states are:

Illinois	0.28
Ohio	0.28
Pennsylvania	0.40

Until 1976, the structural coefficient for LFA base materials in Pennsylvania had been 0.30. However, at that time the Pennsylvania Department of Transportation changed its structural coefficients for LFA and aggregate-cement base materials from 0.30 to 0.40, which is equivalent to bituminous concrete base course.

These changes resulted from the findings of a two-year pavement test track study initiated in 1972 at Penn State University. The purpose of the study was to investigate the structural coefficients of four stabilized base materials used in Pennsylvania, as a logical followup to the AASHTO Road Test. A total of 17 test sections were constructed on a one-mile long oval with two tangent sections, one in cut and one in fill. Among the 17 test sections were two sections using LFA base materials, each of which was 8 inches in thickness. The material for these test sections was supplied by a commercial producer with a pugmill plant in Lancaster County, Pennsylvania and consisted of 3 percent lime, 15 percent fly ash, and 82 percent crushed limestone aggregate.

Over 1 million equivalent 18 kip wheel load applications were applied to each of the pavement test sections during the two-year loading period. It is important to recognize that this type of loading is equivalent to that normally applied on interstate facilities and is far in excess of the wheel loadings experienced on most other facilities. The pavement serviceability of all test sections was monitored throughout the test period by means of several different surface profile measurements, together with an evaluation of cracking and rut depths. The study concluded that

aggregate-cement provided the best pavement performance, with LFA and bituminous concrete base being about equal (but not performing quite as well as aggregate-cement), and aggregate-bituminous base providing the least performance of the four alternatives (Reference I-63).

When using the AASHTO equivalency method of design it is essential to keep in mind that, in addition to equivalent thickness values for various pavement layers, certain specified minimum thicknesses must also be provided. These minimum thickness values are based on the layer thicknesses required to support the heaviest anticipated wheel loadings for different pavement uses without inflicting any structural damage to the pavement layers. Minimum asphalt surface thicknesses are recommended by the Asphalt Institute and are also contained in design manuals used by different state transportation agencies. Table I-10 summarizes recommended pavement surface thicknesses, as suggested by the Asphalt Institute (Reference I-64). These minimum surface thicknesses are used in computation of alternative base thicknesses for economic evaluation.

In order to assess the relationship of using different structural coefficients for different base course materials, the required thickness of crushed stone, LFA, and bituminous concrete base materials have been computed for different structural numbers using structural coefficients from Illinois, Ohio, and Pennsylvania. These comparative thicknesses form the basis for an economic comparison of LFA and other base course alternatives, which is presented later in this report.

The following is a sample computation using a structural number of 4.00 with Illinois structural coefficients of 0.13 for crushed stone base, 0.28 for LFA base, 0.33 for bituminous base, and 0.40 for bituminous surface. According to Table I-10 a minimum of 3 inches of bituminous surface material is required when using either a bituminous base or a pozzolanic base. A minimum of 5 inches of bituminous surface material is required when using a crushed stone base. In this sample computation, no sub-base material was used.

The various thicknesses of the three road base alternatives for this example are computed as follows:

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3 \text{ where } SN = 4.00 \text{ and both } a_3 \text{ and } D_3 = 0$$

$$\text{Bituminous Base: } 4.00 = (.04) (3.00) + (.33) (D_2); \quad .33 D_2 = 2.80;$$

$$\underline{D_2 = 8.5 \text{ inches}}$$

$$\text{Pozzolanic Base: } 4.00 = (.40) (3.00) + (.28) (D_2); \quad .28 D_2 = 2.80;$$

$$\underline{D_2 = 10.0 \text{ inches}}$$

$$\text{Crushed Stone Base: } 4.00 = (.40) (5.00) + (.13) (D_2); \quad .13 D_2 = 2.00;$$

$$\underline{D_2 = 15.4 \text{ inches}}$$

Table I-10

RECOMMENDED MINIMUM THICKNESSES FOR
ASPHALT SURFACES* USING DIFFERENT BASE
COURSE MATERIALS IN DIFFERENT APPLICATIONS

<u>APPLICATION</u>	<u>DESCRIPTION</u>	<u>STRUCTURAL NUMBER</u>	<u>MINIMUM SURFACE THICKNESS (INC.)</u>		<u>BASE COURSE TYPE</u>
			<u>BITUMINOUS BASE</u>	<u>STABILIZED AGGREGATE BASE</u>	<u>UNBOUND AGGREGATE BASE</u>
Very Heavy Duty	Interstate routes	4.0 and above	4	4	6
Heavy Duty	Major through- fares Truck Terminals	3.0 and above	3	3	5
Medium Duty	Residential streets Commercial drives	2.0 to 3.0	2	2	4
Light Duty	Auto parking Driveways	Less than 2.0	1-1/2	1-1/2	2-1/2

*The term asphalt surface includes the combined thickness of both the wearing surface and the binder or leveling course.

NOTE: The Pennsylvania Department of Transportation revised their minimum surface thickness requirements on February 20, 1980 to require that a minimum of 3-1/2 inches of asphalt surface (2 inch binder and 1-1/2 inch wearing surface) be placed over all non-bituminous base materials.

Table I-11 summarizes the results of similar computations performed for pavement structural numbers ranging from 2.0 to 6.0 for Illinois, Ohio, and Pennsylvania flexible pavement designs.

Other Pavement Thickness Design Approaches. In situations where performance data and/or experience with LFA materials are not available, the pavement thickness design should be based on the anticipated strength of the pozzolanic base at the time of loading. Since LFA materials continue to gain strength over time, fatigue due to repeated wheel loadings is generally not a factor. Instead, the number of wheel load applications to be carried during the first winter and the early strength of the base material are more critical to the analysis of the pavement.

The structural capacity of pavements with LFA base materials can be calculated from the material properties and relative layer thicknesses by means of the Westergaard Slab Theory, the Elastic Layered System Theory, or Meyerhof's Ultimate Load Theory. Since procedures have not been standardized for using any of these more theoretical analytical methods for design of LFA pavements, the details of these methods are not discussed in this report.

Applications and Limitations of LFA Materials. Over the past twenty-five or more years, LFA materials have been used in a wide variety of pavement applications. As with all paving materials, LFA is most effective when properly designed, mixed, and handled and should only be used under the proper conditions.

LFA mixtures have been successfully used as base and sub-base material in flexible pavement systems and as a sub-base for rigid pavements. However, it is important that the time interval between placement of LFA base and the installation of a bituminous wearing surface or rigid pavement not be too long or else the surface of the LFA base should be sealed with a tar or asphalt to protect the surface from the long-term effects of traffic, weather, or water. Generally, it is advisable to place a bituminous surface over the LFA base the day after the base has been installed.

Besides its successful use as a base and sub-base, LFA has also been used as a shoulder material. In some areas, LFA use as a shoulder material has met with limited success. This is probably due to several reasons. One is that shoulders are normally covered with a thinner layer of stone chips or bituminous wearing surface than a base course. This affords less protection from freezing and thawing, not to mention the effects of occasional heavy truck traffic. Secondly, in northern states like Illinois, shoulders often receive a heavy dose of road salts during the course of a winter and exposure to such salts has sometimes had deleterious effect on the material (Reference I-65).

Table I-11
THREE STATE COMPARISON OF FLEXIBLE PAVEMENT THICKNESS DESIGNS

Structural Number (SN)	Asphalt Wearing Surface			Aggregate Sub-Base (.11)	ILLINOIS			OHIO			PENNSYLVANIA			
	Ohio .35	Ill. .40	Pa. .44		Aggre- gate Base (.13)	Bitu- minous Base (.33)	Pozzo- lanic Base (.28)	Aggre- gate Base (.14)	Bitu- minous Base (.35)	Pozzo- lanic Base (.28)	Aggre- gate Base (.14)	Bitu- minous Base (.40)	Pozzo- lanic Base (.30)	(.40)
2.0		1.5"		0		4.25"	5.0"		4.25"	5.3"		3.4"	4.5"	3.4"
		2.5"		0	7.7"			8.0"			6.4"			
2.5		2.0"		0		5.15"	6.1"		5.15"	6.45"		4.1"	5.4"	4.1"
		4.0"		0	6.9"			7.9"			5.3"			
3.0		2.0"		0		6.7"	7.9"		6.6"	8.25"		5.3"	7.1"	5.3"
		4.0"		0	10.8"			11.4"			8.9"			
3.5		3.0"		0		7.0"	8.2"		7.0"	8.75"		5.5"	7.3"	5.5"
		5.0"		0	11.5"			12.5"			9.3"			
4.0		3.0"		0		8.5"	10.0"		8.4"	10.5"		6.7"	9.0"	6.7"
		5.0"		0	15.4"			16.1"			12.9"			
4.5		3.0"		6"		8.0"	9.4"		8.0"	10.0"		6.3"	8.4"	6.3"
		5.0"		6"	14.2"			14.9"			11.7"			
5.0		3.0"		8"		8.9"	10.4"		8.8"	11.0"		7.0"	9.3"	7.0"
		5.0"		8"	16.3"			17.0"			13.7"			
5.5		4.0"		8"		9.2"	10.8"		8.7"	11.5"		7.2"	9.5"	7.2"
		6.0"		8"	17.1			18.0"			14.2"			
6.0		4.0"		10"		10.0"	11.8"		10.0"	12.5"		7.9"	10.5"	7.9"
		6.0"		10"	19.2"			20.0"			16.2"			

Aside from proper mix design and blending, the key to good performance with LFA pavements is in adequate field compaction. Most field problems attributed to LFA base over the years seem to have been the result of improper compaction during placement, inadequate moisture control at the mixing plant, placement of the material on a poorly prepared subgrade, or placing the material under adverse weather conditions (Reference I-66).

Durability and Late Season Construction. Durability is the most important single property related to the performance of LFA materials, particularly resistance to cyclic freezing and thawing. There are two schools of thought with respect to late season construction using LFA materials. One holds that unless the pozzolanic material is able to develop a certain level of cementing action and resultant strength, it will be unable to withstand the disruption forces associated with the initial winter freeze-thaw cycle. Since cementing action and strength development is time and temperature dependent, it is felt that material placed beyond a certain cutoff period during the construction season may be unable to develop the strength (and durability) needed for freeze/thaw resistance (Reference I-33).

The other school of thought concerning late season construction holds that, regardless of cementing action, as long as the LFA mix is placed above a certain minimum temperature, contains a well-graded aggregate, and is placed to a sufficient depth to support anticipated wheel loadings, the mechanical stability of the base material will be adequate to support wheel loadings until the following spring. At that time, strength development can proceed as normal (Reference I-68). It should be pointed out that this premise is not necessarily applicable to facilities carrying medium to heavy traffic loadings.

Each of these two schools of thought are discussed in greater detail in terms of how they affect late season construction using LFA materials.

Strength Development and Construction Cutoff Date. During the durability study program performed at the University of Illinois, Thompson and Dempsey evaluated the late season construction for LFA materials in terms of a residual strength concept. The residual strength is the strength of a stabilized material at the conclusion of the first winter of cyclic freezing and thawing. According to Thompson and Dempsey, some residual strength, greater than a minimum tolerable strength, is needed to assure satisfactory pavement response, in terms of durability. Figure I-12 illustrates the residual strength concept and the relationship of residual strength to minimum tolerable strength.

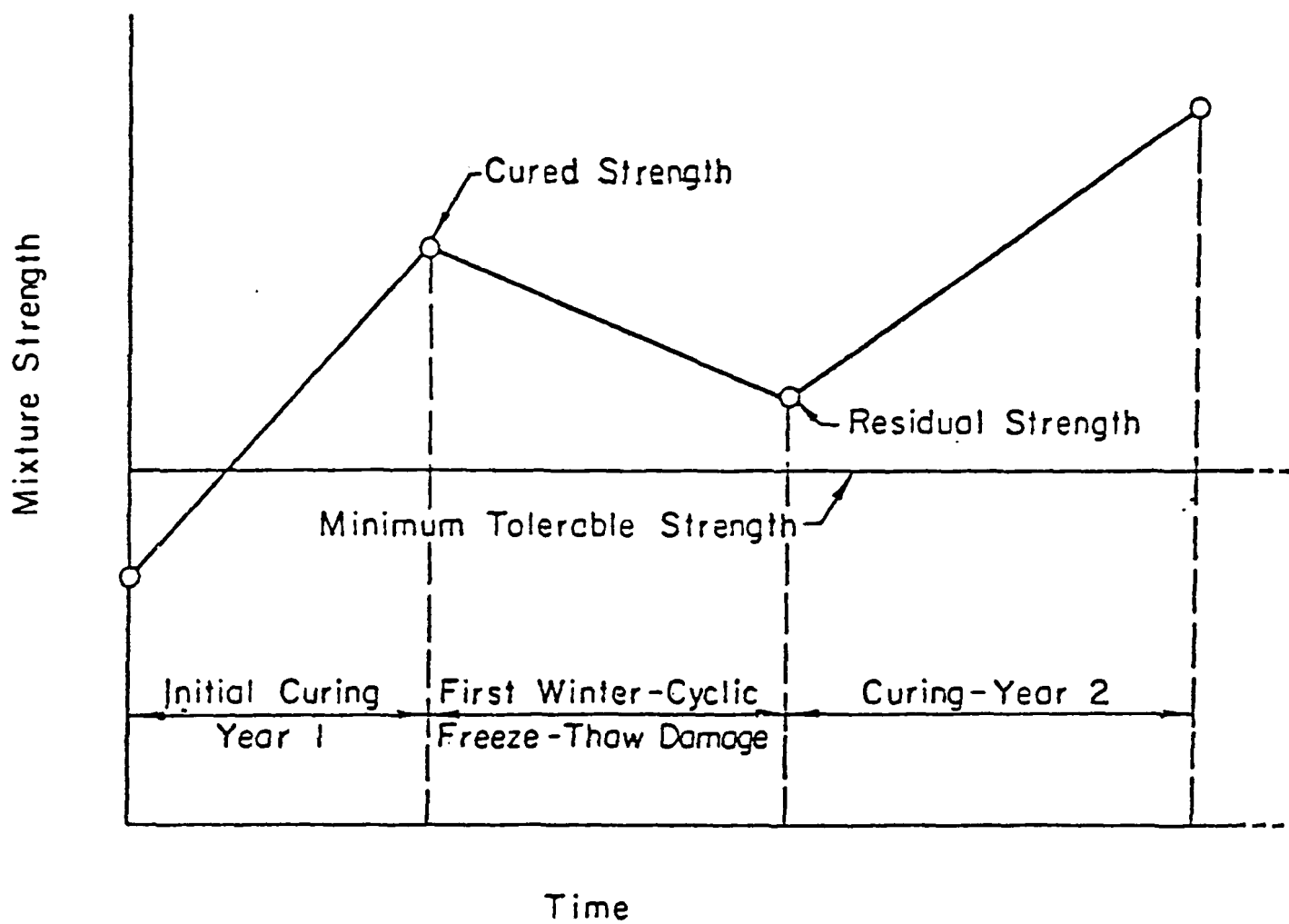


Figure I-12. Residual strength concept for lime-fly ash-aggregate mixtures.

To assure a sufficient cured strength by the onset of the first freeze-thaw cycle, strength development was correlated with degree-days of curing. Since strength development ceases at temperatures below 40°F, degree-days are sometimes computed with a 40°F base temperature. Although degree-days of curing can be related to compressive strength in the laboratory, field curing occurs at varying temperatures. It must also be recognized that degree-days of curing at higher temperatures results in higher strength than with the same number of degree-days at lower temperatures.

By analyzing local weather records, the number of degree-days from any particular date can be determined, using a selected base temperature. Normally, this is based on the coldest late season temperature or earliest winter over a twenty-year period of time. These degree-days represent curing according to air temperatures and not pavement temperatures. However, this type of analysis does enable an engineer to select a construction cutoff date, after which no LFA base material is usually installed without special permission. This concern over late season construction definitely limits the period of time during which LFA base materials can be placed on State and Federally funded highway projects.

State transportation agencies using LFA do specify certain construction cutoff dates, beyond which placement of LFA materials is not permitted unless authorized in writing. In Illinois, LFA is allowed to be placed after September 15th only if test specimens are able to attain the following laboratory compressive strengths:

REQUIRED COMPRESSIVE STRENGTH (psi) -
14 DAY CURE AT 72%

<u>TRANSITION DATE</u>	<u>NORTHERN ZONE</u>	<u>SOUTHERN ZONE</u>
September 15	700	650
October 1	850	700
October 15	950	850

The above transition dates must be verified by samples of LFA material, representative of July production, submitted to IDOT for laboratory testing by August 15. Approval of a particular transition date is based on consideration of cured strength characteristics determined from test results and predicted during degree-days.

In Ohio, the construction cutoff date is September 15th on pavements to be opened to traffic during the summer, fall, and winter months of the construction year. On pavements which are to be opened the following spring, LFA base may be placed later than September 15th but, after that date, a bituminous curing coat and a minimum of one overlying pavement course must be constructed within 72 hours of final compaction of the base. In no case shall LFA be placed during rain or when the temperature is below 40°F in the shade. The material is not allowed to remain uncovered during the winter months.

According to Pennsylvania DOT specifications, LFA is permitted to be placed on State highways only between April 15 and September 21. The late season cutoff date of September 21 was established for selected engineering districts in Pennsylvania where LFA is available as a result of a special study performed by several Penn DOT materials engineers in 1975. This study developed a failure criterion for LFA mixtures and statistically evaluated actual temperature data in certain areas of the State in order to determine failure problems for given placement locations and dates.

The failure criterion for this study was based on a correlation between the results of the wire brush freeze-thaw test and the double punch tensile test method developed at Lehigh University (Reference I-69). A total of 231 LFA samples were tested to develop a relationship between double punch tensile strength and freeze-thaw failure (14 percent weight loss within 12 freeze-thaw cycles). From this relationship, a probability of failure was determined for various tensile strength ranges.

Tensile strength development was then related to curing at several different temperatures to establish a tensile strength vs. degree-day correlation. Then 26 years of temperature data from first order weather stations from the Philadelphia, Harrisburg, and Pittsburgh areas were statistically analyzed by computer. Air temperatures were correlated to reflect base course temperatures and a theoretical frequency of occurrence for various temperatures was established.

A family of curves was developed relating projected tensile strength to frequency of occurrence for different dates. September 21 was selected as a cutoff date because the probability of failure is only one percent on that date (Reference I-70).

Regardless of the method used, there seems to be a reasonably close correlation among the northern states which are principal LFA users, as far as construction cutoff dates are concerned. Despite cutoff dates, it is always possible to make use of additives, such as portland cement, to increase the rate of strength development during the later stages of the construction season. At present, Illinois appears to have the best system for evaluation and possible approval of late season compositions and extension of the construction cutoff date.

Mechanical Stability. A study was performed in 1975 to evaluate LFA pavement base thickness for residential streets in Toledo, Ohio as a function of accumulated service time. The purpose of the study was to determine whether a pozzolanic base placed during the latter part of the construction season could reasonably be expected to have sufficient strength to withstand traffic loads during the ensuing winter and before spring temperature rises could develop significant strength-gaining reactions in the mix.

The study involved the following steps:

- Developing an estimate of travel demand per dwelling unit for a planned 90 unit residential subdivision.
- Apportioning the travel demand in terms of vehicle types and axle load groupings.
- Estimating the number and types of vehicles associated with residential construction and translating this estimate into equivalent 18 kip single axle loads.
- Simulating the average daily traffic on a typical subdivision street during construction and after complete development.
- Generating an estimated accumulation of 18 kip single axle loadings as a function of time.
- Using equations derived from the AASHTO Road Test for a given subgrade condition, determine the required structural number (SN) for the pavement as a function of accumulated pavement service time.
- Compute the required thickness of pavement layers from the pavement structural number and from structural coefficients accepted by the City of Toledo.

Based on calculations for design traffic number, accumulations of equivalent 18 kip single axle loadings for 6 months increments, and an assumed soil CBR value of 3, the pavement structural number (SN) was related to allowable wheel load repetitions, based on the AASHTO Road Test equation. For each six-month increment, the required percentage of total pavement SN was computed. Assuming a 2-inch asphalt wearing surface and an LFA design coefficient of 0.28, the required thickness of LFA base course for each time increment was also computed.

It was concluded from this study that a six-inch thick layer pozzolanic base can withstand the traffic service requirements placed on it during the first year, even without any cementing action. Essentially, the uncemented LFA base was considered as structurally equivalent to a crushed stone base during the first year of service. Computations of the required thickness of crushed stone base showed that a six-inch stone layer was adequate for support of anticipated wheel loadings during the first year (Reference I-71).

This is significant because a substantial percentage of LFA base material is placed during late season due to awarding of contracts and scheduling of work. One LFA producer in northern Ohio has reviewed his annual LFA tonnage figures for the past five years and discovered that approximately 50 percent of all LFA base material from his plant is produced after September 1st and 32 percent is produced after October 1st. Therefore, enforcement of a construction cutoff date of September 15th in Ohio results in a loss of approximately 40 percent of LFA tonnage each year on State projects (Reference I-72). In many instances, this carries over to municipal work, where State highway specifications are often adopted verbatim by local officials.

One exception is the City of Toledo, Ohio, which is now a regular user of LFA base. The City of Toledo has a supplemental specification for Item 835 Aggregate-Lime-Fly Ash Modified Base. This is essentially the same material specification as that of the Ohio Department of Transportation (ODOT). A copy of the City of Toledo supplemental specification is in the Appendix. There is, however, one notable difference between the City of Toledo and the ODOT specification with respect to the construction season. The City of Toledo specification states that Aggregate-Lime-Fly Ash Base Modified shall be placed between April 1 and November 1 and only when the temperature in the shade is 40°F or higher. Placement of the material prior to April 1 or after November 1 must be authorized in writing by the Commissioner of Engineering and Construction or his authorized representative. To date, the City of Toledo has experienced no problems with LFA base material placed after ODOT September 15th cutoff date and even LFA base installed November 1st (if temperatures permit) has performed acceptably (Reference I-73). The City does insist that the LFA base be overlaid with asphalt as quickly as possible and, during late season construction, efforts are sometimes made to keep traffic off newly paved projects.

Another municipality using LFA base is the City of Lancaster, Pennsylvania. When State funds are involved, the City does not place LFA base after the Penn DOT September 21st cutoff date. If no State funds are involved, LFA base has been placed as late as December 1st with no subsequent problems, provided the compacted surface is wet down and covered with black top the following day. It was also felt that restraining the LFA base between curbs results in better performance (Reference I-74).

Although there are numerous examples of successful LFA base placement after State construction cutoff dates, acceptable pavement performance depends on a combination of freeze-thaw resistance and support of accumulated wheel loadings. Therefore, on heavier traffic facilities, adherence to established cutoff dates would appear to provide an adequate margin of safety to assure desired performance, while extension of such dates may be warranted on more lightly traveled facilities.

LFA Use in Highway Construction Projects. Although lime-fly ash-aggregate (LFA) road base materials have been produced and used to some extent in over a dozen states, the particular states in which the largest quantities have been used in highway construction for the longest period of time are Pennsylvania, Ohio, and Illinois. In each of these states, the product is often referred to by its trade name (Poz-O-Pac). LFA is also referred to by different names in state specifications. The material has also been used by the Federal Aviation Administration (FAA) in several airport paving projects.

This section of the report focuses on the quantities of LFA materials used, the types of projects in which these materials have been used, specifications, bidding procedures, and overall product performance in each of these three states, as well as in other selected highway and airport projects.

Illinois. Over the past twenty-five years, the largest tonnage use of LFA road base materials has probably occurred in the State of Illinois, and particularly in the Chicago metropolitan area. The reasons for this are:

1. There is a large amount of comparatively high quality fly ash produced by utilities in the Chicago area.
2. The fly ash broker in the Chicago area has developed and maintained a product-oriented quality control program with the local utility company.
3. Marketing of construction products using this fly ash has been conducted in an aggressive and yet professional manner.

The first known use of Poz-O-Pac, or pozzolanic aggregate mixtures (PAM), as they are known in Illinois, was in the summer of 1955 using a lime-fly ash-boiler slag mix on a Park District project for the City of Chicago. Approximately 800 tons of base material was mixed-in-place on this project. Although this was a crude beginning, the job held up well.

In 1956, the O'Brien Paving Company began operating the first Poz-O-Pac mixing plant in Illinois, located on Chicago Avenue. A total of 25,000 tons of material was produced that first year, with double that quantity the following season. In 1958, the first public road project in Illinois using PAM was installed for the Cook County Highway Department. This was a 3/4 mile section of a county road on the northern edge of Chicago. Installation of the PAM material was overseen by Professor George Hollon of the University of Illinois Civil Engineering Department, who was at that time very active in the research of lime stabilization. The success of this installation prompted Cook County to place yet another PAM base project the following year, this time using the County's own road forces. It was also during 1959 that the first supplemental specification for pozzolanic aggregate material was prepared by the Cook County Department of Highways (Reference I-75).

In 1960, the first PAM mixes using gravel aggregate were produced. Up until that time, the only aggregate used in the lime-fly ash-aggregate mixtures in the Chicago area had been boiler slag because it was plentiful, inexpensive and was a clean, uniform material which produced a well-graded, high strength, high quality base mix (Reference I-76). During 1960, the first County contract that involved contractor bids was let using PAM. The low bidder for that project also purchased a mixing plant and began producing the material. The following year, another contractor was low bidder on a Cook County road project using PAM, and he also purchased a plant and also became a producer. By 1964, the Illinois Department of Highways had compiled a design manual on the use of PAM in municipal road construction throughout the entire state (Reference I-77).

The first use of PAM on a State highway in Illinois was during 1957 on a secondary road project in Chicago. The mix used on this project consisted of 5 percent lime, 35 percent fly ash, and 60 percent boiler slag. Core specimens taken from the base material placed on this project ultimately exceeded 4,000 psi in compressive strength, with some cores approaching 5,000 psi (Reference I-78). After monitoring and sampling this project for a three-year period, Illinois Department of Transportation (IDOT) engineers concluded that PAM could be used as a base course material.

Although PAM has been used extensively on local road projects and in dozens of secondary road projects for IDOT in the Chicago area over the past 25 years, the use of PAM during that time had not been permitted on the IDOT primary road system, except for a project using PAM in the shoulders of Interstate 55 near Chicago. However, during that time the Department has spent over half a million dollars for research involving lime-fly ash mixtures.

Recently, IDOT has developed a new policy allowing PAM to bid as an optional base material on 12 selected primary road projects in Illinois during 1980. Of six projects already let, PAM was low in five bids. Each of the primary road projects was to have a structural number of 5.00 or less and the performance of PAM on these projects is to be carefully monitored (Reference I-79).

On each of these contracts, the low bidder would be given the option of which base course alternate to use on the project and a substitution could be made at a later date prior to installation of the base.

The first construction specification for PAM use on State highways in Illinois was developed in November 1961 and has since been revised eight times. The most recent material specification for PAM was published in April 1980 as a special provision and is not yet included in the Illinois Department of Transportation's Standard Specifications for Road and Bridge Construction.

The new 1980 PAM specifications in Illinois consist of the following:

- Special Provision for Pozzolanic Base Course, Type A
- Supplemental Specification for Section 218. Stabilized Sub-base
- Supplemental Specification for Section 804. Pozzolanic Aggregate Mixture Equipment
- Pozzolanic-Aggregate Mixture (PAM) Laboratory Evaluation/Design Procedure

These specifications were developed through the efforts of a six-man task force over an 18-month time period. The task force consisted of two representatives each from IDOT and the University of Illinois Civil Engineering Department, and one representative each from the PAM producers in northern Illinois and the ash marketing agency supplying these PAM producers. The task force reviewed previous stabilized base research studies, including late-season construction cutoff date procedures, as well as data from IDOT studies of field variability of PAM materials and performance data from previous PAM projects. A copy of each of these specifications is included in the Appendix.

According to the Special Provision for Pozzolanic Base Mixtures, Type A, and the Supplemental Specification for Section 218, Stabilized Sub-Base, the composition of the mixture must be such that test cylinders cured for 14 days at 72°F will have a minimum compressive strength of 600 psi and a minimum lime content of 3.5 percent. A minimum compressive strength of 600 psi is high by comparison with other states using LFA materials, such as Ohio or Pennsylvania.

One of the reasons for the higher strength criterion was because IDOT engineers over the years had observed a difference in strength between laboratory and field mixed PAM specimens. The difference was such that field strengths for the same mixes under very similar curing conditions were approximately 70 percent of comparable laboratory strengths. Therefore, in order to attain 400 psi compressive strength in the field, IDOT engineers now require 600 psi strength in the laboratory to take into account field variability (Reference I-80).

Ohio. In Ohio, aggregate-lime-fly ash has been used on a limited basis in State highway construction as a base course for asphaltic concrete pavement and continuously reinforced portland cement pavement. Aggregate-lime-fly ash is seldom bid as an alternate base material in Ohio because State officials believe that designing for different pavement thicknesses causes a big problem in terms of expense. The legality of optional bids in Ohio is considered questionable.

To date, this supplemental specification has not been included in the Ohio Department of Transportation's (ODOT) Construction and Material Specifications, sometimes referred to as the Blue Book. Until now, it has been decided to allow only a supplemental specification for the material because it had once been covered by a patent and a license was required for its manufacture.

Ten years ago, there were four different producers of aggregate-lime-fly ash in Ohio. As of this time, only one producer in the Toledo area is still supplying this material. The other producers in Ohio stopped marketing the material a number of years ago for several reasons. The principal reason was economics. Until the Arab oil embargo of 1973, the price per square yard for pozzolanic base was not substantially different from black base and there was little or no incentive on the part of ODOT to use the material. In addition a number of areas in the State were experiencing shortages of lime, which at times severely hampered the production of aggregate-lime-fly ash base (Reference I-81).

The initial use of aggregate-lime-fly ash base material on a State highway in Ohio took place in 1960 on State Route 727 in Clermont County. The project was considered experimental and involved 2.5 miles of flexible pavement using various design sections including aggregate-lime-fly ash base. A detailed report on this project was prepared by the ODOT Construction Bureau in 1970, reporting satisfactory performance. At that time, the surface of the road was in excellent condition and samples of the base were very hard. No additional information is presently available.

From 1969 to 1972, aggregate-lime-fly ash was used as a base material on three projects involving continuously reinforced portland cement concrete pavement. One of these pavements is still in excellent condition. The other two projects show a considerable amount of transverse cracking in the surface of the concrete pavement. Because of general problems encountered by ODOT with continuously reinforced concrete pavements, the cause of the cracking could not be attributed solely to the base material. Although the aggregate-lime-fly ash base was not considered the cause of the cracking, a decision was made to discontinue the use of continuously reinforced pavement in Ohio.

Between 1969 and 1972, aggregate-lime-fly ash base was specified in the original bid plans on two projects, one on a two-lane road and one on a heavily traveled section of four-lane road. The pavement of each of these projects is still in good condition after nearly ten years, with only isolated signs of cracking and/or rutting.

Since 1972, aggregate-lime-fly ash has been permitted to be bid as an alternate to 301 bituminous-aggregate base on a total of seven projects. The aggregate-lime-fly ash was used on only two of these projects and not the other five either because the contractor did not elect to use the aggregate-lime-fly ash alternate or because the bid cost of the pavement design using the aggregate-lime-fly ash alternate was higher than the design for the bituminous-aggregate alternate. On one project, constructed in 1973, the aggregate-lime-fly ash was bid as an alternate using a structural layer coefficient of 0.35. To date, the material has performed excellently at this project location. On the other project, built in 1977 aggregate-lime-fly ash was bid as an alternate using a structural layer coefficient of 0.28. To date, there have been no known problems with this installation (Reference I-82).

Aggregate-lime-fly ash base has only been used on eight primary State highway projects in Ohio. The material has been used more extensively in secondary and non-state work, especially in northern Ohio. In general, this material has provided good to excellent performance on the projects in which it has been used and is considered an acceptable base course material by design and construction personnel of the Ohio Department of Transportation (Reference I-83).

Aggregate-lime-fly ash base materials have been used to a greater extent in municipal projects in northern Ohio than on State projects. The material has been used in dozens of road and street projects in the City of Toledo over the years and not a single failure has been reported. Most installations have been made during summer months. In such cases, the material has performed excellently and city officials have been quite pleased. A few projects using aggregate-lime-fly ash have extended as far into the season as mid-November, but still the material did not fail after the first winter.

Over the past several years, aggregate-lime-fly ash base has captured the low bid in 80 percent of all the reconstruction projects in the Toledo area in which it has been bid as an alternate to bituminous base. Although city officials consider aggregate-lime-fly ash to be more economical, each project is designed and evaluated separately and only if substantial cost savings seem possible are alternate bids taken. According to the Construction Engineer for the City of Toledo, their only reservation to the use of aggregate-lime-fly ash is during late season construction in temperatures below 50°F (Reference I-84).

Pennsylvania. Over the past 25 years, LFA or aggregate-lime-pozzolan (ALP) base has been used in over a hundred state highway projects in Pennsylvania, not to mention many miles of local roads and streets in municipalities throughout the state.

Since 1966, there has been a standard specification for aggregate-lime-pozzolan (ALP) base material in Pennsylvania, which is contained in Section 322 of the Pennsylvania Department of Transportation (Penn DOT) Form 408 Specifications. A copy of this specification is included in the Appendix. It has been carried forward in the Penn DOT Form 408 Specifications in an essentially unchanged form since that time. The only specified material testing requirements for the mixture are that the liquid limit of the mixture not exceed 25, the plasticity index not exceed 6, and the durability of the mixture meet the requirements of the Pennsylvania Testing Method (PTM) 110, which is basically the wire brush freeze-thaw test that was formerly part of ASTM C593.

In the preparation of Proctor size (4 inch or 101.6 mm diameter by 4.6 inch or 116.8 mm height) freeze-thaw test specimens, however, the moisture-density test procedures described by PTM 110 for evaluating ALP compositions differ from those used in other states. Pennsylvania is the only state using the standard Proctor density test (5.5 lb. hammer - 12" drop - 3 layers - 25 blows per layer). This procedure has been used for many years by Penn DOT on construction materials such as dense graded aggregate, soil-cement, and cement-treated base and was also chosen as the criterion for ALP base.

Usually, ALP compositions placed in the field are almost always compacted to densities greater than 100 percent of standard Proctor density and that field densities often approach 100 percent of modified Proctor density (10 lb. hammer - 18" drop - 3 layers - 25 blows per layer). This is the procedure used by other states and the Federal Aviation Administration to prepare ALP specimens for strength and durability testing.

The initial reaction to the question of density is that it does not seem to make much difference. However, in designing a base mix, the density of test specimens directly affects both the compressive strength and durability of the specimens, which in turn governs the amount of lime required to achieve acceptable test results. If too much lime must be added to a field mix, overly high strengths may develop soon after placement, resulting in shrinkage cracking. It is, therefore, important to test specimens in the laboratory which approximate field compaction conditions as closely as possible.

Since the expiration of the Poz-O-Pac patents, there is no longer a licensee arrangement for the production and sale of aggregate-lime-pozzolan base. At the time the patents expired, there were at least six Poz-O-Pac producers in the state of Pennsylvania. These production facilities are primarily located in the southeast part of the state, although there is at least one producer from the Pittsburgh area. These producers have supplied Poz-O-Pac using a variety of aggregate types, from blast furnace slag in western Pennsylvania to limestone, traprock, and even some sand and gravel in the Philadelphia area.

The first experience with the use of aggregate-lime-pozzolan (ALP) base on a state highway in Pennsylvania occurred in 1954 when the material was used as a base for the construction of the shoulders along the west side of Germantown Pike (U.S. Route 422) in Plymouth Meeting, west of Philadelphia. The ALP material was mixed in place and compacted to a six-inch thickness. The shoulder was placed too late in the season to allow the material to attain its normal pozzolanic set. The long-term performance of the ALP shoulder was compared with that of an 8-inch crushed stone shoulder material placed directly across the street. Both shoulders were overlaid with a bituminous wearing surface. Within one year, the conventional shoulder exhibited definite signs of early deterioration while the shoulder with the ALP base showed no evidence of distress (Reference I-85).

One of the most outstanding examples of ALP use in Pennsylvania is the reconstruction of Susquehanna Road between York Road and Tennis Avenue in Abington Township, northwest of Philadelphia. The reconstruction of Susquehanna Road was a major construction project on a heavily traveled suburban arterial route. Part of the project was two lanes and part was four lanes undivided. The project was constructed in several sections, which were completed between 1964 and 1965. In one section of the project, the ALP base material was placed as a ramp for trucks to cross a concrete bridge deck. Because of equipment running over this ramp, the material was compacted so hard, it could not be dug, but instead had to be sacrificed.

During construction, a number of Penn DOT engineers who were unfamiliar with Poz-O-Pac witnessed the spreading and compaction of the material. All were very impressed with the ease of operation, uniformity, and quality of the product. Many of them admitted that they had been previously misinformed about the nature of this material and had formulated many wrong ideas about it, such as it being difficult to work with. At the intersection of Susquehanna Road with Fitzwatertown Road, there was a striking comparison between the condition of the pavements for these two roads. The wearing surface over the stone base for Fitzwatertown Road was badly ravelled due to truck traffic, while the paving over the ALP base on Susquehanna Road was in excellent condition (Reference I-86).

Aggregate-lime-pozzolan base materials have been placed in literally hundreds of jobs in Pennsylvania, ranging from small access roads and streets for municipal, industrial, and residential and apartment developments to huge parking lots for shopping centers. Over ten years ago, thousands of tons of Poz-O-Pac were placed as the base course for all parking facilities at the Philadelphia sports complex, which includes the Philadelphia Spectrum and Veterans Stadium.

Typical of the many municipal-scale installations in Pennsylvania in which ALP has been used over the years is the approach roadway to the Penllyn Pike bridge in Montgomery County, northwest of Philadelphia. This bridge was relocated in June of 1965 and the approaches on both sides of the new bridge were built with ALP base and an asphaltic concrete wearing surface.

This was the first roadway application using this material that was done by the Montgomery County highway department. The base course work was completed in two days. However, some material that was not spread the first day was stockpiled overnight. Heavy rainfall occurred that night, but the stockpiled material, although overwet, was still able to be worked and compacted. During construction, the hot, humid weather provided excellent curing conditions.

In October 1965 cores were taken from each side of the bridge. The ALP base material, after being in place for only four months, had already achieved compressive strengths of 1,880 to 2,340 psi. The lime content of the mix used on this job ranged from 3.1 to 3.5 percent (Reference I-87).

Since 1976, when the layer coefficients for ALP and aggregate-cement (AC) base materials were made equal to that of bituminous concrete base course (BCBC), flexible pavement projects in engineering districts 6 (Philadelphia), 8 (Harrisburg), 11 and 12 (Pittsburgh) were to be bid on an alternate basis. Over the past four years, however, very few alternate bids were actually received in any of these four engineering districts. In the first place, Penn DOT has experienced a severe budgetary cutback during this period due to a combination of inflation and past bond indebtedness. Consequently, a sharply reduced number of new construction or reconstruction contracts were let for bid. Most of the projects being awarded over the past two years, at least in the district 6 (greater Philadelphia) area, have involved resurfacing, safety improvements, and intersection reconstruction work. In addition Penn DOT policy is that, when reconstruction projects involve maintenance of traffic, bituminous base is used instead of the aggregate-lime-pozzolan or aggregate-cement alternates. For these reasons, there have been comparatively few opportunities for ALP to bid as an alternate.

During 1979, a decision was made by Penn DOT to discontinue advertising for alternate bids because all of the jobs were going to bituminous base. This decision was also made in order to reduce operating costs because of the extra costs that had been involved in preparing plans and proposals for alternate bidding (Reference I-88).

Overall, the performance of ALP base materials on state highways in Pennsylvania has been acceptable to very good. Out of more than a hundred state projects using APL, only three have involved serious problems considered by Penn DOT engineers to be over and above those associated with normal maintenance. All three projects were in the Philadelphia area, were supplied by the same plant, and involved limited amounts of material being shipped to the job site with moisture contents nearly double that of the optimum value. Clearly, the main source of the problem in each case was poor quality control at the mixing plant, along with inadequate field inspection.

For the most part, the field problems on ALP projects in Pennsylvania have taken the form of longitudinal cracks, alligator cracks, or pot-holes in the road surface. These problems were usually investigated and discussed with the Penn DOT engineer assigned to the particular project. Most, if not all, of these problems were again found to be related to a lack of proper plant or field control and could not be attributed to the material itself.

In addition to state highway work, which has diminished drastically during the past five years, ALP base materials have received rather widespread use in private and municipal work, especially in southeastern Pennsylvania. Although there have been many instances of ALP use in township roads, residential streets, and parking lots, the City of Lancaster is perhaps the best example of ALP use in a municipality. The city has been using the material for many years, with annual usage averaging 10,000 to 12,000 tons.

The city usually prepares alternate bids for either ALP base or bituminous base, but always selects ALP when it is bid because it costs approximately half of what the bituminous base costs. In cases where ALP base in one block abuts bituminous base of equivalent pavement structural number in an adjacent block, there has been no visible difference in the performance of the two pavements under virtually the same traffic conditions.

City officials in Lancaster have been very favorably impressed with both the economics and the performance of ALP base. Where possible, the city uses its own forces to place the material. On a number of occasions, ALP has been placed after the PennDOT cutoff date on non-state projects. If the weather permits, it has even been placed after December 1st, but an asphalt surface was always installed the following day. Thus far, there have been no failures of an ALP project in the City of Lancaster (Reference I-89).

Other States. Although the majority of LFA base course used in state highway projects has been in the three states discussed previously, there has been some use of LFA materials in other states that is also deserving of mention. In the State of Maryland, approximately 22 miles of shoulders on both sides of Interstate 95 north of the Susquehanna River were constructed using LFA base material. A layer of stone chips embedded in an asphalt seal coat was placed over the LFA base. The roadway was opened in the spring of 1963.

Eighteen months later, a thorough inspection was made of the shoulders along the entire stretch of I-95 from the Delaware-Maryland state line to the bridge over the Susquehanna River. The shoulder not underlain by LFA base was constructed using a soil-cement base. During the inspection, there was very obvious rutting and patching of the shoulder underlain by soil-cement, along with settlement next to the edge of the roadway and numerous cracks. The shoulders with the LFA base were far superior in terms of durability, rideability, and overall performance (Reference I-90). These shoulders remained in service for nearly ten years, but were removed when the roadway was widened from two lanes to three lanes in each direction.

Another good example of LFA utilization in highway construction outside of Illinois, Ohio, and Pennsylvania is its use in the Kansas City area. City Wide Asphalt Company markets LFA in Kansas and Missouri under trademark names of Poz-O-Pac or Poz-O-Blend. The company purchased the right to use these trade names from IU Conversion Systems, Inc. in Philadelphia. Since 1977, City Wide Asphalt has produced approximately 600,000 tons of LFA material, most of which has been used in commercial and municipal work.

Most of the LFA base produced in the Kansas City area is pre-blended; that is, the lime and fly ash are blended first, then the additive (lime and fly ash) is later blended with the aggregate. Typically, the pre-blend of lime and fly ash contains 6 to 10 percent lime. In the final Poz-O-Blend product, the additive comprises 12-1/2 to 15 percent, the remainder being aggregate, which is a combination of limestone and limestone dust, a by-product of quarrying. The cost of a ton of Poz-O-Blend F.O.B. plant in Kansas City is presently \$12.00 per ton. The seven-day compressive strengths of Poz-O-Blend mixes in the Kansas City area normally range from 800 to 1,100 psi. Ultimate strengths generally exceed 1,800 psi and some cores have produced compressive strengths of 5,000 psi or more.

The reason why the strengths of Poz-O-Blend in the Kansas City area are consistently high is because City Wide Asphalt has invested a large sum of money on modern plant equipment and product quality control. They receive most of the fly ash used in the product from the Hawthorn Station of Kansas City Power and Light Company and have constructed laboratory facilities at that location. A full-time chemist is employed at the laboratory and every load of fly ash is tested at the plant before it is accepted and put into a mix.

Until recently, no LFA material was used on state highway projects around Kansas City in either Kansas or Missouri. However, the first state highway project in the area (Route 33 in Carney, Missouri) which allowed alternate bids for LFA material was recently bid. On this project, which is scheduled to begin next spring, the LFA base was bid at \$6.00 per square yard, while the bituminous base was bid at \$9.00 per square yard for the same base thickness. Similar cost savings have been realized when the Poz-O-Blend material was bid against bituminous base on projects for the City of Kansas City (Reference I-91).

Federal Aviation Administration. There are at least four known locations where the Federal Aviation Administration has been involved to some extent with the use of LFA compositions as base course materials for the construction of runways and/or taxiways. These locations are the Newark Airport, the John F. Kennedy Airport, the Portland Airport, and the Toledo Airport. Two of these projects are discussed in some detail in this report.

Newark Airport Project. The largest single project ever involving the combined use of lime and fly ash in base and sub-base construction was the building of runways, taxiways, and aprons at the Newark Airport in Newark, New Jersey. On this project, approximately 2 million square yards of pavement were placed over compressible organic silts and peaty soils that were once a tidal marsh. The existing soil surfaces were surcharged and pre-consolidated using some 20 million cubic yards of hydraulically placed sand fill.

Because of the economics and subsurface conditions, the use of a flexible pavement system was decided upon by the Port Authority of New York and New Jersey at the outset of the project. Prior to designing the runway pavements, the validity of current airfield flexible pavement design theories was reviewed for application to the heavier anticipated wheel loadings associated with jumbo jet aircraft. A \$500,000 test program was conducted to develop pavement design criteria for jumbo jet aircraft based on : 1) the interaction of pavement roughness and aircraft response; and 2) the rate of permanent deformation of the pavement surface under repeated jumbo jet wheel loadings.

A test strip 30 feet wide and 1,200 feet long was constructed, consisting of sixteen 75-foot long sections, each having different thicknesses and compositions. Materials investigated included conventional crushed stone aggregate, cement-stabilized base, asphalt-treated base, and a mixture of lime, cement, fly ash, and sand. Test equipment included an extensive network of in-pavement gauges and a 187,000 pound instrument vehicle, borrowed from the Army Corps of Engineers, to simulate the main gear of a Boeing 747 aircraft. The test vehicle was placed in round-the-clock service amounting to 5,000 passes in three months or an equivalent of two years of actual runway use. Every three days, measurements of rutting, cracking, and pavement surface deflections were made. Analysis and interpretation of the test data confirmed the validity of the theoretical design approach used by the Port Authority. This approach was based on maintaining subgrade deformations within elastic limits reduction of load stresses in the overlying pavement sections to insure acceptable pavement surface roughness and related aircraft vehicle response.

The field tests performed by the Port Authority showed that layered mixtures of hydrated lime, portland cement, fly ash, and crushed stone would be able to stabilize the uniformly graded hydraulic sand surcharge material and that these stabilized material layers could be used as a suitable base for new pavements. The portland cement was introduced as an additive in the mixes to accelerate the development of the normal chemical reaction between the lime and fly ash. A copy of the Port Authority specification for the lime-cement-fly ash stabilized fill sand base material used in the Newark Airport project is found in the Appendix of this report.

The compressive strengths of the lime-cement-fly ash-aggregate (LCFA) mixtures used on the project were directly related to the chemical reaction of the lime-cement-fly ash binder, which in turn was affected by the curing temperature. Three basic mix designs were used on the project:

- Mix A - 4 percent lime and cement, 10 percent fly ash, 30 percent crushed stone, 56 percent sand.
- Mix B - 3.5 percent lime and cement, 12 percent fly ash, 84.5 percent sand.
- Mix C - 3 percent lime and cement, 12 percent fly ash, 85 percent sand.

From the results of Port Authority tests, the projected strength development of these base course mixes is shown in Figure I-13. From this figure, it is noted that the long-term (5-year) strength of Mix A is 2,000 to 2,600 psi; the strength of Mix B will range from 1,200 to 1,800 psi; and Mix C will be from 800 to 1,200 psi. All three mixes were used in each section of pavement; Mix A was placed closest to the pavement surface and Mix C placed directly above the subgrade.

The thickest pavement sections were constructed at the terminal gates and holding pads. These areas consist of five layers which were built to a total thickness of 36 to 40 inches. The next thickest sections were the middle portion of the runway ends (34 inches) and the center strip of taxiways (32 inches). Relatively thin pavement sections (26 inches) were designed for the sides of all runways and taxiways and for the midlength portions of runways. All pavement base was constructed of three layers of lime-cement-fly ash-aggregate and overlaid with 4 inches of asphalt concrete wearing surface to protect the base course from weathering and wheel abrasion.

Port Authority engineers recognized a tremendous economic advantage when comparing the 1973 estimated costs for in-place 34-inch thick compacted lime-cement-fly ash-aggregate pavement at \$10.88 per square yard with that of equivalent performance 43-inch full-depth asphalt at \$21.45 per square yard. The cost of the pavement using stabilized LCFA base material amounted to approximately half that of the full-depth asphalt, or a cost savings of \$10.57 per square yard. The total projected cost savings for the entire project, involving about 2 million square yards of pavement, is an astonishing \$21 million (Reference I-92).

A more direct comparison of the costs vs. strength of competitive materials is also revealing. A cubic yard of LCFA material costs about \$3.80 from the plant.* A cubic yard of crushed stone commonly used in road construction costs from \$5.00 to \$6.00.* A cubic yard of lean concrete, 3-sack mix costs about \$12.00.* If the compressive strength of each material is judged on the basis of the strength developed per cubic yard, the following comparison is made:

* These figures are based on 1968 costs in the New York City area.

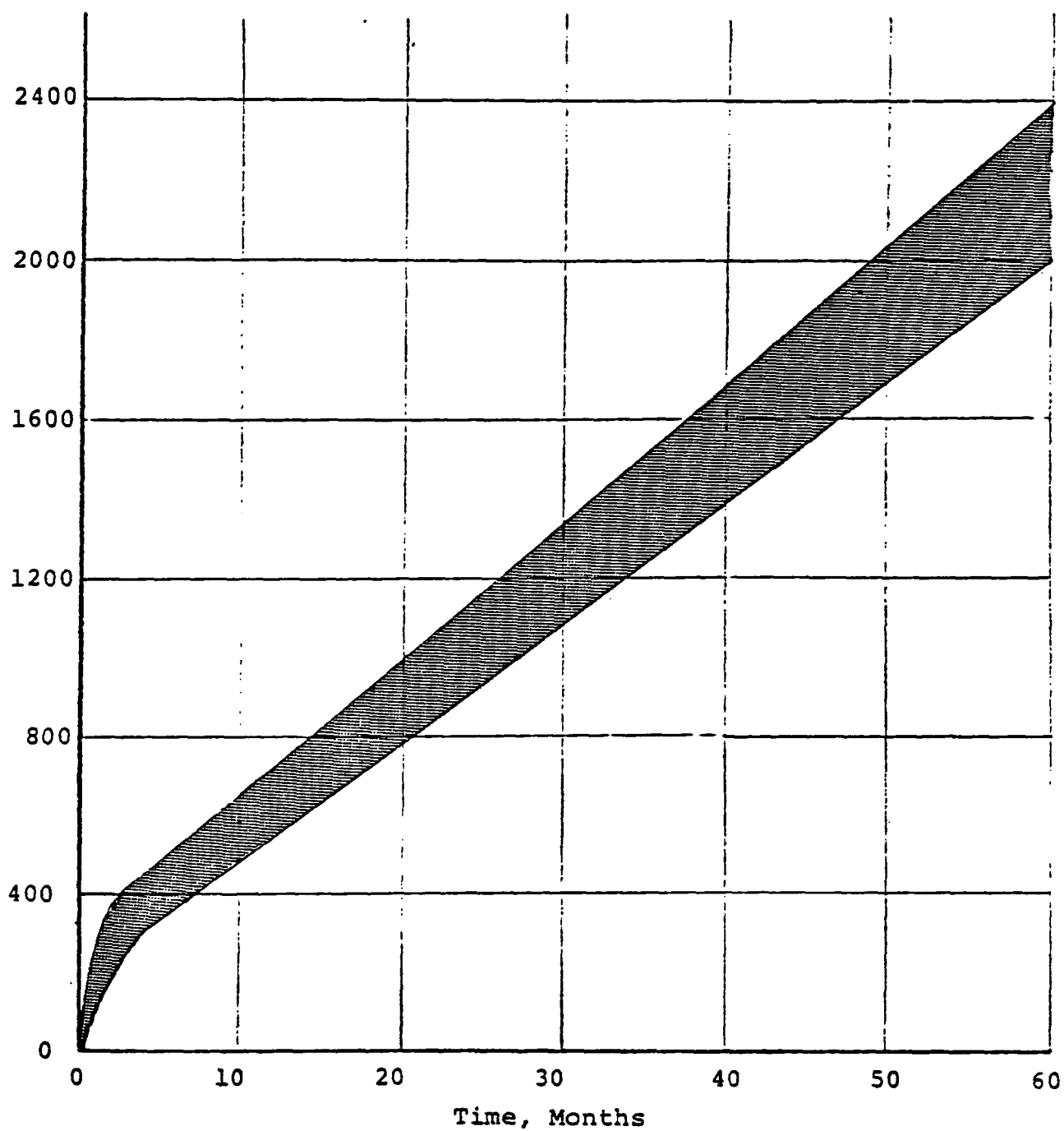


Figure I-13. Projected compressive strength development of lime-cement-fly ash-aggregate composition at Newark Airport project. See text for explanation.

LCFA	500 psi per \$1.00*
Crushed stone	30 psi per \$1.00*
Lean concrete	250 psi per \$1.00*

For this reason, the Port Authority believes that LCFA is stronger per dollar than any pavement material now in use (Reference I-93).

The runway paving on this project began in the spring of 1968. First, a 1,200 ton per hour mixing plant, largest of its kind, was erected for the mixing of the base materials. Fly ash was initially supplied free of charge by the Consolidated Edison Company, followed by conditioning with 16 percent water at the power plant. Before the fly ash was fed into the hopper belt system at the plant, it was passed through a shredder to break up some of the clumped ash. Sand for the base mixes was taken directly from paving surcharge areas and hauled directly to the mixing plant. The hydrated lime and portland cement were stored in silos and charged to the main feeding belt separately. A storage bin added at the discharge end of the pugmill allowed the mixing plant to be operated continuously.

Sprading and grading of the base materials was accomplished by an automatic grading machine. Each machine pass was about 25 feet wide. The compaction of each of the LCFA layers was done by four to eight passes with a pneumatic roller. The finished surface of the pavement base was fine graded to a tolerance of 1/8 inch in 10 feet.

Labor and equipment costs were reduced because of the slow initial set of the LCFA base material. There was no need to finish the paving work on the same day that the LCFA material was mixed and spread. The slow curing time, with little accompanying heat of hydration, together with low moisture contents in the base materials, also minimized the curing shrinkage and cracking.

In December, 1968, well after the first paving season had concluded, the Shell dynamic pavement tester was brought to the airport site to measure the behavior of pavement under simulated loading conditions of moving traffic. These test results were deemed highly favorable and the LCFA paving concept has since been used successfully at Kennedy Airport (Reference I-94).

The Newark Airport expansion project, with its LCFA paving system, was recognized as an Outstanding Civil Engineering Achievement for 1978 by Civil Engineering magazine. Reports of cracks that had developed in the surface of the original LCFA runway prompted recent correspondence between a member of the American Pozzolan Concrete Association, a group representing producers of pozzolan concrete base materials, and the New York Port Authority. The Port Authority's response has clarified the status of the LCFA paving at Newark Airport.

In his letter, the chief engineer for the Port Authority has stated clearly that the Port Authority is "still very strongly in favor of the use of LCFA base courses." He goes on to mention that a maintenance contract was

* These figures are based on 1968 costs in the New York City area.

let in the summer of 1979 to improve the smoothness of the asphalt on the main LCFA runway. At that time, a paving mix using a harder grade of asphalt was used "in order to limit deflection caused by the proposed 747 aircraft." Some pavement grooving was also done at that time to facilitate surface drainage. The grooves in the pavement "remained straight and horizontal up to the day of removal" in a subsequent maintenance contract (Reference I-95).

Unfortunately, "the harder asphalt was subject to a greater degree of cracking," with water penetrating through the cracks in the runway pavement. Therefore, it became necessary to "remove the center keel section of the runway and replace it with a softer penetrating asphalt." No replacement of any of the LCFA pavement was done, nor is any such replacement necessary.

At no time did the Port Authority consider this work to be anything except normal runway maintenance, nor has the Authority ever attributed the cracked asphalt surface to a possible base failure (Reference I-94).

Toledo Express Airport. The Toledo Airport project is a classic example of the kind of problems that can result from bureaucratic inertia (resistance to change) and the lack of knowledge or familiarity with a construction project. Early in 1980, the Federal Aviation Administration (FAA) announced its intention to advertise for bids for the overlay of existing runway 7-25, taxiway A at the Toledo Express Airport. This overlay was initially designed for a full-depth asphalt pavement. In February, 1980, prior to bidding, the Toledo-Lucas County Port Authority, which administers the Toledo Airport, requested that FAA consider the use of a lime-fly ash-aggregate (LFA) base as an alternate to bituminous base for this overlay.

The rationale for the request stemmed from the fact that during the summer of 1978, approximately 500 tons of LFA material was placed as an experimental base course for the overlay of a commercial ramp adjacent to the airport terminal building. Since its installation, this ramp pavement has performed satisfactorily with no apparent problems. Core specimens were taken from the LFA base of the ramp in late March, 1980 and tested for unconfined compressive strength. The average strength of the four core specimens was 1,455 psi, with one core achieving 1,810 psi.

The initial request for consideration of the LFA alternative was turned down by the FAA's district office in Detroit in late February 1980 on the grounds that, at the time, the FAA had no approved specification for the material. The correspondence also advised the Toledo-Lucas County Port Authority that LFA was not identified in the appropriate sections of the FAA design manual as an equivalent stabilized material for construction of runways, taxiways, or apron areas (Reference I-96).

During the next two months, a considerable amount of technical information related to LFA base materials, including the results of strength tests on core specimens taken from the Toledo Airport ramp, was forwarded to various representatives of FAA. Despite FAA claims that there was no specification for LFA materials, a copy of FAA specification P-305, entitled

"Aggregate-Lime-Fly Ash Subbase or Base Course (Central Plant Mixed)" was provided by the National Ash Association and submitted to FAA officials for their review. Information pertaining to the LCFA base at the Newark Airport project, which the FAA district people apparently had not known about, was also transmitted.

A representative of the Port Authority, who is familiar with LFA materials and technology, personally visited the FAA central engineering office in Washington, D.C., in early April and discovered, to his great surprise, that the FAA engineers did not even know what LFA base course was. Their concept of the material was that it involved a combination of lime, fly ash, and clay soil. This misconception came about from their previous exposure to the work of the Army Corps of Engineers with lime-fly ash stabilization of highly plastic clay soils.

After clarification of the nature of the proposed alternate, authorization to advertise for bids was given to the Port Authority by FAA on April 29, 1980, although the correspondence specifically stated that the proposed LFA alternate was still being reviewed.

On May 15, 1980, bids were received, in which the LFA alternate was \$22,000 lower than the original black base design, a savings of 10 percent. Based on the results of the bidding, FAA approval was then given to the use of LFA as an alternate on a portion of taxiway "A" measuring approximately 1,475 feet long by 60 feet wide, subject to a number of conditions, including the following:

1. The thickness of LFA was to be based on a ratio of 5 inches of LFA to 4 inches of bituminous base.
2. The LFA base must have transverse joints every 50 feet.
3. Fly ash must conform to the requirements of ASTM C618, "Fly Ash and Raw or Calcined Pozzolans for Use in Portland Cement Concrete."
4. Placement of the wearing surface shall not be permitted until the LFA material has achieved a compressive strength of at least 750 psi. This must be accomplished within the specified contract time period of 23 calendar days (Reference I-97).

In response to these conditions, LFA producer representatives and associated engineering consultants responded with the following points:

1. The thickness ratio of 5 inches of LFA to 4 inches of bituminous base was in accordance with established pavement design coefficients presently being used by the Ohio Department of Transportation for these materials and was considered acceptable (Reference I-98). It should be noted that even with the greater thickness, the LFA alternative still cost less.

2. Jointing of stabilized base materials is normally considered of questionable value. However, since the LFA material was being used as an overlay, the jointing should match that of the existing pavement (Reference I-98).
3. The proper specification for fly ash quality control for use in a stabilized base material is ASTM C593, "Fly Ash and Other Pozzolans for Use with Lime;" and not ASTM C618, which is applicable only to the use of fly ash in concrete (Reference I-98).
4. It is best to apply an asphalt overlay the following day or within a week after placement of LFA base to reduce moisture loss to a minimum. A requirement for minimum strength of base materials placed over an existing concrete pavement is not a realistic criteria. Most strength criteria are for the purpose of limiting flexural stresses in the base, but, since there are no flexural stresses in this application, such a requirement seems redundant (Reference I-99).

Furthermore, compaction of the wearing surface material is influenced by the degree of compaction of the underlying layers, not by their strength. In a large number of construction projects in which a bituminous surface has been placed immediately after completion of the LFA base, all surface courses have successfully met contract requirements. It has also been observed that LFA pavements gain strength through pozzolanic reaction at a faster rate than wheel loads can accumulate (Reference I-100).

Soon thereafter, the Port Authority formally requested that the 750 psi strength requirement be waived by FAA and that the wearing surface be placed as soon as practical after completion of the LFA base. On July 8, 1980, the FAA finally agreed to the early placement of the wearing surface, but insisted that no aircraft traffic be permitted on the pavement until field cores were taken to verify that an average compressive strength of 750 psi was attained. The FAA further required a minimum 98 percent compaction of the bituminous surface course, subject to penalties on a sliding scale for lower average compaction values.

From August 6 through August 11, 1980, a total of 7,200 tons of LFA base material was placed on the Toledo Airport Taxiway "A" project. The compacted thickness of the LFA base varied, but averaged approximately 14 inches. The mixture used consisted of 3.5 percent by weight hydrated lime, 11 percent

fly ash, and 85.5 percent limestone aggregate. The gradation of the material was within specified limits and all base materials were compacted as specified to at least 100 percent of maximum dry density, as determined by the modified Proctor test (ASTM D1557).

Laboratory mix design tests were performed on the 3.5-11-85.5 mix to determine its compressive strength characteristics prior to placement in the field. The average compressive strength of three specimens after 7 days curing at 70°F was 351 psi. The average compressive strength of three specimens after 7 days curing at 100°F was 904 psi (Reference I-101).

Between August 4 and 11, 1980, a total of 21 test specimens were prepared in the laboratory using LFA materials obtained from each day's production at the mixing plant. Each of these specimens was also cured for 7 days at 100°F. Compressive strength values after curing ranged from 540 to 860 psi, with an average compressive strength of 681 psi, well above the 400 psi specification requirement (Reference I-102).

In order to predict the field curing time needed to develop the required 750 psi strength in the LFA base, laboratory degree-day studies were performed at the University of Illinois to determine the rate of strength development for various curing temperatures in similar base materials. The findings of these degree-day studies are presented in Figure I-14. This figure shows that 750 psi can be attained on 600 degree-days (30 days with an average curing temperature of 75°F, in the pavement) using a 55°F base (Reference I-103).

The first five cores were taken from the pavement on September 8, 1980, which was 29 days after the base material had been placed. Normally, cores are not taken for several months after placement of stabilized base materials. The average compressive strength of these cores was 1,145 psi, considerably higher than the required 750 psi strength.

Thermocouples were installed at two locations within the LFA base material during its placement. Periodic temperature measurements were recorded on a twice daily basis after construction of the base course. Air temperatures were also recorded during the same time period. During the 29-day period between placement and initial coring, pavement temperatures fluctuated between 69°F and 96°F, with an average pavement temperature of 81°F over that time (Reference I-104). Using a 55°F base temperature, an 81°F average temperature represents 780 degree-days. From Figure I-14, this corresponds to a strength development of approximately 900 psi from the University of Illinois data and 1,050 psi using the Toledo Testing Laboratory data.

Throughout all the lengthy discussions concerning the approval of an LFA alternate and the conditions under which this material could be placed, it is ironic that FAA engineers had to be practically coerced into accepting a material which exhibited excellent strength gain characteristics,

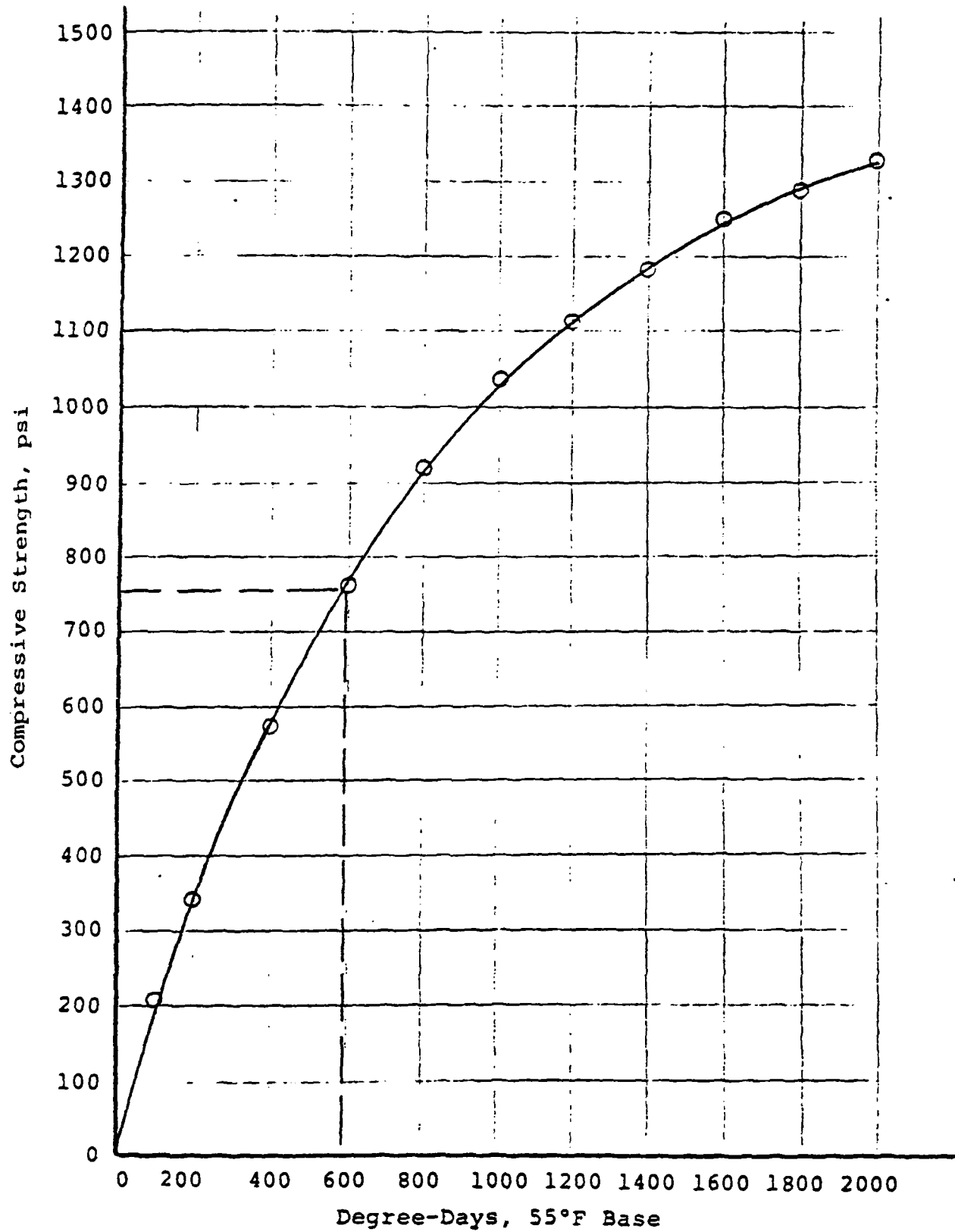


Figure I-14. Compressive strength vs. degree-days for LFA mix at Toledo Airport project.

has a proven service record in the State of Ohio and elsewhere, reduced the total project cost by 10 percent, and conserved nearly 90,000 gallons of petroleum by avoiding the installation of bituminous base. Despite all these advantages, the FAA representatives stated clearly that approval of the LFA alternate for the Toledo Airport project did not constitute an approval of the material on any other FAA-funded projects in the future (Reference I-75).

It should be further noted that FAA has insisted on extensive monitoring of the LFA material and its strength development in order to prove that this product works. This monitoring expense has not only eliminated the entire \$22,000 cost savings attributed to the LFA base, but has caused the overall cost of the project to exceed that of the original black base bid by \$12,000. To make matters worse, the FAA also insists that the cost overrun, resulting from their own directives, be paid by the Toledo-Lucas County Port Authority (Reference I-106).

Economic Evaluation of LFA Base. In this section, the relative economics of using lime-fly ash-aggregate (LFA) base materials are compared with the costs of using competitive base course materials in the states of Illinois, Ohio, and Pennsylvania. The competitive base course materials studied are bituminous concrete base and crushed stone base. Comparisons are made between actual bid prices for each type of base. The bid price data were obtained from Department of Transportation (DOT) personnel in each of these three states.

To analyze these comparative costs in each state, a pavement design example was developed assuming a structural number of 4.00 in order to determine design thicknesses for each of the three pavement options. Relative pavement thicknesses for each state are given in Table I-11. Based on the required thickness of each material and its compacted density, a square yard price was then determined for each wearing surface and base course material combination in a given state. The following compacted densities are assumed for each of the paving materials used:

Wearing surface	150 lbs/ft ³
Bituminous base	145 lbs/ft ³
Pozzolanic base	140 lbs/ft ³
Aggregate base	125 lbs/ft ³

The three pavement alternatives are compared in terms of estimated total in-place costs. Cost comparisons are discussed for each of the three individual states. An overall comparison is then made of costs from each of the three states.

1. Illinois

For a pavement structural number of 4.00, use of Illinois flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses results in the following basic designs:

<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
3" Wearing Surface	3" Wearing Surface	5" Wearing Surface
8.5" BAM* Base	10" PAM** Base	15.4" Stone Base
<u>11.5" Total Pavement</u>	<u>13" Total Pavement</u>	<u>20.4" Total Pavement</u>

* BAM refers to bituminous aggregate mixture.

** PAM refers to pozzolanic aggregate mixture.

Illinois DOT officials have furnished the following in-place cost figures, based on average of five comparative alternate bids received during 1980 on primary projects in District 1 (Chicago) area:

Wearing surface	\$55.80 per cubic yard
Bituminous base (BAM)	\$54.50 per cubic yard
Pozzolanic base (PAM)	\$39.20 per cubic yard
Aggregate base	\$20.45 per cubic yard (Reference I-107)

Converting these prices to square yard costs, based on the design thickness and compacted density of each material, results in the following:

Wearing surface	\$4.64 per square yard (3" thick)
	\$7.74 per square yard (5" thick)
Bituminous base (BAM)	\$12.87 per square yard (8.5" thick)
Pozzolanic base (PAM)	\$10.87 per square yard (10" thick)
Aggregate base	\$8.75 per square yard (15.4" thick)

Using the above figures, the total estimated cost per square yard for each of the three Illinois pavement alternatives is:

	<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
Surface	\$ 4.64	\$ 4.64	\$ 7.74
Base	12.87	10.87	8.75
Total Cost	<u>\$17.51</u>	<u>\$15.51</u>	<u>\$16.49</u>

From the above cost data, it appears that pozzolanic or LFA base is the least expensive of the three alternatives, being \$2.00 per square yard less than the bituminous base in the Chicago area. For a two-lane road 24-feet wide, the projected cost savings attributed to LFA base using these cost figures would be \$28,160 per mile less than bituminous base.

During the Illinois Pozzolanic Concrete Association Seminar, held in Chicago in April of 1980, a paper was presented outlining the actual cost benefits realized over a four-year period due to the use of pozzolanic base materials (PAM) in the Chicago area. These PAM materials were bid as alternates to black base (BAM), cement-treated base (CAM), or portland cement concrete base on a total of 15 public paving projects let between April 1976 and the time of the seminar. Table I-12 summarizes the bid prices received for the base course paving alternates on each of these 15 projects.

Table I-12
SUMMARY OF BID PRICES
FOR BASE COURSE ALTERNATES IN ILLINOIS

Letting Date	Awarding Authority	Project Description	Base Course Quantity	Bid Prices			Cost Savings & % of PAM Price	
				PAM	BAM	Other		
4/27/76	Village of Schaumburg	American Lane	9,318 SY	9" 4.28	9" 8.33		37,700	95%
7/13/76	Village of Schaumburg	Martingale Road	6,950 SY	9" 4.00	9" 8.30		27,800	108%
3/19/77	Village of Frankford	Colorado Avenue	8,182 SY	9" 6.75	8-1/2" 9.22		20,210	27%
5/18/77	Cook County Hwy.	Central Ave. - Vollmer to 183rd Thornton/Blue Island Road	36,683 SY	9" 3.85	8" 5.65		66,029	32%
6/8/77	Cook County Hwy.	155th - 169th	47,168 SY	10" 5.00	9" 6.30		61,318	21%
7/20/77	Cook County Hwy.	115th & Harlem	14,921 SY	10" 5.15	9" 7.00		27,604	26%
8/9/77	Village of Schaumburg	Woodfield Road	15,950 SY	9" 4.09	9" 7.50		55,200	83%
3/1/78	City of Joliet	Plainfield Rd (US-30) I-55	22,282 SY	16" 7.92	15" 12.99	9" PCC 14.50	112,970	39%
5/26/78	Kane County Hwy.	Randall Road	23,311 SY	12" 5.95	10" 9.49	14" CAM 8.12	50,600	35%
6/7/78	Cook County Hwy.	Harlem & Steger Roads	17,840 SY	10" 5.00	9" 9.00		86,046	53%
7/19/78	Cook County Hwy.	167th - Will/Cook Road	17,871 SY	8-1/2" 6.40	8" 8.20		32,168	22%
4/11/79	City of Elgin	Big Timber & N. McLean Roads	16,173 SY	15" 8.25	12" 13.45		84,100	63%
6/30/79	IDOT	Houbolt Rd - Joliet	47,038 SY	9" 9.67	8-1/2" 13.83		195,678	30%
7/19/79	Village of Bollingbrook	111th Street at Rte #53	38,104 SY	12" 7.26	11" 15.53	14" CAM 8" PCC 22.00	157,378	36%
3/28/80	IDOT	Randall Rd - Big Timber to Highland - Elgin	39,124 SY	12" 7.05	10" 13.00		232,787	84%
				TOTAL SAVINGS:			<u>1,247,588</u>	

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As seen in this table, cost savings resulting from the use of the PAM base alternate ranged from \$20,000 to \$232,000 per project. Overall, a total of \$1,247,588 was saved for these fifteen projects (Reference I-107), or an average of \$83,172 per project. This is in addition to the savings of 10 to 15 percent less aggregate, as well as many thousands of barrels of oil from not using a base with an asphalt binder. Furthermore, it was noted in this study that the total cost for asphalt and cement stabilizing agents is increasing at a greater rate than the total cost of lime and fly ash. Another added cost for the bituminous base or BAM alternative is the cost of fuel consumed to dry and heat aggregates and asphalt cement in the dryer (Reference I-108).

2. Ohio

For a pavement structural number of 4.00, use of Ohio flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses results in the following basic designs:

<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
3" Wearing Surface (404)	3" Wearing Surface (404)	5" Wearing Surface (404)
8.4" Black Base (301)	10.5" Pozzolanic Base (835)	16.1" Stone Base (304)
<u>11.4" Total Pavement</u>	<u>13.5" Total Pavement</u>	<u>21.1" Total Pavement</u>

It was noted by ODOT engineers that, even though the design example shows a 3-inch wearing surface over the pozzolanic base, a minimum thickness of 4 inches of asphalt concrete over the 835 base provides a more efficient and durable pavement. Some failures were experienced when using less than a 4-inch thick asphalt layer over a pozzolanic base. Therefore, ODOT has recommended a 4-inch wearing surface and 9.5 inches of pozzolanic base (Reference I-109).

Ohio DOT officials also furnished a summary of the costs per square yard for the various materials in this design example, which was based on a 1979 summary of awarded contracts. These cost figures are:

Wearing surface (404)	\$4.52 per square yard (3" thick)
	\$6.03 per square yard (4" thick)
	\$7.53 per square yard (5" thick)
Bituminous base (301)	\$11.19 per square yard (8.4" thick)
Pozzolanic base (835)	\$7.29 per square yard (9.5" thick)
Aggregate base (304)	\$9.08 per square yard (16.1" thick)

Using the above figures, the total estimated cost per square yard for each of the three Ohio pavement alternatives is:

	<u>Bituminous Base</u>	<u>Pozzolan Base</u>	<u>Aggregate Base</u>
Surface	\$ 4.52	\$ 6.03	\$ 7.53
Base	11.19	7.29	9.08
Total Cost	<u>\$15.71</u>	<u>\$13.32</u>	<u>\$16.61</u>

From the above cost data, the pozzolan or LFA base alternative is the least expensive, and is approximately \$2.40 per square yard less than bituminous base in Ohio. For a two-lane road 24-feet wide, the projected cost savings attributed to LFA base using these cost figures is \$33,792 per mile.

An illustration of the actual cost savings that were actually realized on a project where alternate base course bids were received occurred during August 1979 when the City of Toledo accepted two bids for reconstruction of a portion of Heatherdowns Boulevard. The bid summary sheet shows three alternates for base course: 1) bituminous-aggregate base; 2) aggregate-lime-fly ash base; and 3) aggregate base. The summary of bids for the alternate base items, in costs per cubic yard of material in place, were as follows:

<u>Base Alternate</u>	<u>Bidder No. 1</u>		<u>Bidder No. 2</u>	
	<u>cost per</u> <u>cubic yard</u>	<u>total cost</u> <u>of base</u>	<u>cost per</u> <u>cubic yard</u>	<u>total cost</u> <u>of base</u>
Bituminous-aggregate	\$42.00	\$383,712	\$37.00	\$338,032
Aggregate-lime-fly ash	\$23.00	\$278,803	\$26.00	\$314,364
Aggregate base	\$11.65	\$388,604	\$12.50	\$367,444

The lowest cost alternate was the aggregate-lime-fly ash price of \$278,803 from bidder number 1. When compared to the low price of \$338,032 for bituminous-aggregate base, this represents a cost savings of \$59,229 or a 21.2 percent reduction in base course cost by using aggregate-lime-fly ash instead of bituminous-aggregate. When compared to the low price of \$367,444 for aggregate base, a cost savings of \$88,641 or 31.8 percent can be realized by using the aggregate-lime-fly ash base.

The total bids for this project were as follows:

<u>Base Alternate</u>	<u>Bidder No. 1</u>	<u>Bidder No. 2</u>	<u>Difference</u>
Bituminous-aggregate	\$1,685,884	\$1,632,843	+ \$53,041
Aggregate-lime-fly ash	\$1,580,975	\$1,609,176	- \$28,201
Aggregate base	\$1,690,776	\$1,662,255	+ \$28,521

The job was awarded to Bidder Number 1 using the aggregate-lime-fly ash alternate. This alternate saved \$51,868, or 3.3 percent of the entire job, compared to bituminous-aggregate. The aggregate-lime-fly ash alternate cost \$81,280, or 5.1 percent, less than aggregate base.

3. Pennsylvania

For a pavement structural number of 4.00, use of Pennsylvania flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses initially resulted in the following basic designs:

<u>Bituminous Base</u>	<u>Pozzonlanic Base</u>	<u>Aggregate Base</u>
3" Wearing Surface 6.7" BCBC*	3" Wearing Surface 6.7" ALP** Base	5" Wearing Surface 12.9" CAB C***

* BCBC refers to bituminous concrete base course

** ALP refers to aggregate-lime-pozzolan base course

*** CAB C refers to crushed aggregate base course.

The above designs were reviewed by the PennDOT Bureau of Design. As a result of this review, several changes were proposed to conform to the PennDOT design manual, by taking into account minimum pavement depth, frost design requirements, and the use of sub-base material. Based on these changes, the resultant designs were as follows:

<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
1.5" Wearing Surface 6" BCBC 10" Sub-base <u>17.5" Total Pavement</u>	1.5" Wearing Surface 2" Binder Course 5" ALP 6" Sub-base <u>14.5" Total Pavement</u>	1.5" Wearing Surface 2" Binder Course 8" CAB C 10" Sub-base <u>21.5" Total Pavement</u>

Analysis of the above designs indicates that the resultant structural numbers for each alternative are slightly different. The BCBC pavement has a structural number of 4.16; the ALP pavement has a structural number of 4.20; and the CAB C pavement has a structural number of 4.08.

Pennsylvania transportation officials have furnished the following in-place cost figures, derived from the most recent weighted average of all awarded contracts statewide, as published in PennDOT Bulletin 50:

1-1/2" wearing surface	\$3.30 per square yard
2" binder course	\$3.00 per square yard
6" BCBC	\$9.20 per square yard
5" ALP base	\$8.85 per square yard
8" CAB C	\$8.00 per square yard
6" sub-base	\$3.75 per square yard
10" sub-base	\$4.15 per square yard (Reference I-110).

Using the above figures, the total estimated cost per square yard for each of the three Pennsylvania pavement alternatives is:

	<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
Surface	\$ 3.30	\$ 3.30	\$ 3.30
Binder	-	3.00	3.00
Base	10.20	8.85	8.00
Sub-base	<u>4.15</u>	<u>3.75</u>	<u>4.15</u>
Total Cost	\$17.65	\$18.95	\$18.45

In seeking to verify these unit prices from the latest Bulletin 50 (March 1980), it was discovered that no bid price has been tabulated in Bulletin 50 for the ALP alternate during the past several years. Apparently, the unit price for the 5" ALP base was determined by taking a 1974 bid price from Bulletin 50 and factoring it to 1980 at an inflation rate of 10 percent per year. Furthermore, crushed aggregate base course is rarely used by PennDOT, hence cost data on this item are very limited (Reference I-111).

A July 1979 cost summary of material costs for short projects (less than 1,000 feet) in PennDOT district 6 (Philadelphia area) indicates that bid prices for 5" ALP base on such projects averaged \$4.53 per square yard. District 6 engineers have been using an annual escalation figure of 7.5 percent per year compounded for projecting increased material costs. On this basis, the unit price of 5" ALP base would be \$4.89 per square yard at this time.

In order to verify the in-place cost of LFA base, the costs of a total of six of the most recent ALP projects in District 6 were reviewed. These jobs dated from 1976 and involved quantities ranging from 1,600 to 100,000 square yards of base material. A weighted average cost was determined from the costs of these six projects. This cost figure was also adjusted to take into account variations in the thickness of the ALP base on these different projects. This weighted cost turned out to be \$5.97, so the estimated cost of installing a 5" thick layer of ALP base in Pennsylvania was taken as \$6.00 instead of \$8.85 per square yard.

A figure of \$6.00 per square yard for 5 inches of ALP base course does not seem unreasonable when compared to a cost of \$6.60 per square yard for 9.5 inches of LFA base in Ohio and \$10.87 per square yard for 10 inches of PAM base in Illinois.

Using the revised ALP cost figure, the total estimated cost per square yard for each of the three Pennsylvania pavement alternatives is:

	<u>Bituminous Base</u>	<u>Pozzolanic Base</u>	<u>Aggregate Base</u>
Surface	\$ 3.30	\$ 3.30	\$ 3.30
Binder	-	3.00	3.00
Base	10.20	6.00	8.00
Sub-base	<u>4.15</u>	<u>3.75</u>	<u>4.15</u>
Total Cost	\$17.65	\$16.05	\$18.45

From these data, it appears that the pozzolanic or ALP base is actually the least expensive alternative, being \$1.60 less than bituminous base per square yard. For a two-lane road, 24-feet wide, the project cost savings attributed to ALP base using these cost figures would be \$22,528 per mile less than bituminous base.

Additional comparative cost information on ALP base and bituminous base prices was obtained from the City Engineer for the City of Lancaster, who usually asks for alternate bids for all street reconstruction work. Recent bid prices for pavement designs consisting of 1-1/2 inches of asphalt wearing surface, 6 inches of bituminous base, and 6 inches of sub-base have been ranging from \$20.40 to \$23.80 per square yard in place, which is considerably higher than the \$17.65 per square yard estimate based on PennDOT Bulletin 50 cost figures. Recent bid prices for pavement designs consisting of 1-1/2 inches of asphalt wearing surface, 2 inches of bituminous binder, 5 inches of ALP base, and a 6 inch sub-base have been ranging from \$14.00 to \$17.00 per square yard (Reference I-112), which corresponds well with the estimated cost of \$16.05 per square yard given above. The actual installed price for 5-inch thick ALP base in Lancaster during 1980 was \$4.50 per square yard (Reference I-113). All the above costs are based on prevailing wage rates, making the costs for these projects equivalent to those of PennDOT projects.

On the basis of these costs, reflecting actual bids received during 1980 in the City of Lancaster, it would appear that even more substantial savings, on the order of \$5.00 to \$6.00 per square yard of pavement, can be realized by use of the pozzolanic base alternative. When analyzing the comparative costs of ALP and BCBC out of the plant it is evident why ALP is the less costly alternative. Bituminous base in the Philadelphia area presently sells for approximately \$20 per ton F.O.B. plant, while ALP sells for \$9.50 per ton F.O.B. plant (Reference I-114). In Pennsylvania, these two materials are structurally equivalent.

4. Three State Cost Comparison

The estimated costs for all three pavement alternates in Illinois, Ohio, and Pennsylvania for a flexible pavement with a structural number of 4.00 are compared in Table I-13. These cost figures reflect actual bid costs for all materials and, as such, constitute an accurate current comparison of the cost of alternative pavement systems in each state.

The first and most obvious observation from Table I-13 is that the pozzolanic base material is consistently the lowest cost alternative in all three states, with bituminous base second, and aggregate base third. The cost differential between pozzolanic base and bituminous base ranges from \$1.50 to \$3.00 per square yard. This difference represents potential cost savings of approximately \$20,000 to \$40,000 per mile of two-lane road.

Table I-13
THREE-STATE COMPARISON OF PAVEMENT BASE COURSE COSTS

BASIC PAVEMENT DESIGNS
(STRUCTURAL NUMBER = 4.0)

ILLINOIS			OHIO			PENNSYLVANIA		
<u>BAM</u>	<u>PAM</u>	<u>STONE</u>	<u>BIT</u>	<u>POZ</u>	<u>STONE</u>	<u>BCBC</u>	<u>ALP</u>	<u>CABC</u>
3" wearing 8.5" base	3" wearing 10" base	5" wearing 15.4" base	3" wearing 8.4" base	4" wearing 9.5" base	5" wearing 16.1" base	1.5" wearing 6" base 10" subbase	1.5" wearing 2" binder 5" base 6" subbase	1.5" wearing 2" binder 8" base 10" subbase
11.5" total	13" total	20.4" total	11.4" total	13.5" total	21.1" total	17.5" total	14.5" total	21.5" total

ILLINOIS			OHIO			PENNSYLVANIA		
<u>BAM</u>	<u>PAM</u>	<u>STONE</u>	<u>BIT</u>	<u>POZ</u>	<u>STONE</u>	<u>BCBC</u>	<u>ALP</u>	<u>CABC</u>
\$ 4.64 12.87	\$ 4.64 10.87	\$ 7.74 8.75	\$ 4.52 11.19	\$ 6.03 6.60	\$ 7.53 9.08	\$ 3.30 10.20 4.15	\$ 3.30 3.00 6.00 3.75	\$ 3.30 3.00 8.00 4.15
\$17.51	\$15.51 (LOW)	\$16.49	\$15.71	\$12.63 (LOW)	\$16.61	\$17.65	\$16.05 (LOW)	\$18.45

A study of Table I-13 also shows that total pavement costs in Illinois and Pennsylvania are basically quite similar, while comparative costs for the same materials in Ohio are somewhat lower, particularly the cost of the pozzolanic base. This simply points out the number of variables that must be taken into account when comparing cost figures for the same material from different areas. The most significant of these variables are labor, transportation costs, productivity at the project site, and availability of materials. Despite these variables, the cost comparisons discussed in this section of the report reflect a trend toward significant savings in cost from use of pozzolanic base materials in areas where such materials are available and can be supplied in sufficient quantity to prospective users.

Overview of LFA Usage

LFA Use by State Highway Agencies. The findings of a questionnaire on recovered material usage, which was circulated by AASHTO to all state highway materials and construction engineers during April 1980, show that a total of 14 states have at some time used lime-fly ash-aggregate (LFA) compositions in base course or shoulder applications. Six of these 14 states presently include LFA in their state specifications. One state (West Virginia) used to have a special provision in its state specifications for lime-fly ash-aggregate base, but reports that it was discontinued due to lack of interest by the contracting industry. Instead, West Virginia uses a lot of cement-treated base (Reference I-115).

States indicating some use of LFA base materials are:

Arizona	New Jersey*
Colorado*	North Dakota*
Illinois*	Ohio*
Maryland	Oklahoma
Massachusetts	Pennsylvania*
Michigan	Texas
Missouri	West Virginia

* States which have a specification for lime-fly ash-aggregate.

The only states reporting routine use of LFA are Illinois, Ohio, and Pennsylvania. Most of the remaining 11 states report that LFA base has been used in state projects only on a limited field basis (less than six projects) or as a field experiment (one or two small test sections). Generally speaking, LFA materials have been used to a greater extent on local facilities than state highways.

In addition to the 14 states, noted above, at least four other states are presently evaluating LFA compositions in the laboratory. These states are Georgia, Mississippi, New York, and North Carolina. Of these four states, only North Carolina felt that LFA behaved poorly in the lab because "the strength of lime-fly ash stabilization of aggregate base at 7 days was 12 percent of the aggregate base with 3 percent cement and 3 times as expensive (Reference I-116).

A review of technical reports and promotional literature on stabilized road base materials confirms that LFA mixtures have also been placed in several other states, including Delaware, Indiana, New York, South Dakota, and Virginia. Since none of the DOT personnel in these states has indicated use of this material in their questionnaire responses, it is assumed that LFA use in these states has been confined to local roads and/or private projects, with no use in state or Federally funded highway construction.

Of the 14 states reporting LFA use, 10 consider the performance of the material to have been either acceptable, good, or, in the case of three states, excellent. These three states are Ohio, Texas, and West Virginia. Reasons cited for excellent performance are the pozzolanic activity of lime and fly ash, strength gain with age, and good mixing and compaction in the field. Three states (Maryland, Massachusetts, and Missouri) have experimented with LFA materials on a very limited basis in the field and felt that more study was necessary before being able to evaluate the performance of the material. One state, Michigan, considered that LFA base performed poorly on a job because the material showed "temperature and moisture sensitivity for cure, frost susceptibility, poor drainability, and was more expensive than conventional aggregate mixtures (Reference I-117).

Figure I-15 is a map of the United States showing the locations of all coal-fired power plants and all commercial lime plants. All areas within a 50-mile radius of both a coal-fired power plant and within a 200-mile radius of a commercial lime plant are shaded in on the map and considered as potential use areas for LFA base material usage.

Portions of 39 states have been shaded in on this map, indicating areas where supplies of LFA component materials (lime and fly ash) are available within a reasonable hauling distance. Considering the 14 states that have reported LFA use by the AASHTO questionnaire, plus five additional states where local or private use of LFA material can also be verified, LFA base materials have been used to some extent in at least 19 states. This total represents approximately half of all states which could possibly be using this material. Table I-14 lists the 39 states where there is some potential for use of LFA base materials from the standpoint of lime and fly ash availability and also indicates those 19 states where there has been known use of these materials.

Of these 19 states, there are probably only three (Illinois, Ohio, and Pennsylvania) that are familiar enough with the characteristics and performance of LFA base that they would be able to award more contracts using this material without first requiring extensive laboratory testing and field monitoring of the material. With few exceptions, most of the remaining 20 states would probably need to spend some time in further evaluation of LFA base before feeling ready to proceed with a substantially higher degree of LFA use in state highway construction.

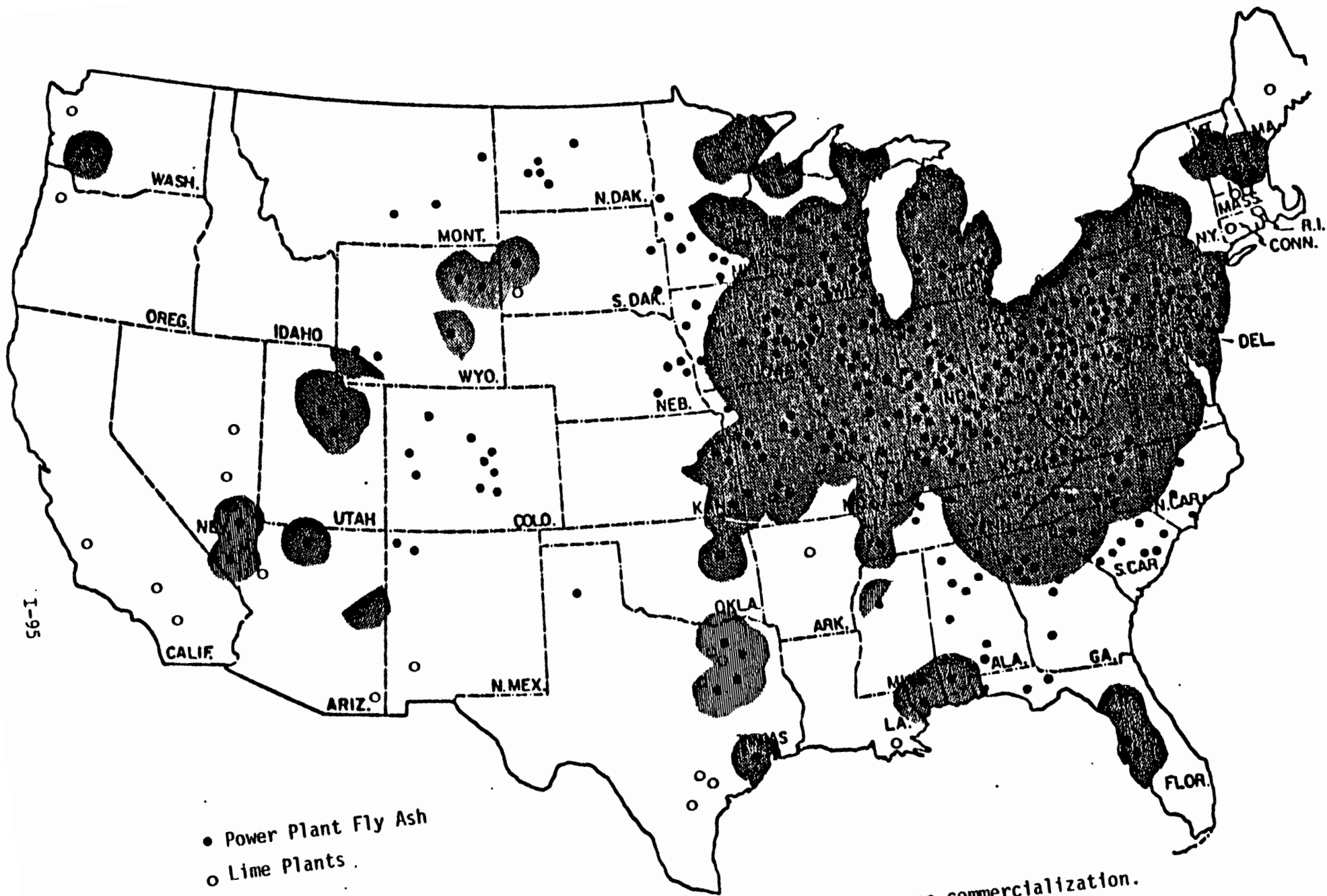


Figure I-15. Most probable areas of lime-fly ash-aggregate base course commercialization.

Table I-14

STATES HAVING POTENTIAL OR ACTUAL
USE OF LIME-FLY ASH-AGGREGATE

<u>State</u>	<u>Extent of LFA Use to Date</u>
1. Alabama	Potential use due to logistics
2. Arizona	Experimental field use
3. Arkansas	Potential use due to logistics
4. Colorado	Limited field use - specified
5. Connecticut	Potential use due to logistics
6. Delaware	Some prior field use
7. Florida	Potential use due to logistics
8. Georgia	Laboratory investigation
9. Illinois	Routine use - specified
10. Indiana	Some prior field use
11. Iowa	Potential use due to logistics
12. Kansas	Potential use due to logistics
13. Kentucky	Potential use due to logistics
14. Maryland	Limited field use
15. Massachusetts	Experimental field use
16. Michigan	Limited field use
17. Minnesota	Potential use due to logistics - bad climate
18. Mississippi	Laboratory investigation
19. Missouri	Experimental field use
20. Nevada	Potential use due to logistics
21. New Hampshire	Potential use due to logistics
22. New Jersey	Some prior field use
23. New York	Laboratory investigation - some field use
24. North Carolina	Laboratory investigation
25. North Dakota	Limited field use
26. Ohio	Fairly routine use - specified
27. Oklahoma	Experimental field use
28. Oregon	Potential use due to logistics
29. Pennsylvania	Routine use until 1976 - specified
30. South Dakota	Some prior field use
31. Tennessee	Potential use due to logistics
32. Texas	Limited field use
33. Utah	Potential use due to logistics
34. Vermont	Potential use due to logistics
35. Virginia	Some prior field use
36. Washington	Potential use due to logistics
37. West Virginia	Very limited field use
38. Wisconsin	Potential use due to logistics
39. Wyoming	Potential use due to logistics

Marketing Considerations. After reviewing and evaluating the utilization of LFA base, and differences that exist in the event of its use from one state to another, it is evident that the level of use of LFA base (or any other construction product) is definitely related to the sales effort applied on its behalf. It must be understood that sales of all construction materials (asphalt, concrete, aggregate, etc.), are dependent to some extent on periodic visits to users and specifiers by sales representatives, as well as spokesmen for material producers lobbying associations. In this regard, it is virtually impossible for advocates of LFA materials to provide a sales effort that can even remotely compare with that of the more recognized and established construction material industries.

There are, no doubt, many instances in which too aggressive a marketing approach on behalf of an unfamiliar material, such as LFA, may have been more detrimental than infrequent sales visits. In addition, most engineers are dissuaded from further use of a material when a marketing representative makes undocumented claims about it or when the material is unable to perform up to its advertised expectations.

A sales representative for a Chicago-based ash marketing firm, which has sold more fly ash for use in LFA base than any other firm anywhere else in the United States, recommends that the following steps be taken to assure success in the marketing of lime-fly ash-aggregate:

1. Cooperation between the utility company and the potential ash vendor on such vital matters as quality control, material availability, and loading hours. Without such cooperation, and a sincere interest on behalf of the utility company, marketing of quality LFA material is doomed to failure.
2. Promote and think in terms of a plant-mixed product. Production plants should have a capacity of at least 400 tons per hour. Contractor-owned blacktop plants can be adapted for LFA production at a probable cost of \$250,000 to \$300,000 for an additional silo and feeding equipment.
3. Sell the product through contractor-owned marketing outlets, using trained and qualified sales and engineering representatives.
4. Draw on the talents of paving experts to evaluate the product, develop promotional literature, and provide technical consultation where needed.
5. Develop attractive and technically accurate promotional literature.

6. Conduct informal seminars on the properties and uses of the product. Rely on experts where needed, emphasizing a direct and honest approach.
7. Invite potential producers and users to tour production facilities and project sites where the LFA material is being mixed and placed or where it has been in service.
8. Make frequent personal calls, again using the direct, honest sales approach. Display cores of the material in addition to sales literature (Reference I-118).

Audio-visual aids are an excellent example of the use of professional marketing tools for product promotion. In 1979, the Federal Highway Administration, in cooperation with the National Ash Association and the American Pozzolanic Concrete Association, developed a 20-minute narrated slide-tape presentation entitled "Lime-Fly Ash Stabilized Bases and Subbases." This presentation consists of 78 color slides which discuss and explain the following aspects of LFA base materials:

- LFA components (lime, fly ash, and aggregate)
- Fly ash production, composition, and handling
- Laboratory testing procedures (ASTM C593)
- Plant-mixing of LFA materials
- Construction equipment used for LFA placement and compaction
- Engineering properties of LFA materials
- Advantages of using LFA materials

A 20-page script of this slide-tape presentation has also been prepared by the Federal Highway Administration and is included in this report. The Federal Highway Administration disseminates this document to district offices and other interested parties as part of its information exchange program. However, it is noted in the script that the contents of the presentation do not necessarily reflect the official views or policy of the government, which does not endorse products or manufacturers.

It must be understood that any product with which state highway engineers are not familiar cannot sell itself. Due to the inherently conservative nature of the highway engineering profession and its reluctance to deviate from the use of familiar and established construction products, a professional marketing effort must be applied by reasonable, technically oriented organizations in order to advance the usage of a product such as LFA base. Even with such an effort, it should be further recognized that complete acceptance and routine use of any material, with which there is little familiarity on the state level, probably involves a minimum five-year time period.

Overall Technical Assessment of LFA Materials. The technology of lime-fly ash-aggregate (LFA) use in base and sub-base construction has been well documented and implemented to various degrees in more than a dozen states over the past 20 or more years. It has been estimated that, since the mid-1950s, from 20 to 25 million tons of LFA materials have been produced and placed in different parts of the United States. There is a large amount of published literature and unpublished data on composition, characteristics, and performance of LFA mixtures. There are hundreds of sections of roadway that have been placed using LFA base materials and which have provided highly satisfactory performance for many years. These projects are testimony to the fact that LFA materials are indeed suitable for use as road base compositions on primary and secondary highways, as well as in the construction of airfields.

Advantages and Disadvantages. The use of LFA materials in areas where they are available offers the prospective user a number of advantages. The principal advantages of these products are:

1. The most obvious benefit of LFA compositions is cost. All other factors being equal, these materials are nearly always less expensive than alternative or competitive base materials such as bituminous concrete or crushed aggregate. In these times of inflation and tight budgets, significant cost savings from the use of LFA bases are not only possible, but have been documented on numerous occasions in many areas of the country.
2. A pozzolanic reaction occurs in these compositions, resulting in gradual, long-term strength development over time. This strength development can be controlled and designed into the mixture by altering the formulation during mix design.
3. Ultimate strength development of LFA base is comparable to that of low-strength concrete. There have been many examples where the ultimate strengths of LFA materials have exceeded 3,000 psi and in some instances have even achieved 5,000 psi or higher strengths. In terms of cost per psi of strength developed, LFA provides more strength for the dollar than any other paving material.
4. LFA base materials are relatively easy to install and can be placed and compacted with conventional construction equipment. There is no need for any exotic hardware or fancy procedures when mixing or laying LFA materials.
5. In states where LFA has been most frequently used, the structural design coefficients for the material are equal, or nearly equal, to bituminous base and substantially higher than crushed aggregate.

6. The use of LFA base provides an excellent opportunity to utilize a material that is considered a disposal problem to the electrical utility industry. From the perspective of fly ash utilization, one cubic yard of concrete can use 100 pounds of fly ash, while one cubic yard of LFA can use 400 pounds of fly ash. In pozzolanic mixtures containing sludge materials, one cubic yard of mix may contain up to 1,000 pounds of fly ash.
7. Once the material ages beyond the first winter, it continues to develop strength at a rate which exceeds the accumulated wheel loadings being applied to the road. Consequently, LFA pavements rarely fail from fatigue. Moreover, it has been determined that, on low traffic volume facilities, LFA mixtures with well-graded aggregates possess sufficient mechanical stability to support wheel loadings through the first winter, even if no cementing of the base occurs.
8. LFA materials contain fly ash, which is a low energy-intensive material. Therefore, use of LFA results in reduced energy input compared to that of alternative materials. Substitution of LFA base in lieu of bituminous base would not only result in lowered costs, but would conserve needed petroleum resources.

On the other hand, there are certain disadvantages associated with LFA materials which must also be considered. The main disadvantages of this product are:

1. On state and Federally funded highway construction work, there are recommended construction cutoff dates which are part of the material specifications. In northern states, where most of the LFA materials have been used, the material is not permitted to be installed on state projects beyond a specified date, usually sometime between September 15th and October 1st. These dates may or may not be overly conservative, but their net effect is to reduce the length of the construction season for LFA placement. On municipal projects, LFA has often been installed well beyond applicable state highway cutoff dates with no failure.

2. LFA base materials are not specified on many reconstruction projects where maintenance of existing traffic is necessary because, in the minds of many highway engineers, the material does not always hold up particularly well to heavy traffic (especially truck traffic). This is more of a problem immediately after the material has been placed and compacted. It is normal practice to blacktop over LFA base as soon as possible (within one or two days) after it has been installed.
3. The production of LFA at the plant, as well as its placement at the job site, requires some reasonable quality control to assure a good performing product. This material is sensitive to variations in moisture which, if large enough, would adversely affect compaction and eventual job performance. The key to a successful LFA job is good compaction. This cannot be achieved unless the product comes out of the plant at or close to its optimum moisture content and is properly compacted.
4. To many engineers, fly ash is a waste material and not a product. When viewed as a waste material, fly ash is considered to be variable and of low quality. While in some cases this may be true, there are many acceptable sources of fly ash available for LFA use. Again, quality control of the ash and cooperation with the utility company is essential. The quality requirements for use of fly ash in LFA materials are far less stringent than for the use of fly ash in portland cement concrete.

In objectively weighing the advantages vs. the disadvantages of LFA base materials, on balance, the good points of this material definitely outweigh its bad points. It is a proven fact that, if this material is designed, produced, and placed properly, it performs well. It is a versatile product, having been produced with almost every kind of aggregate and dozens of different sources of fly ash. The obvious advantage of LFA base offers in dramatic costs savings is, in and of itself, a compelling enough reason for justifying more widespread use of this material.

All of the disadvantages cited above can in one way or another be overcome by applying good, sound engineering coupled with a firm commitment to product quality control. Therefore, from a technical and economic standpoint, use of LFA base is not only justifiable, but also very beneficial.

The question therefore remains: If LFA material is that good, why isn't more of it being used? Although there may be no single answer to this question, a number of possible explanations, not necessarily related directly to technical and/or economic considerations, are offered.

Institutional Barriers and Related Factors. To appreciate why a seemingly acceptable construction material has had such difficulty gaining acceptance since its development nearly 30 years ago, one must understand the state highway engineering function and the relationship of the highway construction industry to each respective state highway agency.

In the first place, there are very few engineers as conservative as the typical highway engineer. They are conservative by necessity, being given a budgeted amount of public funds and at the same time being charged with the responsibility of keeping roads in as good a condition as possible. Most highway engineers are used to operating with sizable construction budgets and relying on well-established construction materials. Consequently, they are somewhat skeptical and reluctant to endorse new or unfamiliar products, no matter what advantages may be associated with the material. They usually resist change and prefer instead to continue utilizing materials with which they are familiar.

Secondly, LFA materials, because of early Poz-O-Pac patents, are considered by many state highway engineers as a proprietary product, even though all patents on the use of these materials have expired. There is still a certain aversion among some state highway engineers to using a product of proprietary nature, such as LFA base.

The specifying and use of highway construction products by engineers and officials at the state and local level is probably as attributable to sales efforts and lobbying pressures as it is to the comparative merits of the material itself. Unfortunately, politics does play a role in determining to what extent various construction materials are included in bids and specifications.

There have been and still are intense lobbying pressures by construction material producers associations on behalf of their products. There is nothing unethical or wrong about such efforts, as long as the sales information is factual and attempts are not made to discredit competitive products. Unfortunately, competitive material lobbyists have not always portrayed LFA in a completely objective fashion to state highway engineers and, consequently, certain misconceptions about the material have persisted. An example of this is the notion that LFA materials are hard to handle and place and require special installation equipment, when the truth is the material is relatively easy to handle and place using conventional spreading and rolling equipment.

To combat ignorance of the product, a professional marketing approach is absolutely necessary at all levels, but particularly at the state level. Unfortunately, LFA materials have never had a real strong advocate or lobbyist to counter the well-financed and well-organized representation from other conventional highway product organizations. Therefore, since the material has not been well sold, it has failed to attract many supporters within the highway establishment strictly on its own merits.

Even though LFA materials are specified and used in some states, other states which may have had less experience with the material sometimes feel the need to "reinvent the wheel," in terms of years of laboratory investigation prior to using LFA on projects. There are also instances where engineers in a particular state gain familiarity with and confidence in a material such as LFA. However, once these engineers retire or pass away, use of the material diminishes and other engineers who are not as familiar with it must be re-educated concerning its use. These are just some examples of the institutional barriers to more widespread use of LFA materials.

Cement-Stabilized Fly Ash Bases and Sub-bases

Another means of using fly ash as a road base or sub-base material in highway construction is by stabilizing the fly ash with portland cement (or, in some cases, hydrated lime). Cement-stabilized fly ash base course and sub-base materials are used in flexible pavement systems in the same manner as lime-fly ash-aggregate and other pozzolanic base materials, except that the cement-stabilized fly ash mixtures do not contain any conventional aggregate.

One of the most obvious advantages to the utilization of cement-stabilized fly ash as a highway base course or sub-base is that between 80 to 90 percent by weight of the base course or sub-base material is fly ash, instead of from 10 to 25 percent, as in the case with most lime-fly ash-aggregate or other pozzolanic compositions. Thus, use of cement-stabilized fly ash mixtures results in a substantially greater utilization of fly ash.

History of Cement-Stabilized Fly Ash. The use of cement-stabilized fly ash is comparatively new in the United States. However, cement stabilization of pulverized fuel ash (PFA) and its subsequent use in road base construction has been in practice in parts of Europe for nearly twenty years. Both Great Britain and France have utilized this material to such an extent that its use is accepted routinely on public roads as well as private projects in both countries. Specifications for fly ash-cement base courses have been adopted by the British Department of the Environment (formerly known as the Ministry of Transport) and commercial manufacturing plants have been established for the production and sale of a ready-mix cement-stabilized fly ash base course material. In France, cement-stabilized fly ash has been used as a sub-base on a number of major highway projects (Reference I-119).

In the United States, there has thus far been very little use made of cement-stabilized fly ash base course and/or sub-base materials. For the most part, this is because American engineers have not had nearly as much experience as their European counterparts with the use of fly ash in general, and in particular, with combinations of fly ash and portland cement containing no aggregate. Consequently, because of an ingrained reliance on conventional materials of construction and an inherent aversion to the use of non-conventional products, such as fly ash, American highway engineers have tended to rely on proven technology and regard fly ash itself, and stabilized compositions containing fly ash, with some mistrust. Furthermore, until recently, there has been a lack of technical documentation, reference materials, or manuals describing the unique properties, design procedures, specification guidelines, and construction techniques related to cement-stabilized fly ash.

Pozzolanic Nature of Cement-Stabilized Fly Ash. As discussed in the preceding section on lime-fly ash-aggregate, fly ash is a pozzolanic material, that is, it will react in the presence of calcium hydroxide and water at normal temperatures to provide cementitious compounds. Therefore, the addition of relatively small amounts of portland cement (or hydrated lime) and water to fly ash can result in significant and oftentimes rapid strength development.

Fly ash itself contains varying amounts of calcium oxide, some of which is present as free lime. The quantity of free lime present in certain fly ashes, particularly the so-called western fly ashes (from the burning of lignite or sub-bituminous coal) is sufficiently great that, when these ash materials are moistened and compacted, they will harden and gradually develop in strength of their own accord. This strength, however, may not be of sufficient magnitude for application in highway base course construction, either in terms of load-bearing capacity or durability in terms of resistance to freezing and thawing. Therefore, the addition of a stabilizing agent, such as portland cement or hydrated lime, in relatively small amounts is required to promote additional and more rapid strength development and improve freeze-thaw resistance.

In general, portland cement is the most desirable stabilizing agent to be added to fly ash, although lime can be added instead of, or even together with, cement. However, the strength gain in fly ash-lime mixes is significantly slower than in fly ash-cement mixes, although comparable strengths may be achieved after many months. The use of lime instead of cement may be considered in situations where longer curing periods or higher curing temperatures can be anticipated or where the use of lime represents an economic advantage over cement (Reference I-120).

The hydration of portland cement in water proceeds rapidly so that cement-stabilized fly ash mixtures normally attain satisfactory early strengths, while continuing to gain in strength over a period of several years. The amount of cement needed to produce a given strength of mixture within a given period of time under specified curing conditions is a function of the reactivity of the fly ash. This, in turn, is related to the physical as well as chemical characteristics of the ash (Reference I-121).

It is presently believed that silica, alumina, and calcium oxide are the principal contributors to the pozzolanic reactivity of fly ash, while the presence of carbon acts to inhibit the pozzolanic reactivity. Generally, high surface area, which is a measure of the fineness of the ash, also aids in the reactivity.

Certain ash handling and storage techniques can directly affect the pozzolanic reactivity of fly ash by altering the physical and chemical characteristics of the material. Sluicing of fly ash to ponds, for example, often results in a non-uniform particle size distribution of the ash throughout different areas of the pond, with coarser particles settling nearest the outlet pipe and finer particles settling farthest from the pipe. Therefore, the fineness of a particular ash sample is a function of its particular location within the sluicing pond. Furthermore, the extent of fly ash exposure to moisture over a period of time, either in ponds or stockpiles, can result in the leaching of calcium oxide and the fly ash thus recovered could have a somewhat reduced pozzolanic reactivity as a result of such leaching (Reference I-122).

Mixture Proportions. Proportioning of cement-stabilized fly ash mixtures is normally accomplished by means of laboratory tests to select a design mix that, when mixed and compacted, is capable of attaining established criteria for strength and durability. The laboratory tests are essentially the same as those recommended for soil-cement samples by the Portland Cement Association (Reference I-123), with some modifications. The details of the recommended criteria for use in mix design, which have been developed by the British Central Electricity Generating Board, will be discussed later in this report.

Portland cement to be used in the construction mix should be Type I cement and comply with the requirements of appropriate state or local highway agencies for portland cement to be used in roadway construction. The fly ash to be used should be tested in advance of trial mix designs in order to determine the following properties:

- Moisture-density relationship (ASTM D698)
- Blaine fineness-specific surface (ASTM C618)
- Loss on ignition at 900°C, percent by weight
- CaO content, percent by weight.

Because of the variability which often occurs in the characteristics of fly ash from most power plants, due to changes in coal source, firing conditions, or ash collection and handling procedures, the concept of a construction mix has also been developed. The construction mix is essentially a design mix in which the mix proportions selected from previous tests may be adjusted in order to accommodate the least reactive fly ash that may be expected to be obtained from a given ash source over the period of construction. Thus, variations in ash quality, disposal and/or storage methods, and moisture conditions can be factored into the mix design procedure.

There is presently no method of accurately determining the amount of cement (or lime) necessary to produce the required amount of strength and durability for a given sample of fly ash, although the percentage of cement is usually between 10 and 20 percent of the fly ash on a dry weight basis. However, the results of the chemical, physical, and laboratory compaction tests provide some indication of the potential reactivity of a sample of fly ash and can serve as a guide for selection of a trial mix.

Based on laboratory test results of fly ash samples, selection of a cement content for trial mixes can be made according to the following guidelines:

1. Loss on Ignition - The carbon content of fly ash is an important factor in strength development of cement-fly ash mixtures. For a fly ash sample with a loss on ignition greater than 5 percent, a trial mix with at least 20 percent cement by weight of fly ash should be assumed.
2. Calcium Oxide - The higher the CaO content of the fly ash, the lower the cement required for stabilization. For fly ash samples with 10 percent or greater CaO content, a cement content of 5 to 10 percent is recommended. For CaO contents below 10 percent, other factors will be of greater influence in the selection of a trial mix.
3. Maximum Dry Density - For fly ash samples with low loss on ignition and CaO content, density can be used as an indicator of reactivity. For fly ash samples with maximum dry densities greater than 85 pounds per cubic foot, cement contents of 10 to 15 percent are recommended. For fly ash samples with maximum dry densities less than 85 pounds per cubic foot, 15 to 20 percent cement is recommended.
4. Blaine Fineness - The fineness of a fly ash sample with low loss on ignition and CaO content is yet another indicator of reactivity. For fly ash samples with a Blaine fineness in excess of 2,500 cm^2 per gram, cement contents between 10 and 15 percent are recommended, with increases in the cement content as the Blaine fineness decreases.

Normally, in laboratory mix design testing, it is standard practice to express the cement content of a mix in terms of a certain percent by weight of dry fly ash. However, this often does not give a clear indication of the actual amount of cement being used in the mix because of variations in the unit weight of fly ash from sample to sample. Therefore, for cement-stabilized fly ash mixes, it is more practical to express the cement content of the design mix in terms of pounds of cement per cubic foot of compacted mix, based on the maximum dry density and optimum moisture content of the mix as determined by ASTM D134-70. This means of expressing the cement content permits a direct comparison between design mixes on the basis of actual quantities of cement required in each mix (Reference I-124).

Engineering Properties. The most significant engineering properties of cement-stabilized fly ash base course materials are compressive strength, durability or freeze-thaw resistance, and moisture-density characteristics. Unfortunately, due to the limited number of projects in which these materials have been used in the United States, there is very little in the way of documentation of these properties. The following paragraphs summarize available information on engineering properties of cement-stabilized fly ash compositions.

Compressive Strength. As noted earlier in this report, the British have developed criteria for cement-stabilized fly ash base courses which have been adopted and published by the National Ash Association (Reference I-124) for mix design purposes. The basis of these criteria are that a specified compressive strength is an indication of the mix's ability to resist damage due to cyclic freezing and thawing and frost action. The following criteria have been developed for cement-stabilized fly ash mixes:

- The seven-day compressive strength of the mix, when cured under moist conditions at $70 \pm 3^{\circ}\text{F}$ ($21 \pm 2^{\circ}\text{C}$) must be at least 400 to 450 psi.
- The unconfined compressive strength of the mix must increase with time.

Since no data are available for laboratory freeze-thaw testing of cement-stabilized fly ash materials, the criteria listed above are assumed to provide a design basis for development of sufficient compressive strength to also satisfy durability requirements.

Determination of mix formulations to meet those criteria must be done by means of trial mixes. Data from an access road project in Stoneleigh, England provides an indication of the possible strength development of cement-stabilized fly ash. Unconfined compressive strength data from this project, using a mix with 10 parts fly ash to 1 part cement by weight, are as follows:

<u>Age of Base Course (days)</u>	<u>Unconfined Compressive Strength (psi)</u>
7	400
28	760
90	1,250
270	1,660

Fly ash samples from different American power plants were tested in the laboratory to evaluate the engineering properties of trial mixes using these materials. The results of these tests, which include compressive strength and moisture-density data, are presented in Table I-15. These test results are useful in illustrating the range of engineering properties that can be expected for design mixes using typical American bituminous coal fly ashes.

In addition, Figure I-16 shows the variation in 7-day compressive strength development with cement content for several of these fly ashes. From this figure, it is evident that the lagoon sample of fly ash from the Willow Island plant requires a considerably higher cement content to achieve strength comparable to the other silo ash samples (Reference I-124).

Some minimal compressive strength data are also available from two projects in West Virginia in which cement-stabilized fly ash has been used as the base course for parking lot facilities. These data, involving both laboratory and field test specimens, are summarized as follows:

<u>Laboratory Test Specimens</u> (Moist Cured at 70°F)		<u>Field Core Specimens</u>	
<u>Philip Sporn Plant - New Haven, W. Va.</u>		<u>Harrison Station - Haywood, W. Va.</u>	
<u>Age of Base Course (days)</u>	<u>Unconfined Compressive Strength (psi)</u>	<u>Age of Base Course (days)</u>	<u>Unconfined Compressive Strength (psi)</u>
7	452	7	566
28	1,362	90	869

It should be noted that the base course material installed at the Harrison Station project was placed rather late in the season and had undergone several freeze-thaw cycles between 7 and 90 days. Nevertheless, these data, limited though they may be, demonstrate that mix formulations have been designed and placed in service in this company that are capable of meeting the six design criteria adopted by the National Ash Association.

Table I-15

**ENGINEERING CHARACTERISTICS OF CEMENT-STABILIZED
FLY ASH MIXES USING DIFFERENT FLY ASH SOURCES**

Utility Company Power Station Location	Potomac Electric Chalk Point Aquasco, Md.	Potomac Electric Morgantown Newburg, Md.	Union Electric Meramec St. Louis, Mo.	Allegheny Power Hatfield's Ferry Masontown, Pa.	Allegheny Power Harrison Haywood, W. Va.	Allegheny Power Willow Island Willow Island, W. Va.
Ash Source	Silo	Silo	Silo	Silo	Silo	Lagoon
Ash Content (lbs. per ft. ³)	78	78	80	78	92	-
Cement Content (lbs. per ft. ³)	12	14	8	12	11	-
601-1 Cement Content (percent)	15	18	10	15	12	430
7-day Average Compressive Strength (psi)	432	440	413	460	421	696
28-day Average Compressive Strength (psi)	857	1341	1142	1020	580	-
Optimum Moisture Content (%)	20.0	20.5	21.0	20.4	19.0	31.0
Maximum Dry Density (lbs. per ft. ³)	90.5	92.6	87.7	89.4	102.5	79.8

NOTE: Data is from final trial mix formulations for each of the above fly ash sources.

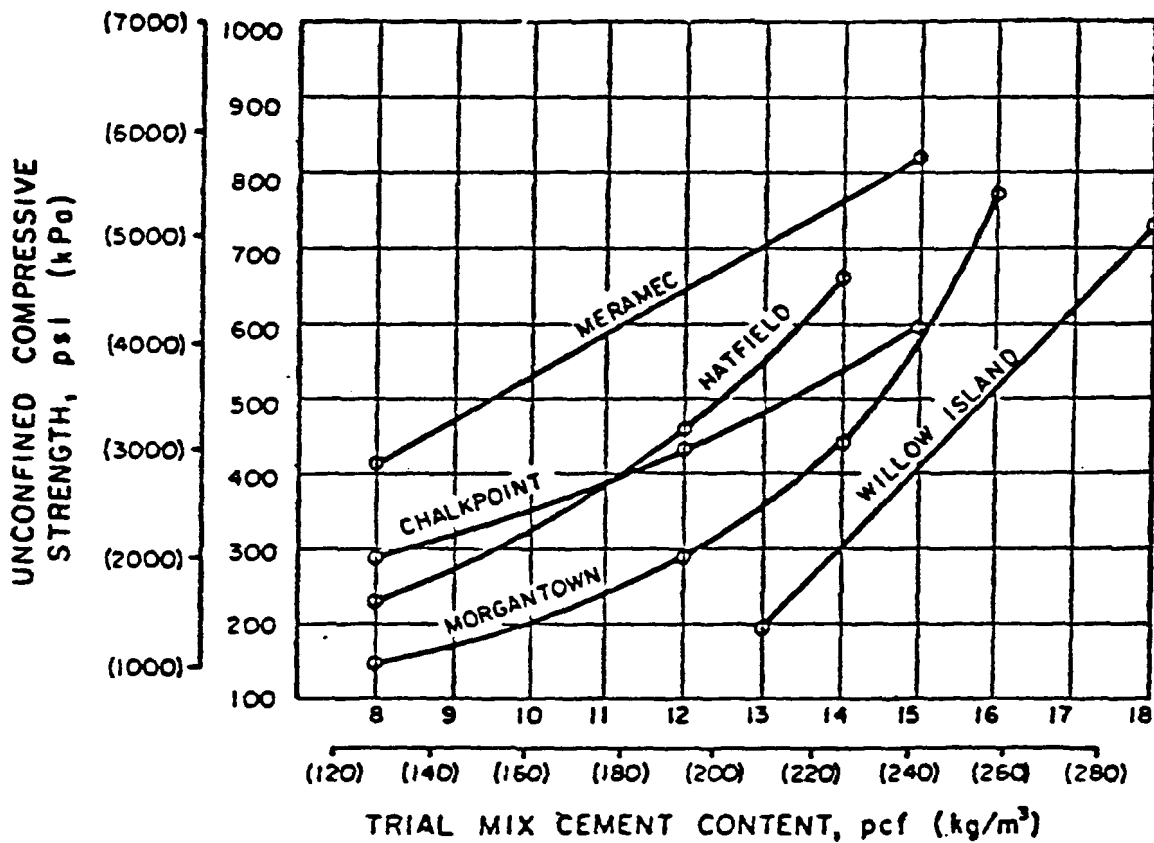


Figure I-16. Variation in 7-day compressive strength development with cement content for cement-stabilized fly ash mixtures using different sources of fly ash.

Moisture-Density. Moisture-density characteristics of cement-stabilized fly ash compositions will, of course, be dependent on the mix proportions used. Data on the moisture-density characteristics of design mixes using bituminous fly ash samples from several different American power plants are shown in Table I-15. Figure I-17 shows the moisture-density curves for several of these design mixes (Reference I-124).

The cement-stabilized fly ash base material placed at the Harrison Station project in Haywood, West Virginia had a maximum dry density of 92.5 pounds per cubic foot at an optimum moisture content of 14 percent (Reference I-124), according to the results of a moisture-density test performed in accordance with ASTM D558. A copy of this test method is included in the Appendix of this report. In-place density tests performed at the site with a nuclear density gauge confirm that the material was compacted to an average of 98.5 percent of the maximum dry density value (Reference I-124). Similar data are not readily available from other cement-stabilized fly ash installations.

California Bearing Ratio. The only published values for the California bearing ratio (CBR) of cement-stabilized fly ash material used in the United States are for the parking lot facility at the Philip Sporn plant in New Haven, West Virginia. It has been reported that seven day soaked and unsoaked CBR values for the mix used on this project were 145 and 150 percent, respectively (Reference I-125).

Pavement Thickness Design Considerations. As previously mentioned, the thickness design procedure developed by the Portland Cement Association (PCA) for soil-cement base courses has also been adopted for cement-stabilized fly ash base courses. This procedure has evolved over the years from previous research, theory, test pavements, and actual construction projects involving soil-cement pavement systems. The design method is theoretically based on the load-deflection and fatigue characteristics of soil-cement. Thickness design curves were previously developed by PCA for both granular and fine-grained soils, but the curves for fine-grained soils are the ones used in determining the thickness of fly ash-cement base courses.

The PCA design procedure consists of the determination of two parameters, the subgrade strength and the fatigue factor, which are then entered into a thickness design chart to yield the base course (Reference I-126). Once the initial thickness of the cement-stabilized fly ash base course has been found, the thickness of the bituminous wearing surface can then be determined. The initial base course thickness can then be reduced to account for the thickness of the bituminous wearing surface.

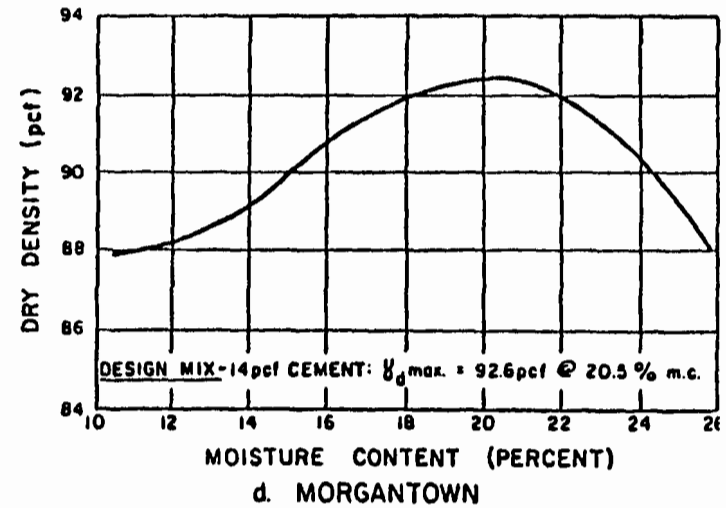
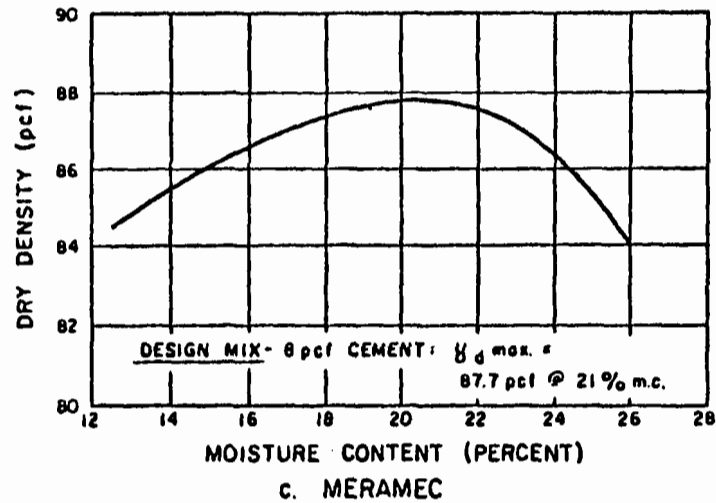
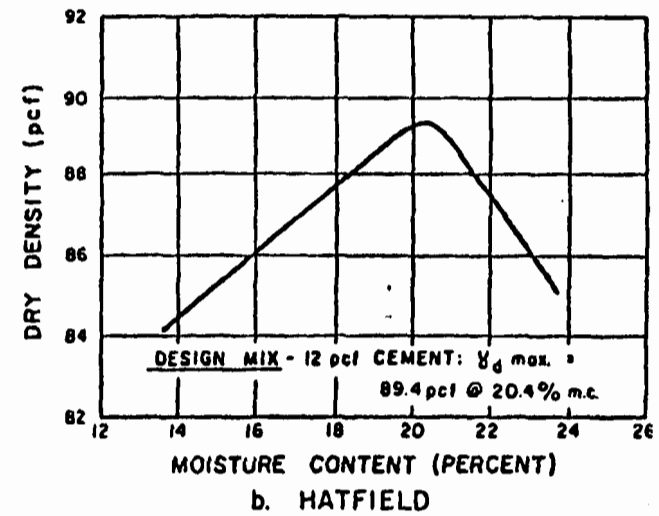
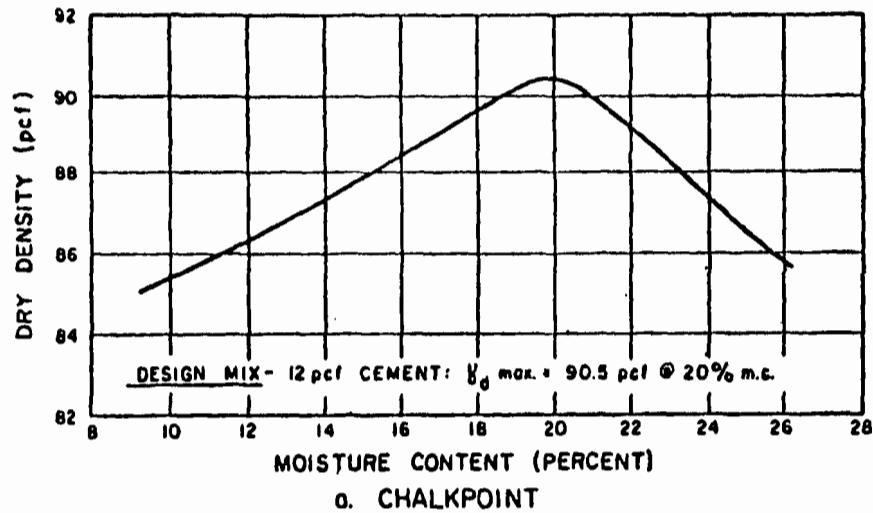


Figure I-17. Moisture-density relationships of design mixes.

The subgrade strength in this procedure is measured by the modulus of subgrade reaction (k), which is determined by means of field plate-load bearing tests. However, CBR and Resistance (R) value tests can also be used to convert to equivalent k values, using appropriate charts (Reference I-127). Where light traffic conditions are expected, such as on rural roads or in parking lots, subgrade strengths can be estimated based on soil classification data.

Four traffic parameters are necessary in order to determine the fatigue factor. These are the average daily traffic (ADT), the percentage of trucks, the axle load distribution of the trucks, and the annual traffic growth rate. The fatigue factor represents the total fatigue consumption of the pavement over a specified design period (usually 20 years) for given conditions of traffic loading. The fatigue factor is calculated using different coefficients for different axle load groups and summing the individual totals. For example, a two-lane road with an ADT of 3,000 vehicles and 3 percent trucks had a calculated fatigue factor of 1,700,000.

Figure I-18 shows the base course thickness design chart used in this thickness design procedure. By entering this design chart with values for fatigue factor and modulus of subgrade reaction (k), a value for the initial base course thickness can be obtained. The final base course thickness is determined by selecting the thickness of the bituminous wearing surface and using this value to adjust the thickness of the base course. Graphs for developing these thickness values are shown in Figure I-19.

Late Season Construction. As with lime-fly ash-aggregate and other pozzolanic pavements, sufficient cured strength must be developed within the base material in order to provide the amount of durability necessary to withstand the initial winter freeze-thaw cycles. To assure that the material is exposed to the required amount of degree-day curing conditions for adequate strength development, a sensible construction cutoff date must be determined.

A general guideline for establishing a construction cutoff date for cement-stabilized fly ash base course is that the ambient air temperature should not fall below 50°F (10°C) for a period of seven days following placement of the base course. Since this material is similar in some respects to lime-fly ash-aggregate, the pozzolanic reaction in cement-stabilized fly ash base course practically ceases at temperatures below 40°F (40°C). However, once the temperature increases, the pozzolanic reaction will again resume.

In the middle Atlantic states, a recommended construction period is from April 15th through October 15th. However, it is further suggested that reference be made to the construction specifications of respective state highway departments for applicable cutoff dates for either lime-fly ash-aggregate or soil-cement construction. Such dates can be safely applied to the construction of cement-stabilized fly ash base course materials (Reference I-128).

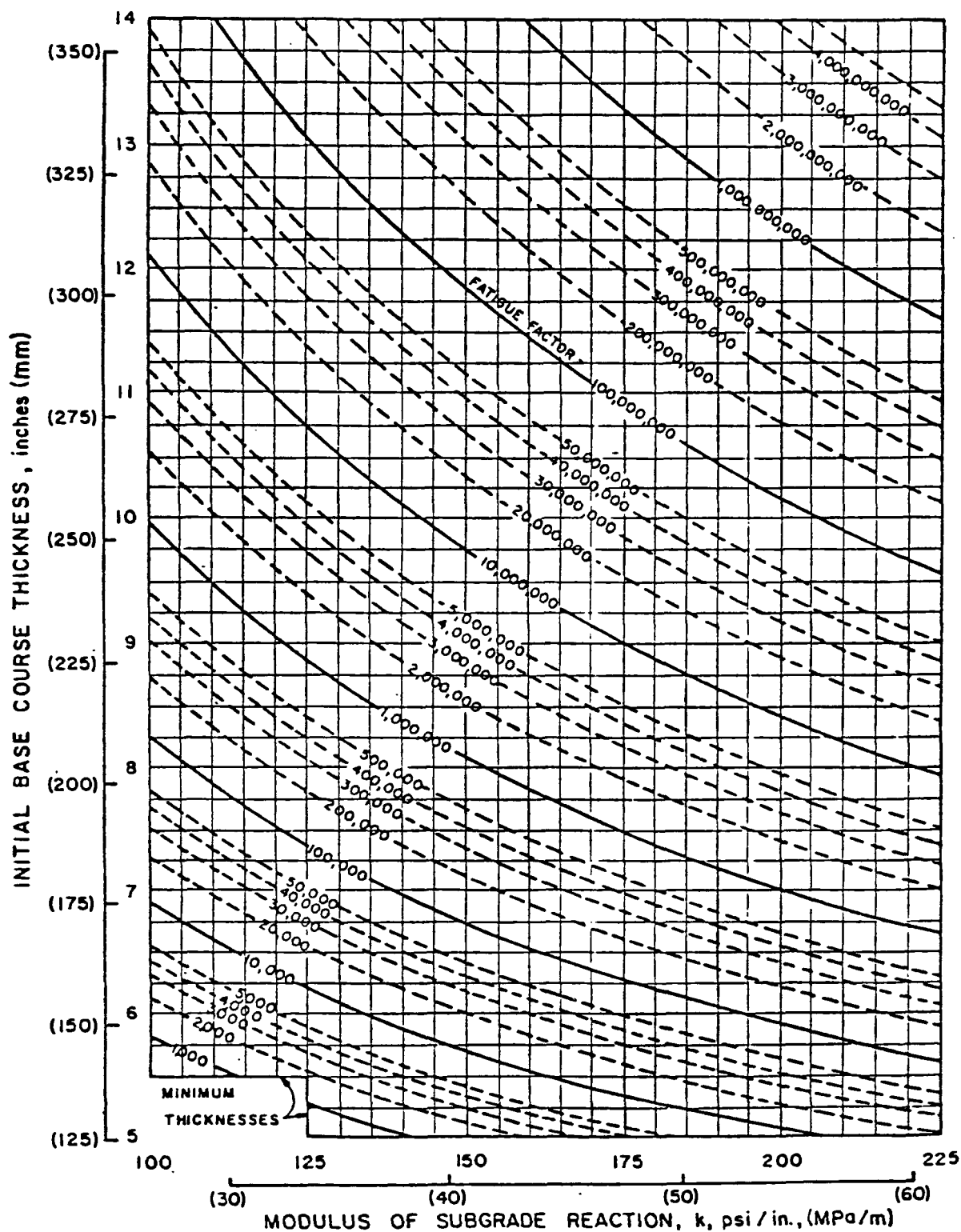


Figure I-18. Base course thickness design chart.

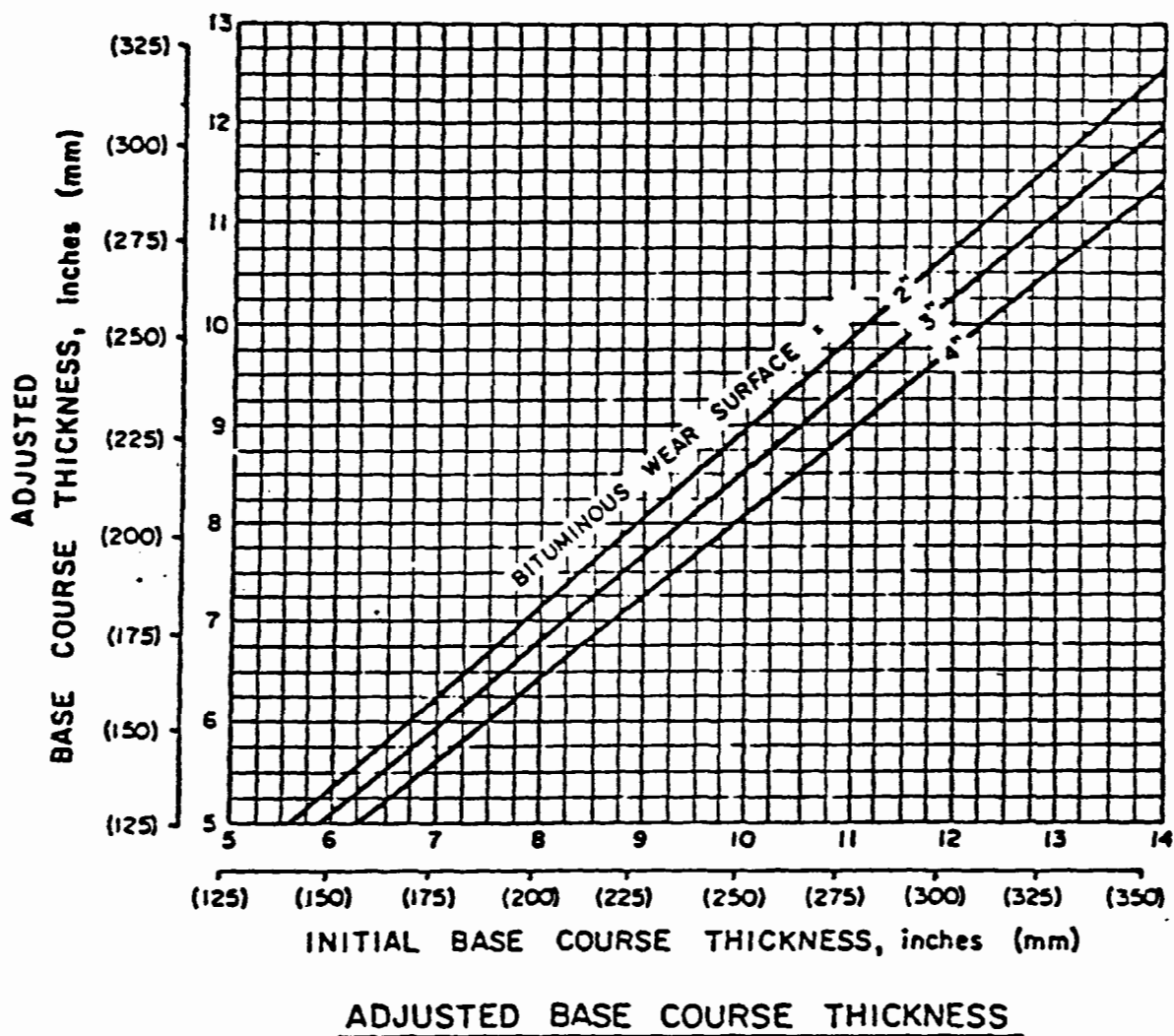


Figure I-19. Relationship between initial and adjusted base course thicknesses for cement-stabilized fly ash base materials.

Assessment of Performance in Specific Projects. In the United States, several field trials and demonstration projects have been undertaken in different locations to evaluate the performance of cement-stabilized fly ash base course materials. To date, at least five cement-stabilized fly ash projects have been constructed and the results of each of these field trials have so far been favorable. Several of these projects are discussed in this section of the report.

Harrison Power Station - Haywood, West Virginia. In September 1975, approximately 10,000 square yards of cement-stabilized fly ash was placed as base course for an access road and parking area at the Harrison Power Station. Cement and fly ash from hoppers at the plant site were pre-mixed in a pugmill with water at the rate of 83 pounds (37.5 kg) of fly ash and 10 pounds (4.5 kg) of cement per cubic yard of compacted mix. This base course material was spread and compacted to an 8-inch (203 mm) thickness and sealed with a bituminous emulsion. The material was tailgated from dump trucks, spread to the required loose lift thickness, and compacted by a vibratory roller having a dead weight of 8 tons. A 3-inch (76 mm) bituminous wearing surface was applied over the base course. Cores taken after 180 days indicated that the base course material had not experienced any loss in strength over the winter months (Reference I-129). As far as is known, this base course is still providing acceptable service.

Philip Sporn Plant - New Haven, West Virginia. During the summer of 1978, a 70 x 300 foot (21 x 91 m) parking lot facility was constructed near American Electric Power Company's Philip Sporn plant along the Ohio River about 35 miles north of Huntington, West Virginia. The experimental parking lot project was divided into five test strips, each 60 x 70 feet (18 x 21 m). Two of these five test strips involved the placement of cement-stabilized fly ash base. One section was 6 inches (152 mm) thick, while the other was 15 inches (381 mm) thick. Two other test strips involved a cement-stabilized bottom ash base, while the final section involved an emulsified asphalt bottom ash base. All ash utilized in the parking lot was obtained from the Philip Sporn plant.

The experimental base course materials were blended in a continuous-feed pugmill and then transported to the site. Initial attempts to place these base materials using an asphalt paving machine proved to be cumbersome and time-consuming, so the materials were simply spread by means of a motor grader or small bulldozer and compacted using a steel-wheeled vibratory roller. All base materials were surfaced with 2 inches (51 mm) of bituminous wearing surface.

The contractor's inexperience with ash materials and initial selection of inappropriate equipment to handle and place these materials was a minor problem on this project. A more serious problem involved the blending of cement and fly ash in the pugmill. Unfortunately, the cement-stabilized fly ash material contained numerous small clumps of unmixed fly ash. This "balling" phenomenon was attributed to the use of damp fly ash, which had been recovered from a disposal pond and mixed in its damp condition with cement in the pugmill. Previous European mixing experience has shown that it is better procedure to mix dry fly ash with cement, then introduce water during additional blending.

Monitoring of the performance of the cement-stabilized fly ash and other base materials placed at this location is still underway. No compressive strength or other data have been made available for the cement-stabilized fly ash base sections at this time. However, it is believed that all of the experimental base materials are still providing satisfactory performance (Reference I-130).

Virginia County Road 665 - Carbo, Virginia. During the summer of 1978, a test section approximately 400 feet long was constructed of cement-stabilized fly ash as part of the relocation of a portion of County Road 665 near the Clinch River power plant at Carbo, Virginia. The pavement section consisted of a 5.5 inch (140 mm) thick cement-stabilized fly ash base course overlaid by a 1.5 inch thick emulsified asphalt stabilized bottom ash wearing course. The base course material had a cement content of 14 percent of the dry weight of the fly ash, with an optimum moisture content of 17 percent. The compacted total unit weight of the mixture in the laboratory was approximately 110 pounds per cubic foot.

Because of logistical considerations, the base material was mixed in-place on the site rather than mixed at a central mixing plant. Some minor construction problems resulted from the contractor's inexperience in the handling and placement of stabilized base materials. The base course material was spread by a motor grader and compacted by means of a 10-ton vibratory compactor and a bulldozer. A tack coat was applied to the base after placement.

Thus far, the completed haul road has been in service for two years with no obvious signs of pavement distress. Examination of a core specimen taken through the base course shows that the cement-stabilized fly ash material is hard and coherent and the bond between the wearing surface and the base appears to be satisfactory (Reference I-130).

Economic Evaluation of Cement-Stabilized Fly Ash Base. In the National Ash Association's "Guide for the Design and Construction of Cement-Stabilized Fly Ash Pavements," a design example is given which compares the costs of a cement-stabilized fly ash base with three alternative pavements. These are full depth asphalt, bituminous wearing surface on a crushed aggregate base course, and reinforced concrete on a crushed aggregate sub-base.

The design methods used for the alternative pavements are those developed by the Asphalt Institute and the Portland Cement Association. The design method developed by the Portland Cement Association for soil-cement pavements has been adopted for cement-stabilized fly ash because of certain apparent similarities between soil-cement and fly ash-cement. Until a design method can be verified by test track operations, it is reasonable to assume that other design methods, such as ultimate strength techniques, may be equally applicable to cement-stabilized fly ash base course.

A two-lane pavement carrying 300 vehicles per day was used in the design example. The modulus of subgrade reaction was 125 psi per inch. The Fatigue Factor, based on 3 percent trucks and an assumed axle load distribution, was computed as 1,700,000. For a bituminous wearing surface thickness of 3 inches, the adjusted thickness for the cement-stabilized fly ash base is 8 inches.

Unit costs for this economic evaluation were based on data from Building Construction Cost Data 1975, The Pennsylvania Department of Transportation 1974 edition of Construction Cost Catalog, and quotes received from private contractors. All unit costs are in-place, unless specified otherwise. It is assumed that the project site is 50 miles from the source of the fly ash.

Costs for each of these four alternatives, on the basis of square yard costs in-place, are computed as follows:

Bituminous Wearing Surface on Cement-Stabilized Fly Ash Base Courses. The base course thickness in the design example was determined as 8 inches and the bituminous wear surface thickness as 3 inches. The base course mix proportions are as follows:

Fly Ash	80 pcf of mix or 480 lb/yd ²
Cement	8 pcf of mix or 48 lb/yd ²
Water	20 pcf of mix or 120 lb/yd ² (2-1/2 gal/cf) (14-1/2 gal/yd ²)

a. Materials Costs:

Fly ash, at a nominal cost of \$0.50/ton;
 $(480 \text{ lb/yd}^2 \div 2,000 \text{ lb/ton}) \times \$0.50/\text{ton} = \$0.12/\text{yd}^2$

Trucking costs of fly ash for 50 miles at
 $\$0.30/100 \text{ lb}; 480 \text{ lb/yd}^2 \times \$0.30/100 \text{ lb} = 1.44/\text{yd}^2$

Cement, in bulk; 48 lb/yd² x \$1.70/100 lb
 $= 0.82 / \text{yd}^2$

b. Mixing Costs:

Central mixing in pugmill at \$1.00/ton (wet);
 $(648 \text{ lb/yd}^2 \div 2,000 \text{ lb/ton}) \times \$1.00 \text{ ton} = 0.32/\text{yd}^2$

c. Placement, Compaction, Finishing and Curing:

For 8-inch thickness, assume construction in one layer; 1 layer x \$1.00/layer-yd² = \$1.00/yd²

d. Bituminous Wearing Surface:

Wearing course - 1-1/2 inches at \$1.50/yd²
 Binder course - 1-1/2 inches at \$1.50/yd² = \$3.00/yd²

TOTAL - BITUMINOUS WEARING SURFACE ON
 CEMENT-STABILIZED FLY ASH BASE COURSE \$6.70/yd²

Full Depth Asphalt. The required total thickness of pavement for the full depth asphalt alternative is 8-1/2 inches. Assume the following pavement configuration:

Wearing Course - 1 inch	= \$1.10/yd ²
Binder Course - 1-1/2 inches	= 1.50/yd ²
Base Course - 6 inches	= <u>6.00/yd²</u>
TOTAL - FULL DEPTH ASPHALT	= \$8.60 yd ²

Bituminous Wearing Surface on Crushed Aggregate Base Course. Based on a substitution ratio of 2.0 for high quality granular base and a total required wearing surface thickness of 4-1/2 inches, the pavement configuration for this alternative is as follows:

Wearing Course - 1-1/2 inches	= \$1.50/yd ²
Binder Course - 3 inches	= 3.00/yd ²
Crushed Aggregate Base - 8 inches	= <u>2.75/yd²</u>
TOTAL - BITUMINOUS WEAR SURFACE ON CRUSHED AGGREGATE BASE COURSE	= \$7.25/yd ²

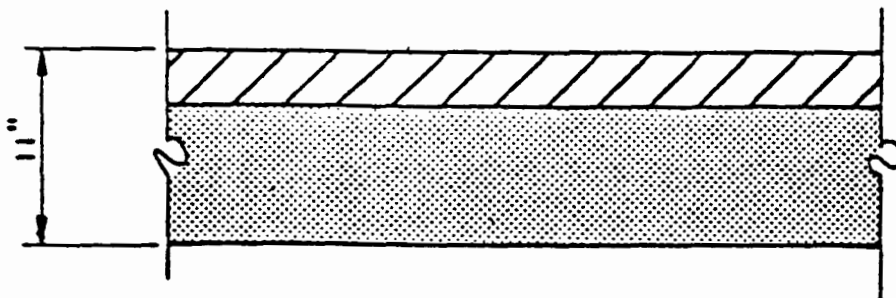
Reinforced Concrete Pavement on Crushed Aggregate Sub-base. Based on a concrete modulus of rupture of 600 psi, the required thickness of reinforced concrete pavement was determined as 7-1/2 inches, and the thickness of crushed aggregate sub-base as 6 inches. The pavement configuration is as follows:

Reinforced Concrete Pavement - 7-1/2 inches	= \$10.00/yd ²
Crushed Aggregate Sub-base - 6 inches	= <u>2.00/yd²</u>
TOTAL - REINFORCED CONCRETE ON CRUSHED AGGREGATE SUB-BASE	= \$12.00/yd ²

The four alternative pavement systems and their relative costs are illustrated in Figure I-20. The unit costs for the alternative paving materials represent gross averages and definitely vary with project location and availability of materials. (Reference I-131). Although the pavement costs shown in this figure are based on 1975 cost data, it is assumed that the costs of each of these pavement systems would not change significantly in relation to the other alternatives, although all costs would definitely have increased.

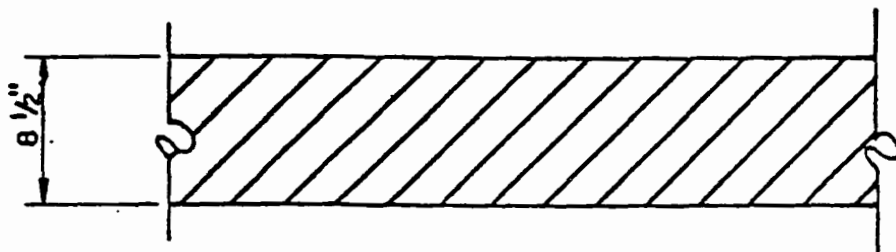
The actual economy of the cement-stabilized fly ash pavement is directly related, of course, to the availability of fly ash in reasonable proximity to the project site. However, in situations where fly ash is more readily available than aggregate, it can be said that cement-stabilized fly ash pavements obviously represent a more economical alternative than a conventional pavement.

1.


 $\$ 6.70 / \text{YD}^2$

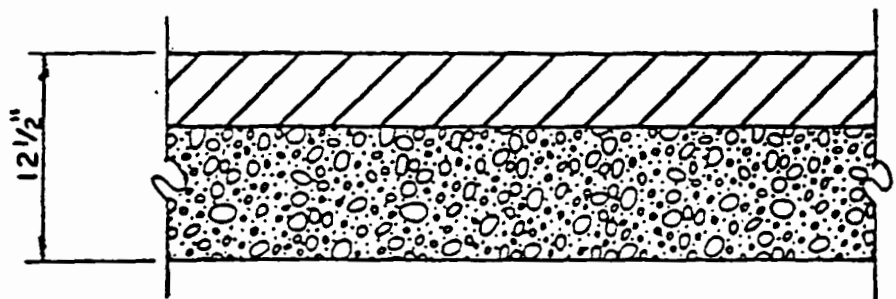
BITUMINOUS WEAR SURFACE ON
CEMENT-STABILIZED FLY ASH BASE COURSE

2.


 $\$ 8.60 / \text{YD}^2$

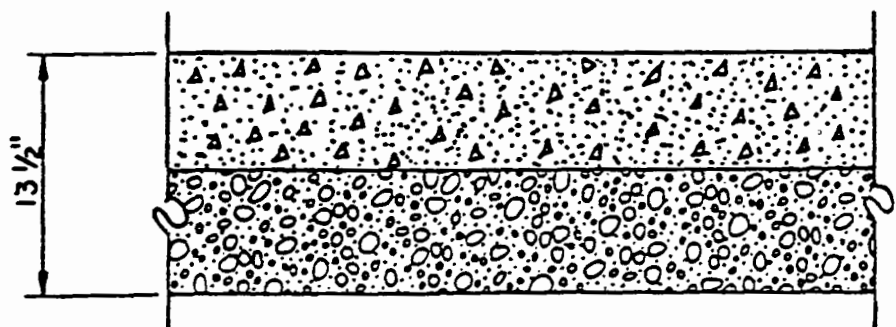
FULL DEPTH ASPHALT

3.


 $\$ 7.25 / \text{YD}^2$

BITUMINOUS WEAR SURFACE ON CRUSHED
AGGREGATE BASE COURSE

4.


 $\$ 12.00 / \text{YD}^2$

REINFORCED CONCRETE ON CRUSHED
AGGREGATE SUBBASE

Figure I-20. Comparison of alternative pavements.

Overall Technical Assessment. Cement-stabilized fly ash base course material has been used on a very limited basis in the United States. Although substantial use has been made of this material in some European countries, and the necessary design procedures and specifications for its use in this country have been published in the form of a manual (Reference I-131), the material itself has only been placed in a handful of projects. Consequently, although cement-stabilized fly ash is similar to that of lime-fly ash-aggregate or soil-cement base materials and the material appears to have a proven record of performance, most engineers and, in particular, road-building contractors are still not familiar with this material. Therefore, experience in the United States with cement-stabilized fly ash is simply not sufficient to utilize the product on a routine basis at this time.

Despite the performance record of cement-stabilized fly ash in Great Britain, it is not appropriate to expect a rapid transfer of testing, design, and construction procedures, as well as specifications, to be made on the part of American engineering practice with a comparatively untried material. In order to gain product acceptance and incorporate the use of cement-stabilized fly ash base materials into American construction use, a program involving several years of laboratory investigation and monitoring of field performance must be undertaken by a number of Federal and state agencies. Only when confidence in this material has been gained through experience can any consideration be given to possible development of guidelines for its use.

Mineral Filler in Bituminous Pavements

The importance of mineral fillers in bituminous paving has been recognized for many years. Asphalt paving mixtures have been designed to include mineral filler since 1980. The term mineral filler generally applies to the fine fraction of a conventional aggregate that is predominantly mineral dust, most or all of which is passing the 200 mesh sieve (Reference I-132).

Mineral fillers in asphalt paving mixtures are particles suspended in the asphalt binder which serve to improve the cohesion of the binder itself while contributing to the internal stability of the mixture by increasing the contact points between aggregate particles. When incorporated in an asphalt mixture, mineral filler greatly increases the surface areas that must be coated with asphalt. If these surfaces are compatible with the asphalt and are easily coated, use of the filler produces considerable benefits. If, on the other hand, the surfaces of the mineral filler are highly susceptible to water, early pavement failure may result.

An early investigation of mineral powders as fillers for bituminous mixtures identified the following characteristics to be important:

1. Fundamental properties - particle size, size distribution, and particle shape.
2. Mineral properties - texture, hardness, strength, specific gravity, and wettability.
3. Dependent properties - void content, void diameter, and surface area (Reference I-133).

Although the use of mineral fillers, either occurring naturally in aggregates or added to mix, is common practice, existing knowledge of the filler's effects on pavement performance is limited. Selection of the amount and type of filler is based largely on experience. However, specification requirements pertaining to particle size and plasticity characteristics of candidate filler materials are often supplemented with additional tests and requirements.

Research on Use of Fly Ash as Mineral Filler. Initial study of the use of fly ash as a mineral filler dates back to 1931, when the Detroit Edison Company recognized the opportunity to market fly ash for bituminous road construction. An initial laboratory investigation by the company compared the physical and chemical properties of fly ash from the Trenton Channel Plant with those of natural filler found in Trinidad asphalt, which has long been recognized as an excellent material. The results of this investigation confirmed that the chemical composition of fly ash did not differ substantially from that of the natural Trinidad filler and that both materials were composed, for the most part, of fine dust with a sprinkling of coarse, gritty particles. The fly ash was composed of spherical particles which were somewhat coarser and of more uniform size than the fine, angular particles in the Trinidad filler, although the coarsest particles in the fly ash were small compared to the gritty particles of the Trinidad filler. It was concluded from this early research that fly ash was sufficiently similar to Trinidad asphalt filler to warrant consideration as a mineral filler material.

A followup program then compared the oil absorption of fly ash and limestone dust fillers. Laboratory tests were performed to compare the particle size distribution and specific gravity of these materials. Trial mixes were made using the same gradation of prepared aggregates in order to measure asphalt absorption, water-asphalt preference, and swelling of the resultant mixes. The results of this investigation indicated that fly ash is an acceptable filler, provided it is proportioned on an equal volume basis, since it has a lower specific gravity than limestone dust (Reference I-133).

A laboratory test program was also performed to compare the suitability of fly ash as a filler in sheet asphalt paving mixtures with limestone and silica dust fillers. The following studies were involved in the program:

1. Void-reducing properties of fillers used in different proportions with sand.
2. Comparison of Hubbard-Field stability values for different percentages of these fillers.
3. Exposure of mixtures to water for a period of one month to determine the effect of such exposure to stability.
4. Effect of different percentages of carbon in the fly ash filler on the stability of the mixtures.

In this program, filler contents were chosen to correspond in volume to percentages by weight of limestone dust of 0, 5, 10, 15, and 20 percent by weight of the aggregate. Mixtures were designed to contain 8 percent by weight of asphalt and 92 percent aggregate. The asphalt content was not sufficient to fill the voids of any of the aggregate-filler combinations. Densities and voids in all mixes were computed from known proportions and from the specific gravities of the constituent materials. Stabilities of all mixes were determined by the Hubbard-Field method of mix design (ASTM D1138), which is intended primarily for the laboratory design of sheet asphalt paving mixes and is included in the Appendix of this report.

A comparison of the data from this testing program led to the following conclusions:

1. Within the range of filler contents generally used in sheet asphalt mixtures, fly ash has virtually the same void-reducing properties as limestone dust and is better than silica dust, when used on an equal weight basis.
2. Mixtures designed to have the same voids and containing equal weight percentages of fly ash and limestone fillers have nearly identical stabilities by the Hubbard-Field test. Of mixtures containing equal volume percentages of fly ash and limestone fillers, those containing fly ash have lower stability.
3. Exposure to water for a period of one month did not appear to affect the stability of fly ash mixtures.

4. The carbon content of fly ash does appear to affect the stability of sheet asphalt mixtures. Maximum stability values seemed to be obtained with fly ash of about 9 percent carbon content in the normal sheet asphalt mixtures tested, although very little difference in stability values were observed with carbon contents of the fly ash filler between 6.5 and 12 percent.

As a result of these studies, the Department of Public Works of the City of Detroit in 1939 accepted fly ash as meeting their specification requirements for mineral filler. Since that time, additional research work has been done to further evaluate fly ash as a filler material in asphalt paving mixtures.

A comprehensive study of various sources of mineral fillers was performed in 1952 by the U.S. Bureau of Public Roads, now known as the Federal Highway Administration. Twelve different sources of mineral fillers, including four fly ashes, were investigated. Filler sources also included silica dust, limestone dust, mica dust, and traprock dust. A total of 87 different laboratory mixtures were investigated using a variety of coarse and fine aggregates with the fillers. The proportions of the test mixtures were 93 percent by weight coarse and fine aggregate and 7 percent by weight filler. All mixtures were tested with asphalt contents of 5.5 and 6.5 percent by weight of aggregate, with the intention of confining the voids contents of the compacted mixtures to between 6 and 7 percent. It was found, however, that the type of filler affected the density and void content of the mixes, so no further attempt was made to adjust mix designs to reduce these differences, which were reflected in the test results.

All test specimens were compacted in accordance with the procedures of the Marshall mix design method, described in ASTM D1559, "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus." A copy of the Marshall mix design test method is included in the Appendix of this report. The principal test characteristic upon which the ratings of the different fillers were based was the resistance of the compacted asphaltic concrete mix specimens to loss of strength after immersion in water. The specimens were tested by the immersion-compression test (ASTM D1075), "Standard Method of Test for the Effect of Water on Cohesion of Compacted Bituminous Mixtures." In this test, a set of three compacted specimens for each mixture is subjected to an unconfined compressive strength test to determine its "dry" strength. A duplicate set of three specimens is immersed in water for 4 days at 120°F, then also tested for unconfined compressive strength to determine its "wet" strength. The average "wet" and "dry" strengths are then compared. The ratio of the "wet" to the "dry" strength is referred to as the retained strength.

Of the 87 mixes tested, a total of 24 mixes contained fly ash as a mineral filler. The average retained strength of the mixes containing the fly ash filler was 94 percent, which was with one exception the highest retained strength of all the filler sources investigated. One source of quartzite dust was used as a filler and the mix containing this dust had a retained strength of 97 percent. All of the retained strengths of the mixes containing fly ash as filler had retained strengths in excess of 85 percent.

By contrast, the average retained strength of 11 mixes containing limestone dust fillers was 88 percent and the average retained strength of 19 mixes containing traprock dust fillers was 87 percent. Normally, the minimum recommended acceptable value of retained strength from the immersion-compression test is 75 percent.

It was concluded from these laboratory studies that the fly ash fillers tested can be expected to provide superior resistance to water in bituminous concrete mixtures of the dense type (Reference I-136).

In 1956, the University of Michigan completed work sponsored by Detroit Edison on a further comparison of limestone dust and fly ash fillers to determine the effects of using various fly ashes as fillers in dense-graded asphaltic concrete paving mixtures. The characteristics of limestone dust fillers were compared with those of low carbon and high carbon fly ashes from four different sources. The specification requirements of the Michigan Department of Highways for dense-graded asphaltic concrete were used in the investigation. At that time, the carbon content of fly ash as mineral filler had to be between 7 and 12 percent by weight.

Typical paving mixture compositions studied had the following proportions by weight:

<u>Component</u>	<u>Percent</u>
Asphalt	5.5
Filler	6.0
Fine aggregate	33.5
Coarse aggregate	55.0

All mixes tested used the Marshall mix design method (ASTM D1559). The following mix design criteria were used:

Marshall stability	1,500 pounds or more
Marshall flow	0.20 inch maximum
Voids	3 to 5 percent
Voids filled with asphalt	75 to 85 percent

All test specimens were prepared and tested in accordance with the Marshall mix design method (ASTM D1559). Mixtures were prepared with three filler contents (4, 6, and 8 percent by weight) for each of six fillers (two limestone dusts and four fly ashes, ranging from 3 to 10 percent carbon content) investigated. Asphalt content was varied slightly to provide 4 percent voids for compacted specimens.

The results of the Marshall stability tests showed that the stability values were somewhat affected by the source of the filler. The limestone dusts gave the highest stability values, followed by the high-carbon fly ash and low-carbon fly ash fillers. However, all mixes possessed stabilities above the 1,500 pound design minimum. The flow values of all mixtures conformed to the design requirement, and only minor variations according to filler type and carbon content of the fly ash were noted.

The relative resistance of each of the test mixtures to water was determined by means of the immersion-compression test (ASTM D1035). The specimens were tested in unconfined compression, three without exposure to water, three after 4 days of immersion in water, and three after 14 days of immersion in water. Unconfined compressive strength tests were performed in accordance with the procedures of ASTM D1074, "Compressive Strength of Bituminous Mixtures," a copy of which is included in the Appendix of this report.

The results of these tests showed that the unconfined compressive strengths of all mixtures, regardless of the source and nature of the mineral filler, were not significantly different. Immersed strengths for all mixes tested ranged from 89 to over 100 percent of dry strength values.

The following conclusions were drawn from this study:

1. The source of a mineral filler can affect the Marshall stability of dense-graded asphaltic concrete mixes. However, all of the fillers studied produced mixtures possessing stabilities above the minimum design limit of 1,500 pounds, as specified by the Michigan Department of Highways.
2. Marshall flow values show no significant difference attributable to the source of the filler when other design criteria are satisfied.
3. The source of filler was not a significant factor in the unconfined compressive strength test. Mixtures containing high-carbon fly ash and low-carbon fly ash possessed equal strengths with those containing limestone dust.
4. All of the mixtures tested, regardless of the source of the filler, were completely satisfactory with respect to their resistance to the action of water, as determined by the immersion-compression test.

5. There are indications that mixtures containing fly ash from three of the sources were more critical with respect to design relationships between asphalt content, voids, stability, and flow than those containing the fourth fly ash or the limestone dusts. However, there appears to be some characteristic, other than carbon content, that seems to be responsible for the behavior of the fly ash fillers (Reference I-137).

The previously described studies all involved research into the use of fly ash from the burning of bituminous coal as a mineral filler. The use of fly ash from the burning of lignite coal as a mineral filler was evaluated in a study conducted during 1968 at North Dakota State University. This evaluation was made by comparing the properties of hot-mix asphaltic concrete specimens that were compacted by means of the Marshall mix design method (ASTM D1559), using either hydrated lime, crusher dust, or lignite fly ash as the mineral filler. Table I-16 presents a comparison of the physical properties of each of these three fillers.

The pH of a material being considered as a mineral filler is important because basic substances usually provide better adhesion than acidic substances. According to Tunnicliff, acidic substances have been known to lead to emulsification (Reference I-138). As shown in Table I-16, the pH of the lignite fly ash is closer to that of the hydrated lime than the crusher dust.

The stability index was developed by Traxler (Reference I-139) as a parameter beyond that of bulk density with which to evaluate the effect of a mineral filler on a given asphalt cement. Traxler pointed out in his research that the viscosity of a liquid-solid mixture is inversely proportional to the average void diameter of the filler present in the mixture, which he used to develop the relationship between viscosity and volume of filler upon which the stability index is based.

The stability index (SI) is computed as follows:

$$SI = 100 (10^A - 1), \text{ where } A \text{ is constant for a given material.}$$

Stability index values have been found to range from 3 to 12. Fillers with a higher stability index value are preferred for use in asphalt concrete mixtures. As shown in Table I-16, the stability index for the lignite fly ash is approximately the same as the crusher dust, but considerably less than hydrated lime.

Table I-16
PHYSICAL PROPERTIES OF MINERAL FILLERS

<u>Type of Filler</u>	<u>Hydrated Lime</u>	<u>Crusher Dust</u>	<u>Lignite Fly Ash</u>
Surface area (cm ² /g)	3900	5900	.2660
Liquid limit (percent)	-	-	-
Plastic limit (percent)	-	-	-
pH	12.4	9.0	11.8
Specific gravity (in water)	2.303	2.760	2.906
Specific gravity (in kerosene)	2.300	2.764	2.900
Stability Index	8.30	4.05	3.87

All mixes in the lignite fly ash study were compacted in accordance with Marshall mix design procedures (ASTM D1559). Gradations of the test mixes were prepared to conform to applicable North Dakota and Minnesota highway specification requirements. The results of Marshall tests on freshly molded and cured compacted samples were compared with mix design criteria recommended by the Asphalt Institute, as shown on Table I-17.

Because of the variation in specific gravity and density of the different filler materials investigated, the proportioning of the filler amounts in the test mixes was done on the basis of volume rather than weight of total aggregate in the mixture.

Each of the three filler types (lime, crusher, dust, and lignite fly ash) were combined with either crushed stone or pit run gravel aggregates. A total of five different asphalt contents were investigated for each binder and aggregate combination.

Table I-17

MARSHALL DESIGN CRITERIA

Traffic Category	Heavy		Medium		Light	
No. of Compaction Blows Each End of Specimen	75		50		35	
<u>Test Property</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>
Stability (lbs.)	750	-	500	-	500	-
Flow (.01 in.)	8	16	8	18	8	20
Percent Air Voids						
Surfacing or Leveling	3	5	3	5	3	5
Sand or Stone Sheet	3	5	3	5	3	5
Sand Asphalt	5	8	5	8	5	8
Binder or Base	3	8	3	8	3	8
Percent Voids in Mineral Aggregate*						
Surfacing or Leveling	15	-	15	-	15	-
Sand or Stone Sheet	21	-	21	-	21	-
Sand Asphalt	18	-	18	-	18	-
Binder or Base	12	-	12	-	12	-

Note:

1. Laboratory compactive efforts should closely approach the maximum density obtained in the pavement under traffic.
2. The flow value refers to the point where the load begins to decrease.
3. The portion of the asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent Air Voids.
4. Percent Voids in the Mineral Aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregate.
5. All criteria, and not stability value alone, must be considered in designing an asphalt paving mix.

*Related to nominal maximum particle size of aggregate used in mix.

Results of Marshall tests are shown in Table I-18. These results indicate that the stability, flow, and voids in mineral aggregate values met specifications for medium and heavy traffic, as recommended by the Asphalt Institute. Air voids values of 5.4 percent were barely in excess of the recommended 5 percent limiting value. However, results of immersion-compression tests show that the retained strength of the fly ash test specimens with either crushed stone or pit run gravel aggregates was in excess of 100 percent for both mixes at optimum asphalt content. Even after seven days immersion, retained strength values for these mixes were 99.0 and 87.9 percent, respectively. Mixtures containing fly ash filler at optimum asphalt content show less loss of compressive strength after immersion than mixtures containing either lime or crusher dust (Reference I-140).

Current studies of lignite fly ash as a mineral filler are being conducted at the Texas Transportation Institute. Early data from these studies indicates that lignite fly ashes function well as fillers in asphaltic concrete and that the asphalt-fly ash binder may actually impart beneficial changes in asphalt paving mixtures.

The high lime content of Texas lignite fly ashes appears to be particularly beneficial when such ashes are used with asphalts from selected sources. For years, lime has been recognized as an effective anti-stripping agent for polish-susceptible aggregates in asphalt concrete mixes. Lime also reduces the rate of service-associated increases in the viscosity of the asphalt binder. The results of the work at Texas Transportation Institute also indicate that the use of Texas lignite fly ashes as mineral filler affect the physical properties of the binder and serve to retard the rate of age hardening of the asphalt cement (Reference I-141).

Utilization of Fly Ash as Mineral Filler. Since mineral filler comprises only 5 to 7 percent by weight of the aggregate in a bituminous paving mix, the use of fly ash as a mineral filler does not presently constitute a high volume application for this material. Since 1970, an average of 140,000 tons per year of fly ash has been used as mineral filler in the United States. This use represents an average of only about 0.3 percent of all the fly ash generated each year in this country. However, in some areas, the use of fly ash as a mineral filler does involve significant quantities. For example, it has been reported that over the past 40 years, the Detroit Edison Company, which pioneered the use of fly ash as a mineral filler, has sold nearly 1.5 million tons of fly ash to the asphalt paving industry for that purpose (Reference I-142). Since 1969, the North Dakota Highway Department has utilized over 40,000 tons of lignite fly ash as a mineral filler (Reference I-143).

Fly ash was also used as a mineral filler in lieu of portland cement in the placement of 35,000 tons of open-graded asphalt overlay surface on the north-south runway at the Sioux City, Iowa Municipal Airport. This open-graded overlay was selected because of its skid resistance qualities. Fly ash was used as the mineral filler to get the proper micron coverage of asphalt on the aggregates, while achieving considerable cost savings to the city according to Byron Brower of Brower Construction Company, contractor for the project (Reference I-144).

Table I-18

RESULTS OF MARSHALL TESTS ON
BITUMINOUS MIXTURES CONTAINING VARIOUS MINERAL FILLERS

<u>Marshall Test Values</u>						
<u>Type of Aggregate</u>	<u>Type of Filler</u>	<u>Percent Optimum Asphalt Content</u>	<u>Stability (pounds)</u>	<u>Flow (.01 in.)</u>	<u>Percent Air Voids</u>	<u>Percent Voids in Mineral Aggregate</u>
Crushed Stone	Fly Ash	6.8	1690	10.0	5.4	16.03
	Lime	5.67	2670	13.5	4.9	15.9
	Crusher Dust	6.5	1750	11.6	7.6	19.1
Pit Run Gravel	Fly Ash	5.5	1500	10.2	5.4	16.85
	Lime	5.76	2150	10.6	4.8	14.4
	Crusher Dust	5.5	1900	10.2	4.0	16.55

The results of a questionnaire on the use of recovered materials by state highway and transportation agencies, which was circulated by The American Association of State Highway and Transportation Officials (AASHTO) during April 1980, show that 22 states have at one time or another used fly ash as a mineral filler in bituminous paving. Of these 22 states, a total of 14 presently have a specification for such use. The states which report the use of fly ash as a mineral filler are:

Alabama	Louisiana	North Dakota*
Arkansas	Maryland	Ohio*
Colorado*	Michigan*	Pennsylvania*
Florida*	Montana*	South Carolina*
Georgia	Nebraska*	Tennessee
Illinois*	New York	West Virginia*
Iowa	North Carolina*	Wyoming*
Kentucky*		

* Fly ash use as mineral filler is included in state specifications.

In addition to the above states, Texas has reported that it is actively investigating the use of fly ash as mineral filler in laboratory studies. Utah and Idaho are also involved in testing and planning activities for consideration of fly ash as a filler, according to the National Ash Association (Reference I-145).

Of the 22 states that have reported using fly ash as a mineral filler, all consider its performance as either acceptable, good, or excellent, except for Iowa, which has not used the material for a long enough period of time to be able to properly evaluate its performance. In Colorado, fly ash has only been used to a limited extent, but its performance is considered excellent because of a "severe need for additional fines and fly ash solved the problem" (Reference I-146). In Nebraska, where fly ash fillers are used more routinely, the material provided "excellent pavement performance, low prices, and a lower asphalt demand than other fillers" (Reference I-147).

Review of Specification Requirements. In order to more fully assess the technical ability of various sources of fly ash to function as mineral fillers on federally funded bituminous highway paving projects, it is essential to compare the characteristics of fly ash with the mineral filler requirements of different specification agencies. Table I-19 presents a summary of mineral filler requirements from a study of mineral filler specification requirements from six states and two Federal agencies, all of which use fly ash as a mineral filler. The overall physical properties of what is considered a typical fly ash are also included in this table. In comparing the physical properties of fly ash with these mineral filler specification requirements, it is apparent that fly ash is capable of satisfying these requirements. Obviously, each source of fly ash must be carefully and separately evaluated prior to use as mineral filler to assure compliance with specifications.

Although North Dakota is the only one of the six states selected for evaluation of specifications that places a limit on loss on ignition for mineral fillers, variation in ignition losses among different lignite fly ash samples do appear to seriously affect Marshall stability, flow, and air voids values. In addition, certain of the more finely graded lignite ashes did produce bituminous mixes that were gummy and difficult to lay in the field. The reason for this was that the fineness of the fly ashes resulted in mixes with a fairly high percentage of uncoated particles (Reference I-148). Therefore, although a particular sample of fly ash may meet applicable gradation specifications, an abundance of very fine (-#325 mesh) particles may be detrimental to its performance as a mineral filler.

Addition of mineral filler to an asphaltic concrete paving mix is a valuable component in improving the characteristics of the mix. The benefits of mineral fillers have been pointed out by many investigators. The principal benefits are increased stability and better durability, both of which are attributable to absorption. Increased stability results from a stiffened binder, while better durability is related to the character of the absorbed film. Fly ash has been proven effective in imparting these properties.

Table I-19

**COMPARISON OF FLY ASH CHARACTERISTICS WITH APPLICABLE
SPECIFICATION REQUIREMENTS FOR MINERAL FILLER IN ASPHALT**

Sieve Size	ALLOWABLE PERCENT PASSING							Physical Properties of Typical Fly Ash*
	FHWA and FAA (AASHTO M17)	Illinois	Michigan	North Dakota	Ohio	Pa.	West Virginia (ASTM D242)	
#30	100	100	100	98-100	100	100	100	100
#50	95-100	N.A.	N.A.	N.A.	N.A.	95-100	95-100	90-100
#80	N.A.	N.A.	N.A.	N.A.	95-100	N.A.	N.A.	80-100
#100	N.A.	92+8	N.A.	85-100	N.A.	90-100	N.A.	75-100
#200	70-100	82+18	75-100	65-100	65-100	70-100	70-100	60-90
Plasticity Index	4 Max.	N.A.	N.A.	Non-plastic	N.A.	N.A.	4 Max.	N.A.
Moisture Content, max. (%)	N.A.	N.A.	N.A.	1.25	N.A.	N.A.	N.A.	N.A.
Loss on Ignition, max. (%)	N.A.	N.A.	12.0 Max.	6.0 max.	N.A.	N.A.	N.A.	0.1-45 (Range) 2-8 (Normal)
Allowable Materials	Rock Dust, Slag Dust, Hydrated Lime, Hydraulic Cement, Other Suitable Mineral Matter	Dry Limestone Dust or Other Approved Material	Limestone Dust, Dolomite Dust, Fly Ash, Hydrated Lime	Limestone Dust, Portland Cement, Hydrated Lime, Crushed Rock Screenings or Fly Ash	Limestone Dust, Portland Cement or Other inert Mineral	Cement, Cement Dust, Fly Ash, or Fines From Crushing of Stone, Gravel or Slag	Rock Dust, Slag Dust, Hydrated Lime, Hydraulic Cement, or Other Suitable Mineral Matter	

N.A. denotes information not available or not given in specification.

*From Figure 4 - FHWA Implementation Package 76-16, "Fly Ash - A Highway Construction Material."

At the present time, utilization of fly ash as a mineral filler in asphalt paving mixtures does not represent a significant use area for the material. Moreover, the actual quantities used for this purpose have remained relatively constant over the past ten years. Increasing quantities of baghouse dusts from hot-mix asphalt plants and kiln dusts from cement and lime plants, which are also being used as mineral fillers, are now competing with fly ash as potential sources of filler material. Therefore, it is possible that the national market for fly ash filler may even be in decline and that overall demand for mineral fillers may continue to diminish. This is because many hot-mix asphalt producers prefer to recycle the baghouse dusts from their plant as fillers rather than use outside filler sources.

Nevertheless, a review of previous research data, which has been discussed herein, clearly indicates that fly ash is not only technically suitable for use as a mineral filler, but is also a superior product for this purpose.

Most fly ashes are able to readily conform to existing specification requirements for mineral fillers. Several million tons of fly ash have been used as mineral fillers in more than 22 states over the past 40 years with more than satisfactory results. Furthermore, the relatively high lime content of Western (lignite and sub-bituminous) fly ashes is an added feature which appears to impact anti-stripping properties to asphaltic concrete mixtures, as well as retarding the age hardening of the asphalt binder.

In addition to technical considerations, use of fly ash as mineral filler is dictated by economics. In many areas where suitable fly ash is available, it is considerably lower in cost than hydrated lime, which now is selling for \$50 or more per ton. Fly ash is also available in many densely populated areas, where demand for asphalt paving is presumably greatest.

Although fly ash has proven to be an excellent filler source, an increase in the future demand for fly ash in this application appears uncertain at this time. Compared to other possible applications for fly ash, mineral filler use does not have the potential for consuming substantial quantities of the material. The continued use of fly ash as a mineral filler in asphalt paving will be determined to a great extent by forces of supply and economics within localized areas surrounding hot-mix asphalt plants. For these reasons, imposition of Federal procurement guidelines are not recommended for stimulation of fly ash use as mineral filler. Greater marketing efforts and education of potential users are seen as more constructive ways to further such use.

BOTTOM ASH

Production and Handling

The residual material which settles and collects at the base of the boiler at coal-fired electric utility plants is termed bottom ash. Approximately 25 to 30 percent of all ash produced annually is bottom ash. Basically, two different types of bottom ash are produced: dry bottom ash and wet bottom boiler slag. The term "power plant aggregate" is often used to include both forms of bottom ash.

Dry bottom ash is produced by injecting pulverized coal (at least 75 percent passing a 200 mesh sieve or 75 microns) into the furnace and burning the coal. This type of boiler is referred to as a "dry bottom" boiler. The ash that is not fine enough to go up the stack with the boiler gases in the form of fly ash instead solidified and agglomerates into coarse particles (from 5 cm down to 75 mm). Some of the larger pieces may be porous particles with varying degrees of friability. These coarse particles then fall into the ash hopper at the bottom of the furnace.

The term "dry" bottom ash refers to the solid state of the ash when it drops into the hopper. A certain amount of molten slag, which forms on the internal surface of the boiler during combustion, also drops into the ash hopper. In a typical dry bottom coal-fired furnace, from 20 to 30 percent of the ash is bottom ash. The ash hopper also generally contains some water. When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high pressure water jets and conveyed by sluiceways to a coarse crusher and on to a storage area.

The other basic boiler type is referred to as a "wet bottom" or "slag tap" boiler. In this type of boiler, the bottom ash is kept in a molten state and tapped off as a liquid. There are two varieties of "slag tap" boilers: those that burn pulverized coals and those that burn crushed coals. Boilers burning crushed coals are known as cyclone boilers. Both boiler types have a solid base with an orifice that can be opened to permit the molten ash that has collected on the base to flow into the ash hopper below. As is the case in dry bottom furnaces, the ash hopper in wet bottom furnaces also contains quenching water. However, when the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms a black angular, glassy material.

The term "wet" bottom boiler slag describes the molten state of the slag as it is drawn from the furnace. In a typical wet bottom furnace, 50 to 70 percent of the ash produced will be boiler slag, with the remainder being fly ash. In cyclone furnaces, production of ash may be up to 80 percent boiler slag and 20 percent fly ash. Wet bottom boiler slag is sometimes also referred to as "black beauty" because of its black, glass-like appearance. At intervals, high pressure jets wash the slag from the hopper pit into a sluiceway in which it is conveyed to a collection basin for dewatering, possible crushing, and disposal or reuse.

In order to simplify terms, dry bottom ash will be referred to in this report simply as "bottom ash" and wet bottom ash or wet bottom boiler slag will be referred to as "boiler slag." As noted earlier, power plant aggregate refers to both bottom ash and boiler slag.

A typical 1,000 megawatt coal-fired power plant may burn 3 million tons of coal per year. With an ash content of 13 percent, approximately 400,000 tons of ash will be produced, of which 120,000 tons will be bottom ash and 280,000 tons will be fly ash.

In 1979, the annual production of bottom ash was 12.5 million tons and the annual production of boiler slag was 5.2 million tons. Therefore, total production of power plant aggregates in 1979 was 17.7 million tons, or 23.5 percent of the total 1979 ash production of 75.2 million tons. Table I-20 summarizes the annual production of bottom ash and boiler slag since 1970. The National Ash Association has forecasted total ash production in 1985 at 90 million tons (Reference I-149). Applying current percentages, the combined production of bottom ash and boiler slag will be between 22.5 and 27.0 million tons.

Physical, Chemical, and Engineering Properties

As a general rule, boiler slag tends to have more uniform properties than bottom ash. This is true for within plant variation and for plant to plant variation. However, the variation in properties of power plant aggregates is minimized in so-called mine mouth plants that burn a single source of coal (Reference I-150).

Power plant aggregates are composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfate, and other compounds. The composition of the ash particles is controlled primarily by the source of the coal and not by the type of furnace. The chemical analysis of selected samples of bottom ash and boiler slag is given in Table I-21. As shown in this table, chemical compositions for these materials are relatively similar and are generally of little practical importance when evaluating power plant aggregates for potential use in highway construction (Reference I-151).

However, it must be noted that in some power plants coal pyrites are disposed of with bottom ash. In such cases, some pyrite or soluble sulfate winds up in the bottom ash and must be separated from the ash prior to use (Reference I-152).

Bottom ashes have angular particles with a very porous surface. Some glassy particles can also be seen, particularly in the smaller sizes. These glassy particles represent the molten slag from the internal surfaces of the boiler. Bottom ash particles range in size from fine gravel to fine sand. Figure I-21 shows the particle size distribution of ash samples taken from a number of dry bottom boilers. As shown in the figure, bottom ash is usually a well-graded material. It should be noted that some variation in particle size distribution can be expected from bottom ash samples taken from the same plant source at different times. (Reference I-153).

Table I-20

ANNUAL PRODUCTION OF POWER PLANT AGGREGATES
IN THE UNITED STATES SINCE 1970

(Millions of Tons)

<u>Year</u>	<u>Total Ash</u>	<u>Bottom Ash</u>	<u>Boiler Slag</u>	<u>Power Plant Aggregates</u>	<u>Percent of Total Ash</u>
1970	39.2	9.9	2.8	12.7	32.4
1971	42.9	10.1	5.0	15.1	35.2
1972	46.3	10.7	3.8	14.5	31.3
1973	49.3	10.8	3.9	14.7	29.8
1974	59.5	14.3	4.8	19.1	32.1
1975	60.0	13.1	4.6	17.7	29.5
1976	61.9	14.3	4.8	19.1	30.9
1977	67.8	14.1	5.2	19.3	28.5
1978	68.1	14.7	5.1	19.8	29.1
1979	75.2	12.5	5.2	17.7	23.5

SOURCE: National Ash Association

Table I-21
CHEMICAL ANALYSIS OF SELECTED BOTTOM ASH
AND BOILER SLAG SAMPLES
(Percent)

Type of Ash:	Bottom Ash	Bottom Ash	Boiler Slag	Boiler Slag	Boiler Slag
Plant:	Kanawha River	Mitchell	Kammer	Muskingum	Willow Island
Location:	Glasgow, W. Va.	Moundsville, W. Va.	Captina, W. Va.	Beverly, Ohio	St. Marys, W. Va.
<hr/>					
SiO ₂	53.6	45.9	48.9	47.1	53.6
Al ₂ O ₃	28.3	25.1	21.9	28.3	22.7
Fe ₂ O ₃	5.8	14.3	14.3	10.7	10.3
CaO	0.4	1.4	1.4	0.4	1.4
MgO	4.2	5.2	5.2	5.2	5.2
Na ₂ O	1.0	0.7	0.7	0.8	1.2
K ₂ O	0.3	0.3	0.1	0.4	0.1

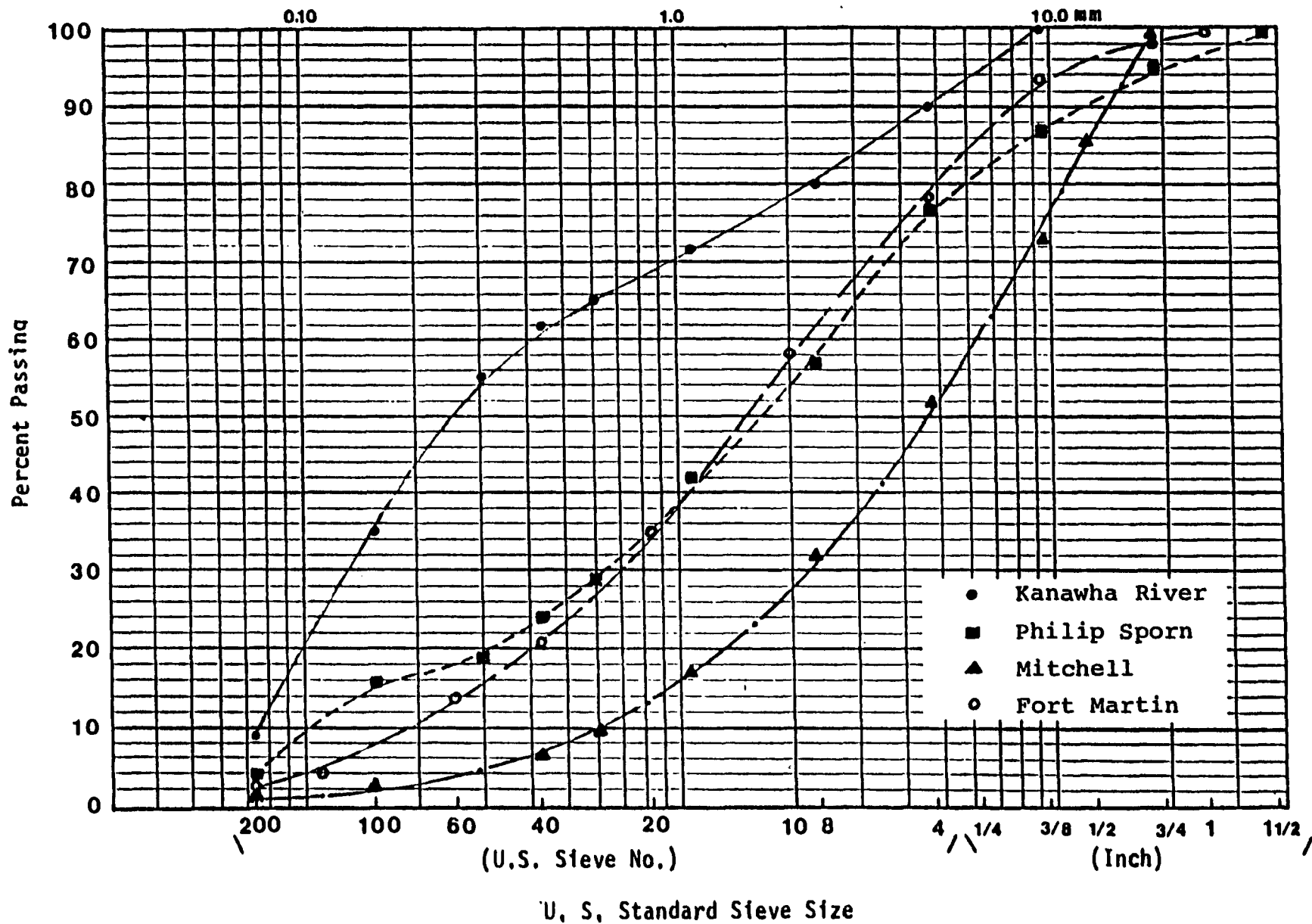


Figure I-21. Typical particle size distribution for selected bottom ash samples.

In contrast to bottom ash, boiler slag is predominantly single-sized in the range of 0.5 to 5.0 mm. The particles themselves are hard, usually black (sometimes dark brown) in color, and glass with a smooth surface texture like crushed glass. However, if gases are trapped in the slag as it is tapped from the furnace, the quenched material will be somewhat vesicular or porous. Some vesicularity may be beneficial, in that it improves the surface texture. Lime injection, used to lower the fusion temperature of the coal during burning, markedly increases vesicularity. Slag from the burning of lignite and sub-bituminous coals also tends to be more vesicular than that of eastern bituminous coals (Reference I-145).

Figure I-22 shows the particle size distribution of slag samples taken from several wet bottom boilers. This figure shows the more uniform size grading of boiler slag, compared to that of bottom ash, with most boiler slag particles being in the minus #4, plus #30 sieve size range.

Table I-22 summarizes the results of tests to determine the key engineering properties of selected bottom ash and boiler slag samples, such as void ratio, compaction characteristics, permeability, and angle of internal friction. The test results are also compared with the properties of a standard Ottawa sand. In general, the properties of the ash samples are similar to those that are obtained for many sands (Reference I-155). Maximum and minimum void ratios were determined by means of the relative density test (ASTM D2049). The angle of internal friction was measured by means of the direct shear test (ASTM D3080). Copies of each test method are included in the Appendix of this report.

Table I-23 summarizes the results of standard aggregate tests such as density (unit weight), Los Angeles abrasion, and sodium sulfate soundness on selected bottom ash and boiler slag samples (Reference I-155). The density test values represent dry rodded weights, taken in accordance with procedures described in ASTM C29, "Standard Test Method for Unit Weight and Voids in Aggregate." Soundness tests were conducted according to ASTM C-88, "Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate," and abrasion resistance tests were performed in accordance with ASTM C-131, "Standard Test Method for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine." Copies of these test methods are also included in the Appendix of this report.

Utilization of Power Plant Aggregates

Table I-24 summarizes the overall utilization of bottom ash and boiler slag since 1970. During this period, the average utilization of bottom ash has been 25.1 percent, while the average utilization of boiler slag has been 49.8 percent. Most of the bottom ash and boiler slag that has been used over the years has been as a fill material for road and construction sites. Substantial amounts of each material are also utilized as anti-skid material on icy roadways during the winter. This use constitutes a large market for bottom ash and boiler slag in some areas like West Virginia and eastern Ohio. There are some power plants that use all or most of the bottom ash or boiler slag produced at their plant on their own property, with little or none being available for use outside the plant (Reference I-156).

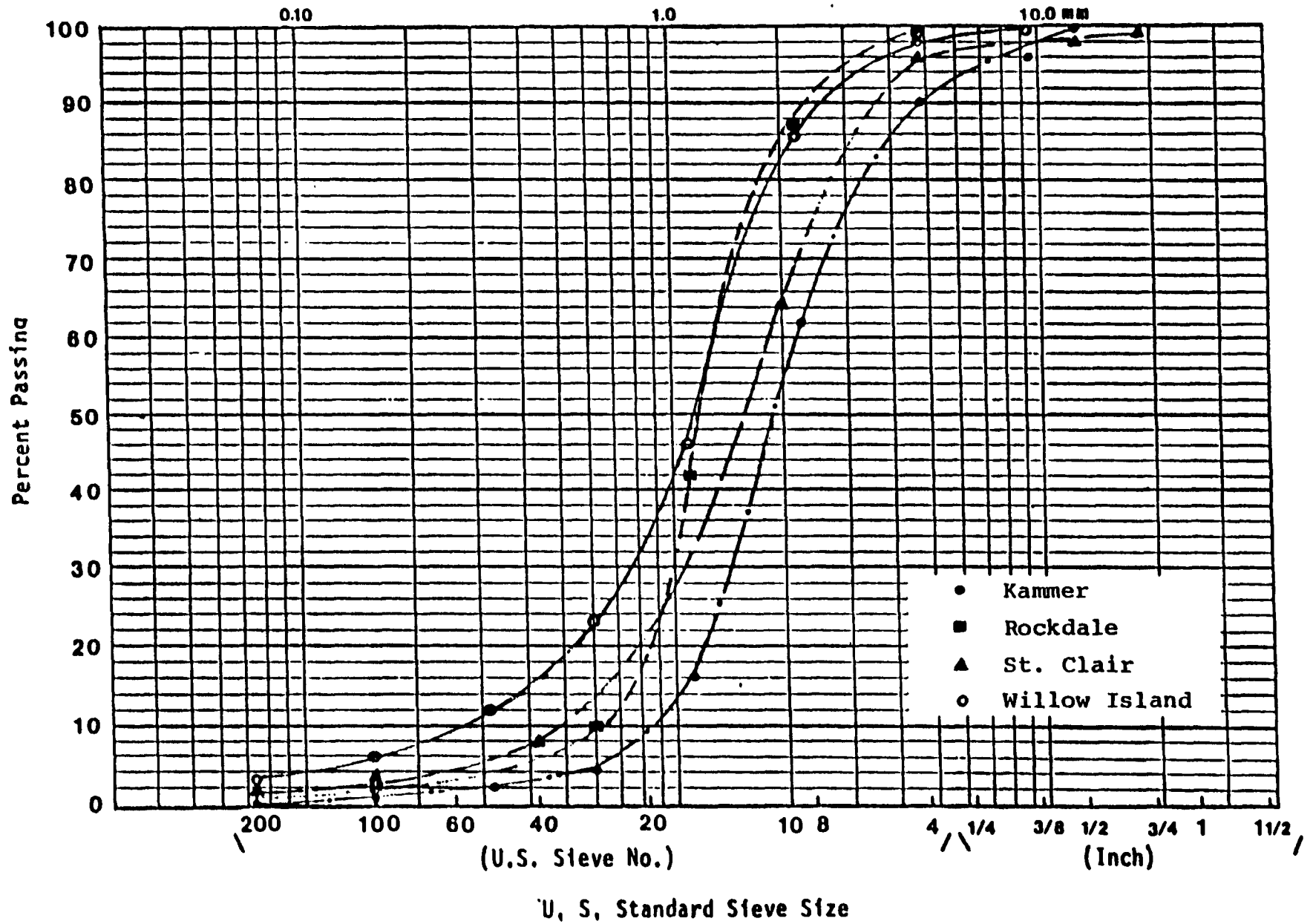


Figure I-22. Typical particle size distribution for selected boiler slag samples.

Table I-22

SUMMARY OF ENGINEERING PROPERTIES OF
SELECTED BOTTOM ASH AND BOILER SLAG SAMPLES

Plant	Location	Type of Ash	<u>Void Ratio</u>		<u>Compaction Characteristics*</u>		Coefficient of Permeability (cm.per sec.)	Angle of Internal Friction (degrees)
			Maximum	Minimum	Maximum Dry Density (lbs. per ft.3)	Optimum Moisture (percent)		
Fort Martin	Maidsville W.Va.	Bottom Ash	1.49	0.73	85.0	24.8	2.8×10^{-2}	40.0
Kanawha River	Glasgow, W.Va.	Bottom Ash	1.86	1.06	72.6	26.2	5.0×10^{-3}	38.0
Mitchell	Moundsville, W.Va.	Bottom Ash	0.91	0.49	116.6	14.6	9.4×10^{-2}	42.5
Kammer	Captina, W.Va.	Boiler Slag	0.92	0.54	102.0	13.8	6.7×10^{-2}	41.0
Muskingum	Beverly, Ohio	Boiler Slag	1.17	0.69	91.1	22.0	4.0×10^{-2}	40.0
Willow Island	St. Marys, W.Va.	Boiler Slag	1.12	0.69	92.4	21.2	2.5×10^{-2}	42.0
Ottawa Sand			.80	.50	N.Ap.	N.Ap.	1.5×10^{-4} to 2×10^{-1}	29-35

* Determined by Standard Proctor Compaction Test (ASTM D698-66T, Method C) using only 3/4 inch material.

N.Ap. denotes test results not applicable.

Table I-23

STANDARD AGGREGATE TEST PROPERTIES OF SELECTED
BOTTOM ASH AND BOILER SLAG SAMPLES

Plant	Location	Type of Ash	Sodium Sulfate Soundness Loss (percent)	Los Angeles Abrasion Loss (percent)	Dry Rodded Weight (lbs.per ft. ³)
Big Sandy	Louisa, Ky.	Bottom Ash	17	N.A.	66
Philip Sporn	New Haven, W.Va.	Bottom Ash	6	46	62
Ft. Martin	Maidsville, W.Va.	Bottom Ash	4-8	27-40	71-83
Kanawha River	Glasgow, W.Va.	Bottom Ash	16	N.A.	47
Mitchell	Moundsville, W.Va.	Bottom Ash	10	37	101
Muskingum	Beverly, Ohio	Boiler Slag	4	35	90
Willow Island	St. Marys, W.Va.	Boiler Slag	N.A.	33	N.A.
ASTM Specification Limits (Values dependent on use)			10	40	

N.A. denotes value not available.

Table I-24

UTILIZATION OF BOTTOM ASH AND BOILER SLAG
(Millions of Tons)

<u>Year</u>	<u>Bottom Ash Collected</u>	<u>Bottom Ash Utilized</u>	<u>Percent Bottom Ash Utilized</u>	<u>Boiler Slag Collected</u>	<u>Boiler Slag Utilized</u>	<u>Percent Boiler Slag Utilized</u>
1970	9.9	1.8	18.6	2.8	1.1	39.1
1971	10.1	1.6	16.0	5.0	3.7	75.2
1972	10.7	2.6	24.3	3.8	1.3	35.3
1973	10.8	2.4	21.9	3.9	1.8	44.3
1974	14.3	2.9	20.3	4.8	2.4	50.0
1975	13.1	3.5	26.7	4.6	1.8	40.0
1976	14.3	4.5	31.5	4.8	2.2	45.8
1977	14.1	4.6	32.6	5.2	3.1	60.0
1978	14.7	5.0	34.0	5.1	3.0	58.8
1979	12.5	N.A.	N.A.	5.2	N.A.	N.A.

SOURCE: National Ash Association

N.A. denotes information not yet available.

There have, however, been numerous successful attempts over the years to utilize power plant aggregates in some form of highway construction. These highway construction uses can be divided into two general categories: base course and asphalt paving. Each of these applications will be considered separately.

Power Plant Aggregates in Base Courses. In discussing applications of bottom ash and/or boiler slag in highway base courses, the versatility of these materials will become apparent. On many projects, they have been blended together or combined with fly ash and/or other by-products, such as blast furnace or steel mill slag, when used as base course materials.

The experiences related herein reflect only selected applications which have been well documented in the technical literature. There are probably numerous other successful projects wherein power plant aggregates have been used on private property or in the construction of local roads that have not been documented.

Utilization of power plant aggregates as a road base material has been accomplished with both unstabilized and stabilized road courses. The majority of experience with both types of base courses has been gained in the state of West Virginia. Each of these uses will be discussed separately.

Unstabilized Bases. One of the first attempts to utilize bottom ash in an unstabilized base course, while satisfying a standard highway specification, was in the construction of an access road to West Virginia University's Evansville campus. Bottom ash from Allegheny Power System's Fort Martin Station was used without any screening. This material was able to meet the specified gradation, abrasion, and sulfate soundness requirements of the West Virginia Department of Highways for Class 2 crushed aggregate base courses, which are in Table I-25. As shown in this table, the bottom ash was clearly able to meet the Class 2 base course specification requirements.

The bottom ash was placed with a conventional spreader box and compacted with a 10-ton tandem steel-wheeled roller. Field densities generally equalled or exceeded the required 95 percent of laboratory maximum dry density, which was 85.0 pounds per cubic foot. However, the bottom ash lost stability when it dried out and it was necessary to keep the material wet so that equipment could operate on its surface. Placement of overlying bituminous concrete binder and surface courses resolved the problem (Reference I-157).

Bottom ash was observed to behave in a similar manner when used as the untreated base course for shoulders and lightly traveled access roads as part of the relocation of West Virginia Route 2 south of Wheeling. In this application, bottom ash from the Ohio Power Company's Cardinal Plant in Brilliant, Ohio was placed at an average moisture content of 14 percent and compacted with a 30-ton pneumatic roller, followed by a 10-ton steel-wheeled roller. This material also became unstable, even though it met gradation and other quality requirements and had been compacted to densities in excess of 95 percent of the Standard Proctor value (Reference I-157).

Table I-25

COMPARISON OF WEST VIRGINIA DEPARTMENT OF HIGHWAYS
 REQUIREMENTS FOR CLASS 2 CRUSHED AGGREGATE BASE
 COURSE WITH TYPICAL PROPERTIES OF FORT MARTIN BOTTOM ASH

Sieve Size	Percent Finer	
	Class 2 Base Course	Fort Martin Bottom Ash
1 1/2"	100	100
3/4"	80-100	97.0
#4	35-75	70.3
#40	10-30	23.0
#200	0-10	4.5
Los Angeles Abrasion	Less than 50	27-40
Sodium Sulfate	Less than 12	4-8

In contrast to these two experiences, high compacted densities and excellent dry stability were achieved on another base course application in connection with the West Virginia Route 2 project. In this case, bottom ash from American Electric Power Company's Mitchell plant was blended with blast furnace slag in order to satisfy the gradation requirements of the West Virginia Department of Highways for Class 1 crushed aggregate base course. In Table I-26, a comparison is made between the Class 1 base course specification requirements and the properties of an ash-slag blend containing 70 percent by weight bottom ash and 30 percent by weight blast furnace slag. As shown in this table, the blend of bottom ash and blast furnace slag was able to satisfy all the requirements for a Class 1 base course.

The mixture was placed and compacted in two lifts to a total thickness of 9 inches. Final compaction was obtained with four to six passes of a 30-ton pneumatic roller. The compacted dry density of the blended material generally exceeded 95 percent of the laboratory maximum dry density value of 105 pounds per cubic foot. This experience proved that it was possible to construct a satisfactory base course using untreated bottom ash when using the proper gradation and combination of materials (Reference I-157).

In an effort to solve the problem of loss of stability upon drying, a laboratory study was performed at West Virginia University using bottom ash and fly ash from the Fort Martin station. The findings of this study showed that the addition of 30 percent fines in the form of fly ash provided the required binder for achieving higher initial density and acceptable dry stability. These results were then verified in the field during the reconstruction of access roads to the Fort Martin station. Although these access roads do not carry high traffic volumes, many heavily loaded vehicles use these roads.

Initially, the 70 percent bottom ash-30 percent fly ash combination was used in the field, but some difficulty was encountered due to excessive moisture and accompanying loss of stability during compaction. A combination of 60 percent bottom ash-40 percent fly ash was then tried and this proved to be a satisfactory blend for the conditions encountered at the project site. The materials were blended in volumetric proportions at the site by a front-end loader. Compaction was obtained by 6 to 10 passes using a vibratory steel-wheeled roller with rubber-tired rear driving wheels. Dry density measurements made on the compacted 60-40 blended material showed densities ranging from 96.0 to 105.7 percent of the laboratory standard Proctor maximum density value of 97.5 pounds per cubic foot. The average field moisture content was 18.1 percent, which was considerably higher than the laboratory optimum moisture content of 10.0 percent. These exceptionally high densities for "wet of optimum" moisture conditions are surprising, but the type and magnitude of field compactive effort are a partial explanation. In addition, the loss in strength of the bottom ash-fly ash mixture wet of optimum was found to be very gradual when evaluated in the laboratory (Reference I-157).

Table I-26

COMPARISON OF WEST VIRGINIA DEPARTMENT OF HIGHWAYS
REQUIREMENTS FOR CLASS 1 CRUSHED AGGREGATE BASE COURSE
WITH TYPICAL PROPERTIES OF
BLENDED MITCHELL BOTTOM ASH - BLAST FURNACE SLAG

Sieve Size	Percent Finer	
	Class 1 Base Course	Bottom Ash Slag Mixture
1 1/2"	100	100
3/4"	50-90	78.6
#4	20-50	40.6
#40	5-20	13.1
#200	0-7	2.5
Los Angeles Abrasion	Less than 50	37*
Sodium Sulfate Soundness	Less than 12	10*

*Values given are for Mitchell bottom ash only.

It has been reported that approximately 178,000 tons of bottom ash from the Fort Martin station have been used to construct a 9 inch thick sub-base along a 3.5 mile section of Interstate Route 79 near Route 50 in West Virginia (Reference I-158).

It has also been reported that approximately 150,000 tons of boiler slag from Central Illinois Public Service's Coffeen Station was used as aggregate sub-base material to construct approach pavements for twin bridges carrying Interstate Route 55 over the tracks of the Chicago, Burlington, and Quincy railroad near Litchfield, Illinois. The boiler slag was evaluated by the Illinois Department of Transportation (IDOT) and approved as a substitute base material after meeting the gradation requirements in the state specifications. Engineers for the project determined that boiler slag was superior to on-site material for sub-base use on this project (Reference I-159).

Current standard highway specifications for base course materials attempt to control the quality and performance of the materials by specifying acceptable limits for gradation, soundness, abrasion, and percent fines (-#200 mesh). Many sources of bottom ash and boiler slag are able to satisfy the requirements for soundness, abrasion, and percent fines, but may or may not be able to meet the gradation requirements. The applications in West Virginia that have been discussed in this report, involving the use of bottom ash as an unstabilized base material, clearly show that other materials can be blended with bottom ash (or boiler slag) to overcome gradation deficiencies.

Within the framework of existing specifications, mixtures containing bottom ash and fly ash with percentages of fines greater than those specified for base course use would be considered unacceptable. However, in the case of bottom ash-fly ash blends, the fines are not only non-plastic, but they are actually cementitious. Therefore, in the case of untreated base courses, strict adherence to standard highway specifications in all instances is not always reasonable, particularly when considering the unique engineering properties of power plant aggregates.

Stabilized Bases.

1. Lime-Fly Ash-Aggregate Bases. The use of fly ash in lime-fly ash-aggregate (LFA) base course compositions was discussed in great detail in an earlier portion of this report. This section of the report discusses the use of boiler slag as the aggregate portion in LFA base courses.

Over the years, the leading market for use of LFA base materials was the Chicago area. In 1954, when the Chicago Fly Ash Company (now called American Fly Ash Company) first became interested in lime-fly ash stabilization, it did so primarily as a means of handling the large tonnages of boiler slag that had accumulated at some Commonwealth Edison power plants in the Chicago area. The first LFA compositions were mixed in place and used boiler slag as the aggregate. In 1955, the first plant-mixed LFA material also used boiler slag. These early mixtures contained on the average 5 percent by weight of hydrated lime, 35 percent fly ash, and 60 percent boiler slag. Cores were taken from these mixtures at various ages and ultimate compressive strengths as high as 500 psi were measured (Reference I-160).

The compressive strength development of a laboratory cured LFA specimen containing 3.6 percent by weight hydrated lime, 36.4 percent fly ash, and 60 percent boiler slag was documented by the University of Illinois. After 28 days at 70°F in the laboratory moist room, the test specimen achieved a compressive strength of 800 psi. This specimen continued to gain in strength, achieving 1,000 psi after 40 days of laboratory curing (Reference I-161).

One of the producers of LFA base course materials in the Chicago area (Premix Base Company of Thornton, Illinois) still uses boiler slag as the aggregate in the pozzolanic aggregate base produced at their plant. This company places nearly all of the LFA material from its plant and is probably the only contractor to use an asphalt paving machine to place LFA base material. The contractor prefers the use of boiler slag because of the black color it imparts to the LFA mix and uses an asphalt paver because his crew formerly placed asphalt base and is more familiar with that type of equipment (Reference I-162).

During 1979, an experimental LFA test section using boiler slag was placed on Illinois Route 9 near the Coffeen power station in Montgomery County, Illinois. The test section was approximately 4 miles long and used a mix containing 3 percent lime, 27.5 percent fly ash, and 69.5 percent boiler slag. The fly ash used was obtained from the Kincaid power station, some 20 miles away, while bottom ash from the Coffeen station was used in the project.

Periodically, core samples have been obtained from the site and measurements taken of their compressive strength. More recently available core sample data indicate that average compressive strengths of 1,400 psi have been obtained after approximately one year in service (Reference I-163). This type of an installation is an excellent example of the use of power plant ash by-products on the local level where strict adherence to material specifications may be occasionally waived in favor of utilizing locally available materials with a savings in cost.

2. Cement-Stabilized Bottom Ash Bases

The use of cement-stabilized fly ash base course materials was presented earlier in this report. This section discusses cement stabilization of bottom ash and/or boiler slag, with and without fly ash, for use in highway base courses.

The first known large-scale application of a portland cement stabilized bottom ash base course in the United States was the relocation and reconstruction of West Virginia Route 2 south of Wheeling during the 1971 to 1972 construction seasons. The cement-treated base course for

this 4-mile long project was constructed using 46 percent by dry weight of cyclone boiler slag from Ohio Power Company's Kammer plant in Captina, West Virginia and 54 percent bottom ash from Appalachian Power Company's Mitchell station in Moundsville, West Virginia. The aggregate blend was stabilized with 5 percent Type I portland cement by weight of total aggregate in the mix.

The optimum moisture content and maximum dry density of the mixture, as determined by the standard Proctor test (ASTM D698), were 8 percent and 114 pounds per cubic foot, respectively. The blended material was placed in one lift and compacted with a 30-ton pneumatic roller to a thickness of 6 inches. Field densities met or exceeded 97 percent of the standard Proctor density value. In this application, excellent results were achieved at a substantial reduction in cost compared to use of conventional aggregates (Reference I-164).

During 1972, a study of cement-treated bottom ash-fly ash mixtures was undertaken at West Virginia University. The bottom ash and fly ash used in this study were obtained from the Fort Martin station. Since consideration was being given to use of the material in reconstruction of secondary roads, production of mixtures with high mechanical stability were desired so that traffic could ride over the material prior to placing a wearing surface on it. High initial stabilities were obtained using mixtures with 70 percent by weight bottom ash and 30 percent fly ash. The mixes were stabilized with 5 percent portland cement by dry weight of aggregate and blended at an optimum moisture content of 12 percent. A total of 10 mixes were made using bottom ash and fly ash samples taken at different times from the plant.

Compacted specimens were stored in a moistroom and tested in unconfined compression at 8, 30, and 60 days. Average compressive strengths for the cement-stabilized mixes were 408 psi at 8 days; 596 psi at 30 days; and 690 psi at 60 days. Although the test results show that satisfactory cement-treated base course mixes can be produced using bottom ash or bottom ash-fly ash blends, the mixtures of 70 percent bottom ash and 30 percent fly ash would not be permitted within the framework of most existing state highway materials and construction specifications in the United States (Reference I-164).

Since 1974, over 300 miles of secondary roads in West Virginia have been reconstructed using cement-treated bottom ash. Most of these roads were primarily dirt and gravel sub-base with traffic counts ranging from 150 to 1,500 vehicles per day. Most of the bottom ash for these projects came from either the John Amos plant in St. Albans, West Virginia or the Kanawha River plant in Glasgow, West Virginia.

Major factors involved in arriving at a cement percentage for mix design were:

- a. Particle size distribution--The gradation of the bottom ash materials was found to be similar to that of the local crushed sandstone used in the West Virginia Department of Highways cement-treated base program from 1970 to 1972.
- b. Maintenance of traffic--Additional cement must be added as a safety factor to compensate for lack of curing time in order to maintain traffic where seven days of curing would normally be available.
- c. Compressive or flexural strength--A sufficient percentage of cement must be used to provide the minimum strength required by West Virginia Department of Highways specifications for cement-treated base to satisfactorily distribute anticipated wheel loads over the subgrade without failure.
- d. Durability--Sufficient cement must be used to resist deterioration from freezing and thawing or wetting and drying. Based on results of a 1974 field test, 10 percent by weight or 200 pounds of cement to 1,800 pounds of bottom ash was used at optimum moisture content.

Core specimens were taken from three typical pavement sections after less than two years in service. Compressive strengths for these specimens ranged from 1,270 to 1,425 psi, with an average compressive strength of 1,322 psi. Not a single base failure was found during visual inspection of 180 miles of roadway using cement-treated bottom ash in the spring of 1978.

All of the secondary road projects using cement-treated bottom ash base have been using a 6-inch thick base overlain by a 1-inch hot-mix bituminous concrete surface. Although this thickness may not be adequate from a frost design standpoint, there have been no reported failures in any of these pavements after several winters in service.

Design of rigid pavement was done in accordance with practices recommended by the Portland Cement Association, based on Westergard analysis. Design of the total flexible pavement system is in accordance with the stabilometer and cohesiometer procedure practiced by the California Division of Highways. Design to resist frost action is in accordance with procedures developed by the U.S. Army Corps of Engineers.

In West Virginia, the thickness of flexible pavement sections is based on a gravel equivalency rather than on structural coefficients. The cement-treated bottom ash base has a gravel equivalent of 1.497, which means that 1.497 inches of gravel is equivalent to 1-inch of cement-treated bottom ash in the base course.

A cost comparison was made using three equivalent base systems: crushed aggregate, cement-treated aggregate, and cement-treated bottom ash. The costs of each of these systems were computed for a 1-mile length of roadway 16-feet wide, using a 6-inch thickness of cement-treated bottom ash and equivalent thicknesses for the other two base systems.

By assuming construction in the Charleston area, certain cost elements associated with producing and transporting component materials for each of the three comparative base systems were developed. Table I-27 presents a tabulation of these cost elements for each base system. The actual cost comparison of the three base systems is presented in Table I-28.

The cost figures in Table I-28 plainly show that the cost savings of cement-treated bottom ash on a one mile basis for a 16-foot wide road is approximately 2 to 1 over cement-treated base and 2.5 to 1 over the crushed aggregate base. These savings result from the cost of the aggregate in the other two base systems and the additional quantities required due to the lower density of the compacted bottom ash in comparison to the aggregate.

3. Bituminous-stabilized Bottom Ash Base

Some 45 to 50 miles of light-duty, rural secondary roads in West Virginia were reconstructed during the summer of 1972 using bituminous-stabilized power plant aggregates. These base materials were placed directly on existing gravel or badly deteriorated chip seal surfaces in single lifts varying from 2 to 6 inches in thickness.

The base materials did not receive a surface treatment until the following construction season. Bottom ash and boiler slag were used in the project. The bottom ash was obtained from the Fort Martin Station and the boiler slag from the Kammer power plant.

The dry bottom ash was used without blending with other aggregate. The design asphalt content was 7 percent. Laydown characteristics of the mix from a spreader box were excellent. Optimum densities were achieved with 3 to 4 passes from a pneumatic roller, followed by one or two passes from a steel-wheeled roller.

On projects using boiler slag, it was necessary to blend the material with locally available bank run gravel to meet the gradation for Class 2 crushed aggregate base course (refer to Table I-25). A 5 percent residual asphalt was added to these mixes. The mixes were pugmilled while cold at a central mixing plant, stockpiled for 10 days or more, then cold laid by paver or spreader box. Adequate compaction was achieved from several passes with a pneumatic roller, followed by a steel-wheeled roller.

Table I-27

COST ELEMENTS
OF
COMPARATIVE BASE SYSTEMS

I <u>TYPE I OR II COMMERCIAL CRUSHED AGGREGATE</u>		
Purchase Cost		\$ 8.00/Ton
(Production, Shipping, Stocking)		
Hauling and Placing		3.00/Ton
	TOTAL	<u>\$11.00/Ton</u>
Sources: Indiana, Kentucky & Ohio Limestone		
Ohio River Gravel		
Weirton and Wheeling Slag		
II <u>CEMENT-TREATED, LOCALLY-CRUSHED SANDSTONE</u>		
Quarrying, Crushing and Stocking Cost		\$ 5.00/Ton
Cement Cost (Per Ton of Mix)		1.80/Ton
Pugmill Mixing Cost		1.00/Ton
Hauling and Placing		3.00/Ton
	TOTAL	<u>\$10.80/Ton</u>
III <u>CEMENT-TREATED ASH</u>		
Bottom Ash		\$ 0.50/Ton
Stocking Cost		0.50/Ton
Cement Cost (Per Ton of Mix)		4.00/Ton
Pugmill Mixing Cost		1.00/Ton
Hauling and Placing Cost		3.00/Ton
	TOTAL	<u>\$ 9.00/Ton</u>

NOTE: The above figures are based on 1978 costs.

Table I-28

COST COMPARISON
FOR SOME
*EQUIVALENT BASE
SYSTEMS-16' WIDE

<u>TYPE OF BASE</u>	<u>THICKNESS</u>	<u>TONS/MI.</u>	<u>COST/TON</u>	<u>TOT. COST/MI.</u>
Crushed Aggregate (Type I or Type II) (W. Va. Item 307)	8"	3736	\$11.00	\$41,096.00
Cement-Treated Aggregate (7% Cement) (W. Va. Item 301)	6"	2802	\$10.80	\$30,261.60
Cement-Treated Bottom-Ash (10% Cement)	6"	1877	\$ 9.00	\$16,893.00

*Thickness equivalent for comparable wheel load distribution over subgrade (does not include wearing surface).

NOTE: The above figures are based on 1978 costs.

During their first year of service, all mixes provided satisfactory service with no appreciable rutting or shoving, despite receiving heavy wheel loads from coal truck traffic in the area (Reference I-166). No further information is available on the performance of these bituminous-stabilized base course materials.

Assessment of Power Plant Aggregate Use as Base Course Material

From the foregoing discussion, it is evident that the use of bottom ash and boiler slag as a base course material has thus far been limited to only a very few states. The results of a questionnaire circulated in April 1980 by the American Association of State Highway and Transportation Officials (AASHTO) show that bottom ash and/or boiler slag in lime-fly ash-aggregate (LFA) base have only been used in six states. These six states are:

Idaho	Oregon
Illinois	Washington
Ohio	West Virginia

Two other states, North Carolina and Texas, report that they are evaluating the use of bottom ash and/or boiler slag in LFA base in the laboratory. Two states, Illinois and Ohio, consider utilization of bottom ash or boiler slag in LFA base courses to be somewhere between limited and routine field use in their respective states. The others consider that the use of bottom ash or boiler slag in LFA base courses in their states is being handled on a limited field basis.

All states considered the performance of bottom ash or boiler ash either as acceptable or good, except for North Carolina, which considered the performance of these materials in their laboratory tests as marginal. Both North Carolina and Oregon are uncertain about the future use of bottom ash or boiler slag in LFA pavements. All other states plan some further field use of these materials.

No mention was made in the questionnaire about the use of bottom ash or boiler slag in unstabilized, cement-stabilized, or bituminous-stabilized base courses. None of the respondents to the questionnaire indicated any such use, although space was provided for describing applications for recovered materials other than those specifically noted in the questionnaire.

In summary, there appears to have been widely scattered examples of the use of bottom ash and/or boiler slag in highway base course applications. Aside from the use of boiler slag in LFA compositions in the Chicago area, there have been no continuing examples of using these materials in base course construction. Several projects in West Virginia, most notably the Route 2 project, have consumed substantial quantities of power plant aggregates, but utilization has been on a project by project basis, not part of an ongoing program. Such is also the case with the use of boiler slag as an aggregate base on an interstate project in central Illinois.

At present, West Virginia is the only state to specify the use of bottom ash or boiler slag as an aggregate in cement-treated and cold-mix bituminous base mixes. The use of bottom ash or boiler slag in hot mix bituminous base courses is specified in five states: Maryland, Nebraska, Ohio, Texas, and West Virginia.

As has been noted previously, use of power plant aggregates in certain types of road base applications may or may not be in accordance with some state specifications. Non-conformity with existing material specification requirements, lack of familiarity with ash materials themselves and their unique properties, absence of a proven performance record, and the relative unavailability and/or unpredictability of sizable quantities of bottom ash or boiler slag for a particular use are factors which may effectively prevent widespread utilization of bottom ash or boiler slag in highway base courses.

POWER PLANT AGGREGATES IN BITUMINOUS PAVING MIXTURES

Over the past 25 years, there has been an increase in the use of power plant aggregates (bottom ash and boiler slag) in bituminous paving mixtures. This section of the report discusses findings from the research and utilization of these materials.

Research Investigations

West Virginia University. A number of bottom ash and boiler slag materials were evaluated as potential aggregate sources in bituminous paving mixtures by the Civil Engineering Laboratories of West Virginia University. These studies were performed over several years during the early to mid-1970s, and involved standard aggregate tests, mix design studies, and evaluation of field performance in test sections.

One of the early discoveries in this work was that there are significant variations in the engineering properties of power plant aggregates, and in particular the bottom ashes. Over a period of several years, Los Angeles abrasion loss values for one source of West Virginia bottom ash varied between 27 and 59. While part of the variation is attributable to the ash itself, selection of representative samples of any material prior to testing also plays an important role.

It was noted during the aggregate testing phase of the program that friable particles, sometimes referred to as "popcorn," were present in some bottom ash samples. These particles are porous, absorb asphalt, and have poor crushing resistance. Specific gravity was recommended as a dependable parameter for identifying the presence of friable particles in bottom ash, with higher specific gravities indicating a better quality ash (Reference I-151).

Boiler slags, in general, were found to have higher specific gravity and lower water absorption values than bottom ashes, probably because of the smoother texture and glassy nature of the slag particles.

In the mixture design studies at West Virginia University, particular attention was focused on the gradation requirements, asphalt contents, air voids and durability, and skid resistance characteristics of bituminous paving mixtures containing bottom ash or boiler slag.

Because of their well-graded particle size distribution and rough, gritty surface texture bottom ash mixes generally had high stabilities. However, bottom ashes containing appreciable quantities of popcorn-like friable particles were found to be highly absorptive to asphalt and have high air voids contents. In general, bottom ash tends to have a higher asphalt demand than natural aggregate. The rough texture of the bottom ash contributes to high air voids, particularly when the Marshall drop hammer method of compaction is used.

The kneading compactor more closely approximates field compaction because of its shearing or kneading action and, therefore, was considered to provide more realistic asphalt content and air voids values. In fact, mixtures considered unacceptable when evaluated by normal Marshall compaction were found to be adequate when compacted with the kneading compactor.

A description of the kneading compactor and procedures employed for preparation of samples using this apparatus are given in ASTM D1561, "Preparation of Test Specimens of Bituminous Mixtures by Means of the California Kneading Compactor." This test method may be found in the Appendix of this report.

The uniform particle sizing and smooth surface texture commonly associated with most boiler slags necessitates that these materials be blended with other aggregates for use in asphaltic mixtures. The type of aggregate used for blending and the relative proportions of the aggregate and the boiler slag were found to significantly influence mixture properties. For a given compactive effort, Marshall stability and flow values generally increase with decreasing percentages of boiler slag. Higher quality mixes resulted from the blending of crushed limestone having angular particles with a rough surface texture than from blending with rounded siliceous aggregates.

The effect of the compaction method on mixture properties was also quite pronounced with the blended mixtures containing boiler slag. Again, kneading compaction was found to improve stability and flow characteristics compared to Marshall drop hammer compaction.

Comparative Marshall test data on bituminous mixes containing bottom ash and boiler slag, prepared using either the Marshall drop hammer or the kneading compactor, are given in Table I-29. From the data in this table, it is evident that greatly improved Marshall stability values result from sample preparation using the kneading compactor. These data also show that the best boiler slag asphalt mixtures are obtained when blending the boiler slag with a rough textured aggregate in which the percentage of the boiler slag is limited to 50 percent or less.

Table I-29

**MARSHALL TEST DATA FOR POWER PLANT AGGREGATE
PREPARED BY DROP HAMMER OR KNEADING COMPACTOR**

Ash Source	Type of Ash	Aggregate Blend	Compaction Method	<u>Marshall Test Values*</u>	
				Stability (lbs.)	Flow (.01 in.)
Fort Martin	Bottom Ash	100% Fort Martin	Drop Hammer	925	7
		100% Fort Martin	Kneading	1320	6.5
Kammer	Boiler Slag	60% Kammer 40% Limestone	Drop Hammer	275	7.5
		50% Kammer 50% Limestone	Drop Hammer	335	7
		40% Kammer 60% Limestone	Drop Hammer	380	7
Kammer	Boiler Slag	65% Kammer 35% Limestone	Kneading	1075	15
		48% Kammer 52% Limestone	Kneading	1452	13.5
Willow Island	Boiler Slag	50% Willow Island 50% Limestone	Drop Hammer	420	6.5
		50% Willow Island 50% River Sand	Drop Hammer	105	6
Willow Island	Boiler Slag	50% Willow Island 50% Limestone	Kneading	773	10

*Marshall test values given only at optimum asphalt content.

Based on the results of these laboratory tests, it was concluded that:

1. Bottom ashes are exceedingly stable and can tolerate large variations in gradation and asphalt content without great loss of stability. However, their use in bituminous mixes is more suited toward base courses where gradation requirements are not as severe as for wearing surfaces. Prior to use, pyrite particles must be separated from the ash.
2. There is no technical reason why boiler slag cannot be used in asphaltic mixtures. As a rule of thumb, mixture stability will suffer if the percentage of boiler slag is in excess of 50 percent. Optimum skid resistance is best achieved in open graded sand mixes where boiler slag is the top aggregate. Boiler slag does not improve skid resistance in coarse graded mixtures if the coarse aggregate is polish susceptible (Reference I-157).

Ohio State University. In 1976, the Federal Highway Administration sponsored a laboratory research study to investigate the characteristics of power plant aggregates and to evaluate their performance in bituminous paving mixtures. The work was performed over a two year period at the Ohio State University Department of Civil Engineering.

A total of 10,000 pounds of ash were collected in the form of 32 different bottom ash and boiler slag samples from 21 power companies in 14 states. Consideration was given to plant type, ash type, source of coal, and tonnage of ash produced in the selection of these samples. Twenty of the samples were bottom ash. Samples were obtained from plants burning bituminous, sub-bituminous, and lignite coals.

Material Characterization

Gradation. The physical and engineering properties of these samples were determined in the laboratory by means of standard testing procedures used to evaluate conventional aggregate materials. Comparing the gradation of these samples to state specifications for aggregate in base, sub-base, and wearing surface mixtures, it was found that most ashes tested could meet specification requirements, although some samples had to be blended, either with coarser bottom ashes or conventional aggregates in order to meet specification limits.

Los Angeles Abrasion and Sodium Sulfate Soundness. Only two of the samples tested were unable to meet Los Angeles abrasion test requirements (ASTM C131). The applicability of this test procedure to evaluation of bottom ash samples is questionable because, due to the gradation of bottom ash and its relatively high percentage of fines (passing #8 sieve), only a small portion of most bottom ash samples would fall within one of the four specified gradations for the test. Consequently, less than 20 percent of each sample was being tested and the test results are not really representative of the abrasion potential of the total sample.

All but one of the ash samples tested met ASTM and state transportation department specifications for sodium sulfate soundness (ASTM C88). However, the applicability of this test is also subject to question. For bottom ash samples, the porosity of these materials may prevent the buildup of internal stresses, as expected in the testing procedure. The opposite may be true for boiler slag samples, in which stresses developed during the quenching process can result in formation of internal fracture planes. Thermal shock and energy release during soundness testing of boiler slags could be misinterpreted as high soundness loss due to the expansive forces of sodium sulfate.

Although these two widely-accepted quality control tests are normally required by transportation agencies for material acceptance, their applicability to the testing of bottom ash and boiler slag is uncertain because they do not take into account the rather distinctive properties of these materials.

Specific Gravity and Absorption. Standard ASTM test methods were used for determining the specific gravity and absorption of coarse aggregates (ASTM C127) and fine aggregates (ASTM C128). Copies of each test method are included in the Appendix. The apparent specific gravity of the bottom ash samples ranged from 2.08 to 2.49 with an average of 2.35. Variations in specific gravity values are related to differences in ferric oxide contents. Bottom ash absorption values varied from 0.4 to 8.0 percent by weight, with greater absorption values for the coarse fraction than the fine fraction.

The apparent specific gravity of the boiler slag samples ranged from 2.60 to 2.86 with an average of 2.75. This is considerably higher than the specific gravity of the bottom ash samples. The absorption values for the boiler slag samples varied from 0.2 to 2.18 percent by weight, significantly lower than the bottom ash samples because of the glassy texture of the boiler slag.

In the sense that most bottom ash and boiler slag samples can meet conventional material specifications, they can be said to compare favorably with conventional aggregates. However, one of the main questions regarding testing of power plant aggregates is whether tests designed for conventional aggregates are truly applicable for evaluation of non-conventional materials (Reference I-2).

Bottom Ash--Bituminous Mixtures. Based on results of the material characterization tests, certain bottom ashes showed greater potential than others for use as aggregate in bituminous paving mixtures. The boiler slags evaluated in the program were considered less versatile and best suited to limited use, such as in granular bases. Therefore, only selected bottom ash samples were further tested as bituminous aggregate in this program.

Five bottom ash samples were tested using the Marshall mix design method (ASTM D1559). Three of the bottom ash samples were also prepared by kneading compaction. For comparative purposes, a mixture containing a blend of limestone and sand aggregate was also tested. Results of these tests are summarized in Table I-30. These results do show that samples prepared by kneading compaction have higher stabilities and lower optimum asphalt contents than drop hammer prepared specimens (Reference I-3).

But the data also point out that optimum asphalt contents for bottom ash mixes are much higher than for mixes with conventional aggregates, as are the air voids values. These high asphalt demands, caused by the porous nature of the bottom ash, are an economic concern. It was, therefore, decided to investigate mixtures in which bottom ash was blended with conventional aggregates.

Bottom Ash-Aggregate-Bituminous Mixtures. In this phase of the program, two of the bottom ash samples (Mitchell and Rockdale) were tested by the Marshall method in varying combinations with crushed gravel and sand in mixes designed to meet state specifications for base course and wearing surface mixtures. The Mitchell bottom ash sample was used in both base and surface mixtures at ash contents of 0, 30, 50, 70, and 100 percent, in combination with the sand and gravel aggregate. The Rockdale bottom ash sample was used only in a surface coarse mix at ash contents of 40, 60, and 100 percent, also with sand and gravel aggregate.

Table I-31 summarizes the mixture designations, asphalt contents, and bottom ash contents of these mixtures.

Figure I-23 shows the Marshall curves for the Mitchell surface course mixes. The relationship between ash content and Marshall properties for these mixes is shown in Figure I-24. As shown in this figure, stability increased with initial introduction of the bottom ash into the mixture up to an ash content of about 50 percent, then a reduction in stabilities with further additions of ash.

Figure I-25 shows the Marshall curves for the Rockdale surface course mixes. The relationship between the ash content and Marshall properties for these mixes is shown in Figure I-26. In this figure, a decrease in stability was noted up to 60 percent ash, then a slight increase in stability was observed to 100 percent ash.

TABLE I-30
COMPARISON OF MARSHALL TEST RESULTS
FOR SELECTED BOTTOM ASH SAMPLES PREPARED
BY DROP HAMMER OR KNEADING COMPACTOR

Sample Description	Source	Drop Hammer Compaction Test Results				Kneading Compaction Test Results			
		Optimum Asphalt Content (percent)	Marshall Stability (lbs.)	Marshall Flow (.01 in)	Percent Air Voids	Optimum Asphalt Content (percent)	Marshall Stability (lbs.)	Marshall Flow (.01 in)	Percent Air Voids
Conventional Aggregate	Sand and Gravel	7.5	1320	8	2	-	-	-	-
Bottom Ash	Mitchell Moundsville, W. Va.	14	1540	9	8	10	1960	10	10
Bottom Ash	Stanton Stanton, Md.	19	1800	16	6	18	2250	10	8
Bottom Ash	Cholla Joseph City, Arizona	17	1600	12.5	8	-	-	-	-
Bottom Ash	Mohave Laughlin, Nev.	29	1340	16	6	23	1700	11	5
Bottom Ash	Alcoa Rockdale, Tex.	12	850	13	6	-	-	-	-

TABLE I-31

**DIFFERENT TYPES OF MIXES AND THE OPTIMUM ASPHALT CONTENT OF
EACH MIX**

Mix Type	Composition	Gradation ODOT	Asphalt	Opt. AC %
5-I	100% B. Ash (Mitchell Plant)	404*	85/100	14
5-II	70% B. Ash + 30% N. Sand&Gravel	404	85/100	12
5-III	50% B. Ash + 50% N. Sand&Gravel	404	85/100	10
5-IV	30% B. Ash + 70% N. Sand&Gravel	404	85/100	8.5
5-V	100% N. Sand&Gravel	404	85/100	6.5
5-A	100% B. Ash (Mitchell Plant)	301**	85/100	11
5-B	70% B. Ash + 30% N. Sand&Gravel	301	85/100	9
5-C	50% B. Ash + 50% N. Sand&Gravel	301	85/100	7
5-D	30% B. Ash + 70% N. Sand&Gravel	301	85/100	6
5-IA	100% B. Ash (Mitchell Plant)	404	60/70	14
25-I	100% B. Ash (Rockdale, Texas)	As is	85/100	12
25-II	60% B. Ash + 40% N. Gravel #8	404	85/100	10
25-III	40% B. Ash + 60% N. Gravel #8	404	85/100	10

* ODOT Item Designation for Surface Course Mixtures

** ODOT Item Designation for Base Course Mixtures

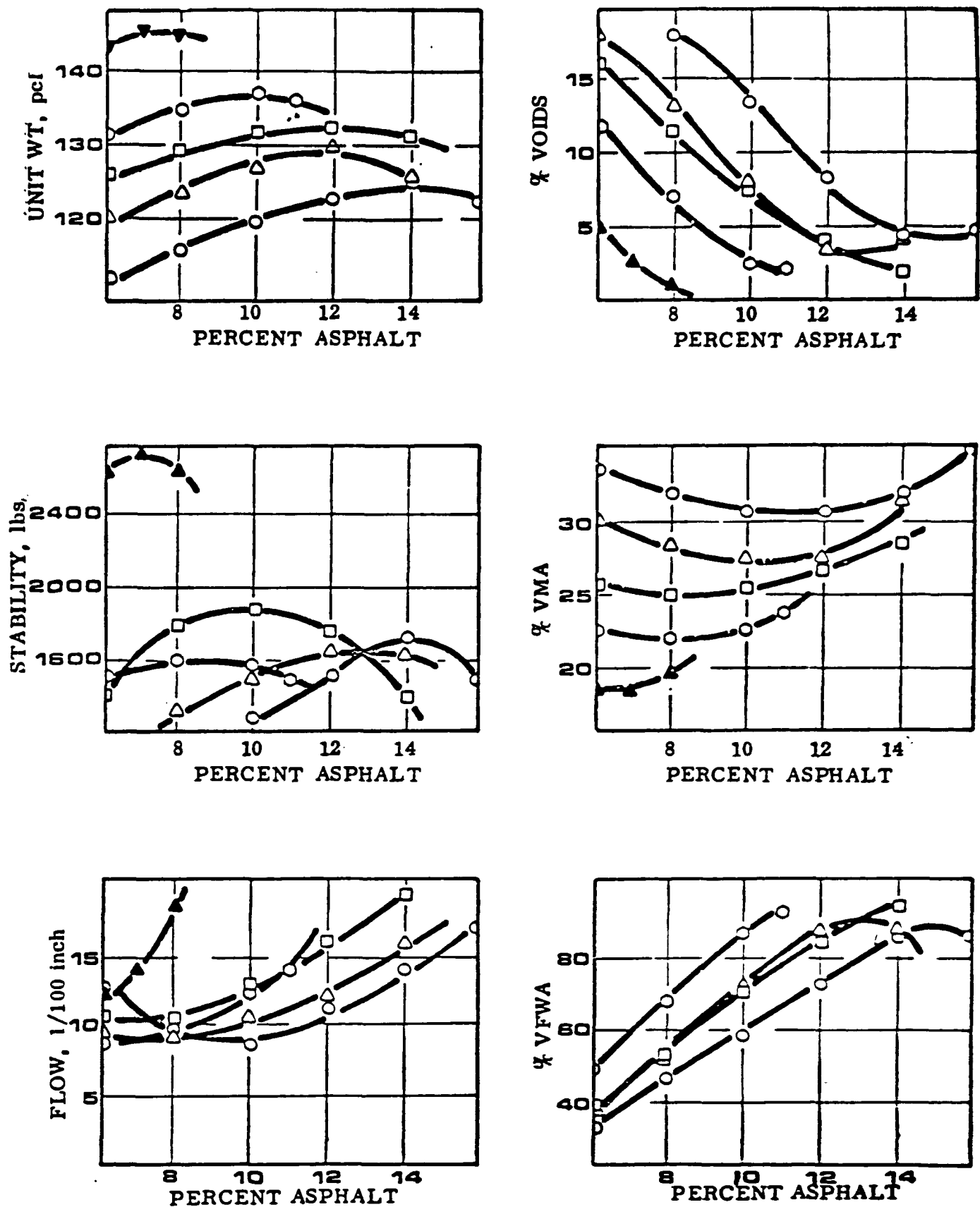


Figure I-23. Marshall Curves for Mitchell Plant Surface Course Mixtures (○ 5-I, △ 5-II, □ 5-III, ◇ 5-IV and ▲ 5-V)

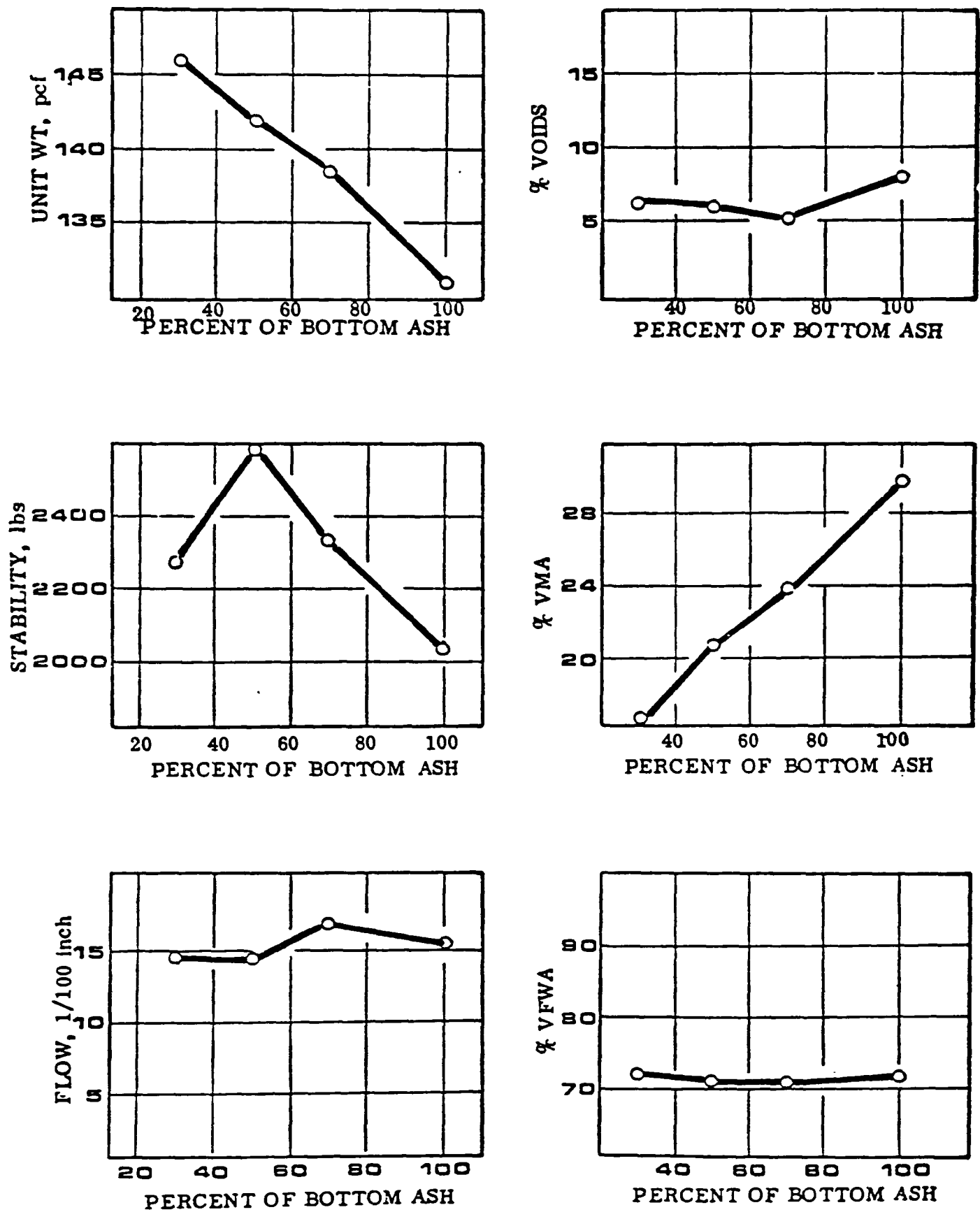


Figure I-24. Relationship between Ash Content and Marshall Properties, Mitchell Plant Surface Course Mixtures

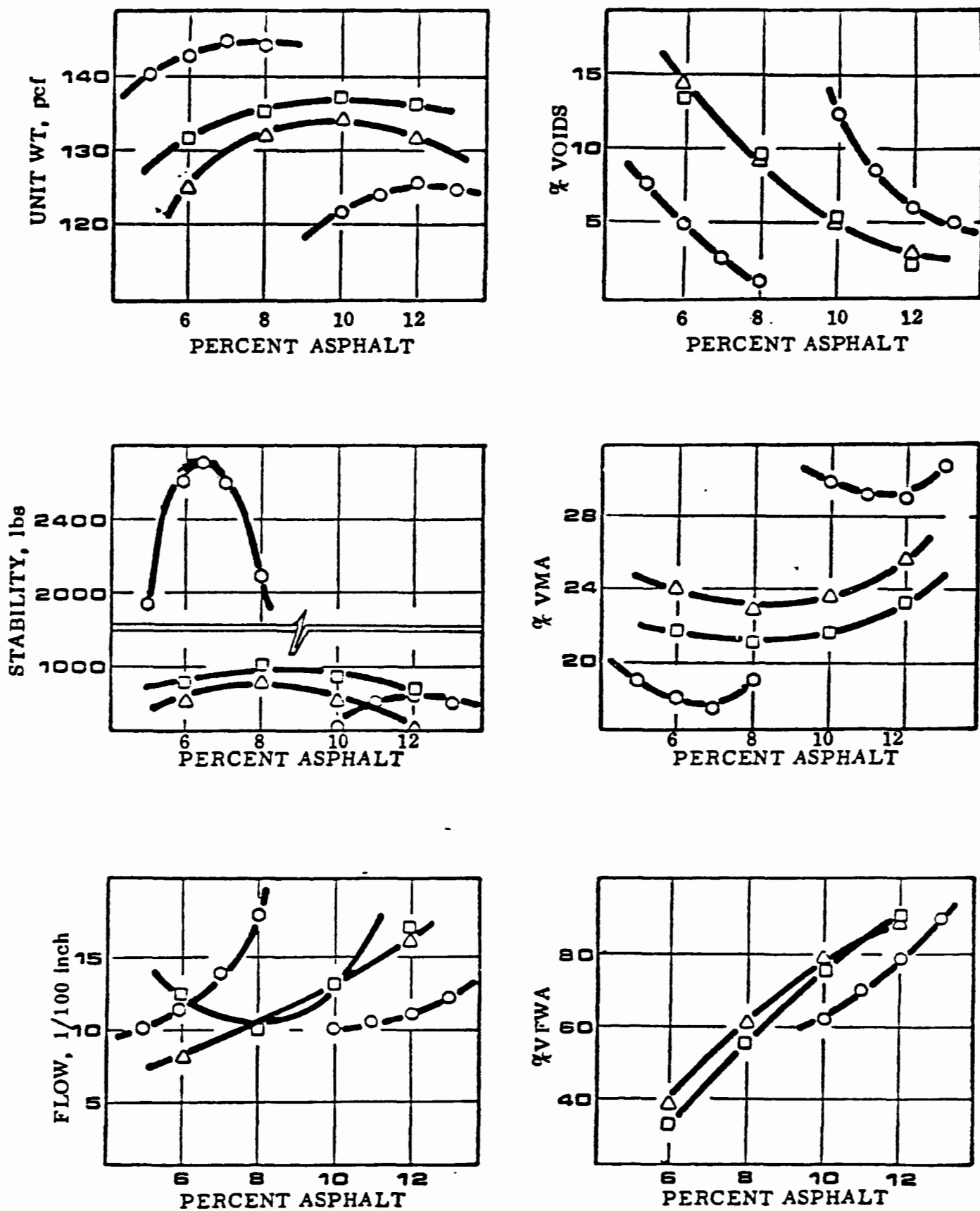


Figure I-25. Marshall Curves for Rockdale Ash Surface Course Mixtures
(○ 25-I, □ 25-II, △ 25-III and ◇ 5-V)

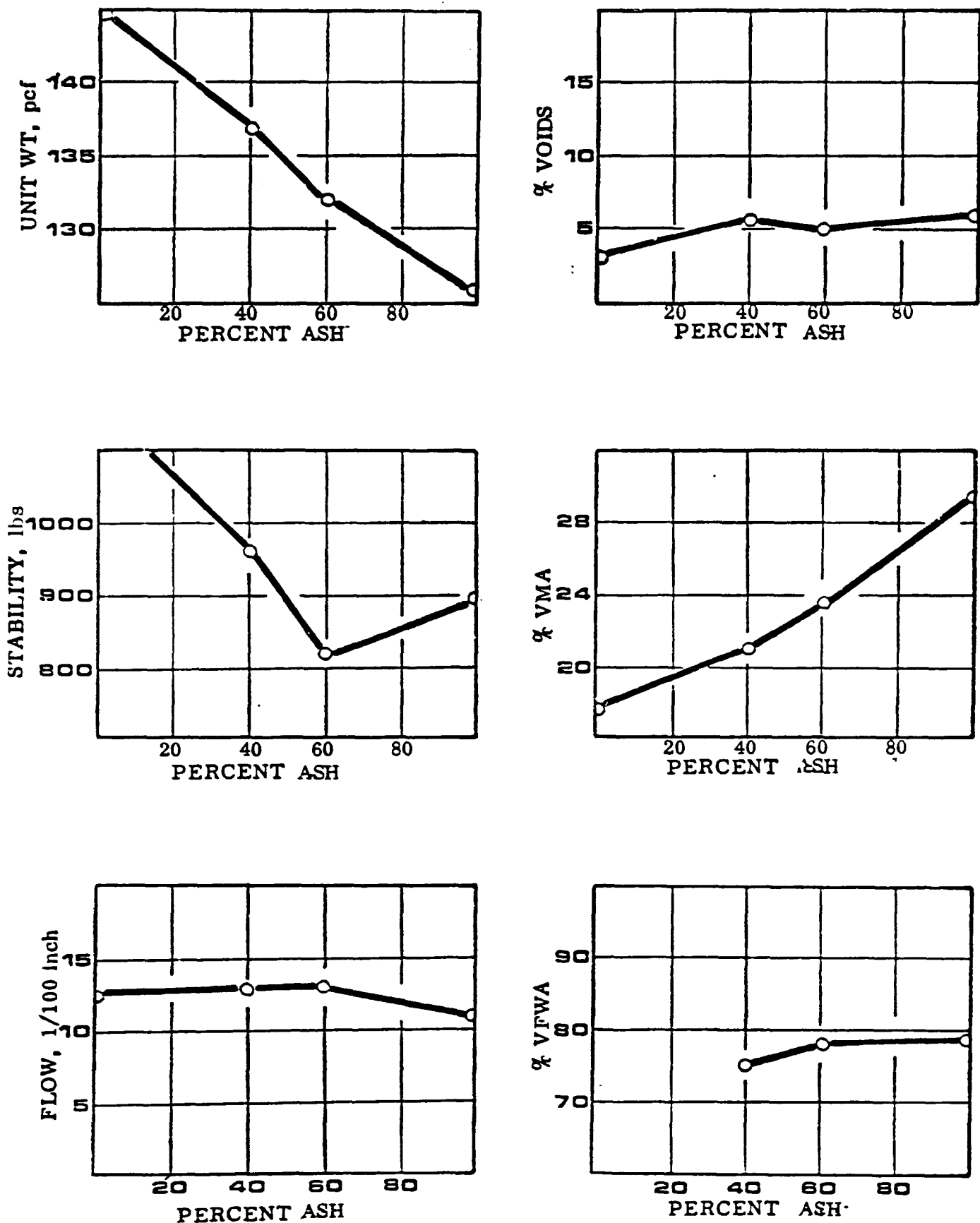


Figure I-26. Relationship between Ash Content and Marshall Properties, Rockdale Ash Surface Course Mixtures

For both the Mitchell and Rockdale surface course mixes, increasing ash contents resulted in sharp decreases in mix densities and an increase in optimum asphalt content and VMA (voids in mineral aggregate) values.

Figure I-27 shows the Marshall curves for the Mitchell base course mix. The relationship between ash content and Marshall properties for these mixes is shown in Figure I-28.

The same general trends observed in the surface course mixes were also noted in the Mitchell base course samples. The use of bottom ash in base course mixes yielded optimum asphalt contents two to three percent less than for comparable ash contents in Mitchell surface course mixtures.

The results of immersion-compression tests (ASTM D1075) indicate that bituminous mixtures using bottom ash are not particularly susceptible to water damage. In fact, mixture stabilities actually increased after immersion, contrary to what would ordinarily be expected in conventional paving mixtures. If the tendency to develop higher stability after saturation is a material property peculiar to bottom ashes, which was not identified in standard quality control testing, this characteristic could be of benefit in designing pavements for areas subjected to high rainfall or multiple cycles of freezing and thawing.

The principal conclusions of this study were:

1. Bottom ash is basically suitable for use in bituminous base course and wearing surface applications. Because of widely varying ash properties, materials from different sources must be carefully tested on an individual basis prior to their acceptance for such use.
2. The properties and performance of bituminous mixtures containing bottom ash depend on the ash content. Increasing ash content results in a higher optimum asphalt content, increased voids, and lower mix density. Marshall stability tends to decrease with initial introduction of bottom ash, up to 30 percent ash content. Beyond that level, depending on the individual bottom ash, stability and other properties are relatively insensitive to ash content.
3. When used in bituminous mixtures, bottom ash materials apparently exhibit unusual behavior in the presence of water. Unlike conventional paving mixtures, which suffer loss of strength and durability as a result of saturation, bottom ash paving mixtures appear to increase in strength following sample saturation (Reference I-3).

5-A = ○ , 5-B = △ , 5-C = □ , 5-D = ◇

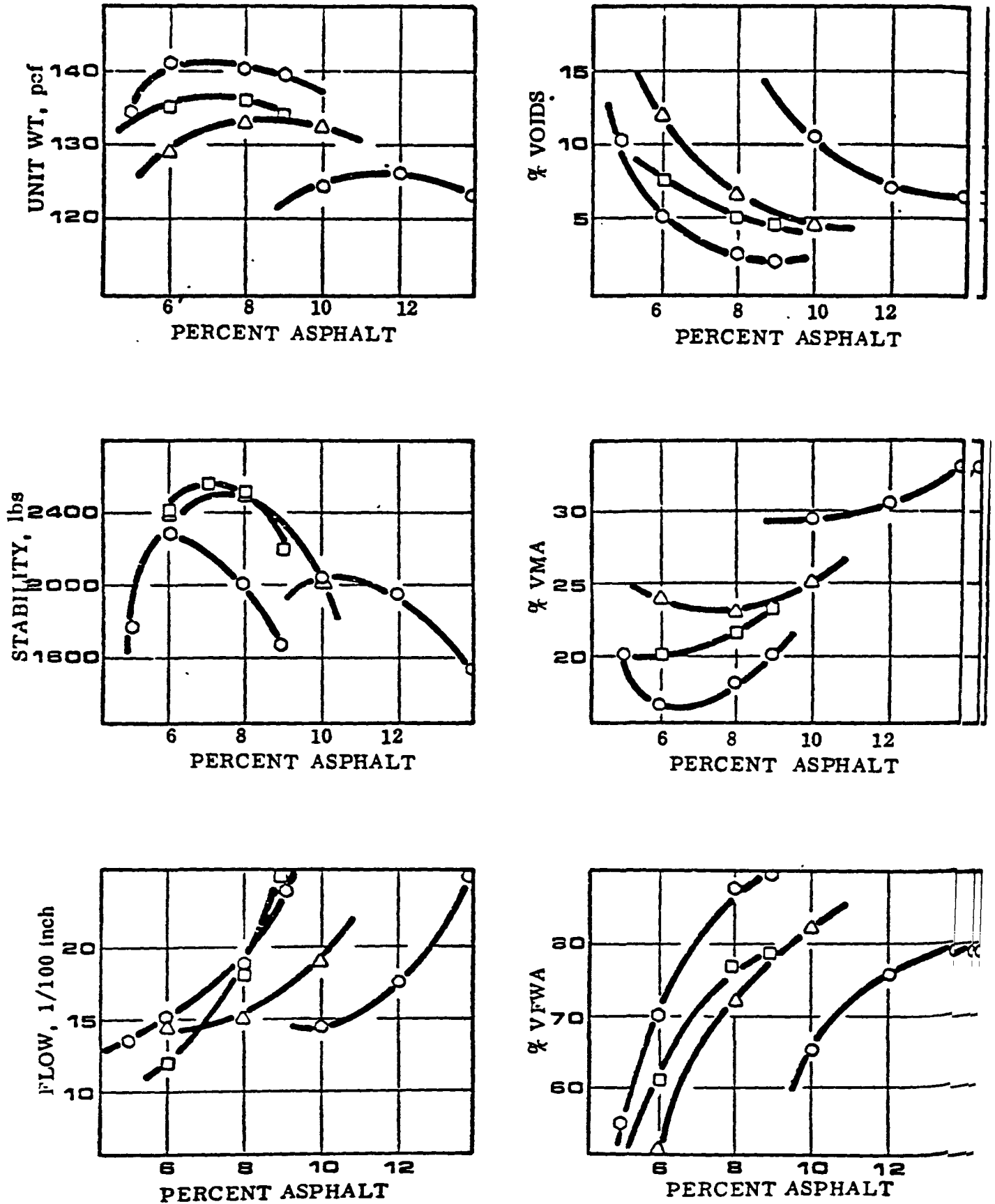


Figure I-27. Marshall Curves for Mitchell Plant Base Course Mixtures

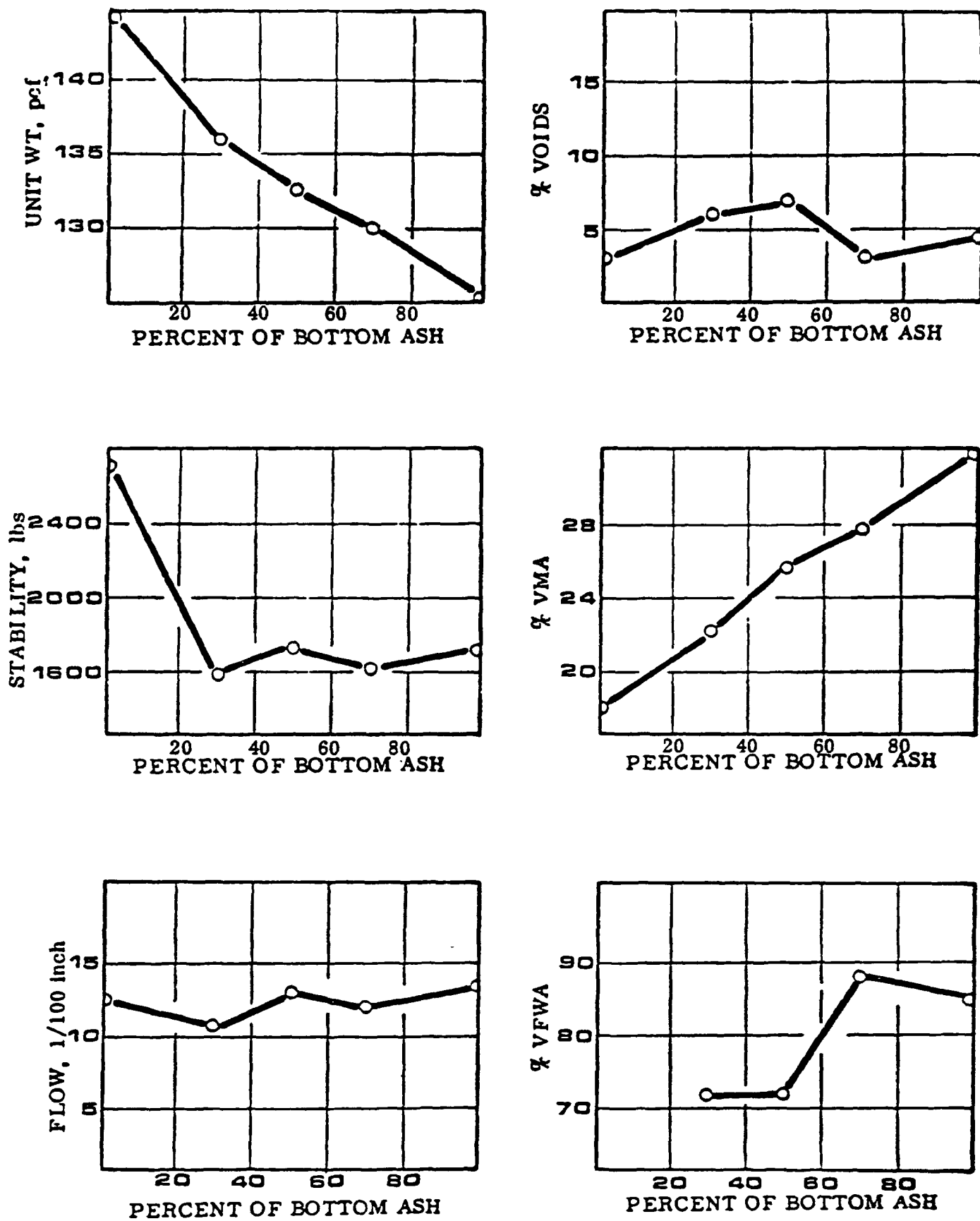


Figure I-28. Relationship Between Ash Content and Marshall Properties, Mitchell Plant Base Course Mix

Use of Power Plant Aggregates in Bituminous Paving

There are numerous examples of the use of power plant aggregates in bituminous paving projects. Most of these, however, involve the use of boiler slag. Despite the favorable test results on bottom ash mixtures at Ohio State University, there has been no known use of bottom ash in hot-mix asphalt pavement applications. The most extensive use of bottom ash in bituminous paving has been in West Virginia where, since 1972, bottom ash has been cold mixed with 6 to 7 percent by weight of emulsified asphalt and used in the paving of secondary "Farm to Market" roads. In some cases, the bottom ash is also blended with boiler slag. Both cationic and anionic asphalt has been used in the preparation of these cold mixes, but asphalt suppliers are of the firm opinion that better coverage and performance can be obtained by using a cationic blend.

More than 200 miles of low-volume traffic roads in the northern part of the state have been improved with these cold mix compositions, which are referred to as "Asphalt." A specification for "Asphalt" is included in the Appendix of this report. Similar applications have also been made in eastern Ohio.

Besides being a relatively inexpensive material, one of the biggest advantages of "Asphalt" is its simplicity. First, the bottom ash is loaded into the hopper of a portable continuous pugmill, frequently located on the power plant site. It is then mixed with a metered amount of asphalt and either loaded directly into haul trucks or stockpiled for future use. There is no need for hot bins or dryers. "Asphalt" can be stockpiled for several weeks and still be suitable for placing on the road.

Because the mix can be stockpiled, crews from the Highway Department are afforded a great deal of flexibility. Those who perform the lay-down work are not dependent on plant production for an uninterrupted flow of material to the job. Furthermore, "Asphalt" can be installed on the roadway without resorting to fancy techniques or sophisticated machinery. In West Virginia, "Asphalt" is usually placed by state maintenance crews using state equipment.

The mix is hauled to the jobsite and placed with conventional spreading equipment. The best compaction results have been achieved with a single 10-ton tandem steel-wheeled roller following closely behind the spreader. Once on the road, the mix requires about 10 days to fully cure. This curing period depends on the season and length of time the mix was in a stockpile (Reference I-160).

State road crews have been placing "Asphalt" at about half the cost of conventional asphalt concrete. And in most applications, the ash will go about one-third farther than comparable materials due to its favorable weight-volume ratio. This material, because it is not a hot-mix

composition, can be placed in cold or inclement weather. The bottom ash can also be blended with sand, gravel, limestone, or blast furnace slag to meet any desired gradation. Aside from occasional problems due to base failures, "Ashphalt" has provided excellent service over the years. It can even be used as a patching material, and frequently is, on some of the more heavily-traveled primary roads (Reference I-161).

Boiler slag has been used to a much greater extent in bituminous paving than bottom ash. Boiler slag has been used frequently in wearing surface mixtures because of the hardness of its particles (average of 7 on the Mohs hardness scale), its affinity for asphalt, and its dust-free surface, which aids in asphalt adhesion and resists stripping. Use of boiler slag helps eliminate fat spots in paving mixes, and subsequent asphalt bleeding that causes slippery pavements. The material is relatively abrasion resistant, enabling it to provide desirable skid resistant characteristics (Reference I-162).

Another of the properties of boiler slag which enhances its value as an aggregate in bituminous paving is its permanent black color, which is not affected by sun or weather. This enables the surface of a blacktop roadway to retain much of its original dark appearance, which is helpful for contrasting with pavement markings and is particularly advantageous for night driving. It also helps roads and streets surfaced with boiler slag dry faster after rain and snow because the black color attracts the sun's heat (Reference I-163).

Boiler slag was first used in asphalt paving on an experimental basis many years ago in Hammond, Indiana, where it was blended with conventional aggregate to help solve the problem of aggregate polishing. The early success of that and several other wearing surface demonstration projects in Indiana led to its acceptance and use in that state and several others, including Ohio, Michigan, Missouri, and West Virginia. In addition, boiler slag has been used in a number of cities, such as Cincinnati and Columbus, Ohio and Tampa, Florida (Reference I-163).

In West Virginia, boiler slag has been blended with graded river sand for resurfacing and deslicking applications, especially where thin overlays are used. A considerable amount of this resurfacing has been done in the northern panhandle using a West Virginia Department of Highways Wearing Course III mixture composed of 50 percent by weight boiler slag, 39 percent river sand, 3 percent fly ash, and 8 percent asphalt cement. The mixture is hot mixed and laid as a conventional sand mix in depths from 1/2 to 2 inches. Some sections have been in service for over 10 years with little change in surface texture under heavy truck traffic and only minor tendency to rut or shove, if at all.

A typical example of the use of boiler slag in a deslicking application was a short section of U.S. Route 119 near Morgantown, which was overlaid in 1969. Accidents on this portion of the road were reduced by about 50 percent in the year following completion of the project. Table I-31A compares the gradation and asphalt contents of the northern panhandle and Route 119 overlays with the requirements of the Department of Highways Wearing Course III mixtures. A comparison of these mixture properties with the Class III specification limits shows that these mixes meet applicable wearing surface requirements. It should be noted that in these applications, boiler slag is considered an economical replacement for locally scarce natural aggregates and is not being promoted as a skid-resistant aggregate (Reference I-164).

Some 10,000 tons of boiler slag were used to construct the wearing surface and shoulders of a portion of Interstate Route 94 near the Detroit Airport. This section of roadway is reportedly still in good condition after more than six years in service (Reference I-165).

Boiler slag from the burning of lignite coal has been used on streets in several parts of Texas for resurfacing work. The mixes have used a blend of 75 percent by weight lignite boiler slag and 25 percent limestone screenings, with an asphalt content of 6 to 7 percent by weight of aggregate. Retained strengths of 90 percent were observed after immersion-compression testing. These pavements have held up well with no signs of shoving or raveling, despite heavy truck traffic, while maintaining their brilliant, black texture, non-skid properties, and smooth, quiet riding qualities (Reference I-166).

Boiler slag has also been used successfully as a seal coat aggregate for bituminous surface treatments in a number of states. The Minnesota Department of Transportation reports that boiler slag seal coat sections have performed in a highly acceptable manner, although these sections set up more slowly than sections using normal aggregate. Once the sealed sections were swept, this problem was solved. The only problems thus far with boiler slag seal coats have been some wearing at intersections where high volumes of turning vehicles are involved (Reference I-167).

Boiler slag is also used as a seal coat aggregate in local road construction. Cost savings of over \$2,000 per mile using boiler slag as a chip seal material have been documented by the Montgomery County Highway Department in central Illinois. In addition, county road crews are able to place 5 miles of seal coat per 8-hour day, compared to 4 miles per day using conventional limestone chips (Reference I-168).

Table I-32 presents a per mile cost comparison between regular crushed limestone chips and boiler slag for a 22-foot wide pavement. According to these figures, the cost per mile for using limestone chips is practically twice as high as the cost per mile for using boiler slag (Reference I-168).

Table I-31A

COMPARISON OF BOILER SLAG-AGGREGATE
WEARING SURFACE MIXTURES TO WEST VIRGINIA
DEPARTMENT OF HIGHWAYS WEARING COURSE III REQUIREMENTS

Sieve Size	Percent Passing		
	Specification Limits	Northern Panhandle Overlays	Route 119 Overlay
3/8"	100	100	100
#4	90-100	95	95
#8	60-90	80	85
#16	40-65	52	48
#50	10-30	14	16
#200	3-15	6	6
Asphalt Content (percent)	5-11	8	7

Table I-32
COST COMPARISON
WET BOTTOM BOILER SLAG SEAL COATS
V. S.
5/8" CRUSHED LIME STONE SEAL COATS

Page 1 of 2

(A) 5/8 " Crushed Lime Stone Chips, single Seal Coat (C.L.S.C.)

- (1) Surface Width = 22' 0"
MC-800 or 3000 Asphalt at 0.25 gallons per square yard
5/8" chips at 25 pounds per square yard
8 - 2 1/2 tons dump trucks & drivers
1 - 955 "Cat" track type end loader & operator
1 - Etnyre Chip Spreader & two operators
1 - Gallion Rubber tired Roller & operator
2 - Pick-up trucks & 2 drivers

Average production of 4 miles per 8 hr. day.

(2) Material Quantities and Cost:

MC-800 or 3000 3227 gals. per mile at 0.82 per gal. spread on roads
 $0.25 \times 22 \times \frac{5280}{9} \times 4 = 12,907 \times 0.82 = \$10,583.74$

C.L.S.C. 161 tons per mile at 7.00 per ton FOB Stockpile
 $25 \times 22 \times \frac{5280}{9} \times \frac{1}{2000} \times 4 = 645 \text{ tons @ } 7.00 = 4,515.00$

(3) Equipment Costs:

8 dump trucks	x \$13.30 x 8	= 851.20	
1 "Cat"	x 30.60 x 8	= 244.80	
1 Etnyre	x 30.00 x 8	= 240.00	
1 Roller	x 13.18 x 8	= 105.44	
2 Pick-ups	x 3.14 x 8	= 50.24	
			= 1,491.68

(4) Labor Costs: \$6.40 per hour

14 x 8 x 6.40 = 716.80

Total Cost = 17,307.22

Cost per mile = $\frac{17,307.22}{4} = 4,326.81$

COST COMPARISON
WET BOTTOM BOILER SLAG SEAL COATS
V.S.
5/8" CRUSHED LIME STONE SEAL COATS

(B) WET BOTTOM BOILER SLAG SINGLE SEAL COAT (W.B.B.S.)

- (1) Surface Width = 22' 0"
 RC-800 or 3000 Asphalt at 0.15 gallon per square yard
 Wet Bottom Boiler Slag at 15 pounds per square yard
 8 - 2 1/2 tons dump trucks & drivers
 1 - 955 "Cat" tracktype end loader & operator
 1 - Etnyre Chip Spreader & two operators
 1 - Gallion Rubber tired Roller & operator
 2 - Pick-up trucks & 2 drivers

Average production of 5 miles per 8 hr. day

(2) Material Quantities and Cost:

RC-800 or 3000 1936 gals. per mile at 0.83 per Gal. spread on roads
 $0.15 \times 22 \times \frac{5280}{9} \times 5 = 9680 \times 0.83 = \$8,034.40$

W.B.B.S. 97 tons per mile at 2.00 per ton FOB Stockpile
 $15 \times 22 \times \frac{5280}{9} \times \frac{1}{2000} \times 5 = 484 \text{ Tons at } 2.00 = 968.00$

(3) Equipment Costs:

8 dump trucks	x \$13.30 x 8	= 851.20	
1 "Cat"	x 30.60 x 8	= 244.80	
1 Etnyre	x 30.00 x 8	= 240.00	
1 Roller	x 13.18 x 8	= 105.44	
2 Pick-ups	x 3.14 x 8	= 50.24	
			= 1,491.68

(4) Labor Costs: \$6.40 per hour

$14 \times 8 \times 6.40 = 716.80$

Total Cost = 11,210.88

Cost per mile = $\frac{11,210.88}{5} = 2,242.18$

Not only does the boiler slag provide better coverage per mile than the limestone chips (97 tons vs. 161 tons), but the boiler slag seal coat retains its black color, while the surface of the stone chip seal gradually acquires a faded, gray appearance. Even after an up-close visual inspection of a boiler slag seal coat pavement, it is difficult to tell that it was not originally placed as a conventional hot-mix asphaltic concrete pavement.

Skid tests on a boiler slag seal coat section north of Hillsboro, Illinois were performed in 1976 by the Illinois Department of Transportation, using a locked-wheel skid trailer run at 40 miles per hour. Friction numbers for the north-bound lane ranged from 46 to 64, with an average value of 56. Friction numbers for the south-bound lane ranged from 43 to 57, with an average value of 50 (Reference I-12). Generally, friction numbers in excess of 40 are desired in terms of skid resistance, although in the state of Illinois a value of 53 is considered acceptable.

Assessment of Power Plant Aggregate Use in Bituminous Paving. According to the results of an AASHTO questionnaire, a total of 23 states have reported some sort of field use of power plant aggregate in asphalt paving. These states are:

Alabama	Indiana*	New Jersey
Arizona	Iowa	New York
Arkansas	Kansas	Ohio*
Connecticut	Kentucky	Oklahoma
Florida	Michigan	Pennsylvania
Georgia	Minnesota	Texas*
Idaho	Missouri*	West Virginia*
Illinois	Nebraska*	

* States currently including power plant aggregates in bituminous material specifications.

Interestingly, two of these states (Connecticut and Idaho) do not have any coal-fired power plants. It is possible that the term "bottom ash" or "boiler slag" may be mistakenly used in referring to another material, such as phosphate furnace slag in one or more of these states. Of the 23 states using power plant ash, five (Alabama, Georgia, Illinois, Kentucky, and Missouri) report routine use. The others report limited field use or field experimentation.

Only one state (New Jersey) considers the performance of power plant aggregate in asphalt paving to have been poor. The reason given for this assessment was poor skid resistance (Reference I-169). Four other states (Arizona, Connecticut, Ohio, and Oklahoma) reported marginal performance. Kentucky considers the performance of bottom ash and/or boiler slag as aggregate in bituminous wearing surfaces to have been excellent because the crushed material had "sharp edges and provided good skid resistance" (Reference I-170). The remaining states all reported either acceptable or good performance.

New Jersey is the only state which does not intend to make any further use of power plant aggregates in the future. Arizona and Oklahoma are uncertain about further use of these materials. The other 20 states all plan to make additional use of either bottom ash or boiler slag in asphalt paving.

Of the 23 states indicating some level of field use, only six have incorporated bottom ash and/or boiler slag into the specifications as an aggregate for use in bituminous paving mixtures. These six states are Indiana, Missouri, Nebraska, Ohio, Texas, and West Virginia.

In summary, there have been 23 states which have at one time or another made use of power plant aggregates in asphalt paving. Only one of these states does not plan to make further use of these materials in this manner. Over the years, boiler slag has been widely used as a partial aggregate replacement in wearing surface mixtures and thin overlays, as well as in seal coat applications, in many sections of the country. During this time, it has acquired a good performance record as a durable, wear-resistant material with a number of unique properties. Except for seal coat applications, boiler slag must be blended with other aggregates to meet gradation specifications and attain sufficient mix stability.

Bottom ash, on the other hand, does not appear to have been utilized to any great extent, if at all, in hot-mix asphalt paving. However, it does have a good performance record as an aggregate in cold-mix, cold-laid emulsified asphalt paving mixes on secondary roads in West Virginia and eastern Ohio.

Based on available laboratory data and documented field performance, it is evident that power plant aggregates can be successfully used in bituminous mixtures. Before this can be done on a routine basis, however, additional effort is needed to develop test methods and specifications that are more appropriate for use in evaluating power plant aggregates, particularly bottom ashes.

In some cases, current test methods and specifications are too restrictive and exclude acceptable materials. In other instances, the standards may not be sufficiently discriminating and allow materials that could be unacceptable from a field performance standpoint. Again, this problem is somewhat more pertinent to the evaluation of bottom ash than boiler slag.

A good example of a standard aggregate test method which is not entirely suitable for evaluating bottom ash is the Los Angeles abrasion test (ASTM C131). This test does not sufficiently identify the highly friable "popcorn" particles in bottom ash, nor is the test indicative of the amount of degradation that may occur under field compaction. The unique properties of bottom ash also obscure test results on asphalt paving mixtures incorporating these materials. Existing methods of assessing moisture damage on bituminous mixtures are not sufficient to properly

identify the potential problems that may be associated with bottom ash, let alone explain the apparent cementing and strength gain of the bottom ash particles in the paving mix following saturation (Reference I-171).

There are yet other questions which can be raised concerning evaluation of the use of power plant aggregates in bituminous paving mixtures, such as:

- Are high air voids values associated with the use of some bottom ashes acceptable?
- How significant is the sodium sulfate soundness test for boiler slags and what are the acceptable test limits?
- Is the specific gravity test an adequate indicator of the presence of "popcorn" particles in bottom ashes and, if so, what should be the acceptable lower limit for specific gravity?

For power plant aggregates to be used successfully, they must also be used properly. These materials should not generally be viewed simply as other conventional aggregates and evaluated with the stock-in-trade question, "Do they meet specifications?" (Reference I-16).

After reviewing available literature and assessing the current status of utilizing bottom ash and boiler slag in bituminous paving, the following technical recommendations are made:

1. Bottom ash is best used in cold-mix emulsified asphalt mixtures on low volume roads, in hot-mix base mixtures, or in shoulder construction where specification requirements for gradation and toughness are not as critical. Many bottom ashes are probably not acceptable for use in hot-mix wearing courses, unless blended with conventional aggregates in relatively low percentages.
2. Boiler slag can be used without any special consideration in conventional hot-mix asphalt paving applications, provided the percentage of boiler slag is limited to less than approximately 50 percent of the total aggregate in the mixture. Boiler slag is also highly recommended in seal coats on comparatively low volume roads. The most favorable use of boiler slag in hot-mix paving is in surfacing mixtures when blended with other aggregates. Mixtures with acceptable skid resistance using boiler slag are possible, provided careful attention is given to mixture design (Reference I-172).

Because of the very limited use of bottom ash in asphalt paving, as well as the variable quality of some sources of bottom ash, it would be inappropriate to consider adoption of guidelines for the use of this material in asphalt paving. Furthermore, bottom ash simply has not gained the level of acceptance necessary for it to be used on anything like a routine basis, except where it is used as "Ashphalt" in West Virginia.

Although boiler slag is better suited for bituminous paving applications from the technical sense, there are also definite reservations about considering guideline development for boiler slag use in asphalt paving. One reason for such reservations is the fact that nearly 50 percent of all boiler slag in the United States is used for ice control during the winter. This use could consume a large percentage of the stockpiled boiler slag at a particular power plant during the winter season, leaving relatively small amounts available for aggregate use. Another substantial market for boiler slag in some sections of the country is roofing granules for the manufacture of shingles. Boiler slag also finds application in sandblasting and as a construction fill material. In addition, some power plants are able to utilize the majority of the bottom ash (or boiler slag) generated at the plant in construction activities on the plant premises. In such cases, little or no ash is even made available to prospective users.

Part I

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Part II

USE OF CEMENT KILN DUST AND LIME KILN DUST IN HIGHWAY CONSTRUCTION

INTRODUCTION

Cement Kiln Dust (CKD)

Cement kiln dust is the dust collected from the exhaust gases of cement kilns. The dust is "a mixture of raw kiln feed, partly calcined material, finely divided cement linker and alkali sulfates (Reference II-1).

Its chemical composition is variable but usually falls within the ranges shown in Table II-1.

CKD is a fine granular material similar in appearance to cement. The gradation of a typical sample is shown in Table II-2.

Lime Kiln Dust (LKD)

Lime kiln dust or lime stack dust is a solid waste generated by the manufacture of lime. "The dust contains a mixture of raw kiln feed, partly calcined material, and finely divided material (Reference II-3).

The chemical compositions of both high calcium and dolomitic lime dusts are shown in Table II-3.

The gradation of a typical sample of LKD is shown in Table II-4.

A good description of the process by which cement kiln dust is produced is contained in a paper UTILIZATION OF WASTE KILN DUST FROM THE CEMENT INDUSTRY (Reference II-14) and is reproduced here.

MANUFACTURING PROCESS

Manufacture of portland cement involves five basic steps: quarrying, raw grinding, blending, burning, and finish grinding. The raw materials for portland cement consist of materials containing four particular compounds: lime, silica, alumina, and iron oxide. The more commonly used materials are various combinations of limestone, shale, clay, sand, oyster shell, cement

Table II-1

Chemical Composition of Cement Kiln Dust

Ingredient	Range		Average %
	Low %	High %	
SiO ₂	6.0	28.5	16.5
Al ₂ O ₃	3.2	9.6	4.35
Fe ₂ O ₃	0.8	5.9	2.66
CaO	16.0	65.0	47.6
MgO	0.8	4.83	2.34
SO ₃	0.7	26.3	7.07
Na ₂ O	0.08	3.18	0.78
K ₂ O	1.08	26.23	5.52
Loss on Ignition	2.50	32.0	16.0

Source: Reference II-1.

Table II-2

Particle Size Analysis of a Typical Cement Kiln Dust

<u>Particle Size Range-Microns*</u>	<u>Weight Percent</u>
48-68	0.3
34-48	0.4
24-34	0.7
17-24	1.8
12-17	5.1
6-12	27.3
< 6	64.4

*The opening of a #200 sieve is 74 microns.

Source: Reference II-10.

Table II-3

Chemical Composition of Lime Kiln Dust

Ingredient	Range					
	High Calcium Lime Dust			Dolomitic Lime Dust		
	Low %	High %	Average %	Low %	High %	Average %
CaO	13.1	80.1	51.3	17.2	50.0.	37.0
MgO	0.1	4.2	1.3	10.0	40.5	23.9
CO ₂	2.2	46.5	22.3	19.0	40.9	25.4
Available Lime	10.0	64.3	35.5	5.0	17.5	10.2
SiO ₂	0.3	28.7	6.7	0.1	10.0	2.4
Fe ₂ O ₃	0.01	4.1	0.9	0.05	6.0	1.5
Al ₂ O ₃	0.01	9.2	1.8	0.05	3.6	1.1
S	0.03	3.0	0.8	0.004	3.0	1.2
P ₂ O ₅	0.001	0.06	0.04	0.1	0.04	0.02

Source: Reference II-4.

Table II-4

Particle Size Analysis of a Typical Lime Kiln Dust

<u>Sieve No.</u>	<u>Sieve Opening-mm.</u>	<u>Percent Finer by Weight</u>
8	2.36	100
20	0.85	97
60	0.25	78
100	0.15	64
200	0.075	42

Source: Reference II-14.

rock, marl, iron ore, and various by-product materials including ash, slag, and tailings from several mineral processing industries. These materials are proportioned as necessary to form a suitable raw mix and ground together either as a dry mixture or as a water slurry. At this stage, most of the material is 200 mesh or finer and after blending is ready for introduction to the kiln.

Kilns for producing portland cement are large, rotating, inclined metal tubes, usually 8 to 15 feet in diameter and 200 to 500 feet in length. At the lower end of the kiln is a burner, fired by gas, oil, or coal, that produces a 3,000°F flame. Raw materials enter the upper end of the kiln and move down the kiln toward the burner as the kiln rotates. As the mix traverses the kiln, its temperature increases and three things happen. Moisture is driven off, calcium carbonate decomposes to calcium oxide (lime), and the mass reaches a temperature of incipient fusion, about 2,700°F, at which hard, marble-size balls called clinker are formed. The clinker is discharged from the kiln, cooled, and ground into portland cement, with a fineness of about 325 mesh. During this process about 3,400 pounds of raw materials have been transformed into one ton of portland cement and 3 to 5 million Btu of energy have been consumed.

Kiln dust originates when finely ground raw materials become airborne in the stream of combustion gases traveling up the kiln. Carbon dioxide, liberated by the decomposition of calcium carbonate, adds to the agitation of the materials and thus to the amount of airborne dust.

Mechanical collectors (cyclones), glass-bag filters (baghouses) and electrostatic precipitators are commonly used to collect kiln dust. Because they are relatively inexpensive and maintenance free, cyclones are often used ahead of baghouses or precipitators to collect the larger dust particles, but the cyclones cannot be used alone because their efficiency for collecting particles less than 10 microns is low. High collection efficiencies, approaching 100 percent, can be achieved with baghouses and precipitators.

QUANTITIES AVAILABLE

Cement Kiln Dust

Twenty million tons of CKD are generated annually. Eight to 10 million tons are recycled into the kilns, while 10 to 12 million tons are wasted (References II-5 and II-6). In addition, it is estimated there are 100 million tons of the material that are reusable piled throughout the country (Reference II-7). Table II-5 summarizes the number of cement plants located in the contiguous 48 states, according to a listing of cement plants in North America (Reference II-8).

Table II-5

Cement Producing Plants in the United States*
(48 contiguous states only)

Alabama	7	Maine	1	Pennsylvania	15
Arizona	2	Maryland	3	South Carolina	3
Arkansas	2	Michigan	5	South Dakota	1
California	12	Mississippi	2	Tennessee	6
Colorado	3	Missouri	8**	Texas	33***
Florida	5	Montana	2	Utah	2
Georgia	3	Nebraska	2	Virginia	1
Idaho	1	Nevada	1	Washington	4
Illinois	4	New Mexico	1	West Virginia	1
Indiana	5	New York	7	Wisconsin	1
Iowa	5	North Carolina	1	Wyoming	<u>1</u>
Kansas	5	Ohio	5	TOTAL	168 plants
Kentucky	1	Oklahoma	3		
Louisiana	2	Oregon	2		

*Does not include plants that grind only

**Includes one plant under construction

***Includes two plants under construction

Lime Kiln Dust

The annual accumulation of LKD is considerably less than that of CKD. In a 1977 survey conducted by the National Lime Association (Reference II-4), in which 60 out of 75 commercial lime plants responded, a reported 4,275 tons per day of dust were collected. It was estimated that this was two-thirds dust and one-third sludge. Of this amount, approximately 75 percent was wasted and 25 percent either sold or given away. If these data are factored up for 330 working days per year, for a 50 percent addition to adjust for captive lime plants,* and for the non-reporting plants in the survey, the following available annual output can be computed:

$$4,275 \times 2/3 \times .75 \times 330 \times 1.5 \times \frac{75}{60} = 1.3 \text{ million tons per year.}$$

This amount was partially confirmed from another source (Reference II-9) which stated that 1.6 million tons of lime kiln wastes were produced in the U.S. A rough estimate can be obtained by using a 15 percent loss factor on the total annual lime production from rotary kilns. This would amount to 1.8 million tons of the 12 million tons of lime production.

In summary, approximately 1.3 to 1.5 million tons of dry LKD is now wasted annually. The locations, by states of the commercial lime plants in the U.S., are shown in Table II-6.

USE OF WASTE KILN DUSTS IN HIGHWAY CONSTRUCTION

The primary application of both kiln dusts would be in kiln dust-pozzolan-aggregate road base compositions. This type of road base would be used in place of black base as a quality base. It would also provide a base superior in quality to an unstabilized crushed stone or gravel base. CKD can also be used in combination with fly ash alone to produce a stabilized composition for use as a road base or structural fill.

One other application in highway construction is the use of LKD as an anti-stripping agent and/or filler in bituminous compositions.

These kiln dusts have additional potential in any highway application for which hydrated lime is used. This would include soil stabilization, combination with sulfate wastes to form stabilized base material, and treatment of wet, plastic subgrades. The use of kiln dusts in these applications has been largely unproven; however, it is anticipated that it will provide a similar product to that where the usual hydrated lime is used.

* Plants where the lime producer uses the lime (steel plant).

Table II-6
Commercial Lime Plants in the United States

States	No. of plants having rotary kilns*	Total No. of plants**	States	No. of plants having rotary kilns*	Total No. of Plants**
Alabama	5	5	Nevada	3	3
Arizona	2	2	New Jersey	1	1
Arkansas	0	1	New Mexico	1	1
California	2	3	Ohio	8	12
Connecticut	1	1	Oklahoma	1	1
Florida	0	2	Oregon	0	1
Illinois	3	3	Pennsylvania	6	7
Indiana	1	1	South Dakota	1	1
Iowa	1	1	Tennessee	0	1
Kentucky	2	2	Texas	6	7
Louisiana	2	2	Utah	1	1
Maryland	0	1	Virginia	4	5
Massachusetts	1	2	Washington	1	1
Michigan	2	3	West Virginia	1	2
Missouri	2	3	Wisconsin	3	5
			Totals	61	81

*Includes lime plants that have rotary kilns only and both vertical and rotary kilns

**Includes lime plants that have

- rotary kilns only
 - vertical and rotary
 - vertical or other kilns (no rotary)
- Does not include hydrating plants only

Source: Reference II-11.

COMMERCIAL AVAILABILITY OF PRODUCTS CONTAINING KILN DUST

The commercial availability of products containing cement and lime kiln dust is considered in three parts:

1. Available amounts and locations of kiln dusts.
2. Locations of current producers of kiln dust, fly ash, aggregate compositions including all plants where the product has been produced in the recent past.
3. Locations of potential producers.

Amounts and Locations of Cement Kiln Dust

As shown in Table II-5, the latest available information on the location of cement plants shows 168 plants distributed throughout 39 states. Over half of these plants are located in eight states. In addition, the geographical distribution of the plants within these states indicates that CKD would be available within reasonable transportation distance at most locations. These states are: Alabama, California, Indiana, Michigan, Ohio, Pennsylvania, Tennessee, and Texas. Three other states have a significant number of cement plants but they are more or less concentrated in one section of the state. These states are as follows:

Kansas--plants are in the eastern portion of state
Missouri--plants are in the eastern portion of state
New York--plants are in the southeastern portion of state

Other states that have four or more cement plants that would potentially have CKD available are: Florida, Illinois, Iowa, and Washington. It can be seen that most of the heavily industrialized states would have CKD available. These states are also among the heavy users of road base materials.

Amounts and Locations of Lime Kiln Dust

Table II-6 shows that there are 61 commercial lime plants in 30 states that have rotary kilns. There are 20 plants that have vertical or other kilns but no rotary kilns. It has been reported that there is minimum dust accumulation from vertical kilns. Based on the location of the rotary kiln plants, the following states would appear to have the most available supply of LKD: Alabama, Ohio, Pennsylvania, Texas, and Virginia. These five states have almost half of the plants. It was reported in 1977 (Reference II-12) that six states, Ohio, Pennsylvania, Missouri, Texas, Michigan, and Alabama, accounted for 57 percent of the total output of lime. In addition, it is known that LKD is available in the Chicago area which would add Illinois to the list. Combining these into one tabulation would produce a list of eight states: Alabama, Illinois, Michigan, Missouri, Ohio, Pennsylvania, Texas, and Virginia. It is believed that this is a fair representation of the most plentiful sources of LKD in the United States.

No precise data on the amounts of LKD and CKD that are available at various locations has been given. It is believed that the information presented is sufficient for the purpose particularly in view of the very limited usage that these materials have had in road base construction and the difficulties of obtaining "hard" data.

Locations of Past and Present Producers of Kiln Dust-Fly Ash-Aggregate Compositions

Three companies have been engaged in the past in providing kiln dust, fly ash, aggregate compositions for field installations. These companies are:

- Nicholson Industries, Toledo, Ohio
- Gallagher Asphalt Co., Chicago, Illinois
- City Wide Asphalt Co., Sugar Creek, Missouri

These organizations would be capable of supplying the material now to local clients.

Locations of Potential Producers of Kiln Dust-Fly Ash-Aggregate Compositions*

While there are only a few plants that have had experience with kiln dust road base compositions, there are many that could supply the material in a relatively short period of time. These potential suppliers would fall into two categories. The first category are those who have in the past or are currently engaged in supplying lime, pozzolan, aggregate base course materials. It would be necessary only to replace the hydrated lime in one of the storage bins with kiln dust and possibly recalibrate the feed system for the new mixture. The second category are those mixing plants that normally supply bituminous mixtures and/or portland cement concrete. With some addition of bins and conveyors, it is conceivable that these plants could be readily (within a matter of months) fitted to produce "pozzolanic concrete." In some plants, additional bins are not necessary. They could be fitted within three months at a cost of approximately \$30,000.

In addition to these possibilities, it has been estimated that a new plant could be put into operation within approximately 9 months--assuming there would be no excessive delay in obtaining the required equipment. The plants are not very sophisticated to assemble or to operate.

The availability of producers is not considered to be a deterrent to the expanded use of kiln dust.

TECHNICAL ASSESSMENT*

Field experience with kiln dust compositions is limited. Details on experimental road bases that have been in service for as much as five years

* Much of the data on which this assessment is based was supplied by Nicholson Industries.

are presented later in this report. Laboratory studies, however, are of much more significance than they ordinarily would be because of the close similarity to lime, fly ash, aggregate compositions which have a long history of solid performance. In addition, it is important to note that the compositions can be improved by small additions of portland cement.

Much of the technical assessment is based on the extensive laboratory work that has been done. The performance of the field installations is used as confirmation of the results of the laboratory evaluations.

Laboratory Investigation - Cement Kiln Dust

Evidence of laboratory data that was generated by a number of laboratories and/or consultants was obtained. A list of laboratories and consultants that were involved in the laboratory work is shown in Table II-7. The list is not necessarily a complete one. It contains only those organizations and individuals who provided data and/or laboratory reports that were reviewed by the writer. Laboratory testing included the use of cement kiln dust from the sources shown in Table II-8.

Compressive Strength. The laboratory investigations of compressive strength were made in accordance with generally accepted standards for the evaluation of compositions of this nature. Much of the testing was done in accordance with ASTM C593, Fly Ash and Other Pozzolans for Use with Lime. The procedure specified in this ASTM test consists of the following steps:

1. Mixing of the dry materials until a uniform mixture is obtained.
2. Mixing in a specified amount of water that would closely correspond to the water required to produce a material that would be most efficiently compacted in the field (the moisture content obtained by the addition of this amount of water is known as the "optimum moisture content").
3. Molding cylindrical specimens (4 inch diameter by 4.6 inches high) in accordance with a specified compactive effort. The specimens are molded in a steel mold. The material is placed into the mold in three equal layers and is packed in by the use of a steel drop hammer of specified weight and height of drop.
4. Curing (allowing the samples to gain strength) of the molded specimens for a specified period of time at controlled temperature and humidity conditions. The usual time periods are 7, 14, 28, and 90 days.
5. Breaking the specimens in compression at the end of the curing period. Specimens are usually soaked in water for at least 4 hours prior to breaking.

Table II-7

Laboratories and/or Consultants That Contributed
Laboratory Data on Kiln Dust Compositions

Bowser-Morner Testing Laboratories, Inc.
Toledo District
5247 Secor Road, P.O. Box 5847
Toledo, Ohio 43613

Flood Testing Laboratories, Inc.
1945 E. 87th Street
Chicago, Illinois 60617

Toledo Testing Laboratory, Inc.
Toledo, Ohio 43624

Department of Civil Engineering
Construction Materials Research Group
The University of Toledo

Ernest J. Barenberg, PhD.
Engineering Consultant
617 W. Church Street
Champaign, Illinois 61820

David C. Colony
Civil Engineer and Surveyor
3648 Maxwell Road
Toledo, Ohio 43613

Table II-8

Sources of Cement Kiln Dust Used in Laboratory Testing

General Portland Cement Co.	- Tampa, Florida
Ideal Cement Co.	- Galena Park, Texas
General Portland Cement Co.	- Paulding, Ohio
Medusa Portland Cement Co.	- York, Pennsylvania
Medusa Portland Cement Co.	- Cleveland, Ohio

The following observations were made after reviewing the compressive strength data:

1. Figure II-1 shows the results of a number of compressive strength determinations. It can be seen that the majority of the strengths at seven days are greater than 600 psi and went as high as 1,200 psi. Figure II-2 shows compressive strengths at 7 days ranging from 420 psi to 1,150 psi (excluding the 4-6-90 mix which is not recommended). It also shows 28-day strengths ranging from 700 psi to 1,400 psi. These strengths are quite comparable to a typical lime-fly ash-aggregate composition. Recent work has shown that kiln-dust compositions can be designed for strength levels as required.
2. The 28-day compressive strengths showed an increase over the 7-day strength that was typical of cementitious products. Although there was a significant variation, the average 7-day strength was about 75 percent of the 28-day strength (see Figure II-2). It must be reported (but not verified) that some of the 28-day specimens were cured at lower temperatures during the period from 8 to 28 days. If so, the percentage (75 percent) would be high.
3. In most cases, the 90-day strength was significantly greater than the 28-day strength. On the basis of the limited data, the 90-day strength was approximately 130 percent of the 28-day strength.
4. There were some instances in which 90-day compressive strength samples disintegrated when they were soaked in water in preparation for strength testing. This did not occur in the 7 and 28-day specimens and there was no apparent explanation for the phenomenon. It is quite likely that this was related to testing technique rather than a material characteristic. Additional data are required.
5. Strength gain was a function of curing temperature. The compressive strengths increased significantly as the curing temperatures increased from 55°F to 85°F. A curing temperature of 100°F did not produce any greater strength than that produced by 85°F. This observation was based on limited data (see Table II-9). Compressive strengths were obtained for one mix, using CKD from one source; and for 4 different temperatures (55°, 70°, 85°, 100°F). Additional data are required to verify this performance.

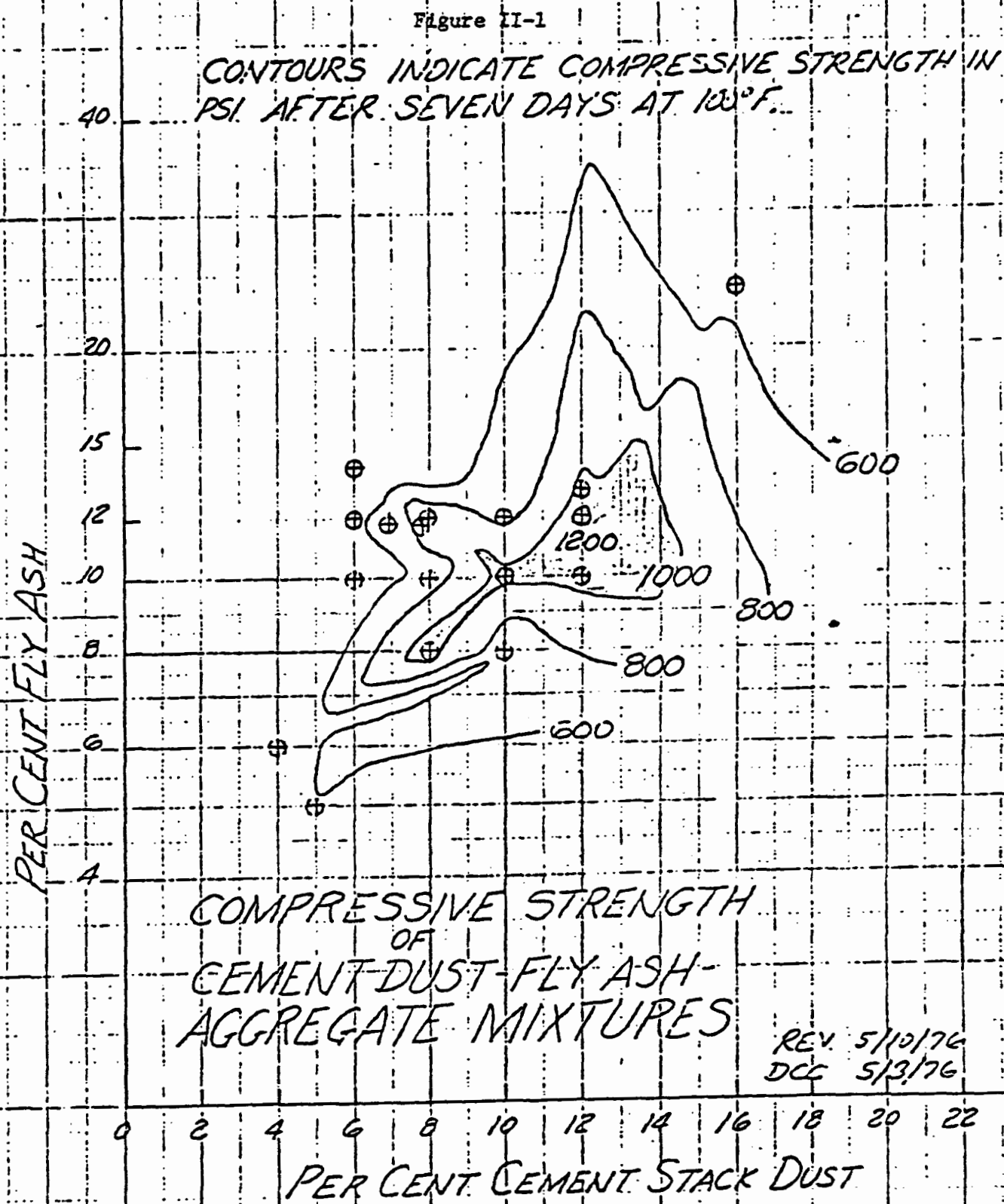


Figure II-2

COMPRESSIVE STRENGTH
OF
POZZOLANIC MIXTURES CONTAINING
CEMENT KILN DUST, FLY-ASH & AGGREGATE

DCC 1/3/76

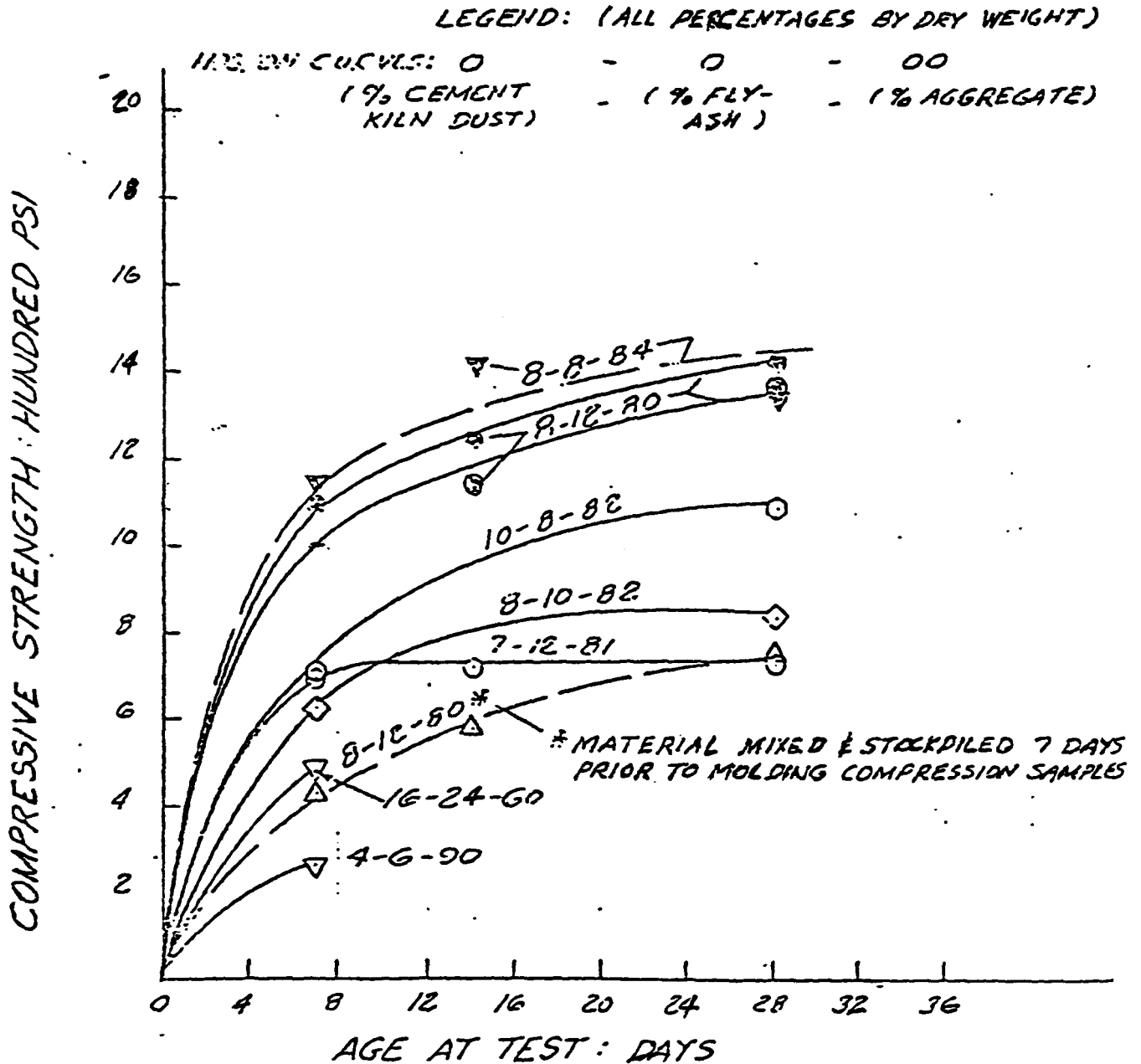


Table II-9

Compressive Strengths of CKD-Fly Ash-Aggregate
Compositions Showing Curing Temperature Effects
(Strengths are in lbs. per sq. in.)

<u>Age Days</u>	<u>Curing Temperature °F</u>			
	55	70	85	100
7	0	502	813	763
14	370	675	987	1029
28	706	912	1074	1059

Note: Mix composition (by weight) was as follows:

- Cement Kiln Dust 8%
- Fly Ash 12%
- Aggregate 80%

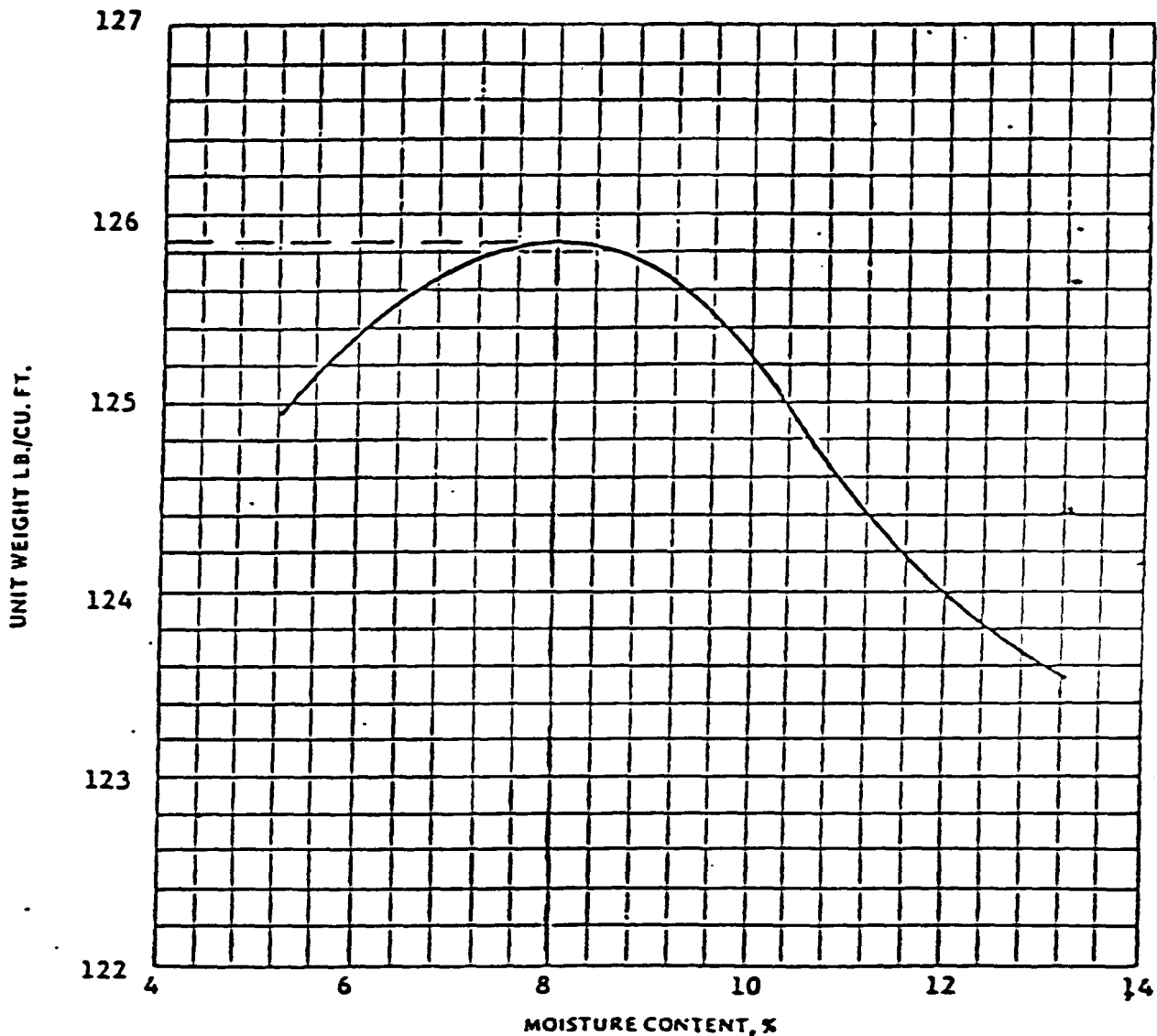
Specimens were compacted in accordance with ASTM C593

6. Twenty-nine sets of data out of 33 showed compressive strengths in excess of 400 psi which is the minimum requirement in ASTM C593; Fly Ash and Other Pozzolans for Use with Lime. Most strengths were considerably in excess of the minimum requirements. ASTM C593 is generally regarded as a standard for lime-fly ash-aggregate road base compositions. It is quite probable that the mix design of low strength specimens could be adjusted to provide suitable strengths.
7. The addition of small amounts (1 to 2 percent by weight) of portland cement produced a significantly higher compressive strength in laboratory specimens. Additions of these small amounts may not be practical in field use.
8. There are indications that the reactivity of CKD varies depending on the source. In one instance, where a comparison was possible between four CKD sources, the strengths using one source were lowest in four out of five comparisons. Except for an apparent anomaly in the data, it probably would have been low in all five cases.
9. The type of fly ash that was used in the compositions also appeared to affect the compressive strength. Evidence of this was not conclusive because of limited comparable data.
10. The surface material (0 to 6 feet in one instance) of stockpiled kiln dust agglomerates and, even though it is pulverized, is virtually inert in producing any cementitious reaction. In addition, it retains considerable moisture (in excess of optimum) which is difficult to reduce.
11. Moisture-density relationships that were determined for the kiln dust-fly ash-aggregate compositions show the usual result with a well-defined maximum dry density and optimum moisture content. A typical moisture-density curve is shown in Figure II-3.
12. The range of dry densities that were obtained on numerous laboratory compacted test cylinders ranged between 124 pcf and 135 pcf with an average of about 130 pcf. The corresponding molding moisture range was approximately 8 percent to 12 percent. In cases where the moisture contents were higher than 12 percent, the compacted densities were quite low indicating that the moisture content was too high.

The preceding observations show that the compressive strength and density characteristics of cement kiln dust, fly ash, aggregate compositions are typical for stabilized materials. In particular, they resemble closely results that would be obtained with lime, pozzolan, aggregate compositions.

Figure II-3
REPORT OF PROCTOR CURVE

CLIENT: _____ DATE 2/20/76
LAB NO. 1522
PROJECT: Pozz-O-Pac Time-Temperature-Strength Tests
MATERIAL: Type 301 Crushed Limestone
SOURCE OF MATERIAL: France Stone Company - Silica Quarry



Type Proctor Modified A.S.T.M. D-1557
Maximum Dry Density 125.9 Lbs./cu. ft. Optimum Moisture Content 8.0 %

Durability. The resistance to freezing and thawing of compositions containing CKD has been measured by the methods of ASTM C593. This method specifies that the compressive strength of vacuum saturated specimens should be used as a measure of freeze-thaw durability. A compressive strength of 400 psi is required on specimens that are vacuum saturated after being cured for 7 days. The results of a number of these tests are shown in Table II-10. The data represents compositions made from cement kiln dusts from five different sources. In each case, the minimum strength required for acceptance was obtained.

Autogenous Healing. There is significant evidence that compositions containing CKD possess the property of autogenous healing. Autogenous healing is the property that enables compositions that gain strength slowly over a long period of time to regain strength after their original strength has been exceeded. It is typically evaluated by testing specimens in compression that have been previously tested to failure. Table II-11 shows a set of test data from such an evaluation. The property of autogenous healing is of obvious benefit for a road base composition. It insures that continual rejuvenation of the structural capability of the base will take place over a long period of time. Damage to the pavement that is caused by temperature changes and load applications is neutralized by the continuous healing.

Laboratory Testing - Lime Kiln Dust

Compressive Strength. Compressive strength evaluations of potential base compositions utilizing lime kiln dust are preformed in a manner identical to those where cement kiln dust is used. The laboratory data that were available for review on LKD were substantially less than for CKD. The following observations can be made about the compressive strengths of the mixtures containing LKD.

1. Figure II-4 shows a plot of compressive strength data. The range of 7-day strengths is from 380 psi to 700 psi. The 28-day strengths range from 380 psi to 1,400 psi. These strengths are on the order of one to two hundred pounds per square inch lower than a typical lime-fly ash-aggregate composition. As with CKD compositions, various strength levels can be obtained by proper mix design.
2. The 28-day compressive strengths showed an increase over the 7-day strengths except for two relatively low strength compositions (see Table II-12). Except for those two compositions, the 7-day strength averaged 46 percent of the 28-day strength. There was insufficient data available to draw any conclusions with respect to the 90-day strengths.

Table II-10

FREEZE-THAW RESISTANCE OF CKD COMPOSITIONS
AS MEASURED BY THE COMPRESSIVE STRENGTH OF
VACUUM SATURATED SPECIMENS

Source of CKD	Mix Formula (% by weight)				Vacuum Saturated Compressive Strength* psi
	CKD	Fly Ash	Portland Cement	Aggregate	
General Portland Cement Co.	8	8	0	84	887
	8	8	1	83	1433
Medusa sylvania	8	8	0	84	1113
	8	8	1	83	1683
Medusa- Dixon	8	8	1	83	666
Marquette	8	8	1	83	825
Kansas City	8	8	0	84	960**
	8	8	0	84	1110 (28 days)

*Average of 3 strengths

**Average of 6 strengths

Figure II-4

COMPRESSIVE STRENGTH vs AGE AT TEST

POZZOLANIC MIXTURES CONTAINING
LIME PRECIPITATOR DUST

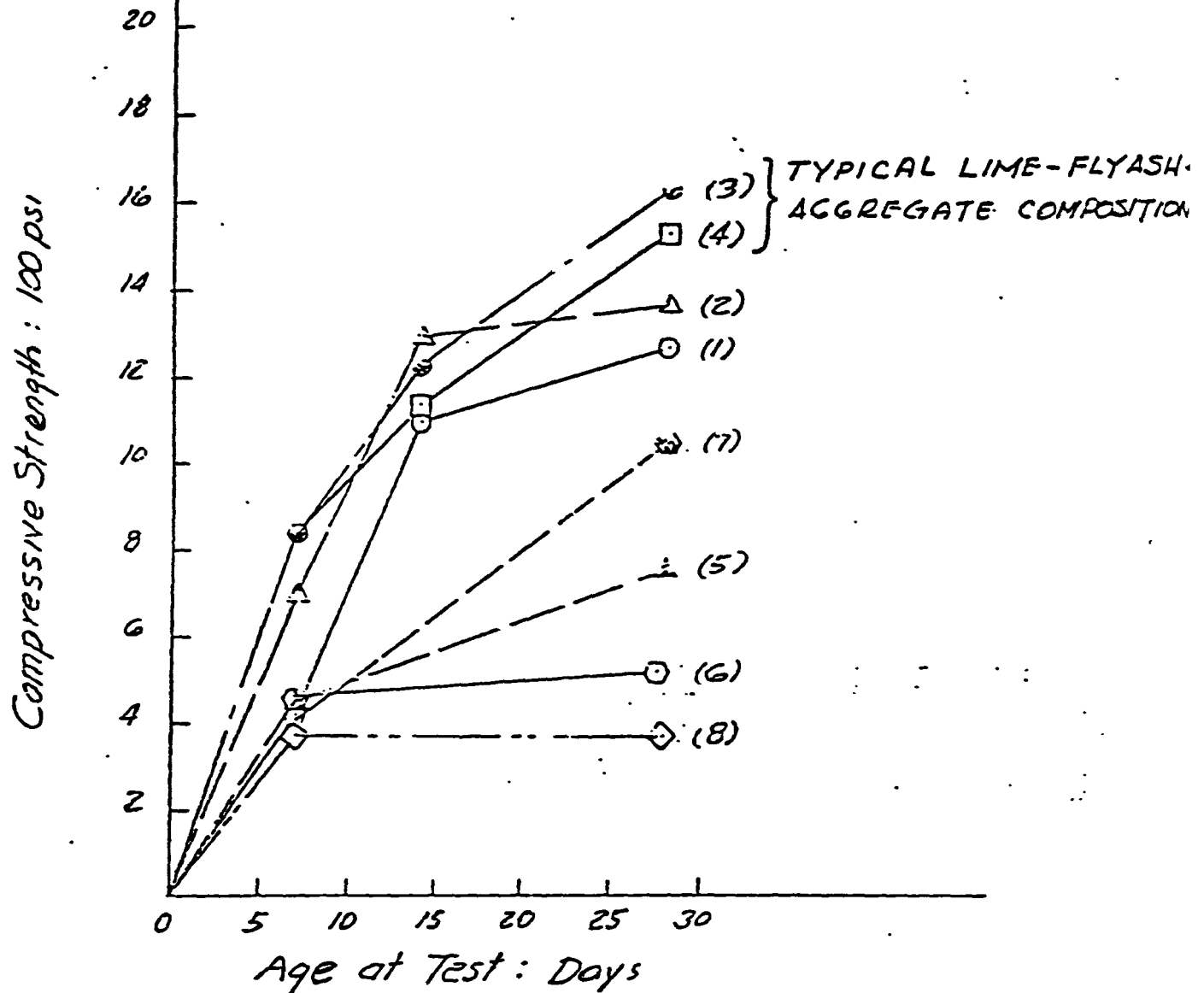


TABLE OF INGREDIENTS

INGREDIENT	% BY WEIGHT : GRAPH NO.							
	1	2	3	4	5	6	7	8
Aggregate	86	86	86	86	81	80	79	69
Fly Ash	7.6	6.0	11.0	11.0	11.0	11.0	11.0	11.0
Precipitator Dust	6.4	8.0	-	-	8.0	9.0	10.0	20.0
Hydrated Lime	-	-	3.0	3.0	-	-	-	-

Table II-11

Autogenous Healing of Laboratory Specimens
Containing CKD*

Mix**	Original Compressive Strength psi	Healing Time Weeks	Compressive Strength After Healing psi	Strength After Healing as a % of Original
6-6-88	850	7.3	952	112
6-6-88	658	10.9	836	127
6-6-88	281	6.3	448	160
8-8-84	1147	7.3	1150	100
8-8-84	989	3.9	1506	152
8-8-84	934	10.9	1117	120
8-8-84	558	9.9	745	134
10-10-80	1200	7.3	1213	101
10-10-80	1167	10.9	1406	120
10-10-80	581	5.3	728	125

*Data was obtained from Reference II-13.

**Mix gives composition by weight in the following order:
CKD-Fly Ash-Aggregate

Table II-12

Compressive Strengths of LKD-Fly Ash-Aggregate Compositions

			Compressive Strengths				
Mixture Formula % by Weight			<u>psi</u>			<u>% of 28-Day Strength</u>	
LKD	Fly Ash	Aggregate	7 Days	28 Days	90 Days	7 Days	90 Days
8	12	80	852	1580	1626	54	103
10	12	80	847	1954	1866	43	96
8	11	81	420	755	NA	56	-
9	11	80	475	518	NA	92	-
10	11	79	400	1050	NA	38	-
20	11	69	375	375	NA	100	-
6.4	7.6	86	420	1270	NA	33	-
8	6	86	700	1370	NA	51	-

NA - not available

3. Moisture-density relationships that were determined for the kiln dust-fly ash-aggregate compositions show the usual result with a well-defined maximum dry density and optimum moisture content. Dry densities that were obtained in a number of laboratory compacted cylindrical specimens ranged from 122 to 133 pcf at an average moisture content of 10.9 percent.

Durability Tests. Limited data on freeze-thaw testing are available. Table II-13 shows data excerpted from a table shown in the patent application (Reference II-3). Figure II-5 shows a phenomenon that is typical of hydrated lime-fly ash-aggregate compositions. That phenomenon is the continued strength gain after 12 cycles of alternate freezing and thawing.

Those compositions that show a weight loss during freeze-thaw cycles of 14 percent or less are considered to have satisfactory durability. The data in Table II-12 shows that this requirement can be obtained by proper mixture design. The ability of the material to gain strength after a long period of adverse temperature variations indicates that any deterioration caused during cold weather will tend to correct itself when the temperature rises (probably at 55°F or higher).

Field Installation

Cement Kiln Dust. A number of field installations of road base consisting of CKD-fly ash-aggregate compositions have been made and are periodically being evaluated. Table II-14 shows the locations and extent of these installations together with other pertinent data.

Specimens have been removed from some installations and tested in compression. The data obtained are shown in Table II-15.

The most complete documentation of the performance of a field installation has been made on a road base in a concrete plant drive in Silica, Ohio (Reference II-13). Test strips of six different mixes, each 100 feet long, were placed at this location. It is reported that "A total of 25,820 equivalent 8,165 kg (18,000 pounds) single axles were recorded in six months with no cracking or surface damage visible except for a localized area." In addition, deflection measurements and periodic compression tests of field samples were performed. The six compositions are given in Table II-14, along with other data relevant to the project.

Deflection measurements, made with a Benkelman Beam, generally decreased with time, an indication that the pavement structure was becoming stiffer with time. The compressive strengths of field samples were obtained after the base was in use for six months and for almost one year. These strengths are shown in Table II-16.

Table II-13

Freeze-Thaw Test Data
LKD Compositions

Mixture Formula (% by Weight)			% Weight Loss after 12 cycles of freeze-thaw	Compressive Strength after 12 cycles of freeze-thaw psi	Compressive Strength after recuring-psi
LKD	Fly Ash	Aggregate			
8	10	82	5		
8	10	82	4	806	
8	10	82	3		1180
8	10	82	3		1075
8	10	82	3	396	
8	10	82	5		
8	12	80	18		
8	12	80	17		
8	12	80	21		
8	12	80	10		
8	12	80	30		
8	12	80	8		

Source: Reference II-3.

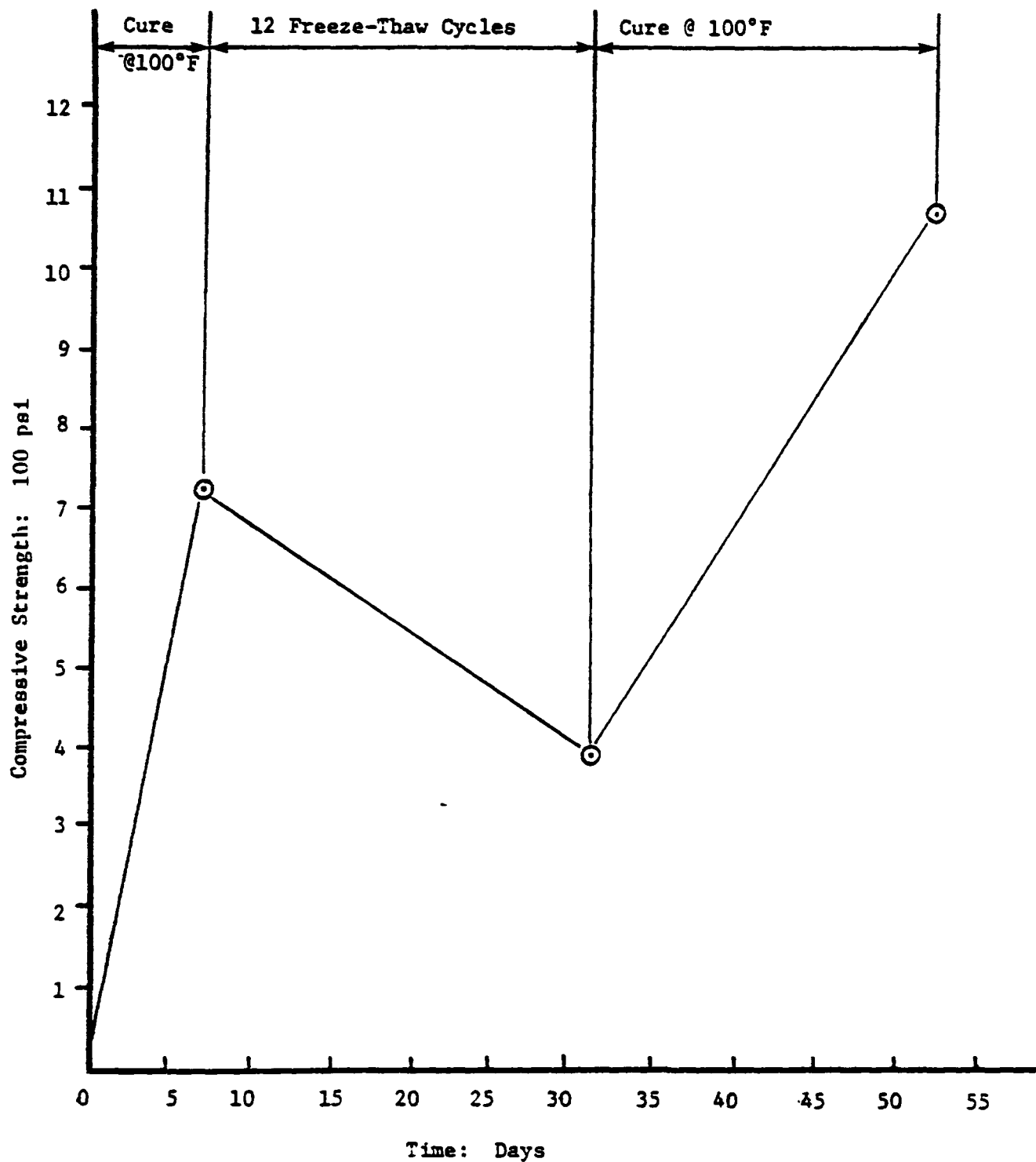


Figure II-5. History of cylinders with 10 percent fly ash and 8 percent "lime" (precipitator dust).

Table II-14

DATA ON FIELD INSTALLATIONS - CKD ROAD BASE COMPOSITIONS

NAME & LOCATION	DATE INSTALLED	LENGTH & WIDTH	ROAD BASE DESIGN					AGGREGATE TYPE	SOURCE OF CKD	DESCRIPTION OF SURFACE
			THICKNESS INCHES	MIX FORMULA (% by weight)						
				CKD	FLY ASH	PORTLAND CEMENT	AGGREGATE			
SILICA, OHIO PLANT ROAD	11/5/77	Six strips each 100' long	10	6 8 10 12 8 8	6 8 10 12 8 8	0 0 0 0 0.5 1	88 84 80 76 83.5 83	Ohio spec. 301 crushed aggregate	Medusa Cement Co. Silica, Ohio	Double "tar & chip" Seal Coat
MEADOWBROOK ESTATES STREETS & MOBILE HOME PARK	Oct 1976	LF 2670' W 24'-36'	5	8	8	0	84	Ohio 304	General P C Paulding	2"
		LF 220' W 24'	5	8	8	1	83	Ohio 304	General P C Paulding	2"
TOLEDO EXPRESS AIRPORT PARKING LOT	Nov 1978	5000 sy	8	10	10	0	80	Ohio 304	General Portland Cement Co. Paulding OH	2" BT
SHERWIN WILLIAMS CO. PLANT DRIVES, CHICAGO, ILL.	10/19/77	LF 500' W 30'	6-10"	9	10	0	81	Illinois CA-6	Universal Atlas Buffington Indiana	3-1/2" - 4"
JOHN OUSKY PARK - PARKING LOT OREGON, OHIO	10/21/77	6000 sy	5"-6"	8	8	1	83	Ohio 304	General Paulding	2" BT

Table II-15

Compressive Strength of Specimens from Field Installations

Project	Construction Date	Type of Specimen	Date Sampled	Compressive Strength	
				Ave. psi	Range
Meadowbrook Estates	Oct. 1976	3" cubes	5/26/77	780 ¹	660-950
Centennial Plant	Nov. 1977	Various sizes of rectangular solids ²	9/30/78	1385 ³	1056-1826
Sherwin Williams Chicago, Ill.	Oct. 1977	4" dia. cores	10/20/78	1511 ⁴	1352-1639
		"	6/20/80	1083 ⁵	

¹5 test specimens

²Vary from 3-1/2" x 4-5/8" x 6-3/8" high to 6" x 6-3/8" x 4-1/2" high

³9 test specimens

⁴4 test specimens, vacuum saturated.

⁵6 test specimens

Table II-16*

Compressive Strengths of Field Samples
(from test strips, Silica, Ohio)

Mix Formulation (% by weight)				Compressive Strength (on dates shown)			
CKD	Ash	Portland Cement	Crushed Limestone	psi			
				Dates Tested			
				5/10/78	5/17/78	10/16/78	10/17/78
6	6	0	88			1177	
8	8	0	84		612	1540	
10	10	0	80		611		1438
8	8	1/2	83-1/2		251	1231	
8	8	1	83	811			355

*Data were obtained from Reference II-13.

NOTES:

- Road base was constructed November 5, 1977.
- All strengths are the average of 3 samples.

Dr. Ernest Barenberg of the University of Illinois, a recognized expert in the performance of stabilized road bases, inspected the Sherwin-Williams Co. plant drives in June of 1980, approximately three years after they were constructed. He reported that the installations were in excellent condition. There was only a slight amount of cracking which is typical of stabilized bases of a similar type. The bituminous wearing surface was adhering properly to the base material. The pavement was cored at the time of the inspection. The mix formulation and other information relevant to this project are shown in Table II-14. The compressive strengths of the cores are included in Table II-15. Split tensile tests were also run on some of the cores. An average of 204 psi tensile strength was obtained on 9 specimens. In this case, the tensile strength was approximately 20 percent of the compressive strength. This is somewhat higher than the 10 to 12 percent normally anticipated.

Lime Kiln Dust. The Chicago area has been using a "polyhydrate" lime in lime-fly ash-aggregate compositions for several years. "Polyhydrate" lime can contain as much as 80 percent lime kiln dust and 20 percent quicklime. This experience has been successful and illustrates an application of LKD but one that has previously not been identified as such.

The first field application of lime kiln dust using the formulations discussed in this report is scheduled for early November 1980 in the Toledo, Ohio area. Developers of the material feel that it will perform in a manner similar to the cement kiln dust compositions. This is based on the fact that the major constituent of portland cement is limestone and the sole constituent of lime is also limestone; therefore, the dust resulting in the processes should be similar. An examination of the chemical compositions of each that are shown in Tables II-1 and II-3 indicates that there is a close similarity between cement kiln dust and high calcium lime kiln dust.

SUMMARY ASSESSMENT

The documentation that is available shows that kiln dust, fly ash, aggregate compositions have considerable potential in a road base application. We would generally agree with a statement contained in a report "N-Viro-Crete, A Current Evaluation, 1978" by D. C. Colony, PhD., Professor and Chairman of Civil Engineering, University of Toledo, as follows: "Substitutions of CKD in place of lime to obtain a pozzolanic mixture provides at least three advantages.

- a. Lower cost of material.
- b. Enhancement of the environment by consumption of waste products which would otherwise require the use of land and other resources to store in a proper manner.
- c. Lower energy consumption per mile of pavement, since both fly ash and CKD are by-products requiring virtually no energy for their own production."

The laboratory data, which is mostly compressive strength testing of various compositions, shows a striking similarity to that obtained with proven hydrated lime, fly ash, aggregate road base compositions. This helps to substantiate the viability of using kiln dust in these applications.

The acquisition of additional data is an ongoing process. Representatives of N-Viro Energy Systems, Ltd., Toledo, Ohio, one of the principal protagonists of the system, state that various strength levels of the compositions can be achieved by proper mix design. This will insure that the compositions will be able to meet strength and durability requirements. It has also been stated by them that this will increase the flexibility of the system beyond that which is possible with lime, fly ash, aggregate materials.

There is also evidence to show that the variability of kiln dust, which is one of the chief disadvantages claimed by some, is not as great or as significant as has been stated (Reference I-15). Sampling procedures for the kiln dust in the past appear to have largely ignored good sampling techniques and the process by which the material is produced and stored.

Studies are now underway to verify the consistency of the significant properties of cement kiln dust when the material comes from a given location in the collection process. There appears to be no reason why the kiln dust should vary significantly if the raw materials and operating procedures of the plant remain constant. It is obvious that control of these two factors is also of vital importance to the quality of the primary product—cement or lime.

Five field installations of road base containing kiln dust prove that the material can be successfully used.

It is obvious, however, that there are significant gaps in the information that is available. This is particularly true with regard to durability. There is also a need for larger, fully documented experimental field installations that will provide the type of information that will be convincing to potential users of road base materials. The Federal Highway Administration (supported by the U.S. Department of Energy) requested and received proposals for the evaluation of Kiln Dust-Fly Ash Systems for Pavement Bases and Sub-bases (RFP #DTFH61-80-R-00056) in January 1980 and was awarded to Valley Forge Laboratories in February 1980. This project is a laboratory evaluation with a followup project involving experimental installations in three states is planned. Projects of this type will go a long way toward providing some of the additional documentation that is required.

Kiln dust is a promising material whose use should be developed by support of experimental work, including field demonstrations, that will prove its value. It is essential that the combined FHWA-DOE project, described briefly in the previous paragraph, be implemented without delay.

EPA should monitor this project so that as soon as sufficient information becomes available it may influence guideline decisions. There are strong reasons for utilizing kiln dusts, beyond their applicability in highway construction. Of great importance among these reasons is the energy saving involved in the use of a material that requires virtually no additional energy in its production and a much reduced energy consumption during construction when compared to materials it would replace. There are also environmental and economic benefits derived from reduced disposal requirements.

Part II

REFERENCES

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- II-3 U.S. Patent #4,038,095, Mixture for Pavement Bases and the Like.
- II-4 Report of Second NLA Dust Disposal Survey prepared by Kenneth A. Gutschick, National Lime Association, June 1977.
- II-5 July 21, 1977 issue of The Blade, Toledo, Ohio newspaper quotes J. E. Poole, President and Chairman of the Board, Marquette Co., a major cement producer.
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- II-11 Commercial Lime Plants in U.S. and Canada (map) published by National Lime Association, Washington, D.C., 1978.
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- II-14 Utilization of Waste Kiln Dust from the Cement Industry; Thomas A. Davis and Don B. Hooks, Proceedings of The Fourth Mineral Waste Utilization Symposium, 1974.
- II-15 Interviews with J. Patrick Nicholson, Chief Executive Officer, N-Viro Energy Systems, Ltd., Toledo, Ohio, and Steven A. Hayden, Vice President-Operations, Keystone Portland Cement Company, Bath, Pennsylvania.

Part III

USE OF ASPHALT-RUBBER IN HIGHWAY CONSTRUCTION

INTRODUCTION

Asphalt-rubber is a mixture of a blend of various types of rubber with asphalt. The mixture may be modified with an extender oil or by the addition of kerosene. The rubber blend is mixed with asphalt after the asphalt has been heated to 350° to 425°F. Heating of the mixture is continued for a period of between 30 and 90 minutes. It is applied while hot. In those highway applications where the material is applied in a layer which will be subjected to traffic, a layer of stone (chips) is immediately spread and rolled into the still hot asphalt-rubber.

The recovered material in asphalt-rubber is the rubber. The rubber consisting of vulcanized and devulcanized, natural and synthetic is obtained from scrap automobile and truck tires. Special purpose processing plants reduce the rubber to a granulated or ground form in accordance with a given specification. The rubber usually is reduced to a size such that 100 percent is finer than a #10 sieve (2.00 mm opening).

Asphalt-rubber is a relatively new material, being a man-made mixture that does not occur in nature. It was originally developed sometime in the early 1960s, and was first used in a limited field test in 1964. A summary of its development since that time is presented in Table III-1.

APPLICATIONS

There are seven present and potential applications for asphalt-rubber: 1) chip seals;* 2) SAMI-stress absorbing membrane interlayer; 3) encapsulating membrane; 4) crack and joint sealant; 5) bridge deck waterproofing; 6) hot-mix binder; and 7) roofing material.

The present study is concerned primarily with uses (1) and (2) above, although reference will be made to uses (3) and (4) which appear to have progressed beyond the experimental stage. Uses (5) to (7) inclusive are still very much in the experimental period and will not be considered.

* When chip seals are used over a distressed (severely cracked) pavement it is sometimes referred to as SAM-stress absorbing membrane. If it is covered with an overlay it becomes a SAMI.

Table III-1

HISTORY OF THE DEVELOPMENT OF ASPHALT-RUBBER

Early 1960s	Early experimentation by Charles H. McDonald who is credited for originating the concept of using a relatively large amount (25 percent) of granular rubber in the asphalt-rubber mixture. Mr. McDonald was an engineer with the City of Phoenix, Arizona.
1964-65	Field trials were initiated in Phoenix.
1967	First full-scale field trial--taxiway at Phoenix Sky Harbor Airport.
1968	Sahuaro Petroleum and Asphalt Co., Phoenix, Arizona began to develop the formulations, construction techniques, and special equipment.
1968	Arizona Department of Transportation became interested in the concept for preventing reflection cracking. Placed 2-1/2 miles of asphalt-rubber seal on freeway frontage and access roads.
1968-71	ADOT and other public agencies placed several projects.
1971-73	Three special projects known as the Aguila, Flagstaff, and Minnetonka Projects were carried out by ADOT. The Minnetonka Project was part of the NEEP program on Prevention of Reflective Cracking in Overlays.
1973	Publication of Implementation Package 73-1, Rubber-Asphalt Binder for Seal Coat Construction, by FHWA.
1974-75	A second commercial producer, Arizona Refining Co., Phoenix, Arizona enters the field.
1975	Arizona DOT implements the use of stress-absorbing membrane interlayer (SAMI) as standard procedure for all overlays less than 4-inches in thickness that are placed over cracked pavements.
1976	FHWA implemented Demonstration Project No. 37, Discarded Tires in Highway Construction.
1976 on	Continued application of the asphalt-rubber concept by Arizona DOT, City of Phoenix, Corps of Engineers, Province of Saskatchewan, and many other agencies. Somewhere between 35 and 42 states, several Canadian provinces and organizations in Australia, England, and the Scandanavian countries have been involved in use of the materials.
1980	Genstar Conservation Systems, Inc. begins production of crumb rubber in a new and innovative tire recycling plant in Phoenix, Arizona.

References: III-4, III-6, III-27, and III-28.

Crack Control

The consensus is that asphalt-rubber is a unique product having distinct properties that enhance its use as a paving material in rather well defined situations. It has been particularly effective as a technique for restoring and increasing the life of distressed (cracked) bituminous pavements. Highway pavements, portland cement concrete as well as bituminous, are subjected to destructive forces such as traffic and climate immediately after they are put into service. Eventually these forces cause deterioration of the pavement to the extent that corrective measures are required. In many cases the pavement is severely cracked and may be marked with a substantial number of pot holes. In the past, bituminous overlays of one inch or more in thickness have been used over the cracked pavement in order to restore its serviceability. One of the disadvantages of this type of remedy has been that in a relatively short period of time cracking of the overlay occurs at the same places that the original distressed pavement was cracked. These cracks in the overlay are commonly referred to as "reflection" cracks. The elimination or control of reflection cracks is possible by the proper use of asphalt-rubber.

An understanding of the various types of cracks that occur in highway pavements is necessary in order to understand why asphalt-rubber is effective in their control. There are three types of cracks:

- fatigue cracking--due to repeated deflection of the pavement caused by traffic loads.
- cracks caused by direct tensile strength--usually caused by temperature change or shrinkage of the pavement material.
- cracks caused by differential vertical movement (Reference III-1).

The formation of these cracks is resisted by a material that has sufficient elasticity that will enable it to deform under stress without rupturing.

The use of rubber in asphalt has a direct effect on two important properties: (1) it improves the elasticity of the asphalt; (2) it reduces the susceptibility of the asphalt to changes in temperature. It therefore makes the asphalt-rubber more elastic and keeps it in this condition at temperatures 20 to 30°F lower than conventional asphalt (Reference III-2).

When the layer of asphalt-rubber and chips is placed as a surface layer (SAM) on top of a cracked pavement it has been shown to be effective in controlling fatigue cracks. The underlying cracks do not come through the SAM for a much longer period of time than if a conventional seal coat is used. As an interlayer (SAMI), where a 2-inch to 4-inch bituminous overlay is added on top, it appears to control all types of cracking. In this case the underlying cracks will not be reflected through the overlay. In both these instances little or no maintenance is required for extended periods.

One of the most comprehensive analyses made on the effectiveness of asphalt-rubber for crack control is presented in Reference III-10. This case study was conducted in conjunction with Federal NEEP Project, Number 10 - Reducing Reflective Cracking in Bituminous Overlays. Eighteen selected roadway test sections were evaluated in this study which was carried out on a 9-mile section of Interstate 40 near Winslow, Arizona. Among five treatments "found to have significantly reduced cracking" were listed: "Asphalt-rubber membrane seal coat under ACFC*" and "Asphalt-rubber membrane flushed into asphaltic concrete overlay". The report also recommended that one of the five treatments "be used in conjunction with a thin overlay (less than 4 inches of AC)". In 1978, 6-1/2 years after construction, the asphalt-rubber membrane seal coat under ACFC showed the least amount of reflective cracking of the 18 test sections. By that time the highway had been subjected to over 1,000,000 18 kip equivalent loads. The following statement is also included in the above report: "As a result of this project and other evidence, ADOT implemented in 1975 the use of the stress absorbing interlayer (SAMI) as standard procedure for all overlays under four inches in thickness that are placed over pavements where cracking is a problem."

A recent analytical study (Reference III-3) has also determined that "the effect of including a low modulus interlayer (rubber asphalt) can be significant in the inhibition of reflection cracking resulting from both load and temperature changes,..."

Waterproofing

When asphalt-rubber is used as a waterproofing layer it is referred to as an encapsulating membrane. It has been used successfully in a number of cases to prevent water from entering expansive soils that make up the subgrade (foundation) of highway and airfield pavements. Moisture increases in expansive soils causes them to increase in volume with a subsequent buildup of high pressures under the pavement. These high pressures will raise the pavement (cause heave). Since this phenomenon rarely occurs in a uniform manner, differential heave or vertical movement will occur. This will create an uneven riding surface and, more seriously, unusual stress conditions that will significantly reduce the life of the pavement.

If, in this application, the asphalt-rubber layer is in an area that will be subjected to traffic, it will be covered with stone. If it is in an area not subjected to traffic, such as on the side slope, no stone cover is necessary.

Crack or Joint Sealant

Asphalt-rubber is poured while hot into cracks or joints in pavements for the purpose of sealing them against intrusion of dirt and water. This application is similar in nature to that of other asphalt products. No stone chips are added. The high elasticity enables the material to adjust to deformations caused by load or temperature stresses.

* ACFC stands for Asphaltic Concrete Friction Course.

COMMERCIAL AVAILABILITY OF PRODUCTS CONTAINING RECOVERED MATERIALS

The current situation can be summarized by pointing out that volume use of the asphalt-rubber product has occurred in only one state--Arizona. The asphalt-rubber product is readily available from two suppliers. The recycled rubber that goes into the asphalt-rubber is obtained from out of state sources in California and Mississippi. This, too, is readily available and of satisfactory quality. A new modern facility for processing recycled rubber is under construction in Phoenix and is scheduled to go into production in early 1980. As for future availability, facilities will be forthcoming as the market develops. There is an ample supply of scrap tires. Plants for recycling the rubber are scattered throughout the country and a new plant can be put into service within 12 to 15 months of a decision to proceed. Special distributor trucks have been manufactured by Bear Cat Manufacturing Company of Wickenburg, Arizona. In addition one of the processes uses conventional distributor trucks that are available from several sources. The lack of availability of personnel experienced in the use of asphalt-rubber could be a temporary bottleneck to development. With the probability that use of the product will develop slowly over a long period of time there does not appear to be any constraint due to availability of the recovered material.

There are two companies that provide asphalt-rubber in Arizona. Both are located in Phoenix. They are Sahuaro Petroleum and Asphalt Company and Arizona Refining Company. The asphalt-rubber products that are produced by these companies are not identical. A comparison of the two materials is shown in Table III-2. Projects supplied by one supplier date back to 1962 while the other supplier has more recently entered the field (1975). The results obtained by each supplier appear to be comparable. It is difficult, however, to fully document this conclusion because of the disparity in the length of history of each.

In assessing the ability of asphalt-rubber suppliers to meet the demand, the following aspects have been studied.

1. Availability of recycled rubber.
2. Availability of the asphalt-rubber mixture (including availability of equipment).
3. Availability of experienced personnel to insure proper construction.
4. Industry demand for asphalt-rubber.

Availability of Recycled Rubber

The raw material from which recycled rubber is obtained consists of scrap tires from both automobiles and trucks. It has been determined that there are 200 million automobile tires (Reference III-4) and 40 million truck tires scrapped each year. In addition, an estimated 1-1/2 to 2 million tires are recoverable in stockpiles or landfills. Approximately 20 pounds (Reference III-5) of recycled rubber can be obtained from each passenger car tire. If it is assumed that this applies to truck tires as well as automobile tires, a total of 2,400,000 tons of recycled rubber could be produced annually.

Table III-2

COMPARISON OF ASPHALT-RUBBER PRODUCTS

<u>Supplier</u>	<u>Asphalt-Rubber Composition ^{1/}</u>			<u>Distributor Trucks</u>	<u>Mixing Process</u>	<u>Remarks</u>
	<u>Rubber</u>	<u>Asphalt</u>	<u>Other</u>			
Sahuaro Petroleum & Asphalt Company	Ambient ground 25% by weight of asphalt-rubber mix	AR-1,000 or 120-150 pen.	7% kerosene is added to control viscosity	Special-contains pugmill mixer, heater, heat controls, load cells, and automatic viscosity measurement	Performed in special distributor truck. Rubber added manually. Process is closely monitored	Mixing temp. 350-400°F. Application temperature 375-425°F.
Arizona Refining Company	40% powdered devulcanized rubber, 60% powdered vulcanized rubber with a 30% minimum natural rubber content. 20% ±2% by weight of asphalt-rubber mix.	AR-4,000 or 8,000.	2-6% aromatic extended oil (luboextract) is added if asphalt is deficient in aromatic oil.	Conventional	Bath process in any tank that provides for mixing by recirculation, stirring, air agitation, or other appropriate means & heat exchanger & temperature controls. ^{2/}	Mixing temp. 350-400°F. Application temperature 375-425°F.

^{1/} ARCO ARH-R-SHIELD process is detailed in U.S. Patent 4,068,023.

^{2/} Claimed that mixing can be done in conventional pressure distributor truck.

At an application rate of 4-1/2 pounds or 0.6 gallon per square yard for the asphalt-rubber, 8,000 pounds (4 tons) of rubber would be required per lane mile. There is, therefore, a potential for supplying sufficient rubber to place the asphalt-rubber chip seal on 600,000 lane miles of highway per year. It is difficult to obtain the number of lane miles that have already been placed. Approximately 200 lane miles have been placed in the City of Phoenix with an additional equivalent of 51 lane miles on the south runway of Sky Harbor Airport (Phoenix) (Reference III-6). Reference III-1 is based on the "Results from approximately 2,000 lane miles of construction...". The report was prepared in 1975. Since that time asphalt-rubber was placed on an estimated 200 kilometers of 2-lane low traffic roads (250 lane miles) (Reference III-7) in the Canadian province of Saskatchewan as of spring 1980. The anticipated production for 1980 was 186 kilometers or 230 lane miles. The results have been so encouraging that the use of asphalt-rubber on low cost roads in Saskatchewan is almost routine. There are approximately 6,000 miles of these roads, with ADT no greater than 800 vehicles per day, in the Province. In an article on Asphalt Rubber in the April 1979 issue of Construction West Magazine, Gary Heiman of the Saskatchewan Highway and Transportation Department is quoted as follows: "Just from rough calculations we are looking at using all the rubber we can get our hands on in Saskatchewan. Even on the pessimistic side we're looking at requiring 7,000 tons* a year." In the same publication he is also reported to have said that the future of rubberized asphalt in Saskatchewan will depend on the supply of rubber and its cost. Additional mileage of experimental sections has been placed throughout the United States in connection with the FHWA Demonstration Projects. It is believed that the total usage would be less than 10,000 lane miles. Sahuaro Petroleum and Asphalt Co. says in promotional literature "Proven on over 8,000 lane miles." Even with these rough figures, it can be seen that the potential supply of recycled rubber would far exceed the demand for its use in highways.

A crude forecast of total usage of asphalt-rubber could be based on the experience, to date, in Arizona. If the 2,000 lane miles constructed in Arizona was assumed to occur between the first full scale trial (1967) and 1975, a period of 8 years, the production rate would be 250 lane miles per year. This would use 1,000 tons of rubber annually. Assuming that this would be the average consumption in each state, a total of 50,000 tons would be involved. This would represent about 2 percent of the potentially available rubber in scrap tires. It has been reported that Sahuaro Petroleum and Asphalt Co., probably the largest producer of asphalt-rubber, produced 15,000 tons in 1979 (Reference III-4). This quantity of asphalt-rubber would utilize 3,750 tons of rubber or about 0.15 percent of the potential.

* 7,000 tons would surface approximately 875 miles of 2-lane road.

CHARACTERISTICS OF THE RUBBER USED IN ASPHALT-RUBBER MIXTURES

For the most part, the rubber used in the asphalt-rubber mixture is an ambient ground product with approximately 100 percent finer than 2 millimeters. The introduction of rubber into the asphalt is intended to improve the resulting binder in three ways:

1. Improve its response to temperature change by reducing the temperature at which it becomes "glassy" and increasing the temperature at which it softens.
2. Improve its long-term durability.
3. Improve its ability to adhere to aggregate.

There are essentially three types of rubber than can be included in the rubber component of the asphalt-rubber mixture: natural, synthetic, and devulcanized (also called "reclaim"). The natural rubber contributes a high degree of elasticity and tackiness to the rubber product; the synthetic rubber provides toughness and resilience; and the devulcanized rubber is more easily dispersed into the asphalt. The particle size of the ground rubber is important. The finer rubber has greater surface area and thus probably speeds up the asphalt-rubber reaction.

Manufacturing of ground rubber consists essentially of six steps: tire shredding; metal removal; fabric removal; grinding; sizing; and packaging. A brief description and flow chart of the new plant in Phoenix, Arizona of Genstar Conservation Systems, Inc. is contained in the Appendix. With plants such as this, a carefully controlled rubber product can be furnished to the asphalt-rubber producers.

AVAILABILITY OF THE ASPHALT-RUBBER MIXTURE (INCLUDING AVAILABILITY OF EQUIPMENT)

There are two suppliers of the asphalt-rubber mixture in Phoenix, Arizona. These companies operate not only in Arizona, but throughout the United States. One company is capable of supplying, with their present capacity, 100 tons of asphalt-rubber per day. Approximately 15.8 tons of asphalt-rubber is used per lane mile. At these rates, it would be possible to supply 6.3 lane miles per day. Since their system involves the use of conventional distributor trucks, they could provide additional capacity quickly. The heating of the asphalt and the mixing of the rubber with the hot asphalt takes place in the distributor truck. After allowing the proper time for the asphalt-rubber to take place, the material is sprayed on the roadway. It is necessary for the distributor truck to be in good operating condition.

It was not possible to obtain accurate information on the capacity of the other supplier. This company uses special distributor trucks. In early 1978 it was reported that they owned 16 of these trucks. They send their trucks all over the United States and into Canada. A route is established in the early part of the construction season that enables them to start work in the warmer locations and to proceed to the colder areas. The company maintains that they have no problem in handling the present demand. Only a few months would be required from the time an order is placed for a special distributor truck until delivery of the truck is made. This might create a temporary inability to satisfy the demand should there be a sudden and dramatic increase in this demand. The possibility of such a shortage developing does not appear to be realistic.

AVAILABILITY OF EXPERIENCED PERSONNEL TO INSURE PROPER CONSTRUCTION

Assuming that adequate specifications relating to design, materials quality control, and construction have been developed, there are two operations that require the availability of experienced personnel. They are: (1) acceptance testing of materials and the design of satisfactory mixtures in cases where materials are to be combined; and (2) the actual construction work in which the material(s) is utilized. The most often used statement by people who work with asphalt-rubber was "good results are obtained if it is used properly by people who know what they're doing." At least one person should have intimate knowledge of the laboratory procedures and one should have detailed knowledge of the construction practices in each jurisdiction in which the material is to be used. The jurisdictions would include the city, county, and state agencies that are normally responsible for conducting these activities. These individuals would then be available to train additional personnel in the techniques that are peculiar to the materials.

In addition to the requirements for trained personnel on the part of the users, it will be necessary to have their counterparts in the employ of the producers.

The Federal Highway Administration through its Demonstration Projects Program FHWA-DP-37, has initiated a technology transfer activity that will support the training of new personnel. As of September 1979, asphalt-rubber projects were constructed or planned in 23 states. It is estimated that a total of 70 individuals either experienced laboratory or construction people were introduced to the techniques of using asphalt-rubber.

INDUSTRY DEMAND FOR ASPHALT-RUBBER

It is extremely difficult to quantify the demand for asphalt-rubber in its two major uses as a chip seal and as a stress-absorbing membrane interlayer. The amount of potential demand would be related to the amount of serious deterioration in the condition of existing pavements. The evidence suggests that both of the above applications should be used

only on pavements that show excessive cracking. It is apparent that many existing roadways are approaching this condition. It can at least, then, be assumed that there will be substantial potential demand for a product such as asphalt-rubber that is effective in controlling the reflection* of these cracks.

COST OF ASPHALT-RUBBER AND COMPARISON WITH COMPETING SYSTEMS

Proponents of the SAM and SAMI approach to restoring deteriorated pavements claim that the asphalt-rubber chip seal performs a unique function, that of preventing reflection cracking. There is no other established method of doing this effectively that would enable a one to one cost comparison to be made. This limitation is further complicated by a lack of well documented data that would provide a base for life-cycle cost comparison between competing systems. It is clear that many potential users consider asphalt-rubber to be "expensive" as far as initial cost is concerned. Some of these potential users have not been convinced by the available data and evidence of precisely what the long-term economic benefit is. In the present atmosphere of belt tightening that exists in most state highway departments, first cost considerations are becoming more and more important. In summary, (1) comparing the cost of asphalt-rubber with competing systems is hazardous, (2) first cost of asphalt-rubber is high and this could serve as a deterrent to the further development of its use, (3) a reliable data base documenting long term improvement in pavement serviceability is necessary, and (4) a life cycle cost analysis is needed in order to address the question of economic benefit.

The following cost information has been developed. The cost of an asphalt-rubber chip seal where the asphalt-rubber is applied at 0.6 gallon per square yard with 40 pounds per square yard of chips is \$1.25 per square yard.** The source of this information contains the following introductory statement: "A research study has shown that an Arm-R-Shield*** surface treatment, followed by a 3/4-inch thick conventional overlay, is as effective, and sometimes more effective, as four inches of regular asphalt concrete overlay when it comes to resisting reflective cracking. So, the thinner resultant structure reduces construction costs, even though Arm-R-Shield is more expensive than regular asphalt. A subsequent cost comparison shows that the Arm-R-Shield plus the 3/4-inch overlay would cost \$2.59 per square yard which is \$3.16 per square yard less than the \$5.75 per square yard for the 4-inch overlay.

* Reflection cracks are cracks that are propagated through a layer of material that is placed on top of existing cracks.

** From a cost analysis prepared by Arizona Refining Co. entitled ARM-R-SHIELD, Cuts Resurfacing Cost in Half, Saves Energy, Consumes Old Tires. (See Appendix for the entire analysis.)

*** Arm-R-Shield is Arizona Refining Company's trade name for the asphalt-rubber mixture.

Other cost estimates obtained were: (1) the asphalt-rubber chip seal is equivalent to 1-inch of asphaltic concrete which would mean between \$1.00 and \$1.25 per square yard (Reference III-5) and (2) the asphalt-rubber is equivalent to a 1-1/4-inch asphalt overlay or \$1.50 per square yard (Reference III-8).

The City of Phoenix reported the following costs (Reference III-9):

Year	Standard Chip Seal		Asphalt-Rubber Chip Seal
	Major Streets*	Residential Streets**	
1970-71	\$0.27 per sq. yd.	0.24 per sq. yd.	0.96 per sq. yd.
1979	0.47 per sq. yd.	--	1.05 per sq. yd.
1980	0.67 per sq. yd.	--	Not Available

* 3/8 inch chips + AR8000 asphalt.

** 1/4 inch chips + AR4000 asphalt.

This cost history shows the narrowing relationship between the cost of a conventional chip seal and the asphalt-rubber chip seal between 1970 and 1979.

On the basis of eight projects bid in 1978 for the Arizona Department of Transportation, the average cost of asphalt-rubber was \$1.121 per square yard (Reference III-10). The costs ranged from a low of \$0.83 per square yard to a high of \$1.452 per square yard.

An experimental project carried out at Wrightsville, Pennsylvania consisted of a hot-mix application. This is a more recent development in the use of asphalt-rubber. Two-thousand and sixteen tons of an open graded hot mix were placed in a single layer 1-1/2 inches thick. The mix contained 6.2 percent by weight of a blend of ground rubber and AC 20 asphalt cement. The blend was 20 percent rubber and 80 percent AC 20 by weight. Equipment from Arizona Refining was dispatched to Pennsylvania on a rental basis for the project. The cost was \$52.24 per ton in-place. Because of the experimental nature of the project, the cost was higher than might normally be expected. Under ordinary circumstances the cost of the asphalt-rubber open graded mix in-place would be between \$38 and \$40 per ton. The conventional open graded mix would be \$29 to \$30 per ton. These costs per ton convert to the following cost per square yard based on a unit weight of 153 pcf and a layer 1-1/2 inches thick:

\$52.24 per ton	\$4.50 per square yard
\$38.00 per ton	\$3.27 per square yard*
\$29.00 per ton	\$2.50 per square yard

* This cost is very close to that used by the Arizona Refining Company cost analysis (see Appendix).

The cost of rubber for this project was 23.25¢ per pound plus shipping charges of \$3.50 per hundred weight for a total of 26.75¢ per pound. The rubber was supplied by the U.S. Rubber Reclaiming Company in Vicksburg, Mississippi (Reference III-11). The mileage from Vicksburg to the asphalt mixing plant in Bridgeport, Pennsylvania is approximately 1,150 miles. Estimates of the cost of rubber that were developed during the interviews varied from 10¢ per pound at the plant to 30¢ per pound delivered. The cost would vary depending on the composition of the rubber.

SPECIFICATIONS

Specifications have been developed by both producers and users of asphalt-rubber products. These include both material and construction specifications for chip seal (SAM), stress absorbing membrane interlayer (SAMI), bridge deck waterproofing membrane, joint and crack filler and open graded asphalt-rubber friction.

The materials that are covered in the specifications are:

- asphalt cement
- rubber extender oil
- ground rubber
- asphalt-rubber blend
- diluent
- cover aggregate
- blotter material

The following examples of specifications are included in the Appendix:

1. SPECIFICATION FOR ARM-R-SHIELDTM, Arizona Refining Company Specification M 101-80, dated 2/80.
2. CONSTRUCTION SPECIFICATION FOR ARM-R-SHIELDTM STRESS ABSORBING MEMBRANE INTERLAYER, Arizona Refining Company Specification C 202-80, dated 2/80.
3. CONSTRUCTION SPECIFICATION FOR ARM-R-SHIELDTM SURFACE TREATMENT, Arizona Refining Company Specification C 201-80, dated 2/80.
4. GUIDE SPECIFICATIONS FOR ASPHALT RUBBER FOR STRESS ABSORBING TREATMENTS (SAM or SAMI), Sahuaro Petroleum and Asphalt Co., dated November 1979.
5. STRESS-ABSORBING MEMBRANE (INTERLAYER) and STRESS-ABSORBING MEMBRANE (SEAL), Arizona Department of Transportation, dated 8/22/79 and 8/23/79.

6. SPECIFICATION FOR ARM-R-SHIELD-CF, Arizona Refining Company Specifications, dated 1/80.
7. OPEN GRADED RUBBERIZED ASPHALT FRICTION COURSE, SRL-H (Reclaimed), Pennsylvania Department of Transportation, for experimental project in 1979.

These specifications are, for the most part, typically definite in their requirements. Many of them, however, contain statements that reflect the lack of precise methods for controlling the properties of the asphalt-rubber blend. The following examples are provided to illustrate these uncertainties:

- Under a section of ASPHALT-RUBBER MATERIAL MIXING one specification says: "The materials* shall be carefully combined and mixed and reacted for a period of time as required by the engineer which shall be based on laboratory testing by the asphalt-rubber supplier or contracting agency."**
- The same specification also allows for adding a diluent not to exceed 7-1/2 percent by volume of the hot asphalt-rubber mixture in order to adjust the viscosity for "spraying and/or better "wetting" of the cover material."
- One specification calls for mixing the asphalt and rubber "as rapidly as possible for such a time and at such a temperature that the consistency of the mix approaches a semi-fluid material."
- Another specification says with regard to the asphalt cement: "It shall be fully compatible with the ground rubber to be used...". There is no further explanation of what "fully compatible" means.

There are various other statements that indicate that the determination of a suitable asphalt-rubber mix is still an art that must be practised by an experienced expert rather than an science that can be applied by a qualified practitioner.

* Writer's note--refers to the asphalt and the rubber.

** Three experts in laboratory evaluations of this material indicate that the time-temperature relationship for the reaction between asphalt and rubber and its correlation with field performance of the material are still in need of additional study.

RESEARCH NEEDS - ASPHALT-RUBBER

It is clear that there are serious gaps in the information that is available in evaluating asphalt-rubber mixtures for construction conditions (sprayability) and service conditions (durability). As a result, there is a lack of standard tests that are available to measure appropriate properties and specifications are vague on requirements of the asphalt-rubber mixture.

Dr. Gerald D. Love, of FHWA, in a talk presented at the Asphalt-Rubber Users-Producers Conference, Scottsdale, Arizona, May 1980, gave the following estimate of research needs.

<u>Research Topic</u>	<u>Estimated Required Funding-Dollars</u>	<u>Time Estimated Required - Years</u>
Energy requirements for asphalt rubber and alternatives	100,000	-
Develop end product specifications	1,000,000	2 to 3
Develop design procedures for crack control	1,000,000	2 to 3

The following additional information was suggested by Dr. John Epps of Texas A&M University at the Scottsdale Conference.

<u>Topic</u>	<u>Estimated Required Funding-Dollars</u>
Optimum Use Conditions	200,000
Summary of Existing Performance	150,000
Standard Performance Information and Data Base	400,000

An expanded list of research topics would include the following:

1. The nature of the physical-chemical reaction between rubber and asphalt.
2. Development of appropriate tests and laboratory equipment for evaluating application and service related properties.
3. Determination of the temperature susceptibility of various asphalt-rubber mixtures.
4. Determination of the interaction of A-R with aggregate.

5. Evaluate durability and other field performance parameters.
6. Develop design procedures for crack control.
7. Develop better specifications—probably of the performance type.
8. Establish energy requirements and costs--particularly life cycle costs.

The working group on construction and maintenance at the Scottsdale Conference emphasized the following "problems:"

- Lack of knowledge on the part of the designers, supervisory engineers, and construction personnel (control people). There is a need for additional training probably through a coordinated technology transfer program.
- Lack of coordination of control on the ADOT projects. There must be an established quality control procedure about which the necessary people are informed.
- There is a need to consolidate the available information.

Most of these "problems" seem to be in the technology transfer category.

CORPS OF ENGINEERS EXPERIENCE WITH A-R

The Corps of Engineers is evaluating asphalt-rubber installations at several locations. The data shown in Table III-3 presents preliminary information on the extent of reflection cracks in test sections designed to evaluate the crack control provided by various systems. The asphalt-rubber sections are those shown as Sections 1 to 4 inclusive at Fort Stewart, Georgia, and Sections 1, 6, 7, 11, 15, 16, 18, and 19 at Fort Devens, Maine. The following test sections are at the Fort Stewart location:

Asphalt-rubber - tack coat,* SAMI, 1-1/2 inch overlay.
Fabric - emulsion (CRS2), fabric, 1-1/2 inch overlay.
Control - .35 gallon/square yard asphalt cement, 50 to 60 pounds/square yard of stone chips, 1-1/2 inch overlay.

* On Sahuarro sections only—at the rate of 0.05 gallon per square yard.

TABLE III-3

Summary of Performance of Field Test Sections - Corps of Engineers
Waterways Experimental Station

Section No.	Material	Lineal Feet of Reflected Cracks, %		
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Ft. Stewart, GA - Sections Placed in October 1977

<u>Airfield</u>		<u>May 1978</u>	<u>Aug 1979</u>	<u>Apr 1980</u>
1	Sahuaro	0	0	0
2	Sahuaro	0	0	0
3	U. S. Rubber	0	0	13.6
4	U. S. Rubber	0	16.4	17.9
5	Monsanto-Bidim	0	5.0	31.3
6	Monsanto-Bidim	0	26.5	35.8
7	Celanese-Mirafi	29.7	37.0	48.6
8	Celanese-Mirafi	8.3	19.9	33.6
9	Control (Keystone)	0	0	0
10	Control (Keystone)	0	0	0

Ft. Devens, MA - Sections Placed in October 1977

<u>Airfield</u>		<u>Jun 1978</u>	<u>Aug 1979</u>	<u>Jun 1980</u>
1	U. S. Rubber	0	34.4	
2	Control	0	49.9	
3	Monsanto-Bidim	0	54.5	
4	Celanese-Mirafi	0	33.8	
5	Control	0	70.7	
6	Sahuaro	0	27.5	
7	Sahuaro	0	25.5	
8	Control	0	66.7	
9	Monsanto-Bidim	0	29.5	
10	Celanese-Mirafi	0	65.6	
11	U. S. Rubber	0	58.3	
12	Control	0	26.3	
13	Monsanto-Bidim	0	61.4	
14	Celanese-Mirafi	0	32.8	
15	Sahuaro	0	37.3	
16	U. S. Rubber	0	20.2	
17	Control	0	37.0	

Roadway

18	Sahuaro	0	0
19	U. S. Rubber	0	9.8
20	Celanese-Mirafi	0	12.2
21	Monsanto-Bidim	0	16.3
22	Control	0	0

Source: Reference III-12.

The fabrics used were the following:

- Bidim, a polyester fabric manufactured by Monsanto Textiles Company--\$0.75 per square yard.*
- Mirafi, polypropylene and nylon manufactured by Celanese Fibers Marketing Company--\$0.75 per square yard.**

These materials were placed on an airfield parking apron that had a 10-inch soil cement base and 1-1/2-inch bituminous concrete surface. Another competing fabric is Petromat, a polypropylene fabric manufactured by Phillips Fibers Company (\$0.55 per square yard).*

At Fort Devens, the sections are the following:

Asphalt-rubber--same as Fort Stewart but with a 2-inch overlay

Fabric--AC10, fabric, 2-inch overlay

Control--2-inch overlay only.

The experimental sections at Fort Devens were placed on top of three different types of paving: an airfield runway; an airfield parking apron; and a roadway. The bases for each were as follows:

Airfield runway--6-inch soil cement base, 2-inch bituminous concrete surface

Airfield parking apron--6-inch soil cement base, two bituminous concrete surfaces each 1-1/2-inch thick

Roadway--5 to 7-inch aggregate bituminous base, 1-1/2-inch bituminous concrete surface.

The results of these sections are inconclusive and it is felt that there has been an insufficient lapse of time for reflective cracking to occur.

Additional roadway test sections have been constructed at three other Army installations: Ft. Lewis, Washington; Ft. Carson, Colorado; and Ft. Polk, Louisiana. In these tests, a SAMI has been placed under a thin (1-1/2-inch) overlay. At Ft. Polk, Louisiana the existing pavement is a 6-inch portland cement concrete slab with a 2-inch bituminous concrete overlay. At the other two locations, the existing base is crushed stone or gravel with a 1-1/2-inch bituminous surface. Evaluation of these sections is continuing; the results, as yet, are not conclusive, and a final report will be issued when sufficient time has elapsed.

* Cost of fabric only.

The Corps of Engineers seems to have the present position that the use of asphalt-rubber is still in the experimental stage and its long-term benefit has not as yet been proven. They have a funding at the Waterways Experiment Station for a laboratory program to develop test methods and specifications. This seems to indicate a feeling that the concept shows promise. They have a real need for a material that will control cracking. Maintenance of roads and streets at Army installations is a big problem since most of them have far exceeded their economic life. The Air Force is also investigating the use of asphalt-rubber.

SUMMARY ASSESSMENT

1. Proponents of the use of asphalt-rubber, and these include users as well as producers, are convinced that the material is unique in controlling cracking when used on top of a cracked pavement and then covered with a thin overlay. The State of Arizona requires its use in this situation when the overlay is less than four inches in thickness. The material should be thought of as a unique product having desirable properties rather than as a disposal mode for scrap tires.
2. Opponents object to the first coat of the material and maintain that it is difficult to achieve consistently successful applications. Advocates contend that the first coat is amply offset by a reduction of maintenance requirements and that the material can be placed properly when done by experienced people.
3. There are enough miles of asphalt-rubber membranes in service for enough years to prove that the material has been successfully used.
4. An analysis of life cycle costing is necessary in order to determine whether or not an economic benefit results.
5. The use of an asphalt-rubber chip seal has been used with apparent success as a surface treatment on severely cracked pavements where the only other available option seemed to be reconstruction. It should not, however, be used on high speed roads or under other circumstances where loose chips would create a hazard.
6. There is need for additional research into the nature of the asphalt-rubber reaction and the manner in which it is affected by asphalt type, composition of the rubber, and reaction time and temperature.
7. One of the goals of asphalt-rubber research should be to develop laboratory and field tests that will insure consistent success in construction and that will correlate with field performance of the installations.
8. There are ample supplies of scrap rubber and facilities for producing the asphalt-rubber mixture in order to cope with the present demand for the product.

9. It is apparent that demand for the material will increase slowly and that the industry will be capable of responding to the demand and will respond as the market develops.

10. The availability of experienced technical and construction people is essential to successful application. Disastrous results have occurred where the material has been used by people who were not aware of the difficulties. These unhappy results have caused some highway people to "sour" on the material, an attitude that may continue for years.

11. There are competent organizations and people involved in all phases of asphalt-rubber development. They are unanimous in their feeling that use of the material should be developed carefully with full knowledge of its capabilities and its pitfalls. They are fearful that extravagant claims of success and a "snake oil" approach will lead to failures that can retard development indefinitely.

12. Considerable interest is developing in pavement recycling. The material and energy savings inherent in this process make it attractive. This system will compete in those situations where asphalt-rubber would be feasible.

13. The current lack of highway funds acts against the use of asphalt-rubber because of its high first coat and the pressure that is brought to bear on highway administrators to "do something about our roads."

14. Exact estimates of the potential use of asphalt-rubber are difficult but it is believed that if used for all situations where it is applicable there would be a significant reduction in the number of scrap tires that would need to be disposed of.

ASPHALT-RUBBER AS A CRACK AND JOINT FILLER

Asphalt-rubber may be applied as a filler for longitudinal joints between the concrete riding surface and asphalt shoulder, for longitudinal and transverse joints on concrete surfaces, for reflection, alligator and other cracks, and for potholes and spalling.

Some state highway departments use rubber-asphalt as the sole crack and joint filler material and are very satisfied with the results (Reference III-17). Other highway officials prefer to use asphalt-rubber for joints and cracks in portland cement concrete while applying bituminous filler for asphalt surfaces. There are also highway maintenance operations which do not use any asphalt-rubber crack filler. Asphalt-rubber has been used to varying extents in 49 states, including Canada and Puerto Rico (Reference III-18).

Filler Materials

There are many products on the market today which are used as crack and joint fillers. These products vary in cost and effectiveness. Some of the notable products include: hot and cold asphalt cement compounds, neoprene strips, cold sand emulsions, asphalt with limestone dust, powder or latex, polyvinyl chloride, polysulfite, urethane, low modulus silicon, epoxy, powdered devulcanized rubber-asphalt mix, vulcanized asphalt-rubber mixes, roofing tar and felt and other rubberized products. This section will focus on the asphalt-rubber fillers.

Source. There are several manufacturers and distributors of prepared rubber and asphalt-rubber crack sealing products throughout the U.S. Not representing a complete listing, there are known sources in Arizona, Pennsylvania, and Mississippi which illustrates a wide geographical distribution (Reference III-19).

Preparation. One of the more common rubber-asphalt filler materials is similar to the rubberized stress absorbing membrane in composition. According to specifications, the granulated crumb rubber (100 percent vulcanized) should meet the following requirements:

<u>Passing Sieve</u>	<u>Percent</u>
No. 8	100
No. 10	98-100
No. 40	0-10

The specific gravity of the rubber should be 1.15 ± 0.02 and should be free of fabric, wire or other contaminating materials, except that up to 4 percent calcium carbonate may be included to prevent particles from sticking together. The proportions by weight of the asphalt-rubber mixture shall be 75 percent \pm 2 percent asphalt and 25 percent \pm 2 percent rubber (Reference III-20).

The secret to a successful seal is proper crack or joint preparation. This holds for rubberized and non-rubberized fillers. Smaller cracks must be routed to a minimum width and depth to allow the asphalt-rubber to flow into the crack. For larger cracks or joints, routing is not necessary to remove all dirt or dust and non-compressible particles. With warmer weather and surface expansion, non-compressible particles will cause spalling and cracking of the edges.

The asphalt-rubber is applied hot and may require special equipment for heating and placement. A typical procedure is to heat the material to 375 to 400°F for 25 to 30 minutes before placement (Reference III-21). Pumps may be necessary to place the thick filler material. The asphalt-rubber may require more care than traditional crack sealers. If the mix is overheated, it may not go into dissolution and if underheated it won't properly form or pour (Reference III-21). The additional cost and labor must be compared with the benefits of asphalt-rubber fillers.

Properties. The asphalt-rubber filler material combines the sealing quality of asphalt with the expansion and contraction properties of rubber. Asphalt-rubber has shown higher bonding strength than traditional asphalt fillers. It is also functional over a wider temperature range and does not embrittle as easily. Asphalt-rubber has demonstrated a notably longer life although exact figures are difficult to obtain at present due to insufficient and uncompleted studies. One manufacturer states that given proper application, the asphalt-rubber should last from seven to ten years (Reference III-18).

Asphalt-rubber may be more suitable for portland cement concrete joints where bituminous products often flow out of the joints in warmer weather. It is sometimes difficult for the asphalt-rubber to flow into smaller cracks in bituminous surfaces if not properly prepared.

The ductile, adhesive and durable properties of asphalt-rubber filler have been very successful on many projects.

Potential Quantity Consumption

Asphalt-rubber has been used to varying extents in 49 states including Canada and Puerto Rico (Reference III-18). In some states, it is used as the sole crack filler material (Reference III-17). A conservative estimate of potential consumption based on present consumption of several states (Reference III-22) and one asphalt-rubber supplier's projections (Reference III-23) would be a consumption of roughly one million pounds per state per year. If the asphalt-rubber composition included 25 percent rubber, this would represent a rubber consumption of 250,000 pounds of rubber per state per year. This would imply a national consumption of rubber in crack and joint fillers of 12.5 million pounds per year, as compared to 6,018 million pounds of waste rubber tires discarded during the year 1968.

Although asphalt-rubber as a crack filler has been proven cost effective for many applications, there are still many competing products on the market. It is unlikely that the rubber consumption of 12.5 million pounds per year will be realized in the near future.

Economic Evaluation

Asphalt-rubber crack and joint filler has been found to be cost effective in many applications. The initial cost is usually higher for the asphalt-rubber as compared to common bituminous fillers. This is due to the cost of rubber preparation, crack preparation, and special equipment required to place the thicker material. The additional cost is offset by greater serviceability and life of seal.

Life expectancy information is sketchy and incomplete. Observations up to the present have shown asphalt-rubber to be serviceable for up to 10 years and more. Few suppliers give guarantees with asphalt-rubber crack filler products. The life expectancy of asphalt-rubber crack filler

given proper application is seven to ten years (Reference III-18). With improper preparation or placement, the material may only last two to three years (Reference III-19). In almost all cases, the rubber-asphalt has outperformed conventional bituminous fillers. There are other exotic crack filler products which may out-perform asphalt-rubber but these would incur additional cost.

The cost of purchasing asphalt-rubber crack and joint filler material is approximately \$0.30 per pound or \$2.50 per gallon (Reference III-23). The total in-place cost including materials, labor, equipment, traffic control, etc., will depend on many factors including road surface, type of crack or joint, degree of deterioration, weather and climate. A rough estimate for total in-place costs would be about \$0.45 per linear foot (Reference III-24). The amount of coverage in terms of linear feet of crack would obviously vary depending primarily on the size of crack. Estimates that were obtained varied from 16 (Reference III-23) to 50 (Reference III-19) linear feet of crack per gallon of asphalt-rubber. This factor alone would cause a variation of approximately \$0.10 per linear foot in the in-place cost.

There are alternative non-rubberized products which perform various functions with various costs. These range from non-sealing filler materials such as asphalt cement products to sophisticated epoxy, polysulfite, polyvinyl chloride and silicate sealers. The following estimated costs are provided for a cost comparison of the various materials.

<u>Material</u>	<u>Approximate In-Place Cost (Reference III-24)</u> <u>(\$ per Linear Foot)</u>
Liquid Asphalt	0.15
Asphalt-Rubber	0.45
Silicon	1.00
Neoprene	1.30
PVC	3.00

Advantages and Disadvantages

In order to evaluate the potential or feasibility of using asphalt-rubber as a crack and joint filler, it is often helpful to review the advantages and disadvantages as related to an individual project or area. Following is a general list of these advantages and disadvantages:

(Note: Some of the advantages and disadvantages are in comparison to standard asphalt cement crack filler mixtures.)

Advantages

- Functions as crack sealant rather than just as a filler (Reference III-27).
- Cost effective (Reference III-17).
- Longer life.
- High bond strength.
- More ductile (stretches further) (Reference III-23).

- Expands and contracts within wide temperature range.
- Outperforms bituminous sealers (especially on concrete pavement).
- Stays in joints better.
- No tracking problem (with overfilling joint) (Reference III-20).
- Costs less than more exotic sealants.
- Does not embrittle (Reference III-26).
- Maintains integrity of crack.

Disadvantages

- Costs more than asphalt cement fillers.
- More difficult to place.
- Have to apply hot.
- Thicker material (flows slower).
- Requires pump for placement.
- Doesn't penetrate as well.
- Longer to heat.
- Requires special equipment.
- Not as suitable for all surfaces and types of cracks.
(More effective on concrete than on bituminous surfaces.)

CONCLUSIONS

There are various asphalt-rubber crack and joint filler products. These different products are suited to different surfaces, climates, etc. There are also many non-rubberized products. In many cases, the non-rubberized crack filler materials can be replaced by asphalt-rubber products with cost-effective results.

The largest potential of asphalt-rubber sealants for joints in concrete pavements, longitudinal joints between concrete pavements and asphalt shoulders, and fatigue cracks in asphalt pavements (Reference III-29). Asphalt mixtures may better seal small bituminous cracks because they flow more easily, but they are very poor as concrete joint fillers because they often flow out or are squeezed out with expansion of slabs.

The main problems with asphalt-rubber crack filler are the difficulty in placing and additional costs. The main benefits are the longer life and performance ability over ordinary bituminous fillers.

A rough estimate is that asphalt-rubber as a crack and joint filler may consume up to 12.5 million pounds of rubber per year. This figure is unlikely to be realized because of competing products.

In terms of solving the rubber tire solid waste problem of over 2 million tons per year, crack fillers will likely not result in use of 2,000 tons of tires per year, or less than one-tenth of one percent.

Part III

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- III-27 Asphalts, Aggregates, Mixes and Stress-Absorbing Membranes, Morris and McDonald, Transportation Research Record, 595, 1976.
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Part IV

USE OF INCINERATOR RESIDUE IN HIGHWAY CONSTRUCTION

INTRODUCTION

The term "incinerate" is defined as, to burn or reduce to ashes (Reference IV-1). The incineration process, however, is commonly viewed as a tool merely to reduce the volume and weight of heavy, wet, bulky refuse.

In this country, most refuse is disposed of directly into landfill sites. This direct disposal accounts for over 90 percent of the net municipal solid wastes generated annually (Reference IV-2).

In some parts of the country, a shortage of available landfill sites exists. Present incineration methods can reduce the volume of incoming refuse by as much as 85 percent to 95 percent (Reference IV-3). This is advantageous because massive hauling and landfilling efforts can be substantially reduced. In addition, limited landfill areas can be preserved.

With the recent concern for the conservation of materials and energy, residue disposal from incineration plants has attracted attention. Application of this residue material in some form of highway construction is currently being investigated. The following addresses the present status of incinerator residue as a highway construction material.

BACKGROUND

Construction of incinerators in this country began around the late nineteenth century (Reference IV-4). Following World War II, there was a significant increase in the number of incinerators constructed. Most of the incinerators built at that time were of a small capacity (i.e., 100 to 200 tons per day units).

Over the last two decades, many incinerators have been closed due to operation and maintenance costs (including large investments required for air pollution controls). This has come about by more stringent government control of the effects of the incineration process (i.e., air quality and disposal methods). The escalating costs of the required pollution control equipment in most cases, do not warrant the upgrading of smaller capacity plants.

Incinerators being constructed today can handle volumes of refuse in the 1,000 to 1,500 tons per day range. Economy of scale is predicted for the larger plants. In the newer, larger volume plants, energy recovery and selective materials recovery are of significant consideration.

QUANTITIES OF MATERIALS

It is estimated that the net municipal solid waste disposed of annually in the United States, approximates 150 million tons (Reference IV-2). This appears to be a small percentage of the 3.5 billion tons of total solid waste generated each year (Reference IV-4). Total solid wastes generated include agricultural, animal, mineral, industrial, commercial, and household wastes. Of the net municipal solid waste disposed of annually, less than 10 million tons are processed by incineration. From the less than 10 million tons incinerated annually, there is a production of approximately 2 million tons of incinerator residue.

On the following page is a map (Figure IV-1) of the United States which shows the location of the currently operating municipal incinerator plants.

Table IV-1 is a listing of the currently operating municipal incinerators in the United States. The list does not include existing operational resource recovery facilities.

The list was compiled using various sources of information. Among these sources were: a list published in Federal Highway Administration Report RD79-B8, prepared by the Jaca Corporation of Fort Washington, Pennsylvania; a June 1980 computer printout from the United States Environmental Protection Agency's Compliance Data System (CDS); and written and verbal communication with numerous state and municipality solid waste management agencies and divisions.

It should be mentioned at this time that in addition to municipally operated incinerators, residues are also produced by privately owned incineration facilities. The determination of the quantities of residue produced by these private facilities is impractical due to the sheer total number of facilities. Preparing a list of privately owned incineration facilities which produce residue that could be used in construction applications, would involve individual screening of the thousands of incinerator emission sources compiled by the Environmental Protection Agency. In addition to the sheer number of facilities, the residue output from each facility would have to be categorized, as each private incinerator burns a widely variable refuse which results in an individual characteristic residue.

A program such as this, which would include the listing of private incineration facilities, is beyond the scope of this report.

In Table IV-1, a predicted yearly residue output volume for the municipally operated plants is listed. This volume is approximated using a procedure developed by Messrs. Pindzola and Collins published in a Federal Highway Administration Report FHWA-RD-75-81.

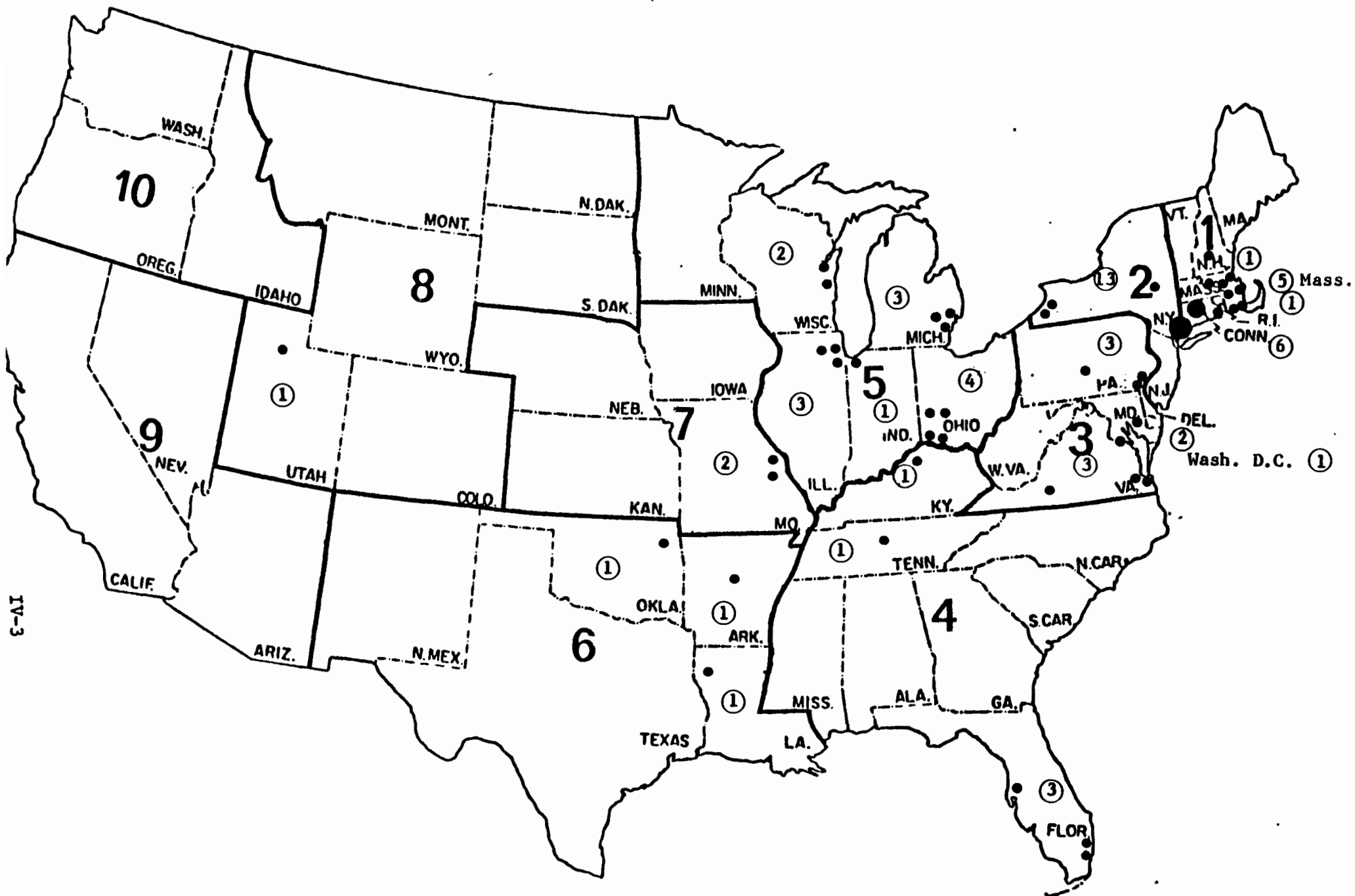


Figure IV-1. Location of Currently Operating Municipal Incinerator Plants.
(Encircled is the number of operating plants)

Table IV-1

List of Currently Operating Municipal Incinerator Plants - 1980

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Furnace Type & Grate</u>	<u>Predicted Residue Quality</u>
<u>ARKANSAS</u>						
1.	No. Little Rock	1966	100	8,800	Batch/Traveling	3
<u>CONNECTICUT</u>						
2.	Ansonia	1968	200	17,500	Cont./Traveling	3
3.	East Hartford	1956	350	35,000	Batch/Rocking	4
4.	Hartford	1954	600	60,000	Batch/Mech.	4
5.	New Canaan	1956	125	12,500	Batch/Mech.	4
6.	New Haven	1963	720	31,500	Cont./Traveling	3
7.	Waterbury	1952	300	30,000	Batch	4
<u>FLORIDA</u>						
8.	Miami (NE)	1975	300	26,300	Cont.	3
9.	Orlando		100	10,000	N.A.	4
10.	Pahokee		50	5,000	N.A.	4
<u>HAWAII</u>						
11.	Honolulu (Waipahu)	1969	600	52,500	Cont.	3

Table IV-1

List of Currently Operating Municipal Incinerator Plants (Continued)

IV-5

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Type & Grate</u>	<u>Predicted Residue Quality</u>
<u>ILLINOIS</u>						
12.	Chicago (Calumet)	1959	1200	105,000	Cont./Rocking	3
13.	Chicago (NW)	1970	1600	120,000	Cont./Recip.	2
14.	Chicago (SW)	1963	700	52,300	Cont./Rot. Kiln	1
<u>INDIANA</u>						
15.	East Chicago	1970	200	17,500	Cont.	3
<u>KENTUCKY</u>						
16.	Louisville	1957	1000	75,000	Cont./Rot. Kiln	1
<u>LOUISIANA</u>						
17.	Shreveport	1960	200	15,000	Cont./Rocking	2
<u>MARYLAND</u>						
18.	Baltimore #4	1956	800	80,000	Batch/Rocking	4
19.	Baltimore - Pyrolysis	1963	1000	36,000	Cont./Rot. Kiln	1
<u>MASSACHUSETTS</u>						
20.	Braintree	1971	240	18,000	Cont./Recip.	2
21.	East Bridgewater	1973	800	60,000	Cont./Recip.	2

Table IV-1

List of Currently Operating Municipal Incinerator Plants (Continued)

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Type & Grate</u>	<u>Predicted Residue Quality</u>
<u>MASSACHUSETTS (Cont.)</u>						
22.	Fall River	1973	600	45,000	Cont./Recip.	2
23.	Framingham	1973	500	37,500	Cont./Recip.	2
24.*	Saugus (Resco) ¹	1975	1500	112,500	Cont./Recip.	2
<u>MICHIGAN</u>						
25.	Central Wayne County	1964	800	60,000	Cont./Recip.	2
26.	Clinton-Grosse Pointe	1972	600	45,000	Cont. Rot. Kiln	1
27.	S.W. Oakland Co.	1953	600	60,000	Batch/Mech.	4
<u>MISSOURI</u>						
28.	St. Louis (North)	1956	400	40,000	Batch/Rocking	4
29.	St. Louis (South)	1951	400	40,000	Batch/Rocking	4
<u>NEW HAMPSHIRE</u>						
30.	Dunham	1970	50	5,000	Batch	4
<u>NEW YORK</u>						
31.	Canajoharie	1964	50	5,000	Batch/Mech.	4
32.	Hempstead (Oceanside)	1965	750	56,300	Cont./Rocking	2

Table IV-1

List of Currently Operating Municipal Incinerator Plants (Continued)

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Type & Grate</u>	<u>Predicted Residue Quality</u>
<u>NEW YORK (Continued)</u>						
33.	Hempstead (Merrick)	1952	600	60,000	Batch/Mech.	4
34.	Huntington	1966	300	22,500	Cont./Rocking	2
35.	Lackawanna	1949	150	15,000	Batch/Manual	4
36.	NYC (Betts Ave.)	1959	1000	87,500	Cont./Trav.	3
37.	NYC (Greenpoint)	1959	1000	87,500	Cont./Trav.	3
38.	NYC (Hamilton)	1961	1000	87,500	Cont./Trav.	3
39.	NYC (South Shore)	1954	1000	87,500	Cont./Trav.	3
40.	N. Hempstead	1966	600	45,000	Cont./Rocking	2
41.	Old Bethpage	1967	400	30,000	Cont./Recip.	2
42.	Old Bethpage	1962	500	37,500	Cont./Recip.	2
43.	Tonawanda	1933	300	22,500	Cont./Recip.	2
<u>OHIO</u>						
44.	Dayton (N. Montgomery County)	1940	600	52,500		3
45.	Dayton (S. Montgomery County)	1970	600	52,500	Cont./Traveling	3
46.	Franklin ²	1969	150	13,100	Fluidized Bed	3

Table IV-1

List of Currently Operating Municipal Incinerator Plants (Continued)

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Type & Grate</u>	<u>Predicted Residue Quality</u>
<u>OHIO (Continued)</u>						
47.	Miami County	1968	150	13,100	Cont./Pusher	3
<u>OKLAHOMA</u>						
48.	Tahlequah		50	5,000	Batch	4
<u>PENNSYLVANIA</u>						
49.	Harrisburg ³	1973	720	54,000	Cont./Recip.	2
50.	Philadelphia (E. Central)	1966	750	65,600	Cont./Trav.	3
51.	Philadelphia (NW)	1960	750	65,600	Cont./Trav.	3
<u>RHODE ISLAND</u>						
52.	Pawtucket	1964	200	17,500	Cont./Trav.	3
<u>TENNESSEE</u>						
53.	Nashville ⁴	1974	720	63,000	Cont./Traveling	3
<u>UTAH</u>						
54.	Ordan	1966	450	39,400	Cont./Traveling	3
<u>VIRGINIA</u>						
55.	Newport News	1968	400	35,000	Cont./Traveling	3

Table IV-1

List of Currently Operating Municipal Incinerator Plants (Continued)

<u>Plant No.</u>	<u>Plant Location</u>	<u>Year Built</u>	<u>Refuse Capacity (Tons Per 24-Hr. Day)</u>	<u>Residue Output (Tons Per Year)</u>	<u>Type & Grate</u>	<u>Predicted Residue Quality</u>
56.	<u>VIRGINIA (Continued)</u>					
56.	Portsmouth	1963	350	35,000	Batch/Rocking	4
57.	Salem	1977	90	7,900	Cont./Pusher	3
	<u>WASHINGTON, D.C.</u>					
58.	Solid Waste Reduction Center #1		1500	112,500	Cont./Rocking	2
	<u>WISCONSIN</u>					
59.	Sheboygan	1965	240	18,000	Cont./Rocking	2
60.	Waukesha		200	<u>15,000</u>	Cont./Rocking	2
				2,621,400		

¹Steam generation facility combined with resource recovery operation.

²Operated as a resource recovery facility.

³Designed and operating as a steam producing facility.

⁴Operated as an energy recovery plant.

NOTE: 1 short ton = .9072 tonne.

N.A. denotes information not available.

The predicted residue output of each plant may be calculated by multiplying plant design capacity times the number of operating days per year* times the weight fraction of the refuse remaining after incineration.

From these computations, it is predicted that approximately 2.6 million tons of residue are produced annually from the currently operating municipal incinerators as listed in Table IV-1.

It is noted, however, that in publication FHWA-RD-79-83 prepared by the Jaca Corporation of Fort Washington, Pennsylvania, it is stated that, "the use of the prediction procedure on a national basis is likely to overstate the amount of residue available for use as highway material."**

Using the 2.5 million tons of municipal incinerator residue which may be produced annually as an upper limit, and applying a factor of .55; this yields an amount of approximately 1.4 million tons of municipal incinerator residue which may be produced annually. This 1.4 million ton number is a reasonable estimate of the lower limit of annual municipal incinerator residue production.

Assuming a number somewhere in the middle of this range (2.5 to 1.4) would be the most accurate approximation to the actual, annual production. It is, therefore, reasonable to state that the current annual production of municipal incinerator residue in the United States is approximately 2 million tons.

As a basis for judging the quantities of materials involved, the United States total annual production of aggregate for the year 1979, which was used for highway construction, was 1,074 million tons (Reference IV-5). The amount of municipal incinerator residue which may be produced annually represents only approximately 0.2 percent of this total annual production of aggregate. The United States total annual production of hot mix asphalt paving for the year 1978, was 376 million tons (Reference IV-6). The amount of municipal incinerator residue which may be produced annually represents only approximately 0.5 percent of this total annual production of hot mix asphalt. As indicated by the annual quantities of aggregate used in the United States, if all the municipal incinerator residue which may be produced was used in construction applications, only a minute portion of the national aggregate market would be affected.

* Operating schedule of 120 hours per week was used unless reported otherwise. A 50-week operating period per year was used for all plants.

** This statement was based on an in-depth investigation of 10 municipal incinerators operating during 1979. A ratio of residue quantity actually produced to residue quantity predicted for the ten incinerators (employing the Pindzola and Collins technique) was reported as approximately .55.

DESCRIPTION OF MATERIAL

All incinerators do not handle and process refuse in the same manner. The basic differences in refuse processing within the incinerator plants occur with the feeding and supply of refuse to the furnace, and the type of furnace itself.

The four types of furnaces used for municipal solid waste refuse are: the vertical circular furnace; the rectangular furnace; the multi-celled rectangular furnace; and the rotary kiln furnace (Reference IV-3). These furnaces may be considered as either being batch fed or continuous fed.

A grating system transports the refuse and residue through the furnace. The types of grates currently used in refuse processing may be described as traveling, reciprocating, rocking, rotary kiln, circular, vibrating, oscillating, and reverse reciprocating (Reference IV-7).

In combustion, the important variables which affect the quality of the residue produced (well burned as opposed to poorly burned) are time of combustion, temperature of combustion, and the turbulence during combustion. It is noted that the different types of grates are somewhat correlated to the quality of the residue produced. As an example, with the use of a rocking grate as opposed to a traveling grate, better burnout may be achieved due to the better agitation action of the refuse on the rocking grate.

A special type of incineration process, known as pyrolysis, should be mentioned along with the aforementioned incinerator types. Pyrolysis involves the combustion of refuse in an oxygen controlled chamber. This results in the oxidation and thermal decomposition of combustibles (Reference IV-3).

Variations in the composition of incoming refuse for incineration occur often. This is due to variations in seasonal quantities such as food wastes and yard wastes. Even with the variation of the incoming refuse, residue compositions tend to be reasonably uniform. Below is the estimated national average composition of municipal refuse (Reference IV-8):

<u>Component</u>	<u>Percent by Weight</u>
Paper	51.6
Food Wastes	19.3
Metals	10.2
Glass	9.9
Wood	3.0
Textiles	2.7
Leather and rubber	1.9
Plastics	1.4
	<u>100.0</u>

NOTE: These composition figures have been developed on a "yard waste" free and "miscellaneous" free basis. "Yard waste" includes leaves, grass, branches, etc. "Miscellaneous" includes bricks, rocks, and dirt. These two fractions are highly variable and can constitute up to one-third of the refuse at certain times.

It is noted, however, that the principal objective of municipal incineration is the reduction of the volume of the refuse. Normally, no attempt is made to control the quality of the residue. Thus, some fluctuations in the composition of the residue will occur even under well maintained incinerator operating conditions.

The quality of incinerator residue may best be described in terms of the burn-out achieved. The burnable fraction of the incoming refuse represents 75 percent of the refuse weight.

A classification system for the residue was developed identifying six basic categories of residue according to degree of burnout (Reference IV-3). These classes are: ultra-well burned out residue; well-burned out residues, intermediately burned out residues; poorly burned out residues; residues with especially low metal content, and pyrolysis residues. In general, these six categories may be related to basic plant design. Well burned residues are usually produced from refuse that is transported by agitating type grates (i.e., rocking, reciprocating). Intermediately burned residues are usually produced on well operated traveling grates. Poorly operated traveling grates and batch fed furnaces will usually produce a poorly burned residue.

It is noted that lower percentages of combustible material are found in well burned residues, and that very low percentages of combustible materials are found in pyrolysis residues. High percentages of glass are also found in pyrolysis residues.

Table IV-2 is a breakdown of the quantities of incinerator residue produced according to type and state. The number of operating plants in each state is also listed. Table IV-3 is strictly a tabulation of quantities of types of residue produced, and number of plants producing the residue.

Generally, incinerator residue is primarily composed of glass, metals, minerals, ash, and unburned combustibles. The percentages of its components are not subject to huge variations. A representative average approximation of percentage by weight of the residue components is as follows (Reference IV-3):

Glass	48 percent
Metals	18 percent
Minerals and ash	21 percent
Combustibles	<u>13</u> percent
	100 percent

Table IV-2

LIST BY STATE OF QUANTITIES AND TYPE OF RESIDUE, OPERATING PLANTS

<u>Number of Operating Plants</u>		<u>Type of Residue*</u>	<u>Quantity Produced (Tons per year)</u>
1	Arkansas	3	8,800
6	Connecticut	3	49,000
		4	137,500
3	Florida	3	26,300
		4	15,000
1	Hawaii	3	52,500
3	Illinois	1	52,300
		2	120,000
		3	105,000
1	Indiana	3	17,500
1	Kentucky	1	75,000
1	Louisiana	2	15,000
2	Maryland	1	36,000
		4	80,000
5	Massachusetts	2	273,000
3	Michigan	1	45,000
		2	60,000
		4	60,000
2	Missouri	4	80,000
1	New Hampshire	4	5,000
13	New York	2	213,800
		3	350,000
		4	80,000
4	Ohio	3	131,200
1	Oklahoma	4	5,000
3	Pennsylvania	2	54,000
		3	131,200
1	Rhode Island	3	17,500
1	Tennessee	3	63,000
1	Utah	3	39,400
3	Virginia	3	42,900
		4	35,000
1	Washington, D.C.	2	112,500
2	Wisconsin	2	33,000
			<u>2,621,400</u>

* See text for explanation.

Table IV-3.

TABULATION OF QUANTITIES OF TYPES OF RESIDUES PRODUCED

		<u>Number of Plants Producing This Residue</u>	<u>Quantity of Residue Produced</u>
Ultra Well Burned	Type 1	4	208,300
Well Burned	Type 2	18	881,300
Intermediately Burned	Type 3	22	1,034,300
Poorly Burned	Type 4	16	<u>497,500</u>
			2,621,400

Incinerator residue is also fairly uniform with respect to particle size distribution, if all the gross oversized materials (such as appliances) have been initially removed. Nearly all residue is able to pass through a 3-inch screen. Approximately 70 to 90 percent of the residue by weight can pass through a 1-1/2-inch screen (38 millimeters). The material passing this screen can usually conform to existing gradation specifications for bituminous base course aggregate (Reference IV-3). The Pennsylvania Department of Transportation Gradation Requirement for Bituminous Concrete Base Course is (Reference IV-9):

Base Course

<u>Sieve Size</u>	<u>Percent Passing</u>
2" (50.8 mm)	100
1-1/2" (38.1 mm)	95-100
3/4" (19.1 mm)	52-100
3/8" (9.52 mm)	36-70
#8 (2.38 mm)	16-38
#30 (0.590 mm)	8-24
#50 (0.297 mm)	6-18
#100 (0.149 mm)	4-10

An additional property of significance with respect to incinerator residue (other than physical composition and material grain size) is moisture content. The moisture content of residue varies greatly. Residues that have been freshly quenched (due to heat of incineration) obtain a high moisture content. As a range value, the water content of as received residues (reported in a Federal Highway Administration Report No. FHWA RD78) varied between 28 percent and 47 percent. It has been observed that residues that have been stockpiled for a period of time contain a much lower moisture content than non-stockpiled residues.

It has been recommended in a report prepared by Valley Forge Laboratories for the Federal Highway Administration in 1976, that only well burned or intermediately burned incinerator residues should be considered for use in highway construction. This same report recommended that residues for construction be stockpiled for several months prior to use; and that a loss on ignition test value of greater than 10 percent of the residue, would deem the residue undesirable for highway construction.

With respect to the residues produced by resource recovery and reclamation plants, only some of the residues may be used for roadway construction materials. The determination of what residues from which plants can be used, should be made on individual and specific application criteria. This is so, as some of the resource recovery facilities produce a synthetic type fuel which is similar in consistency to peat moss. With all the pre-separation and screening involved to produce this fuel, the residue characteristics are appreciably altered. Residues produced, often do not contain

acceptable amounts of desirable components (for construction applications) such as glass, and often contain appreciable amounts of undesirable components which may be considered as hazardous. The residues from these recovery facilities would be unacceptable as an aggregate replacement in highway construction applications.

In a report written by Valley Forge Laboratories in 1977 (FHWA RD77 151), the moisture content of six different types of incinerator residue were listed as follows:

<u>Residue Type</u>	<u>Point of Sampling</u>	<u>Average Moisture Content (Percent)</u>	<u>Type of Grate</u>
1	Discharge Chute	42.9	Rotary Kiln
2	Stockpile	17.8	Reciprocating
3	Stockpile	23.8	Traveling
4	Discharge Chute	45.9	Traveling
5	Stockpile	21.6	Traveling (Metal Recovery)
6	Stockpile	0.8	Pyrolysis

NOTE: The average of all moisture content values (except for Type 6 residue) was 31.6 percent. However, the average moisture content of the stockpiled residues (except for Type 6 residue) was 21.1 percent.

Below is the average particle size distribution of these six different types of incinerator residue (expressed as percent passing):

<u>Sieve Size</u>	<u>Type 1</u>	<u>Type 2</u>	<u>Type 3</u>	<u>Type 4</u>	<u>Type 5</u>	<u>Type 6</u>
3" (76.2 mm)	100	100	100	100	100	100
1" (25.4 mm)	100	86	65	79	79	100
1/2" (12.7 mm)	96	66	60	65	67	100
1/4" (6.35 mm)	87	45	49	48	53	83.5
#10 (2.00 mm)	41	24	29	29	32	46.4
#40 (0.420 mm)	15.5	11	15	12	13	9.6
#200 (0.074 mm)	4.5	4	5	4	5	3.3

NOTE: Size control of "as received" samples involved only the removal of oversize material prior to sieve analysis. The maximum particle size in this analysis was limited to 3 inches (76.2 mm). Sieve analyses were performed in accordance with ASTM Designation C136 using samples of 1,000 gram size.

On the following page is Figure IV-2, a gradation chart of the six types of incinerator residue as compared to the specification limits of PennDOT for base course aggregate.

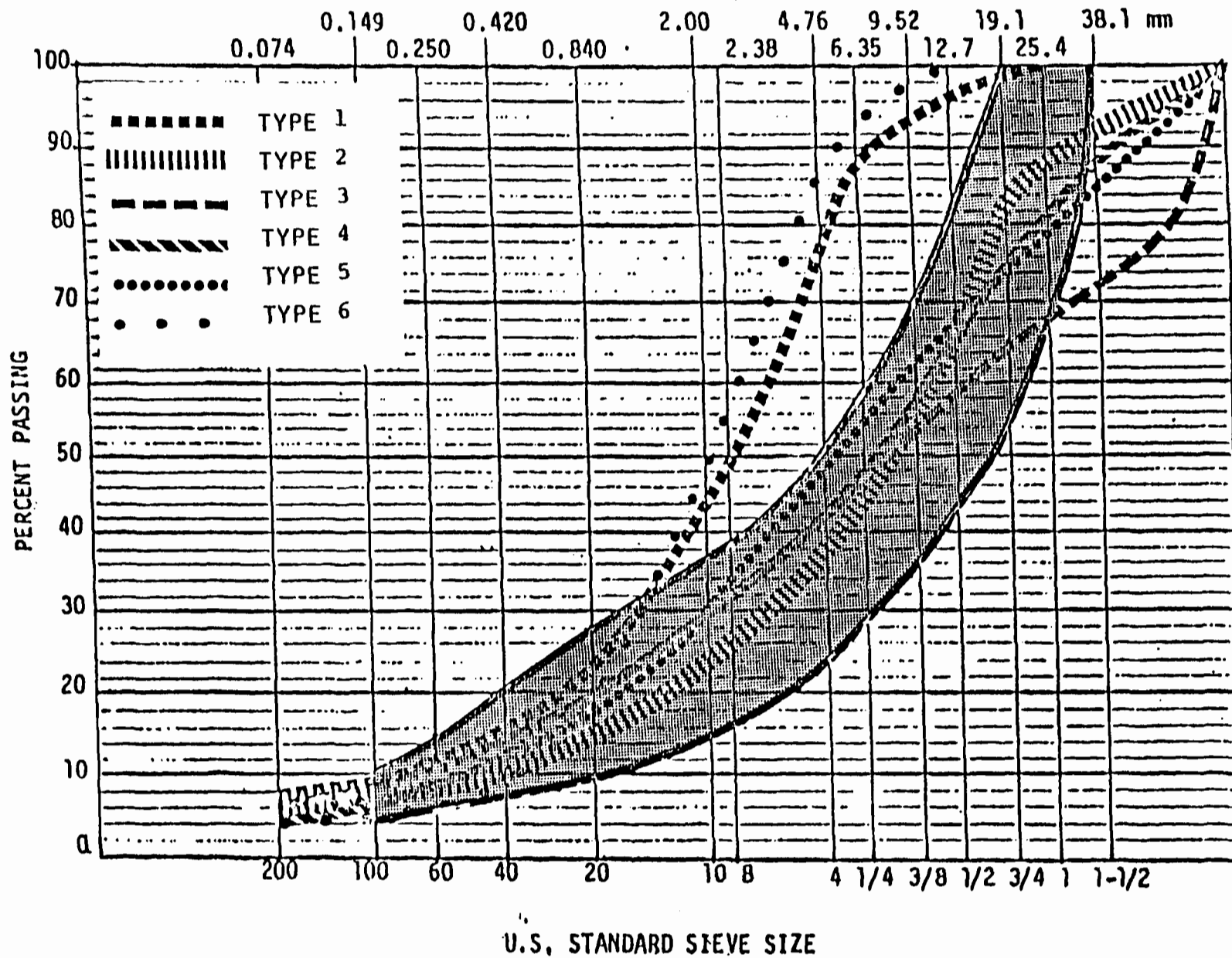


Figure IV-2. Particle size distribution of "as received" incinerator residues.
(Shaded area is PennDOT base course aggregate specification limits.)

A laboratory test program on these six types of residues was conducted by Valley Forge Laboratories, Inc. during 1976. Below is the average particle size distribution of the six types of graded incinerator residue, expressed as percent passing, which were used in the program (1-1/2" maximum top size).

<u>Sieve Size</u>	<u>Type 1</u>	<u>Type 2</u>	<u>Type 3</u>	<u>Type 4</u>	<u>Type 5</u>	<u>Type 6</u>
1-1/2" (38.1 mm)	100	100	100	100	100	100
1" (25.4 mm)	100	95	94	96	97	100
1/2" (12.7 mm)	96	69	64	80	82	100
1/4" (6.35 mm)	87	43	33	55	57	83.5
#10 (2.00 mm)	41	25	17	33	34	46.4
#40 (0.420 mm)	15.5	12	8	18	17	9.6
#200 (0.074 mm)	4.5	6	3	10	4	3.3

NOTE: Size control of graded incinerator residue samples involved passing all materials (except types 1 and 6) through a 1-1/2 inch (38.1 mm) portable screen. Sieve analyses were performed in accordance with ASTM Designation C136 using samples of 1,000 gram size.

On the following page is Figure IV-3, a gradation chart of the six types of graded incinerator residue as compared to the aggregate specification limits of PennDOT for wearing surfaces.

Incinerator residue is able to satisfy many of the quality control standards used for conventional aggregate materials. Some tests presently being used, however, require modification of their present form for testing incinerator residue. An example of such a test is specific gravity. The difficulty of accurately determining the apparent specific gravity of incinerator residue is due to its property of high absorption.

PRINCIPAL USES.

Incinerator residues have been used in a variety of highway applications. These include bituminous base courses, wearing surfaces, stabilized bases and sub-bases, and fused aggregate material uses.

In fused aggregate applications, prepared municipal incinerator residues are burned out to completion and then channeled through a second furnace (Reference IV-10). The second furnace melts or fuses this burnt out material together at temperatures near 2,000°F. The melted product is allowed to cool, and is subsequently crushed and broken to a desired size (i.e., with all particles smaller than 1-1/2 inches).

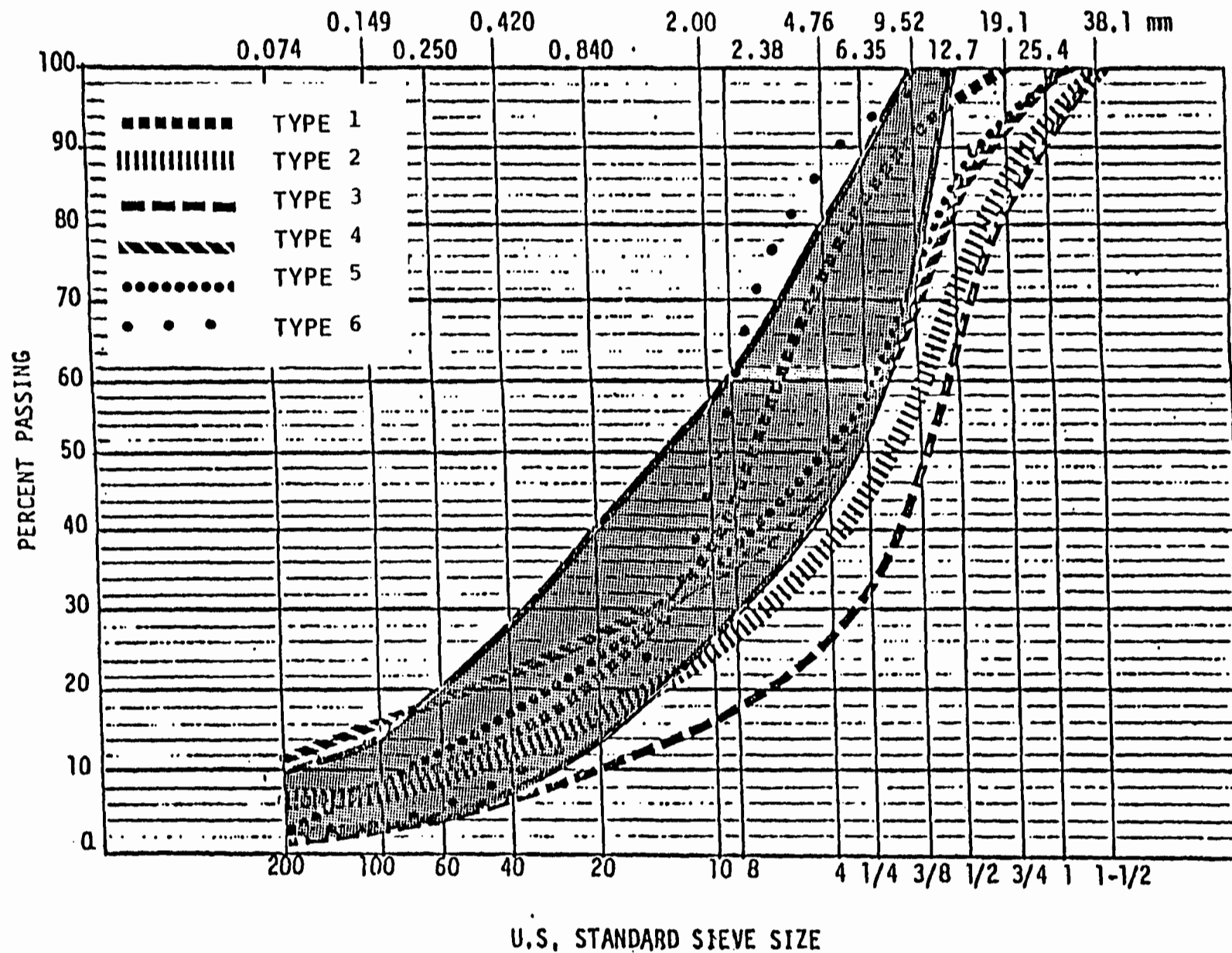


Figure IV-3. Average particle size distribution of graded incinerator residues.
(Shaded area is PennDOT ID-2A wearing surface specification limits.)

Bituminous Base Courses

In Houston, Texas, construction of a test section of roadway using incinerator residue in a bituminous base was undertaken in 1974 (Reference IV-11). This test section consisted of construction of approximately 200 feet of roadway at the intersection of Bingle Road and Hempstead Highway. The incinerator residue bituminous base used in the construction has been termed "littercrete" in numerous publications (References IV-12, IV-13).

Roadway construction consisted of a 1-1/2-inch thick conventional wearing surface, placed on a 6-inch thickness of littercrete. The littercrete was placed on top of a 6-inch thick lime stabilized soil having a sandy soil subgrade.

The incinerator residue used in the littercrete had passed a 1-inch (25 mm) screen. The gradation of the material had passed the Texas AA Type C specification. The percentage of glass in the residue was approximately 45.

The approximate composition of the placed littercrete was as follows:

<u>Composition</u>	<u>Incinerator Residue</u>	<u>RC 20 Asphalt</u>	<u>Hydrated Lime</u>
% Volume	80.9	17.4	1.7
% Weight	89.0	9.0	2.0

A control section of conventional materials was placed alongside the test section for comparison purposes. The control section base had a 6 percent asphalt composition by weight.

The particle size distribution of the graded incinerator residue used in the Houston, Texas Test Section, in percent by weight was as follows (Reference IV-11):

<u>Sieve Size</u>	<u>Percent Passing</u>
<u>Unwashed</u>	
1" (25.0 mm)	100
3/4" (19.0 mm)	95
1/2" (12.7 mm)	80
3/8" (9.52 mm)	63
#4 (4.76 mm)	46
#8 (2.38 mm)	25
#16 (1.19 mm)	17
#30 (0.590 mm)	11
#50 (0.297 mm)	7
#100 (0.149 mm)	4
#200 (0.074 mm)	2
<u>Washed</u>	
#4 (4.76 mm)	48
#80 (0.180 mm)	11
#200 (0.074 mm)	7

On the following page is Figure IV-4, a gradation chart of the littercrete base used in the Houston test section, as compared to the Texas Class AA Type C, aggregate gradation specification for base courses.

Both sections of pavements, have been evaluated for performance employing testing methods for stability, thermal expansion, direct tension, splitting tensile strength, resiliency and flexural fatigue. The pavements have also been evaluated visually. Three-year tests and evaluations of the two pavements indicated that the littercrete and the control section are performing equally.

A summary of laboratory test results of optimum mix design (asphalt 9 percent by weight of total mix) for the bituminous base test section placed in Houston, Texas was as follows (References IV-12, IV-13):

	6 Months Field		3 Year Field	
	<u>Test Mix</u>	<u>Control Mix</u>	<u>Test</u>	<u>Control</u>
Stability (pounds)	1,150	920	1,340	1,940
Flow (0.01 inch)	.17	.15	.18	.12
Air Voids (percent)	4.2	8.5	4.7	6.9
Recovered Asphalt Content (percent)	10.8	5.3		
Maximum Specific Gravity	2.06	2.43	2.13	2.43
Density (pounds per cubic foot)	129			

In Anacostia, Washington, D.C., construction of a test section of roadway with an incinerator residue base was completed in June of 1977 (Reference IV-14). This test section consisted of construction of approximately 400 feet of roadway on 14th Street, S.E., near Cedar Street.

The roadway wearing surface consisted of a 1-1/2-inch thick conventional hot mixed asphalt. This was placed on top of a 4-1/2-inch bituminous incinerator base with 6 inches of gravel sub-base. For this test section, 30 percent aggregate was blended with the residue in the base mix.

The particle size distribution of incinerator residue plus aggregate used in the Washington, D.C. test section was as follows:

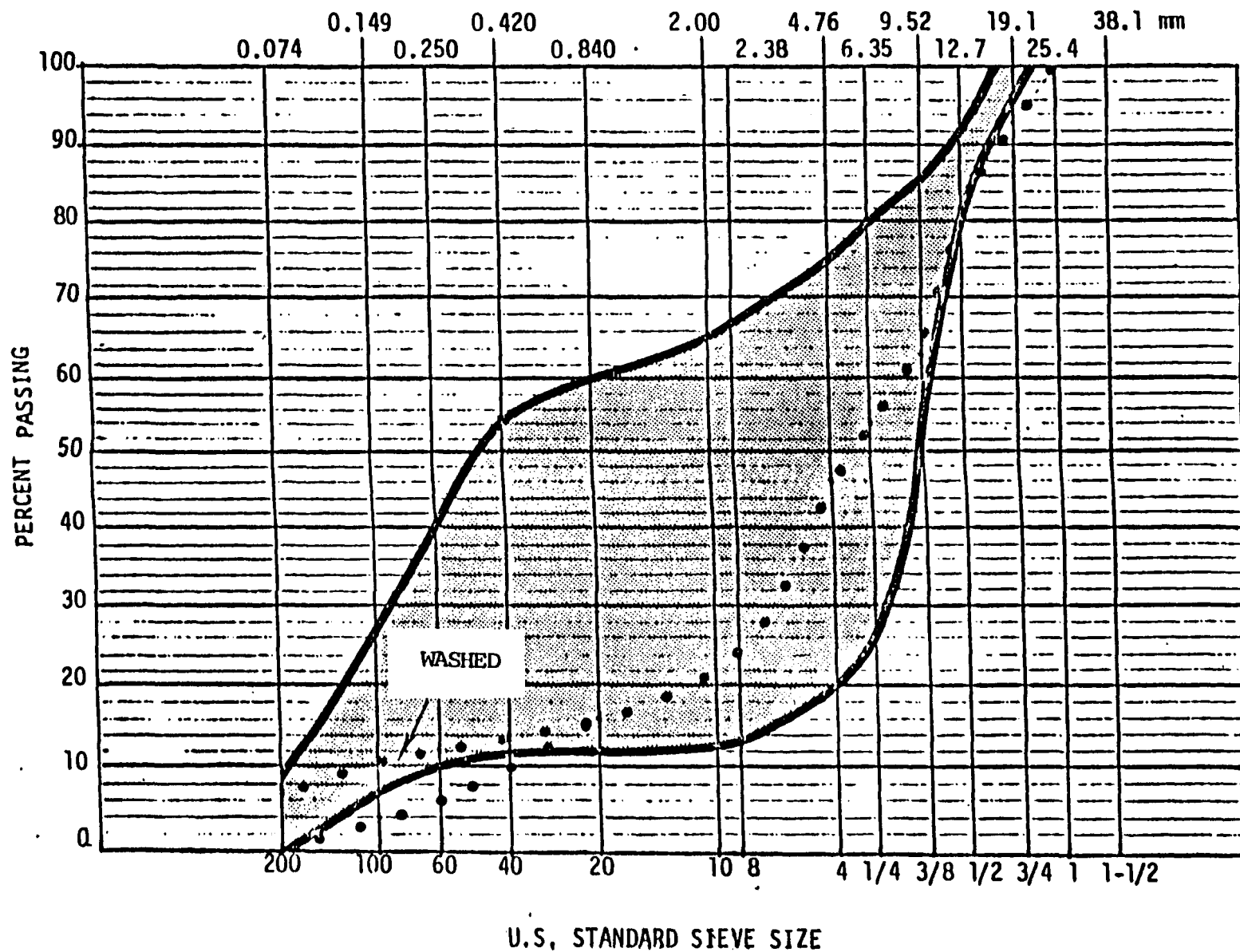


Figure IV-4. Particle size distribution of littercrete base used in the Houston test section.
(Shaded area is Texas Class AA Type C grading specification).

PERCENT PASSING

<u>Sieve Size</u>	<u>DC Residue</u>	<u>Sand</u>	<u>Stone</u>	<u>Lime</u>	<u>Mix*</u>	<u>DC Spec.</u>
1" (25 mm)	100		100		100	100
3/4" (19 mm)	98		91		97	90-100
1/2" (12.5 mm)	91		50		86	71-91
3/8" (9.5 mm)	80	100	26		75	60-85
#4 (4.75 mm)	53	98	3		53	45-65
#8 (2.36 mm)	39	90	2		42	33-52
#16 (1.18 mm)	30	79	0		34	22-40
#30 (0.60 mm)	24	53			26	14-30
#50 (0.30 mm)	19	12			16	6-21
#100 (0.15 mm)	15	5			12	3-15
#200 (0.075 mm)	11.7	0		100	9.5	2-8

* Mix contains 68.5 percent residue, 15 percent sand, 15 percent stone, and 1.5 percent lime.

On the following page is Figure IV-5, a gradation chart of the particle size distribution of the material used in the Washington, D.C. test section as compared to the District of Columbia DOT aggregate grading specification for base courses.

A summary of laboratory test results of the Mix Design for bituminous based used in the Washington, D.C. test section is as follows (Reference IV-14).

	<u>Test Mix</u>	<u>Criterion</u>
Stability (pounds)	2,600	Minimum, 5,100
Flow (0.01 inch)	16	8 to 18
Air Voids (percent)	1.8	3-8
VMA (percent)	13.4	Minimum, 14
Asphalt Content (percent)	9.0	--
Bulk Specific Gravity	2.20	--
Density (pounds per cubic foot)	137	--

This test section is presently being completely evaluated for performance.

In Baltimore, Maryland, a test section of incinerator bituminous base was installed along Harford Road in July of 1972 (Reference IV-15). The incinerator residue used in this base test section, comprised 50 percent by weight of the total mix. The residue was combined with 17.5 percent #4 stone, 10 percent #10 stone, 20 percent sand, 2.5 percent lime and 6.5 percent asphalt by weight.

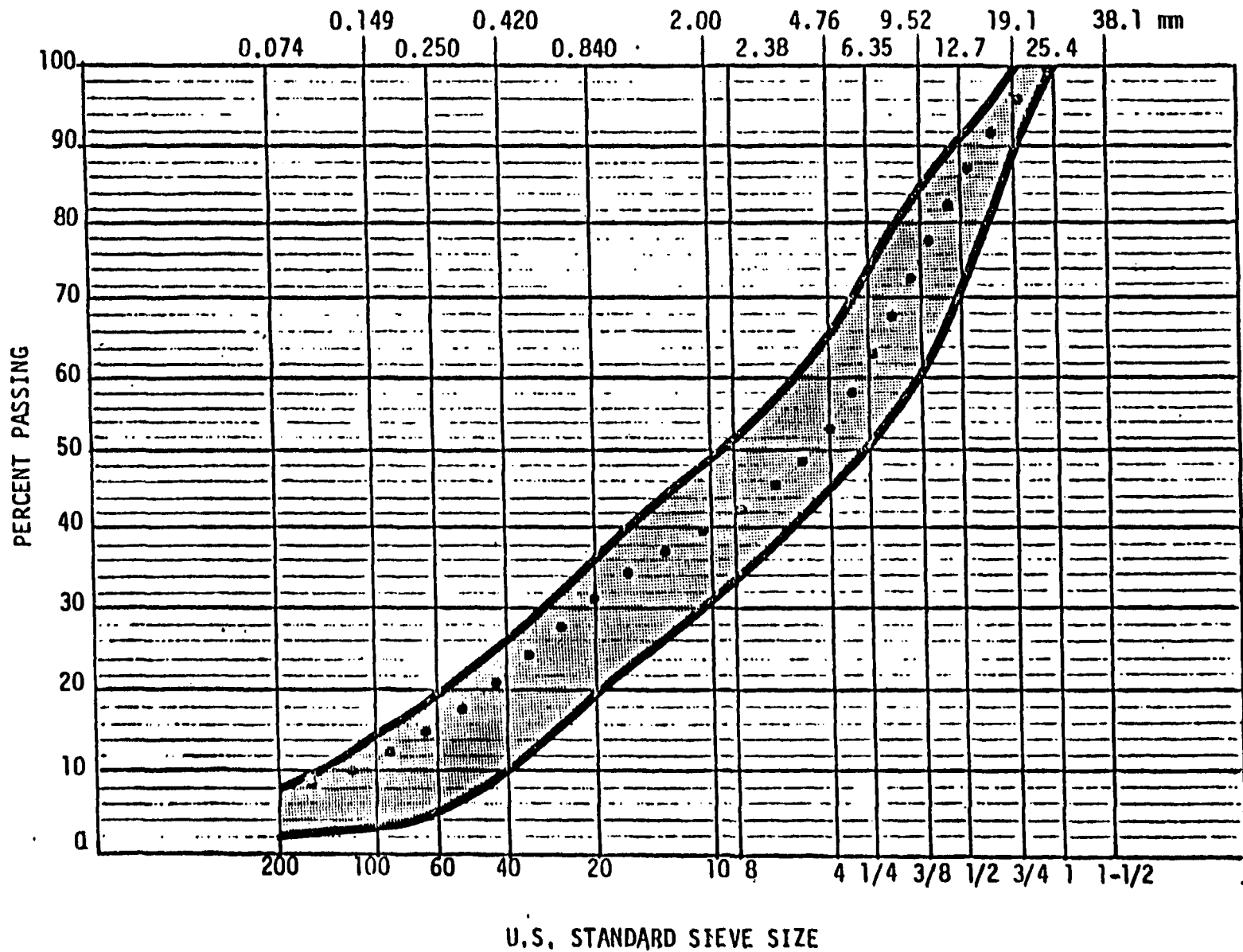


Figure IV-5. Particle size distribution of mix design used in the Washington, D.C. test section*

*Contains 68.5% residue, 15% sand, 15% stone, 1.5% lime.

(Shaded area is the District of Columbia Dept. of Transportation grading specification)

Below is a listing of the sieve sizes of the raw materials used in the Baltimore test section.

Sieve Number (1)	Hydrated Lime (2)	Sand (3)	Number 4 Stone (4)	Number 10 Stone (5)	Baltimore Treated Residue (6)
1-1/2 inch					100
3/4 inch			100		100
3/8 inch		100	57	100	64
4		98	17	94	31
8		91	6	81	21
16		81	3	65	15
50	100	26	2	37	8
200	95	1	1	11	3
Specific Gravity	2.20	2.63	2.82	2.82	2.50
Loss on Ignition as a Percentage	-	-	-	-	6.0

On the following page is Figure IV-6, the gradation chart of the particle size distribution of the material used in the Baltimore test section as compared to the Maryland State Roads Commission grading specification for base course aggregate.

A summary of test results for the bituminous base test section placed in Baltimore is as follows:

<u>Parameters</u>	<u>Plug No. 1</u>	<u>Plug No. 2</u>	<u>Baltimore Specification</u>
Asphalt Concrete, as a Percentage	6.5	6.5	-
Stability, in pounds	910	974	>500
Flow, in hundredths of an inch	10	10	8-18
Weight per cubic foot, in pounds	144.2	143.1	-
Air Voids, as a percentage	2.9	3.0	3-8

The most recent field report for this section indicated that there was acceptable performance of the residue material.

Wearing Surfaces

In Philadelphia, Pennsylvania construction of a test section of roadway using incinerator residue as a wearing surface was performed in December of 1975 (Reference IV-7). This test section consisted of approximately 108 feet of roadway at the intersection of States Drive and Belmont Avenue (Reference IV-3).

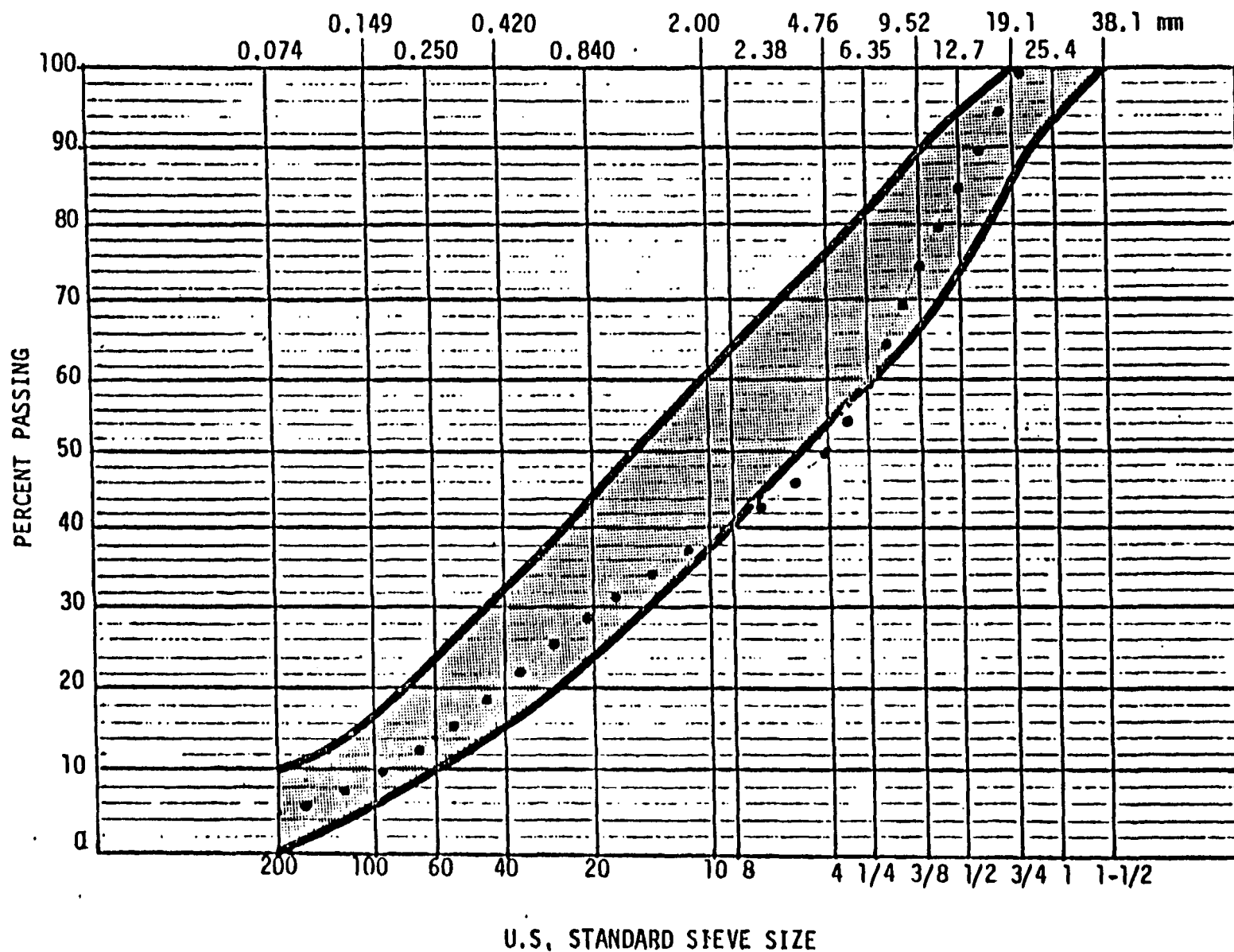


Figure IV-6. Particle size distribution of mix design used in the Baltimore, Maryland test section*.

*Contains 50% residue, 20% sand, 17.5% #4 stone, 10% #10 stone, and 2.5% lime.

(Shaded area is the Maryland State Roads Commission grading specification).

The wearing surface placed was approximately 1-1/4-inches to 1-1/2-inches in thickness.

The residue materials used in the wearing surface had been passed through a 5/8-inch screen and stockpiled for approximately two weeks prior to use. Incinerator residue comprised approximately 50 percent by weight of the aggregate in the mix. Asphalt content comprised approximately 7 percent by weight of the total mix.

On the following page is Table IV-4, the design gradation for the Philadelphia test section (in percent passing by weight).

On the following page is Figure IV-7, the gradation chart of the particle size distribution of the material used in the Philadelphia test section as compared to the PennDOT ID-2A wearing surface specification limits.

Below is a comparison of the design and field gradations for the Philadelphia test section (as percent passing by weight).

<u>Sieve Size</u>	<u>Design Gradation</u>	<u>Field Gradation*</u>	<u>ID-2A Limits</u>
1/2 inch (12.7 mm)	100	100	100
3/8 inch (9.52 mm)	91.0	92	80-100
#4 (4.76 mm)	59.3	60	45-80
#8 (2.38 mm)	39.3	40	30-60
#16 (1.19 mm)	27.4	26	20-45
#30 (0.590 mm)	19.1	16.5	10-35
#50 (0.297 mm)	13.0	10	5-25
#100 (0.149 mm)	9.2	7	4-14
#200 (0.074 mm)	6.4	5	3-10

* Derived from asphalt extraction and sieve analysis.

A summary of Laboratory Test Results for the Incinerator Residue and ID-2A Wearing Surface Mixes Used in Philadelphia Test Section is as follows (Reference IV-17).

DESIGN GRADATION FOR PHILADELPHIA TEST SECTION PAVING MIX
IN PERCENT PASSING BY WEIGHT

	<u>Type 3 Residue</u>		<u>Natural Sand</u>		<u>Type 1B Stone</u>		<u>Design</u>	<u>ID-2A</u>
	<u>Gradation</u>	<u>50% Blend</u>	<u>Gradation</u>	<u>30% Blend</u>	<u>Gradation</u>	<u>20% Blend</u>	<u>Gradation</u>	<u>Limits</u>
1/2" (12.7 mm)	100	50.0	100	30.0	100	20.0	100	100
3/8" (9.52 mm)	86	43.0	100	30.0	90	18.0	91.0	80-100
#4 (4.76 mm)	50	25.0	99	29.7	23	4.6	59.3	45-80
#8 (2.38 mm)	34	17.0	73	21.9	2	0.4	39.3	30-60
#16 (1.19 mm)	26	13.0	48	14.4			27.4	20-45
#30 (0.590 mm)	19	9.5	32	9.6			19.1	10-35
#50 (0.297 mm)	14	7.0	20	6.0			13.0	5-25
#100 (0.149 mm)	10	5.0	14	4.2			9.2	4-14
#200 (0.074 mm)	8	4.0	8	2.4			6.4	3-10

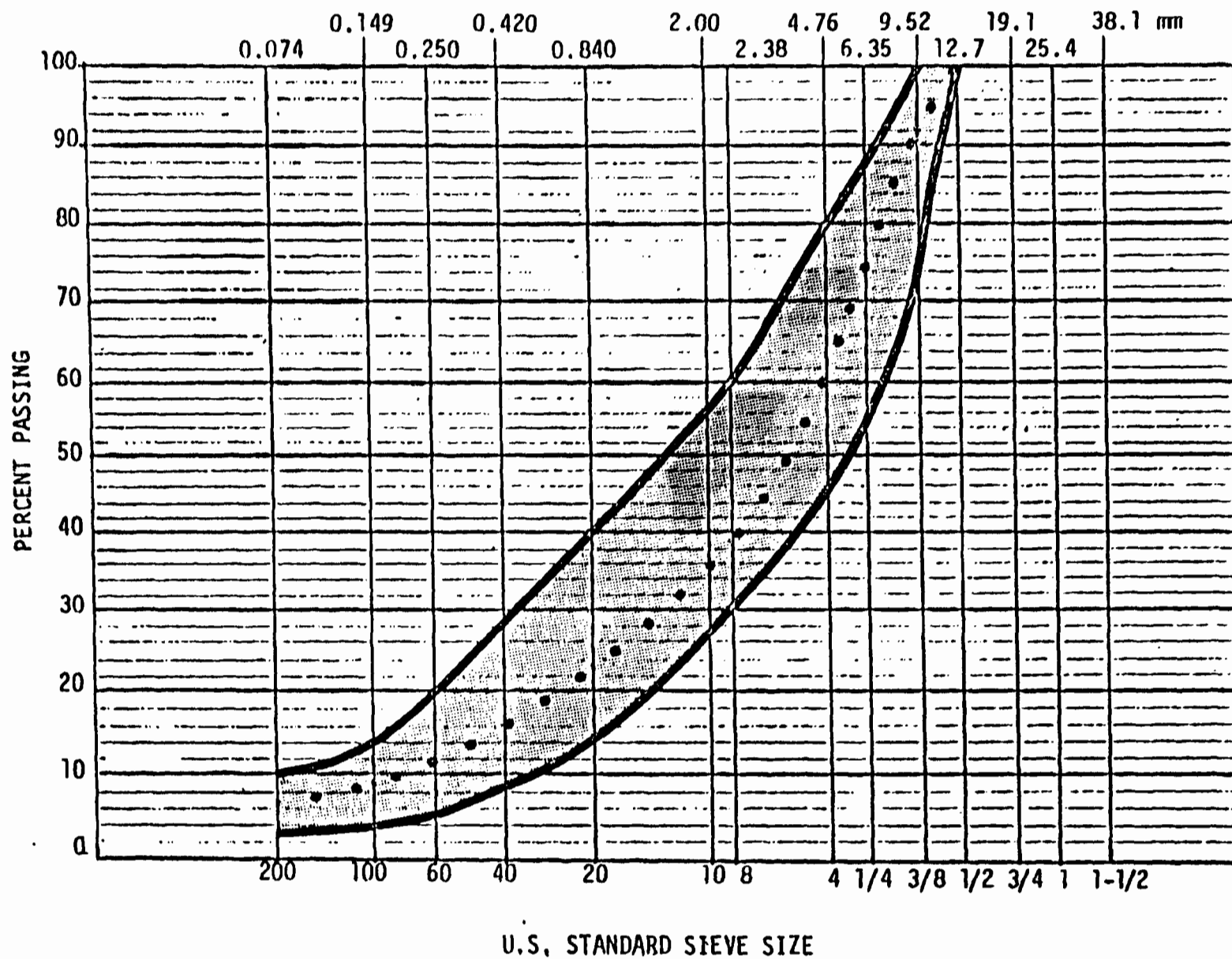


Figure IV-7. Particle size distribution of wearing surface mix used in Philadelphia test section.
(Shaded area is PennDOT 1D-2A wearing surface specification limits.)

	<u>Design Mix</u>	<u>Field Mix</u>	<u>ID-2A Mix</u>
Stability (pounds)	1,472	1,562	1,508
Flow (0.1 inch)	12.3	19.5	11.5
Air Voids (percent)	5.7	0.7	3.17
VMA (percent)	24.9	14.9	11.1
Retained Strength*	72.8	83.3	
Asphalt Content**	8.0	7.0	4.9
Bulk Specific Gravity	2.13	2.39	2.44
Density (lb/ft ³)	132.9	149.1	152.3

* Retained strength expressed as percent of molded strength as determined by immersion-compression test.

** Asphalt content expressed as percent by weight of total mix.

1 pound = 0.4536 kilogram

1 inch = 25.4 mm

1 lb/ft³ = 16.02 kilograms/cubic meter

Testing and inspection after one year, indicated that the wearing surface had performed adequately.

A visual inspection, during the summer of 1980, revealed it to be in good condition. The Philadelphia test section appears to be performing as well as the control section.

In Harrisburg, Pennsylvania, construction of a test section of roadway using incinerator residue as a wearing surface was also performed in December of 1975 (Reference IV-3). This test section consisted of approximately 250 feet of roadway at Wayne Street between 14th and 15th Streets.

The wearing surface placed was approximately 1-1/2-inches in thickness.

The residue materials used in the wearing surface had been passed through a 1/2-inch screen and stockpiled for approximately two weeks prior to use. Incinerator residue comprised approximately 50 percent by weight of the aggregate in the mix. Asphalt content comprised approximately 7 percent by weight of the total mix.

On the following page is Table IV-5, the design gradation for the Harrisburg test section (in percent passing by weight).

On the following page is Figure IV-8, the gradation chart of the particle size distribution of the material used in the Harrisburg Test Section as compared to the PennDOT ID-2A wearing surface specification limits.

Table IV-5

DESIGN GRADATION FOR HARRISBURG TEST SECTION PAVING MIX
IN PERCENT PASSING BY WEIGHT

<u>Sieve Size</u>	<u>Type 2 Residue</u>		<u>1/4" Limestone</u>		<u>Screenings</u>		<u>Design Gradation</u>	<u>ID-2A Limits</u>
	<u>Gradation</u>	<u>50% Blend</u>	<u>Gradation</u>	<u>30% Blend</u>	<u>Gradation</u>	<u>20% Blend</u>		
1/2" (12.7 mm)	100	50	100	25	100	25	100	100
3/8" (9.52 mm)	86	43	100	25	100	25	93.0	80-100
#4 (4.76 mm)	53	26.5	51	12.75	100	25	64.3	45-80
#8 (2.38 mm)	34	17.0	7	1.75	75	18.75	37.5	30-60
#16 (1.19 mm)	23	11.5	4	1.00	46	11.50	24.0	20-45
#30 (0.590 mm)	17	8.5	3	0.75	28	7.00	16.3	10-35
#50 (0.297 mm)	12	6.0	2	0.50	17	4.25	10.8	5-25
#100 (0.149 mm)	9	4.5	1	0.25	10	2.50	7.3	4-14
#200 (0.074 mm)	6	3.0	0.7	0.18	6	1.50	4.7	3-10

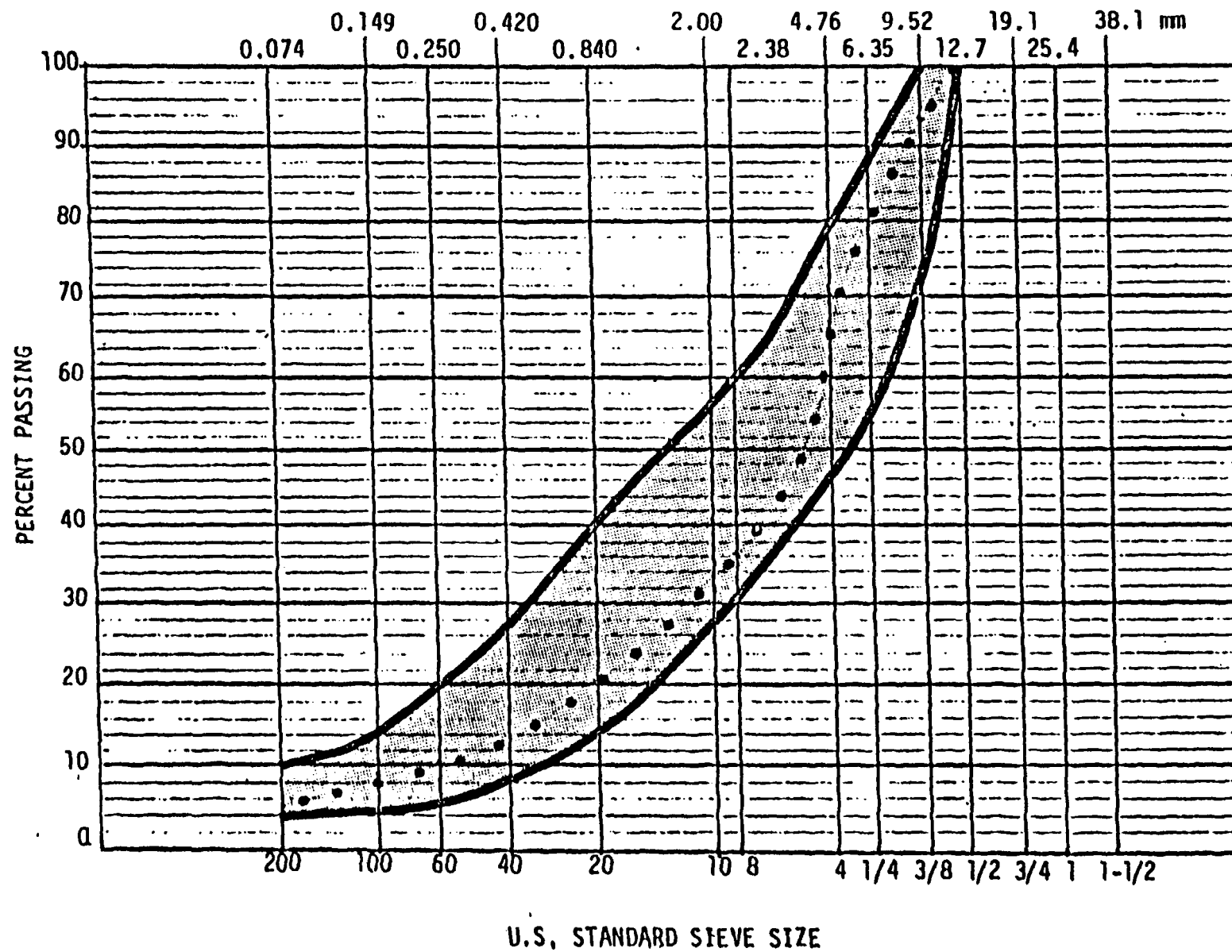


Figure IV-8. Particle size distribution of wearing surface mix used in Harrisburg test section.
(Shaded area is PennDOT ID 2A wearing surface specification limits.)

Below is a comparison of the design and field gradations for the Harrisburg test section (as percent passing by weight).

<u>Sieve Size</u>	<u>Design Gradation</u>	<u>Field Gradation*</u>	<u>ID-2A Limits</u>
1/2" (12.7 mm)	100	100	100
3/8" (9.52 mm)	93.0	93	80-100
#4 (4.76 mm)	64.3	61	45-80
#8 (2.38 mm)	37.5	37	30-60
#16 (1.19 mm)	24.0	24	20-45
#30 (0.590 mm)	16.3	17	10-35
#50 (0.297 mm)	10.8	13	5-25
#100 (0.149 mm)	7.3	9	4-14
#200 (0.074 mm)	4.7	5	3-10

* Derived from asphalt extraction and sieve analysis.

A summary of Laboratory Test Results for the Incinerator Residue and ID-2A Wearing Surface Mix Used in Harrisburg Test Section is as follows (Reference IV-17):

	<u>Design Mix</u>	<u>Field Mix</u>	<u>ID-2A Mix</u>
Stability (pounds)	1,401	1,558	1,221
Flow (0.01 inch)	10.0	14.0	10.5
Air Voids (percent)	8.2	2.6	7.5
VMA (percent)	25.2	19.4	17.6
Retained Strength*	86.4	96.8	-
Asphalt Content**	7.6	7.6	5.7
Bulk Specific Gravity	2.14	2.31	2.36
Density (lbs/ft ³)	133.5	144.1	147.3

* Retained strength expressed as percent of molded strength as determined by immersion-compression test.

** Asphalt content expressed as percent by weight of total mix.

1 pound = 0.4536 kilogram

1 inch = 25.4 mm

1 lb/ft³ = 16.02 kilograms/cubic meter

Testing and inspection after one year, indicated that the wearing surface was in a poor condition. Some of the glass particles on the surface had lost their asphalt coating.

A visual inspection during October of 1980 was performed. Although the thickness of the wearing surface placed had been reported as 1-1/2-inches, the majority of the test section wearing surface actually placed appeared to be much thinner than reported. Areas of the pavement examined established that the wearing surface placed was approximately 1/2-inch in thickness.* It appeared that no tack coat had been placed on the contact surface to the underside of the wearing surface. It is noted also that this experimental section was placed during a period of cold weather.

Despite the unfavorable conditions in which the test section was placed (re. minimal pavement thickness, minimal tack coat preparation of base, and seasonal weather) the October 1980 inspection confirmed that other than asphalt stripping from the glass particles of the test section, there was no discernable difference between the performance of the test section and the control section.

In Lima (Delaware County), Pennsylvania, construction of a test section of roadway using incinerator residue as a wearing surface was performed in October of 1975 (Reference IV-3). This test section consisted of approximately 60-feet of roadway at the main entrance to Fair Acres Farm off of Middletown Road.

The wearing surface placed was approximately 1-1/2-inches in thickness.

The residue materials used in the wearing surface had been passed through a 1/2-inch screen. The materials had been obtained from a stockpile at the Northwest Philadelphia incinerator. The age of the stockpile was unknown, but it was estimated to have been approximately two to three months old. Incinerator residue comprised approximately 50 percent by weight of the aggregate in the mix. Asphalt content comprised approximately 7 percent by weight of the total mix.

On the following page is Table IV-6, the design gradation for the Lima test section (in percent passing by weight).

On the following page is Figure IV-9, the gradation chart of the particle size distribution of the material used in the Lima test section as compared to the PennDOT ID-2A wearing surface specification limits.

* Pennsylvania Department of Transportation guidelines for resurfacing of roadways recommends that wearing surface overlays be placed in thicknesses no less than 1-1/2-inches.

Table IV-6

DESIGN GRADATION FOR DELAWARE COUNTY TEST SECTION PAVING MIX

<u>Sieve Size</u>	<u>Type 3 Residue</u>		<u>Pa. 1B Stone</u>		<u>Anti-Skid Material</u>		<u>Design</u>	<u>ID-2A</u>
	<u>Gradation</u>	<u>50% Blend</u>	<u>Gradation</u>	<u>25% Blend</u>	<u>Gradation</u>	<u>25% Blend</u>	<u>Gradation</u>	<u>Limits</u>
1/2" (12.7 mm)	100	50.0	100	25.0	100	25.0	100.0	100
3/8" (9.52 mm)	91.5	45.75	84.5	21.13	100	25.0	91.9	80-100
#4 (4.76 mm)	68.7	34.35	21.5	5.38	90.6	22.65	62.4	45-80
#8 (2.38 mm)	55.0	27.5	10.0	2.5	40.0	10.0	40.0	30-60
#16 (1.19 mm)	44.0	22.0	4.8	1.2	19.0	4.75	28.0	20-45
#30 (0.590 mm)	33.0	16.5	4.0	1.0	9.0	2.25	19.8	10-35
#50 (0.297 mm)	24.0	12.0	3.0	0.75	4.0	1.0	13.8	5-25
#100 (0.149 mm)	15.0	7.5	2.0	0.5	3.0	0.75	8.8	4-14
#200 (0.074 mm)	11.1	5.55	0.8	0.2	2.3	0.58	6.3	3-10

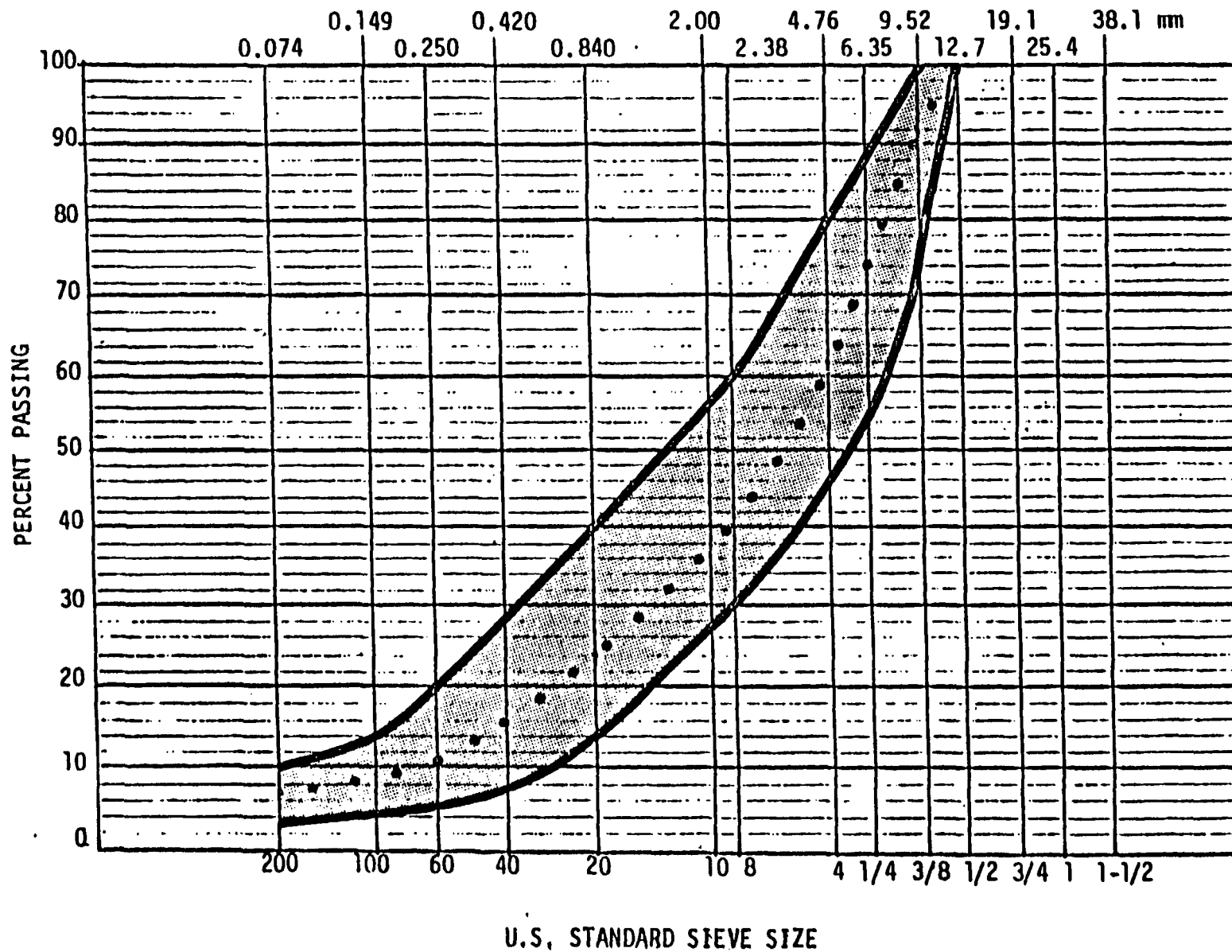


Figure IV-9. Particle size distribution of wearing surface mix used in Delaware County test section.
(Shaded area is PennDOT ID-2A wearing surface specification limits.)

Below is a comparison of the design and field gradations for the Lima test section (as percent passing by weight).

<u>Sieve Size</u>	<u>Design Gradation</u>	<u>Field Gradation*</u>	<u>ID-2A Limits</u>
1/2" (12.7 mm)	100	100	100
3/8" (9.52 mm)	91.9	94.0	80-100
#4 (4.76 mm)	62.4	68.2	45-80
#8 (2.38 mm)	40.0	36.5	30-60
#16 (1.19 mm)	28.0	24.5	20-45
#30 (0.590 mm)	19.8	17.5	10-35
#50 (0.297 mm)	13.8	12.4	5-25
#100 (0.149 mm)	8.8	8.0	4-14
#200 (0.074 mm)	6.3	6.1	3-10

* Derived from asphalt extraction and sieve analysis.

A Summary of Laboratory Test Results for the Incinerator Residue Wearing Surface Mix Used in Delaware County Test Section is as follows (Reference IV-17):

	<u>Design Mix</u>	<u>Field Mix</u>
Stability (pounds)	1,195	1,165
Flow (0.01 inch)	11.7	16.8
Air Voids (percent)	2.4	5.5
VMA (percent)	26.0	18.9
Retained Strength*	35.2	49.5
Asphalt Content**	7.0	7.1
Bulk Specific Gravity	2.05	2.25
Density (lbs/ft ³)	127.9	140.4

* Retained strength expressed as percent of molded strength as determined by immersion-compression test.

** Asphalt content expressed as percent by weight of total mix.

1 pound = 0.4536 kilogram

1 inch = 25.4 mm

1 lb/ft³ = 16.02 kilograms/cubic meter

Testing and inspection after one year, indicated that the wearing surface was in a fair condition. There were some signs of asphalt stripping from the glass particles.

This test section had been paved over in 1977. The resurfacing of this section was not connected with poor performance of the test pavement, but was a result of an extensive resurfacing project which randomly included the test section.

Stabilized Bases and Sub-bases

"Chempac" is a trade name for a mixture of incinerator residue and lime used in stabilized base applications. This mixture has certain qualifications (Reference IV-17). "Chempac" is defined as "a mixture of processed ash produced by rotary kiln type incinerators operating at temperatures in the vicinity of 1,800°F, and hydrated lime, in the approximate proportions of 95 percent processed incinerator ash and 5 percent lime." These percentages are subject to slight variations.

Qualifications regarding the gradation specifications of the incinerator residue used in the "Chempac" mix are as follows:

Passing 1" sieve	100%
Passing 1/2" sieve	85-100%
Passing #4 sieve	60-90%
Passing #10 sieve	40-70%
Passing #40 sieve	15-40%
Passing #80 sieve	5-20%
Passing #200 sieve	4-15%

Suggested limits with respect to carbon content, organic content, and water content for "Chempac" mixtures have also been established.

To date, "Chempac" base course mixtures have been used primarily in parking lot type applications. Perhaps the largest area application of a "Chempac" base material has been in north and south parking lots of Lawn-dale High School, Chicago, Illinois (Reference IV-19). In June of 1976, approximately 1,700 tons (dry weight) of "Chempac" was placed at this site. "The average percentage flue dust lime based on a dry weight of the delivered Chempac of approximately 1,700 tons was 15 percent + (Reference IV-19). Residues from the Chicago Southwest Incinerator and the Stickney, Illinois incinerator were used for this project. These residues have been characterized in a U.S. Department of Transportation Report as follows (Reference IV-20):

Sieve Size	1"	3/4"	3/8"	#4	#10	#40	#100	#200
Sample Collection								
#	Date							
1	09/02/73	100	99.5	91.2	74.8	53.7	38.4	30.9
2	09/11/73	100	94.9	93.2	82.5	57.6	29.6	20.8
3	09/25/73	100	90.6	61.6	38.1	17.6	7.5	4.3
4	10/05/73	100	95.5	87.5	74.5	51.6	26.3	16.0
5	10/15/73	100	100.0	81.0	65.0	43.4	19.4	10.3
6	10/24/73	100	97.3	90.6	76.3	53.1	27.4	14.6
7	11/02/73	100	96.6	89.1	78.4	53.8	22.0	12.5
8	11/09/73	97.6	97.6	88.7	71.4	48.3	23.9	13.0
9	11/13/73	100	98.3	93.3	80.7	49.5	18.6	10.7
10	11/23/73	100	98.9	90.3	74.2	46.7	22.3	12.6
11	11/29/73	100	95.0	86.8	68.7	46.1	23.4	14.3
12	12/06/73	100	98.1	87.4	71.2	48.9	25.1	15.1
13	12/14/73	100	97.0	88.6	76.0	49.0	16.2	7.9

Sieve Size		1"	3/4"	3/8"	#4	#10	#40	#100	#200
Sample Collection									
#	Date								
14	01/08/74	100	9.1	74.6	58.6	37.4	14.3	8.3	5.9
15	01/18/74	100	97.2	89.2	77.1	49.8	19.6	11.6	8.8
16	01/24/74	100	98.0	88.8	76.0	52.3	19.7	10.9	7.9
Average		99.9	96.6	86.4	71.5	47.4	22.1	13.4	9.9
High		100	100	93.3	82.5	57.6	38.4	30.9	25.0
Low		97.6	90.6	61.6	38.1	17.6	7.5	4.3	3.1

* Percent Passing Sieve - ASTM Method D-422

On the following page is Figure IV-10, the gradation chart for the 39th and Iron Street 16 weekly samples. This chart includes a gradation of the incinerator residue from a stockpile created by the Associated Contractors, Chicago, Illinois.

Twenty-nine field tests for water content, and in-place dry density were taken at the time of the Lawndale installation. All tests reported compaction of greater than 95 percent of maximum lab dry density, with 19 of the 29 results of the tests exceeding 100 percent maximum density.

Maximum lab dry density was 75 pounds per cubic foot, with an optimum water content of 14 percent by dry weight of residue.

The Lawndale "Chempac" base is reportedly in a good condition at present. No additional testing has been performed at the site since the time of the initial installation.

In St. Charles, Illinois, construction of a section of a parking lot using incinerator residue as a stabilized base was performed in October of 1974 (Reference IV-20). This test section was placed in the southwest corner of Illinois Bell Telephone parking lot. The "Chempac" material used at this site was from the Stickney, Illinois incinerator. This material had been aged for at least one month in the yard stockpile of Associated Contractors, Chicago, Illinois.

The Stickney residue material had been laboratory tested with a lime concentration of 8 percent by weight.

Field compaction data for the subgrade and "Chempac" at the Bell Telephone site test area is shown on the following page in Table IV-7.

Field tests and visual examinations of the test area were conducted over the next 2-1/2 year period. The following data were reported for dry density and CBR testing:

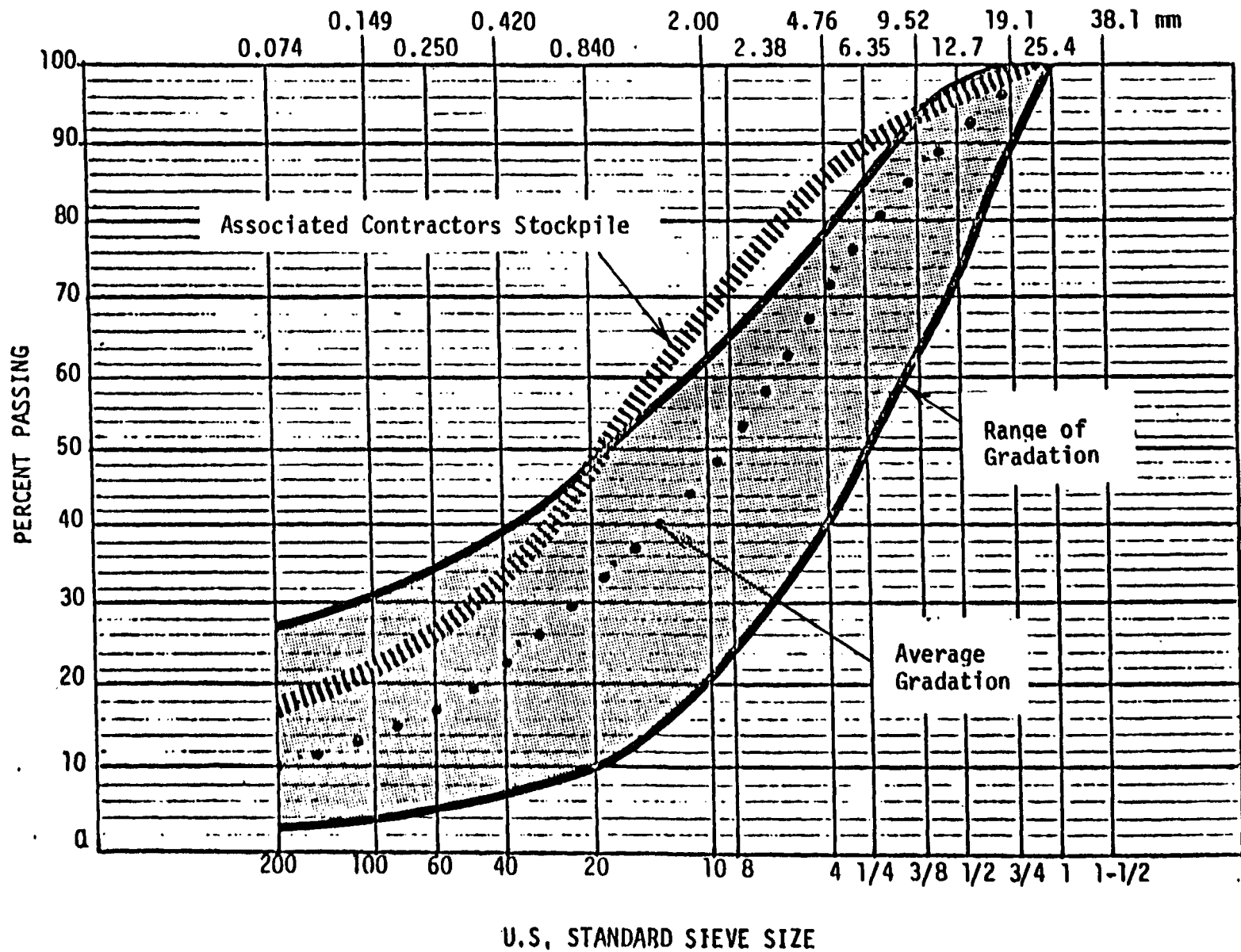


Figure IV-10.

Gradation Range of Weekly Samples From
39th & Iron St. Incinerator, Chicago, Ill.

Table IV-7

Field Density Test Results* - Demonstration Site

Test No.	Paved Areas for Parking and Drive	Depth Below Final Subgrade Elevation	Description of Material	Use of Material	FIELD		LABORATORY		% of Maximum Dry Density Obtained	% of Specification Requirements
					Dry Density (pcf)	Moisture Content %	Maximum Dry Density (pcf)	Optimum Moisture Content %		
SUBBASE	1 30' South & 10" West of Southwest corner of building	-8.0"	Brown silty clay with sand and gravel	Fill	125.6	10.7	132.0	9.1	95.2	90.0
	2 60' South of Center of South side of building	-8.0"	"	Fill	123.0	12.1	132.0	9.1	93.2	90.0
	3 45' West & 21' South of Southeast corner of building	-8.0"	"	Fill	129.0	8.3	132.0	9.1	97.8	90.0
BASE	8 39' East & 21' South of Southwest corner of building	-8.0"	CIEMPAC	Fill	70.7	16.3	81.6	25.0	86.6	95.0
	9 95' West & 25' South of Southeast corner of building	-8.0"	CIEMPAC	Fill	69.8	21.2	81.6	25.0	85.5	95.0
	10 75' East & 42' South of Southwest corner of building	-8.0"	CIEMPAC	Fill	77.2	15.6	81.6	25.0	94.6	95.0

*Source Testing Service Corporation
1 pcf = 16.01 kg/m³

<u>Location</u>	<u>Dry Density, pcf*</u> <u>(% Proctor)**</u>			<u>C.B.R.</u>	
	<u>3/13/75</u>	<u>11/14/75</u>	<u>6/28/76</u>	<u>10/22/76</u>	
				<u>Deflection</u>	
				<u>0.1 inc.</u>	<u>0.2 in.</u>
B-1	Sample	67.9	68.1	34	27
	Damaged	(84%)	(84%)		
B-2	69.7	70.5	75.1	61	54
	(86%)	(87%)	(92%)		
B-3	75.5	74.0	76.1	74	75
	(93%)	(91%)	(94%)		

* 1 pcf - 16.01 kg/m³

** Percent of optimum density

1 inch = 2.54 cm.

At the end of the 2-1/2 year monitoring period, it was observed that there was some distress of the test section. The observed cracking of the pavement of the test section ("Chempac base") however, did not appear to be as extensive as the cracking of the adjacent control (crushed stone base) pavements. At present, the "Chempac" base appears to be performing as well as the crushed stone base control.

A "Chempac" test section of roadway placed in Stickney, Illinois in 1963 has since been removed due to pulling and shrinkage of the base materials over time (Reference IV-21). Another residential street application of "Chempac" material in Illinois had to be removed because a wearing surface was not placed on top of it. It is noted, however, that one of the first applications of "Chempac" type materials was in the parking lot of Soil Testing Services, Inc. of Northbrook, Illinois in 1962; this section is still in good condition.

The total number of "Chempac" material field tests that have been performed to date is approximately 12 (Reference IV-21).

Fused Aggregate

As to date, the only test section of fused aggregate placed, has been in 1976 in the area of Harrisburg, Pennsylvania (Reference IV-22). This test section consisted of approximately 180 feet of roadway placed on the southbound lane of Traffic Route 22, Dauphin County, between 181 and the Rockville railroad bridge.

The wearing surface placed was approximately 1-1/2-inches in thickness.

The fused residue used had been passed through a scalper which had removed the particles larger than 3/4 of an inch. The materials had been obtained from a stockpile of fused incinerator residue produced at Catasauqua, Pennsylvania, and broken at Broomall, Pennsylvania.

Fused aggregate comprised all of the aggregate in the mix, as the gradation of the material was such that it did not require the addition of a fine aggregate.

The asphalt content comprised approximately 6.5 percent by weight of the total mix.

Testing and inspection after one year, indicated that the wearing surface was in an excellent condition.

Below is the particle size distribution of the graded incinerator residue used in the Harrisburg Fused Incinerator Test Section, in percent by weight.*

<u>Sieve Size</u>	<u>Percent Passing</u>
5/8" (15.9 mm)	100
1/2" (12.7 mm)	99.0
3/8" (9.52 mm)	88.7
#4 (4.76 mm)	63.2
#8 (2.38 mm)	44.4
#16 (1.19 mm)	28.1
#30 (0.590 mm)	18.9
#50 (0.297 mm)	12.0
#100 (0.149 mm)	7.6
#200 (0.074 mm)	4.4

* From truck mix, draft report (Reference IV-22).

On the following page is Figure IV-11, a gradation chart of the particle size distribution of the wearing surface mix used in the Harrisburg fused aggregate test section as compared to the PennDOT ID-2A wearing surface specification limits.

A summary of Laboratory Test Results for the Fused Aggregate Incinerator Residue used in the Harrisburg test section is as follows:

	<u>Job Mix</u> <u>PA DOT</u>	<u>Control</u> <u>Mix</u>	<u>PA DOT</u> <u>Spec.</u>
Stability (pounds)	1,784	2,250	1,200 min.
Flow (0.01 inch)	10	10.6	6-16
Air Voids (percent)	4.0	3.9	3-5
VMA (percent)	19.6	17.7	--
Asphalt Content	6.8	5.9	4.5-8.0
Laboratory Specific Gravity	2.354	2.418	--
Density (lbs/ft ³)	147.1	150.9	--
% weight of total mix			

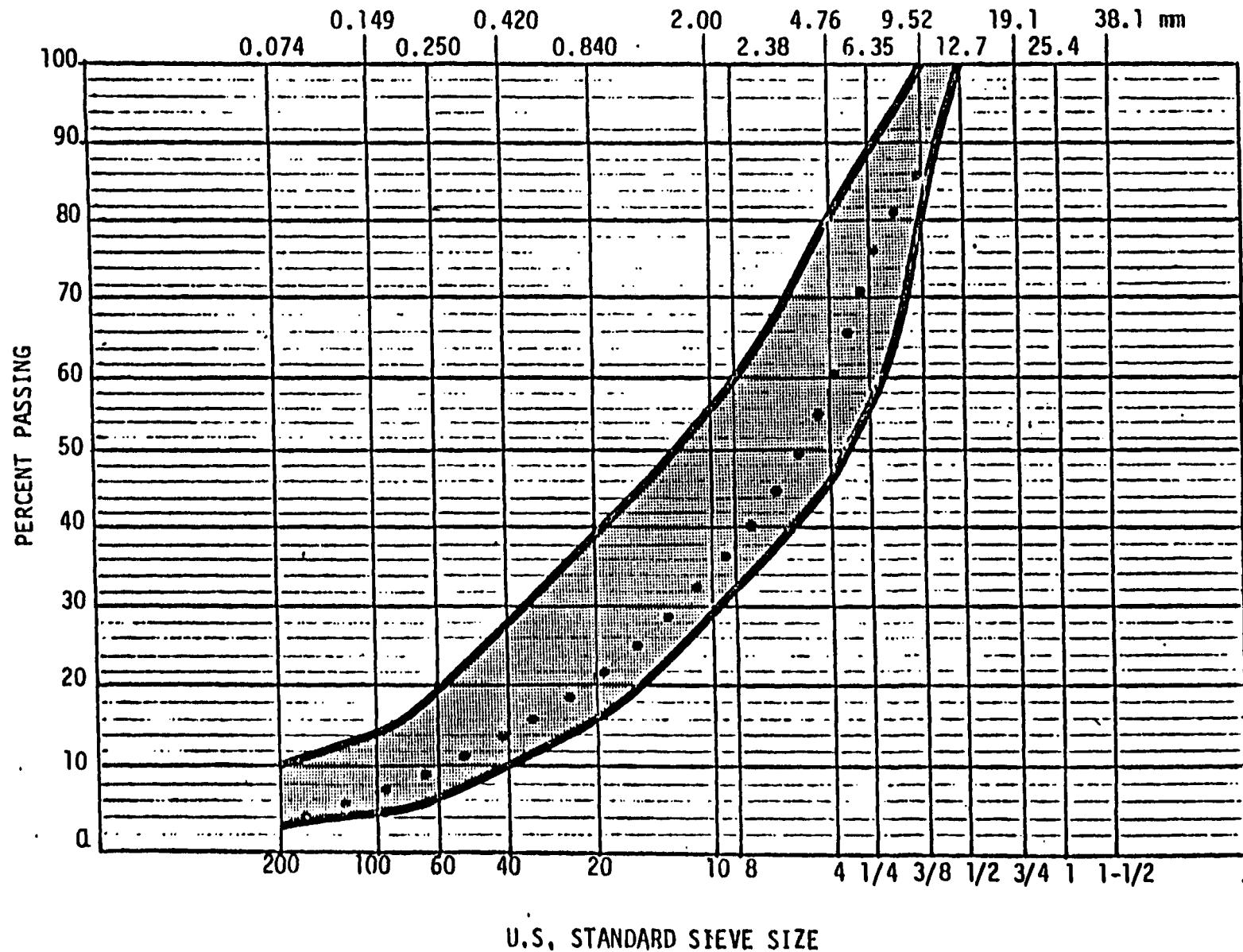


Figure IV-11. Particle size distribution of wearing surface mix used in Harrisburg fused aggregate test section.
(Shaded area is PennDOT ID-2A wearing surface specification limits.)

Additional field core data for the Harrisburg test section is as follows:

FIELD CORE DATA FOR SEPTEMBER, 1976 EXTRACTIONS
TEST PAVEMENT SECTION

	Station 300+26			Station 301+31		
	Core 1	Core 2	Core 3	Core 4	Core 5	Core 6
Theo. Sp. Gr. @ 77 F	2.454	2.454	2.454	2.454	2.454	2.454
Sp. Gr. @ 77 F	2.214	2.210	2.217	2.300	2.281	2.311
Voids % by Volume	9.8	10.0	7.5	6.3	7.0	5.8
VMA % by Volume	24.4	24.6	22.4	21.4	22.1	21.1
VFA % by Volume	59.9	59.4	66.7	70.8	68.1	72.3
Compaction % of Theo.	90.2	90.0	92.5	93.7	93.0	94.2
Avg. Thickness, Inches	-	1-3/4	-	-	1-1/2	-

FIELD CORE DATA FOR NOVEMBER, 1979 EXTRACTIONS

	Recovered Asphalt				% Voids in the Mineral Aggregate (VMA)*
	Absolute Viscosity @ 140 F, poises	Penetration @ 77 F	Specific Gravity @ 77 F	% Voids by Volume	
Core T-6A	17,555	24.5	2.288	6.8	21.4
Core T-8A	25,899	22.0	2.322	5.4	20.3
Core T-9A	10,877	31.0	2.297	6.4	20.7
Core C-8A	6,014	41.0	2.424	3.7	17.5
Core C-9A	4,848	49.0	2.447	3.7	17.7

* Calculated from total asphalt content, not effective asphalt content.

A visual inspection during October of 1980 confirmed that this test section was performing as well as the control section of pavement. The only noticeable difference between the test section and the adjacent pavements, was that the test section had retained a darker natural color (black), and had not faded to grey.

TECHNICAL ASSESSMENT OF USES

Overall performance (durability, life expectancy, visual appearance, etc.), of pavements and subgrades which contain incinerator residue have varied from good to poor.

An initial problem encountered with using incinerator residue in pavement applications, is that a great amount of material quality control is needed. This is so, as only certain quality residues may be used in pavement applications. The problem is having to monitor all the residue

(which is to be used in pavement applications) arises from the incineration process itself. As previously mentioned, the factors affecting the quality of the residue are time of combustion, temperature of combustion, and turbulence during combustion. These three factors are normally of little significance during municipal incineration operations.

An example of this type of uncontrolled combustion is evidenced by the procedure which may occur at an incineration facility having more than one furnace. If the facility operates two furnaces at a certain incoming volume of refuse and is subsequently only able to operate one furnace, due to breakdown of, or maintenance on, the other furnace; the constant volume of refuse would be cycled through the single operating furnace. The channeling of the refuse through the single unit would produce a residue of poorer quality than that produced by dual furnace combustion. Also, in municipal refuse processing, variations in seasonal quantities and incoming moisture contents of refuse are not adjusted for during combustion operations for the production of a uniform residue.

A disadvantage in processing of residue material to be used in construction applications (other than quality control), is that stockpiling is necessary. In conjunction with stockpiling, additional screening, shredding or trommeling of residue (to that of conventional materials) may have to be done as a means of preparing the residue to a desired gradation.

Incinerator residue, however, can be used in pavement applications if properly prepared. An advantage of using incinerator residue in base, sub-base, and wearing surfaces is that it may be placed with conventional equipment. Placement of materials on various jobs has been performed with conventional paving equipment, dump trucks, hand raking, and standard compaction rollers. Another advantage is that the residue material is also easily mixed and handled in the field. Mixing techniques of lime in the residue on different base and sub-base projects varied from handraking to pugmill mixing. The addition of lime to the residue in asphalt mixes may be performed in a dry or slurry form. Slurry addition is done in advance of pugmill mixing, but requires added time and effort as compared to the dry mixing technique. Dry addition of lime of the pugmill is an effective mixing method, though dust control measures must be implemented for this operation, as appreciable amounts of dust can be generated.

It is noted that blending of a natural aggregate with the residue in mixes is necessary to economize on the use of asphalt while at the same time increasing coatability of the mix. Control of the quantities of the components to be blended in the mixtures is of importance. The feeder control for blending of residue in residue/aggregate mixes is sometimes not easily controlled, due to the clogging and clotting capacity of the residue. This was evidenced in the Washington, D.C. section, as the designed residue to aggregate ratio in the mixture was not achieved for the first truckload batches. This situation was corrected at the beginning of placement operations, but not until after some of the mis-proportioned material had been placed in the field.

Stabilized Base and Sub-base

A disadvantage of using incinerator residue in a Chempac type base application is that the material requires a time period of approximately 3 days before placement of the wearing surface may be performed. This is required to dissipate potentially damaging (to the wearing surface) hydrogen gas pressures.

Residue material compacts well in the field, but a determination of optimum moisture for compaction is difficult due to the high absorption of the material.

Incinerator residue/lime material does not appear to perform well under laboratory freeze-thaw testing, though high 180-day compressive strengths of +700 pounds per square inch and good California Bearing Ratio values have been attained for certain products (i.e., Northbrook, Illinois).

Below is the CBR data for the St. Charles, Illinois site (Reference IV-20):

CBR - 10/22/76

<u>Boring Location</u>	<u>0.1 inch Deflection</u>	<u>0.2 inch Deflection</u>
B1	34	27
B2	61	54
B3	74	75

It is noted that variations of the type and quality of the lime in residue mixtures slightly affect the strength of the mixtures. Types of lime used in base applications are calcitic lime, dolomitic lime, flue dust lime, and carbon sludge. Calcitic lime and dolomitic lime are the two most commercially desirable limes. Below is a comparison of these two limes (Reference IV-3):

Results of Compressive Strength Evaluation of Stabilized Base Course Mixtures with Variable Binder Types

1. LIME STABILIZED BASE COURSE

- 1 "as received" residues
- 2 average of 3 specimens cured for 7 days @ 100°F.

<u>Residue Type*</u>	<u>Residue</u>	<u>Crushed Stone</u>	<u>Lime</u>	<u>Type of Lime</u>	<u>Average Compressive Strength** (lbs/in²)</u>
2	45	45	10	Dolomitic	197
				Calcitic	149
2	48	48	4	Dolomitic	197
				Calcitic	164

Wearing Surfaces

Wearing surface mixtures which contain incinerator residue may be batched directly at the asphalt plant as conventional mixes are, although more dust at the mixing plant may be created during the mixing operations than occurs from the mixing of conventional materials.

The residue/aggregate mixtures can perform as well as conventional aggregate mixtures. Marshall design criteria for medium to heavy traffic road surfaces have been met by the test sections placed to date.

There appears to be an advantage for using residue/aggregate mixtures instead of conventional aggregate mixtures with respect to skid resistance. To measure the safety performance of incinerator residue in wearing surfaces, skid resistance tests were made on the control and experimental pavement sections. Two different types of skid resistance tests were used in evaluating the pavements (Reference I-23). The two skid tests used were the BPN and SN 40.*

To evaluate the Harrisburg fused aggregate section of pavement, the SN40 test was used. This test is standard ASTM test E274. The test procedure involves using a specially equipped vehicle which can measure the tractive force of a test tire (horizontally applied force) as compared to a vertical load on the test wheel. On the following page are the results of the Harrisburg fused aggregate section (Reference IV-22).

SKID TEST DATA (SN40)

	<u>Incinerator Residue</u>	<u>Control Section*</u>	
		<u>Passing Lane</u>	<u>Traffic Lane</u>
October 1976	52	40	44
April 1977	53	41	39
June 1977	50	--	--
October 1977	51	33	33
October 1978	46	36	33
September 1979	49	38	35

* Adjacent section (Station 302+50 is an experimental blend of gravel and limestone aggregates.

Skid number is average of three separate passes.

* A BPN (British Pendulum Number) of 55 correlates with a skid number (SN) of 40, as obtained from skid trailer measurements. A skid number of 40 is generally considered a minimum acceptable value for skid resistance of bituminous pavements in Pennsylvania (Reference I-23).

Traffic counts for the Harrisburg fused aggregate section of pavement are as follows (Reference IV-3):

TRAFFIC COUNTS FOR
TEST AND CONTROL
PAVEMENT SECTIONS

	<u>Test Pavement Section</u>	<u>Control Pavement Section</u>	<u>Total</u>
March 15, 1978	9,710	4,917	14,627
July 18, 1978	9,769	3,693	13,462
September 18, 1978	1,482	640	2,122
November 16, 1978	3,713	782	4,495
September 6, 1979	3,742	1,173	4,915

To evaluate the Philadelphia section of pavement, the BPN test was used. The British Pendulum Number (BPN) test is standard ASTM test E303. This test procedure involves measurement of forces on a dynamic pendulum impact device. This test was used due to the inaccessibility of the pavement to the SN40 test vehicle with respect to safety. On the following page is Table IV-8, the results of the BPN testing of the Philadelphia section (Reference IV-17).

As a means of comparison to the traffic count data for the Harrisburg section, the Philadelphia section had a total count of 1,777 vehicles between 8:00 a.m. and 7:00 p.m. as observed on January 7, 1976 (Reference IV-17).

The test results from these two experimental sections indicate that the wearing surfaces with incinerator residue show slightly better skid resistance characteristics than their adjacent control pavement sections. This may be due to differential wearing of the particles of residue and aggregate. The BPN test results of the Harrisburg (Wayne Street) section also showed better skid resistance of the incinerator residue pavement as compared to the control pavement section.

Bituminous Base Mixes

A disadvantage of using incinerator residue in bituminous mixes is that additional asphalt is required in the mix, beyond that required in conventional aggregate mixes.

Incineration facilities often recycle the stack ashes from their burning operations back through the furnace. This results in the production of a more powdery or finely sized residue. If placed in a bituminous mix, this finely sized residue would require a greater amount of asphalt than a coarser sized residue.

Table IV-8

SUMMARY OF SKID RESISTANCE VALUES

PHILADELPHIA TEST SECTION

<u>Date</u>	<u>Sample No.</u>	<u>Mix Type</u>	<u>British Pendulum Number (BPN)</u>	<u>Average BPN Value</u>
March, 1976*	1-1	Control	88	87.0
	1-2		80	
	1-3		93	
March, 1976	1-7	Residue	92	88.3
	1-8		92	
	1-9		87	
	1-10		86	
	1-11		86	
	1-12		87	
September, 1976	2-1	Residue	92	87.7
	2-2		90	
	2-3		82	
	2-4		92	
	2-5		87	
	2-6		83	
September, 1976	2-7	Control	89	84.7
	2-8		80	
	2-9		85	
November, 1976	3-1	Residue	105	92.5
	3-2		111	
	3-3		85	
	3-4		87	
	3-5		80	
	3-6		87	
November, 1976	3-7	Control	88	86.0
	3-8		77	
	3-9		93	

* A total of six control mix specimens were taken. However, no test could be performed on three of the core specimens due to the uneven surface of these specimens.

An advantage of using incinerator residue in bituminous mixes as opposed to lime stabilized mixes is that the asphalt tends to bind or encapsulate the residue particles, thus diminishing detrimental leachate characteristics.

ENVIRONMENTAL FACTORS

It is considered that incinerator residue base materials are more economically attractive than fused materials at present. The primary environmental considerations related to incinerator materials in construction applications (base/lime base) are leachate characteristics. Leachate production and composition are related to solubility, permeability, and chemical composition of the residue.

Generally, water penetration through incinerator residue is relatively low, as the permeability of residue may be considered equivalent to that of a silty sand or fine sand. The toxic substances contained in residue materials are trace metals including arsenic, cadmium, copper, and lead. With respect to these toxic substances, the Environmental Protection Agency has established a guideline for Safe Drinking Water Standards. A waste material is considered hazardous if the extract from the material (obtained by the EPA extraction procedure) has a concentration of any constituent greater than one hundred times the established drinking water standard.

Permissible concentrations of chemicals are listed in the drinking water standard established by the U.S. Public Health Service include (Reference IV-24; also see Summary on Page I-24).

It was reported in leachate testing performed during 1980 by the Pennsylvania Department of Transportation, as well as by the Port Authority of New York and New Jersey, that concentrations of chemicals in excess of one hundred times the drinking water standard were measured on tested samples of incinerator residue. The samples tested by the Pennsylvania Department of Transportation came from an incinerator located in Central Pennsylvania (Reference IV-25). The samples tested by the Port Authority of New York and New Jersey came from two resource recovery plants located in the northeastern region of the United States (Reference IV-26). It was noted that a reported concentration of lead in the Port Authority report was greater than three hundred times the drinking water standard.

The material from which these samples were taken would be classified as hazardous by the Environmental Protection Agency. The use of this material, "as is," in a construction fill application would be highly restricted.

There is the possibility, however, that this material may be used in a bituminous base application. In the bituminous base application, the leachate from the residue may not be deemed as hazardous due to the encapsulating effect of the asphalt on the residue (i.e., restricting permeability, etc.).

In addition to the leachate problem, the potential of having pathological wastes make their way into the refuse stream (and residue) is an additional complication with respect to use of the residue as a highway construction material. Many existing incineration facilities such as Harrisburg, Pennsylvania are authorized to burn hazardous materials including chemical wastes and hospital wastes. If the temperatures during the incineration process are not maintained high enough to destroy the pathogens (in hospital wastes) and control chemicals, serious health problems of those in contact with the materials would result.

Appreciable amounts of these specialized wastes can be burned at incinerators licensed to do so. In addition to the refuse burned in conjunction with the hazardous materials, residual effects of the burning of these hazardous materials on subsequently burned refuse are also sources of potential problems. Especially tight quality control would be a necessity in any attempt to use the residue from these specially licensed incinerators in construction applications.

Air pollution control poses an additional environmental problem with respect to using incinerator residue in highway applications. In addition to the air quality problems at the incineration site, dust generation at the asphalt plants (for bituminous base applications) occurs. It is noted that air pollution problems at incineration sites have also been experienced at the newer resource recovery facilities, as evidenced at the Hempstead, New York plant.

Aside from environmental drawbacks, the political system should be recognized as a major factor which influences the use of incinerator residue in construction applications. General problems and restrictions which are inherent in the political processes regarding the use of residue deal with budgeting, length of personnel employment, coordination with various departments, and existence of priority programs.

The Resource Conservation and Recovery Act of 1976 requires existing landfill sites to be upgraded to acceptable governmental specifications or be closed. If strict adherence to this Act is maintained, the economics of this procedure (of upgrading) will most likely be the most important factor with respect to municipal solid waste management programs. Any amendments to this act or followup legislation will be of significance to the direction of current waste disposal operations.

ECONOMICS

At this time, a detailed analysis of the economics of incinerator residue in construction applications (residue vs. virgin aggregate) does not provide the means to realistically judge the most economic alternative. The reason for this is that incinerator residue is not being presently widely used in the aggregate market. Supported by the fact that residue is not being used in the current market, and that there has been a considerably limited number of field applications to date; exact cost comparison figures for in-place materials using incinerator residue cannot be ascertained. Hidden and undetermined costs involved with the use of incinerator residue on a large scale basis include dollar costs in the following areas: provisions for control of degree of burnout; provisions for monitoring of residue to be used including leachate testing, equipment and maintenance costs, transportation costs, and mixing and preparation costs. For example, long range effects on machinery that handles and processes residue for construction applications has not been observed, as the machinery used in the past has not been operated for sustained periods of time. Detrimental long range effects may relate to unanticipated costs in the following areas: additional cleaning; part replacement from excessive wear; or even modification of equipment.

Although research into the economics of using incinerator residue as a construction material has begun (Reference IV-2), it should be realized that research analysis can provide only projected cost figures. Until a detailed breakdown analysis on a minimal number of specific projects is performed, actual representative costs of using incinerator residue as a construction material cannot be accurately ascertained. However, Reference IV-2 does provide a basis for developing cost categories and in determining approximate costs.

OTHER APPLICATIONS

Incinerator residue has been tested for applications other than direct roadway usage. This testing includes incinerator residue as a structural fill, as a soil cover substitute in a lined sanitary landfill, as a soil stabilizer, and in portland cement concrete. Incinerator residue has also been used as a wearing surface on "off highway" trails (i.e., bicycle and foot paths).

In portland cement concrete mixes, a volume expansion of the material is caused by the reaction of the aluminum in the residue and the cement in the mixture. Accompanying this volume expansion is a loss of strength. In these mixes, high strengths are not attainable (even where the same proportions of aggregate and residue are used) as the inherent strength of the residue is a limiting factor.

Lime slurring of the residue can eliminate some of the aluminum cement reaction, but compressive strengths comparable to those of conventional mixes are still not achieved. It is noted that pyrolysis residues in portland cement concrete have better strength gains than the other types of incinerator residues in these mixtures.

In use as a fill material, the leachate from incinerator residue is considered as a negative factor. Incinerator residue does compact well though, and can serve as an adequate fill material.

MISCELLANEOUS

Solid waste is now considered as a raw material and source of energy. Energy recovery systems appear to be an area upon which emphasis will be placed. Working energy recovery systems are already a reality.

In Europe, resource recovery and incineration systems are largely based on optimum design principles, as opposed to minimum cost principles. A justifying factor in this type of analysis relates to population density. In the United States, cost principles are a major factor in design analysis.

In this country, good burnout, energy recovery, and excellent air pollution control have been reported by such facilities as Chicago's 1,600 tons per day steam generating incinerator. "Resource recovery plants in northwest Chicago, Ames, Iowa, and Nashville are already considered financially successful, but the first structured to show a profit that has actually done so is the mass-burn waterwall boiler system in Saugus, Massachusetts. Operated by a joint venture including Wheelabrator-Frye, Inc., Hampton, New Hampshire, the plant showed a profit in 1979, but revenues included a Federal subsidy from DOE's entitlement program. The Saugus plant is the first to have received these funds" (Reference IV-27).

Current problems with regard to growth and expansion in the area of resource recovery in this country vary. In New York City, for example, a New York State law which prohibits cities from contracting with one entity and giving that entity full responsibility for a job, is the current resource recovery project stopper. A bill is being considered by the state legislature which may give the city relief. In some cities such as Detroit, financing troubles are the biggest project stoppers. The solution to these financing problems are as yet undetermined.

In addition to financing and political problems, some existing resource recovery facilities have had technological difficulties. For example, the Hempstead, Long Island plant has "been plagued by odor problems, labor strife, contractual disagreements...and even by the discovery of traces of dioxin in stack emissions. ...Repairs have included doubling the size of the ventilation system, rebuilding the odor control system, replacing a pneumatic fuel feed system and installing a new ash handling system" (Reference IV-27).

Despite current drawbacks, resource recovery systems appear to be along the most desirable path of future projected incineration processes. Cities with current waste disposal problems such as Harrisburg, have developed their own remedies for potential solutions. Harrisburg's solution involves construction of a separate metals recovery and screening separation facility to function in conjunction with their existing steam generation incinerator (Reference IV-28). Harrisburg's solution also involves the use of the residue, produced from the combined incineration process system, in limited situations such as roadway patching and pothole filling. Harrisburg has no current plans to use the residue from their new program on a large scale basis. In any event, an evaluation of the new program residue will be necessary prior to any type of re-use application.

Environmental factors notwithstanding, the present annual amount of incinerator residue produced as compared to the national annual production of aggregate used for highway construction, is approximately 0.2 percent and is not large enough to present a serious business conflict within the highway industry. Some factors which may affect the price and supply of virgin aggregates may be surface mine reclamation laws, air pollution controls, and blasting and safety regulations. These may make the use of substitute aggregates such as incinerator residue more attractive than at present. Disinterment, or the unearthing of incinerator residue, may also become increasingly attractive at some future time.

United States Government patents on certain mixtures which contain incinerator residue and other "waste materials" have been issued. The use of patented products, such as "Chempac," have dated back as far as 1962.

In an attempt to achieve an environmentally balanced condition, research and investigation projects are currently being sponsored by numerous governmental agencies. With the passing of the Resource Conservation and Recovery Act, further investigation and research especially in the area of the individual incineration/recovery plant residue characteristics, should be continued.

SUMMARY

Annual production of municipal incinerator residue in the United States is approximately 2 million tons. This represents only approximately 0.5 percent of the annual production of hot mix asphalt paving in the United States.

Non-uniformity of incinerator residue has precluded it from being used on a large scale in construction applications to date. Quality control, including environmental testing, should be exercised on all samples scheduled for construction applications. Extremely tight controls should be exercised over samples from municipal incinerators which are licensed to burn chemical and hazardous wastes.

Strict adherence to the Resource Conservation and Recovery Act of 1976 will have a substantial impact on existing refuse disposal programs.

The current focus in the waste management field is on resource recovery plants. The residue from these plants is not well suited for construction applications. It appears that the number of municipally operated incinerator plants, which produce residues acceptable for construction applications, will most likely not substantially increase.

Properly processed incinerator residue can be used in construction applications.

Monitoring of residue sources from municipal incinerators, as well as from privately owned incinerators and resource recovery plants, should be continued.

Part IV

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Appendix A

SUPPORT DOCUMENTATION - POWER PLANT ASH

This Appendix contains copies of specifications, patents, and other related documents cited in Chapter 5 of Volume 1 of this report. At the end of this Appendix there is also a list of relevant ASTM specifications. The reader is referred to the appropriate standard ASTM documents for the complete specification.

Memorandum

FEDERAL HIGHWAY ADMINISTRATION
Washington, D.C. 20590

DATE: JUN. 22 1977

In reply
refer to: HHO-33

SUBJECT: Use of Fly Ash

FROM: Associate Administrator for
Engineering and Traffic Operations

TO: Regional Federal Highway Administrators
Regions 1 - 10

The need to effect measures to conserve our resources whenever possible in all facets of our private and public endeavors has been well publicized. The Federal Highway Administration and the State highway agencies can be very proud of our joint responsiveness to the national goals and objectives as articulated by both the executive and legislative branches of our Government. However, we can anticipate being called upon further to account for positive conservation actions in highway construction and maintenance activities.

Considerable research and experimentation has been conducted on conservation strategies in highway construction and maintenance. The use of waste materials in areas where they are readily available ranks high in conservation payoff. In addition to the potential for energy conservation, the use of such materials would have the benefits of preserving land use, ridding the environment of a waste product, conserving the materials for which they are substituted, and possibly providing a more economical end product with no loss in performance.

One waste material, fly ash, is presently in abundant supply in many areas of the country. Fly ash is a waste product which is collected from the stack gases from coal burning power plants. In 1975, some 42.3 million tons of fly ash were produced while only 4.5 million tons were utilized. The costs of disposing of the remainder of this fly ash in stockpiles and ponds is passed on to the consumers of electrical power. Considering the present condition of the petroleum industry, it is likely that coal will be the primary source for power generation and the production of fly ash will increase.

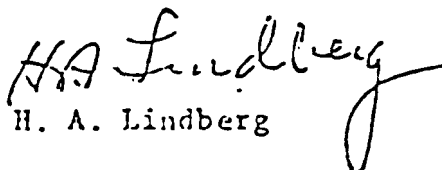
The use of fly ash, either alone or in combination with lime or cement, has been demonstrated to be a viable construction material, soil modifier, and stabilizer for all elements of the pavement structure up to and including base courses for bituminous pavements. Much has been

written about the use of fly ash in highway work. The two most pertinent documents are Transportation Research Board's (TRB) National Cooperative Highway Research Program (NCHRP) Synthesis 37, "Lime-Fly Ash-Stabilized Bases and Subbases" and FHWA Implementation Package 76-16, "Fly Ash A Highway Construction Material." Both of these publications contain comprehensive references.

In recent contacts with industry representatives (particularly the fly ash industry), we were advised that there are many areas where fly ash is readily available but that its use is not being realized by highway agencies. Their expressed concern was particularly that cement-stabilized fly ash and lime-stabilized fly ash mixes were not being considered for base courses and subbases in flexible pavement systems. This is in contrast to other areas where such consideration is given.

Therefore, we request that you bring this matter to the attention of State highway agencies and ask that this material be given full consideration in the pavement selection process in those States where fly ash is available. We further request the appropriate States which are not experienced in the use of cement-fly ash or lime-fly ash in bases and subbases be strongly encouraged to incorporate experimental sections of this material on flexible pavement projects.

We believe this matter is of sufficient importance as to warrant it being discussed with the highest levels of the State highway agencies. The Washington Headquarters staff is available to assist the field offices if deemed desirable.


H. A. Lindberg



U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT

Use of Fly Ash in Portland Cement
Concrete and Stabilized Base
Construction

FHWA NOTICE

N 5080.4
January 17, 1974

1. PURPOSE. To direct the attention of Federal Highway Administration (FHWA) field offices and highway agencies to methods which have been approved by FHWA for substitution of pozzolanic materials, such as fly ash, for a portion of the cement for concrete pavements and structures, and in lieu of cement for stabilization of soils and bases by combination with lime.
2. BACKGROUND
 - a. In the current year, spot shortages of portland cement have occurred in various parts of the country on highway work. The opinion of those knowledgeable in the cement industry is that these shortages are likely to increase in number in the near future and may become a general condition for some years to come. The problem is aggravated by the lack of incentive to increase production because of lack of capital under existing market conditions and the high cost of renovating existing plants to meet new environmental controls.
 - b. If a general cement shortage becomes a reality, it may be necessary to take the additional step of substituting acceptable pozzolan materials for a portion of the cement in portland cement concrete pavements and structures, and as an agent for the stabilization of soils, subbases, and bases. A readily available pozzolan is fly ash, a waste product obtained from the burning of pulverized coal. The use of this fly ash in construction would contribute to the alleviation of environmental problems caused by storage and accumulation of the material.
 - c. Fly ash has been used extensively for years in mass concrete for such structures as dams. In Europe large amounts are routinely used in highway construction. Except for special concretes, such as for grouting or pumping, fly ash has not been used very much in highway construction in this country. One notable exception has been the State of Alabama, where a substantial supply of fly ash has made it feasible to require

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Mr. [illegible]
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[illegible]

Mr. [illegible]
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[illegible]

the use of fly ash as a substitute for part of the cement in pavement concrete, as well as its optional use in other classes of concrete.

- d. The minimal use in this country possibly results from several factors, such as: handling and mix control details, especially when air entrainment additives are used; lower initial concrete strengths when fly ash is substituted in the field for part of the cement; variations in the quality of fly ash, depending on sources and coal types; and possible pollution effects when incorporating fly ash in portland cement concrete mixtures. These factors, which apply primarily when fly ash is used directly as an admixture to concrete, can be adequately controlled by the use of proper design, handling, and control procedures with fly ash conforming to ASTM C618, Type F specification. When fly ash is added to concrete as an ingredient of the cement, as in Type IP cement under AASHTO Specification M240, the factors mentioned above should not pose any greater problems than when normal portland cement is used without fly ash.
- e. There has also been a reluctance to use fly ash in paving concrete because of uncertainty concerning the scaling resistance of such concrete when subjected to deicing salts. Available laboratory data indicates that replacing part of the cement with fly ash tends to lower the resistance of concrete to scaling, although there is no evidence that fly ash concrete is inherently susceptible to scaling under field conditions. In this connection, it would be desirable to avoid late season paving with fly ash concrete where salt is likely to be applied before appreciable aging of the concrete has taken place, except on an experimental basis. This precaution is deemed desirable since the full potential of fly ash as a cementing agent develops slowly over time. Additional experimental work, either in the laboratory or under field conditions, is encouraged in order to more properly define the salt scaling problem, if indeed this problem exists.
- f. Generally, the factors noted above are more than offset by such advantages of fly ash use as greater ultimate concrete strengths, increased resistance to sulfate attack by corrosion agents, reduced heat liberation (less heat of hydration), reduced permeability, reduced concrete expansion due to alkali-silica reaction, decreased segregation in concrete mixtures and greater mixture workability.

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- g. Attachment "A" contains a short bibliography of the very extensive number of reports and publications on the use of fly ash in portland cement concretes and as a stabilizer in lime-fly ash-soil combinations. It indicates that the technology is well researched and developed and is ready to be put to immediate use.

3. ACTION

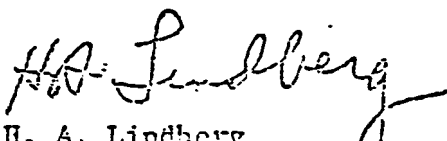
- a. In view of an anticipated general cement shortage and the potential value of fly ash in lowering concrete costs, the States should be encouraged to allow substitution of fly ash for cement on a partial basis as an alternate whenever feasible. Tests have shown that replacement of cement with fly ash of up to 30 percent by weight has been satisfactory and no quality losses were noted. It has also been shown that replacement of cement with fly ash of the order of 10 percent to 15 percent can be made without loss of concrete strength at 28 days of age. These figures apply to situations where the fly ash is substituted in the field for part of the cement. The appropriate specification to refer to is "ASTM C618, Type F - Specifications for Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete."
- b. In some areas of the country, cement plants produce Type IP cement wherein fly ash or other pozzolanic material is inter-ground or otherwise blended directly with portland cement. The generally finer grind of this cement produces a blended product having about the same strength characteristics as a Type I cement. The appropriate specification is "AASHTO M240 - Specifications for Blended Hydraulic Cements." If available highway agencies will probably find the use of this cement to be a more satisfactory means of using fly ash in concrete than as an admixture from the standpoint of handling and product control.
- c. In the case of stabilization of soils and subbases, there is perhaps an even greater potential for savings in cement by the substitution of lime-fly ash as the stabilizing agent. Mixtures of this type have been used in years past by a number of agencies in construction of highways and is based upon the centuries old experience of the additional strengths obtained by the addition of lime and volcanic cinders to soils. Use of these lime-fly ash mixtures has not been very extensive due to

-more-

the ready availability in the past of relatively inexpensive cements. The States should be encouraged to allow the use of lime-fly ash combinations as either the specified stabilizing agent, or as a permissible alternate to cement in situations where this type of stabilization would ordinarily be used and appropriate design parameters of strength and durability can be satisfied.

d. Approaches by industry representatives to minimize impending shortages which we support are:

- (1) Promote closer coordination between suppliers and contractors. The approach of placing firm orders for cement needs well in advance of actual delivery will be particularly helpful to the industry in reducing or even eliminating the spot or temporary shortages which occur. There are often areas where surplus cement exists at the same time as a shortage elsewhere.
- (2) Allow the use of different brands of cement on a project. Except for architectural considerations where different brands may produce different colored concretes, FHWA has no objections to the use of different brands meeting project requirements. Generally, such cements should be used in different parts of the concrete construction and should not be intermixed.
- (3) Allow the use of foreign cements. This practice is acceptable to FHWA since such cements must be subject to the same requirements for acceptance as specified for United States cements, such as the standard specifications for portland cement, ASTM C150 or AASHTO M85. Foreign cements would probably have to be sampled from a ship, and the most appropriate method would be by tube sampling from distributed points of the shipment. Only by such a method can the entire depth of the cement be sampled while still in the ship. If this is not feasible, then sampling can be done from the conveyor as the cement is being unloaded from a ship into a silo or other container.



H. A. Lindberg
Associate Administrator for
Engineering and Traffic Operations

Attachment "A"



DEPARTMENT OF TRANSPORTATION

CIRCULAR LETTER

SUBJECT		DATE
Changes to Pavement Design Criteria		April 28, 1976
EXPIRES	RESCINDS	
April 30, 1978	C-2779-2	

TO: CENTRAL OFFICE
ENGINEERING DISTRICTS
ENGINEERING CONSULTANTS

Research Project No. 71-7, "An Evaluation of Pennsylvania's Flexible Pavement Design Methodology" is now complete. Results from this research project coupled with results from other projects and research conducted by the Bureau of Materials, Testing and Research have indicated a need to change portions of our pavement design criteria. Recent truck weight studies have indicated that the 18 kip equivalent factors for various types of trucks considered in design should be revised. Annual maintenance costs and the interest rate to be used in the present worth analysis for type determination have been studied and are revised.

The following criteria shall supersede the applicable portions of Chapter 14 Design Manual Part 2 until such time this criteria is incorporated into the Manual.

Form D-4332, page 2, which is shown as page 2.14.11 in the Design Manual, contains the 18 kip equivalents for the various types of trucks considered in pavement design. The following equivalents shall supersede those shown on the form:

	<u>Rigid</u>	<u>Flex. and Mod.-Flex.</u>
2 Axle - 6 Tire	.24	.24
3 Axle SU	1.15	.82
3 Axle ST	.43	.44
4 Axle ST	.90	.76
5 Axle ST	1.59	1.00

Existing supplies of Form D-4332 should be used until exhausted. The old factors should be crossed out and replaced by the above factors.

→ The structural coefficients (relative strength factors, page 2.14.29) for Aggregate - Cement and Aggregate - Lime - Pozzolan base courses shall be 0.40. The structural coefficients for all other base courses shall remain as they are.

When the economic analysis or engineering decision indicates that a modified-flexible pavement structure should be used and the design was completed for a bituminous concrete or stabilized aggregate base course, the project bid proposal shall incorporate an alternate of Bituminous Concrete Base Course or Aggregate - Cement Base Course or Aggregate - Lime - Pozzolan Base Course. As an example, a pavement was designed to be $1\frac{1}{2}$ inches of ID-2 Wearing Course on $6\frac{1}{2}$ inches of Bituminous Concrete Base Course, the bid proposal would read as follows:

EITHER

Bituminous Wearing Course, ID-2
 $1\frac{1}{2}$ inch Depth, SRL - (H,M,G,L)

AND

Bituminous Concrete Base Course, $6\frac{1}{2}$ inch Depth

OR

Bituminous Wearing Course, ID-2
 $1\frac{1}{2}$ inch Depth, SRL - (H,M,G,L)

AND

Bituminous Binder Course, ID-2
 $1\frac{1}{2}$ inch Depth

AND

Aggregate - Cement Base Course, 5 inch Depth

OR

Bituminous Wearing Course, ID-2
 $1\frac{1}{2}$ inch Depth, SRL - (H,M,G,L)

AND

Bituminous Binder Course, ID-2
 $1\frac{1}{2}$ inch Depth

AND

Aggregate - Lime - Pozzolan Base Course, 5 inch Depth

The slight difference in Construction Numbers that would be obtained with these alternate designs is not considered significant. It is recognized that the alternate bidding described above will not be possible with all designs. When the alternate bidding is not feasible the reasons should be documented and included with the pavement design file.

The previous design approach to minimizing the effects of frost action was to replace a portion of the frost-susceptible soils with non-frost-susceptible materials consisting of surface, base, subbase and modified subbase materials. Available data now indicates that providing thicknesses of subbase over approximately 12 inches adds minimal increases in strength and does not substantially retard the depth to which freezing temperatures penetrate the subgrade.

More emphasis is now being placed on providing adequate pavement systems to withstand the structural distress imposed by the frost phenomena of heaving and subgrade softening. The following is a revised procedure for the structural design of Flexible and Modified-Flexible pavements:

The Required Structural Number (SN) is determined as described in Chapter 14. The pavement is designed so that the Construction Number (CN) is equal to or slightly greater than the Required SN. If the resulting total pavement thickness is equal to or greater than the Required Total Thickness determined from Figure 1, no further design is required. If the total pavement thickness is less than the Required Total Thickness, the difference, in inches, is multiplied by .10 per inch and the resulting value is added to the required SN to determine the Adjusted SN. The pavement structure is redesigned so that the CN is again equal to or slightly greater than the Adjusted SN. In doing so, the subbase course should have a maximum depth of 12 inches. Total pavement thicknesses resulting from this procedure, which are less than the Required Total Thickness from Figure 1 are considered adequate.

Rigid pavement design procedures shall remain as described in Chapter 14 with the exception that the depth of subbase or combination of subbase and modified subbase should not exceed 12 inches.

The above procedures do not preclude the use of additional granular material (subbase or modified-subbase) or other design and construction techniques as recommended by the District Soils Engineer or in the Soils Report.

The table on page 2.14.38 shall be revised as follows:

	<u>Rigid</u>	<u>Flexible</u>	<u>Mod. Flexible</u>
Interest Rate	6%	6%	6%
Annual Maintenance Cost Per Lane Mile Per Year	\$325	\$500	\$400

pavement designs for projects currently under design should be reviewed for compliance with this new criteria. Where there is a total thickness change of 4 inches or less it will not be necessary to change individual cross-sections, only the Typical Sections. Exceptions to the use of this new criteria on any specific project shall be documented as to why it cannot be used and this documentation shall be forwarded to the Central Office, Bureau of Design.

This criteria shall be used for all pavement designs approved subsequent to the issue date of this Circular Letter and for all projects scheduled for letting after December 31, 1976.

If there are any questions concerning this revised criteria please contact the Design Division, Bureau of Design.



David C. Sims, P.E.
Deputy Secretary for
Highway Administration

430/DAF/1ckg

STATE AND/OR FEDERAL SPECIFICATIONS

State of Illinois
Department of Transportation

SPECIAL PROVISION
FOR
POZZOLANIC BASE COURSE, TYPE A

Effective April 1, 1964
Rev. April 1, 1980

DESCRIPTION. This item shall consist of a base course composed of lime, pozzolan, aggregate and water, plant-mixed and constructed on a prepared subgrade, in accordance with the requirements of this special provision and applicable portions of the Standard Specifications for Road and Bridge Construction to the lines, grades, thicknesses and cross sections shown on the plans or established by the Engineer.

MATERIALS. All materials shall meet the requirements of the following Articles of Section 700 - Materials:

Item	Article
(a) Water	702.01 - 702.02
(b) Aggregate (Note 1)	704.05
(c) Lime	718.06
(d) Pozzolan (Note 3)	718.19
(e) Water Reducing Admixture (Note 2)	718.13
(f) Sand Cover	703.01(a), 703.01(e)

Note 1. The gradation requirements shall be as follows:

Passing 1 1/2 inch sieve	100%
Passing 1 inch sieve	90-100%
Passing 1/2 inch sieve	60-100%
Passing No. 4 sieve	40-70%
Passing No. 40 sieve	0-25%
Passing No. 200 sieve	
(gravel)	0-10%
(crushed stone and slag)	0-15%

Alternate gradations will be considered provided mixture design data is furnished to the Department for analysis. Specialized durability testing may be required for unique aggregate gradations or proposed combinations of materials for which the Department does not have historical performance data. Production gradation tolerances shall be as stated in Articles 703.01 and 704.01. The coarse or fine aggregate gradation which most nearly resembles the proposed gradation will be utilized for production tolerances.

Boiler Slag. In addition to the aggregates permitted in Article 704.05 boiler slag may be used. The slag shall be wet-bottom boiler slag produced as a by-product of a power plant burning pulverized coal. The slag shall be composed of hard durable particles and shall be free of excessive or harmful amounts of foreign substances. Boiler slag in an oven dry condition shall meet the following gradation requirements.

Passing No. 4 sieve	80-100%
Passing No. 10 sieve	55-90%
Passing No. 40 sieve	0-25%
Passing No. 200 sieve	0-10%

Note 2. A water reducing admixture may be used if permitted by the Engineer. No adjustments will be made in the required lime and pozzolan contents for this addition.

Note 3. A maximum of 15% of the gradation samples may be below the Minimum Percent Passing the No. 10 sieve. No individual test shall be less than 65% passing the No. 10 sieve.

The Contractor shall assure the Department that sufficient quantities of inspected materials are available to complete the work.

SAMPLES. The Contractor shall at his own expense, submit to the Engineer a minimum of 25 pounds of lime, 50 pounds of fly ash, and 100 pounds of the aggregate which he proposes for use in the pozzolanic mixture. The lime, when sampled, shall immediately be placed in a sealed container and shall be kept sealed. Samples shall be furnished at least 60 days prior to the construction of the pozzolanic base course. The samples as submitted will be tested for acceptance of materials and also to determine whether or not they will produce a satisfactory mixture and will be used to determine preliminary proportions for the mixture composition.

EQUIPMENT. The equipment shall meet the requirements of the following Articles of Section 800 - Equipment.

Item	Article
(a) Three-wheel Roller (Note 1)	801.01
(b) Tandem Roller (Note 1)	801.01
(c) Tamping Roller (Note 2)	801.01
(d) Pneumatic-tired Roller	801.01
(e) Trench Roller (Note 3)	801.01
(f) Vibratory Roller	801.01
(g) Pozzolanic Aggregate Mixture Equipment	804

Note 1. Three-wheel rollers and tandem rollers shall weigh from 6 to 12 tons and shall have a compression on the drive wheels of not less than 190 pounds nor more than 400 pounds per inch width of roller.

Note 2. In addition to the requirements of Article 801.01, the tampers shall be long enough to penetrate within one inch of the prepared subgrade on the initial rolling.

Note 3. Trench rollers shall be self-propelled and shall develop a compression of not less than 300 pounds nor more than 400 pounds per inch of width on the compaction wheel.

GENERAL CONDITIONS. The pozzolanic aggregate base course shall be constructed between April 15 and the transition date indicated in TABLE A and only when the air temperature in the shade is above 40° F. The Contractor shall submit samples from July production representative of those proposed for use under this provision no later than August 15. The Contractor shall request, in writing, specific mixture design modifications for extension of the transition dates in TABLE A. The Department may extend the construction season beyond the transition dates indicated. Approval will be based on consideration of the cured strength development characteristics as determined by the Department's test procedure and the predicted curing degree days. The amount of pozzolanic aggregate base course constructed shall be limited to that which can be surfaced during the current construction season. No mixture shall be deposited on a frozen or muddy roadbed.

TABLE A TRANSITION DATES FOR POZZOLANIC AGGREGATE BASE COURSE

<u>Transition Date</u>	<u>Required Compressive Strength, p.s.i. (14 Day Cure @ 72 F) 1/</u>	
	<u>Northern Zone^{2/}</u>	<u>Southern Zone^{3/}</u>
Sept. 15	700	650
Oct. 1	850	700
Oct. 15	950	850

1/ The transition date must be verified by samples, representing July production, submitted to the Department by August 15 for testing.

2/ Districts 1, 2, 3, 4.

3/ Districts 5, 6, 7, 8, 9.

COMPOSITION OF POZZOLANIC AGGREGATE BASE COURSE MIXTURE. The lime, pozzolan, and aggregate shall be proportioned within the following approximate limits on a dry weight basis:

APPROXIMATE PERCENT BY WEIGHT
OF OVEN DRY AGGREGATE

<u>Ingredient</u>	<u>Gravel, Crushed Stone, Crushed Slag or Aggregate Blend</u>	<u>Boiler Slag</u>
Lime	2 to 6	2 to 6
Pozzolan	9 to 20	18 to 40
Aggregate	74 to 89	54 to 80

The actual proportions of lime, pozzolan, water, and aggregate will be set by the Engineer before work begins and will be based on tests conducted on mixtures composed on samples of the constituent materials furnished by the Contractor. The Department's design method will be utilized (available on request). The composition of the mixture will be such that when molded into cylinders (as prescribed in the Department's design method) and cured at $72^{\circ}\text{F} \pm 2^{\circ}\text{F}$ (14-day cure), the cylinders will have a minimum average compressive strength of 600 p.s.i. with no individual test below 500 p.s.i.. The minimum lime content shall be 3.5% or 3.0% plus one standard deviation based on ten (10) or more tests of lime content (by the Department's titration procedure) made by the Contractor on production samples from his plant. The right is reserved by the Engineer to make changes in proportions during the progress of the work as he may consider necessary.

MIXING. Mixing shall be accomplished in accordance with Article 218.15 except the control of the mixture shall be of such accuracy that the proportions of the mixture based on total dry weight will be maintained within the following tolerances:

- Lime ± 0.5 percent by weight
- Pozzolan ± 1.5 percent by weight
- Aggregate ± 2.0 percent by weight.

If a water reducing admixture is used, the automatic dispensing system shall be capable of continuously introducing the desired quantity of admixture within the range of ± 0.03 gallons per minute.

PLACING AND COMPACTING AND FINISHING POZZOLANIC AGGREGATE BASE COURSE MIXTURE. The pozzolanic base course mixture shall be constructed in layers not less than 4 inches (compacted) in thickness. If tests indicate that the desired results are being obtained, the compacted thickness of any layer may be increased to a maximum of 10 inches. When the thickness specified is more than 10 inches the mixture shall be placed in 2 or more approximately equal layers. Each layer shall be deposited, full width directly on the prepared subgrade or on the preceding layer of compacted mixture with a mechanical spreader or spreader box of a type approved by the Engineer. Where the mixture must be placed in more than one layer, the previous layer shall be maintained in a moistened condition until the succeeding layer is placed. After having been tested for density and approved by the Engineer, the previous layer shall be dampened with water, if required by the Engineer. The second layer must be placed the same day as the first layer. When placed, the pozzolanic base course mixture shall be free from segregation and shall require minimum blading and manipulation.

The pozzolanic base course shall be compacted to at least 97% of maximum density except that if more than one layer is required the first layer shall be compacted to 97% of maximum density and succeeding layers shall be compacted to 100% of maximum density. The maximum density will be determined in accordance with AASHTO T-180, Method C, except that the five lift requirement is replaced with three lifts.

The density of each layer of the compacted base course will be determined by the Engineer for compliance with these specifications in accordance with the following test methods, AASHTO T 238 - Method B and AASHTO T 239, AASHTO T 191, or by other methods approved by the Engineer. If these tests indicate that the layer does not comply with the density requirements, the condition shall be corrected or the material replaced to meet these specifications.

All pozzolanic base course mixture shall be placed and compacted the same day it is mixed. Compaction must be completed as soon as possible after the mixture is placed on the grade.

In constructing the top layer, the grade shall be kept at sufficient height so that the top surface, when compacted, will be at or slightly above grade, rather than below grade. Finish grading shall be accomplished by removing excess material followed by recompaction by rolling. In the event that low areas occur, they shall be reconstructed to the satisfaction of the Engineer.

If any subgrade material is worked into the pozzolanic base course mixture during the compacting or finishing operations, all pozzolanic base course mixture within the affected area shall be removed and replaced with new material. The Engineer may restrict hauling over partially completed work after inclement weather or at any time when the subgrade is soft and there is a tendency for the subgrade material to work into the pozzolanic base course.

If for any reason construction operations are delayed or suspended and the Engineer orders any loose or uncompacted material removed and disposed of, the Contractor shall perform this work at his own expense. No pozzolanic base course may be salvaged.

CURING. After the pozzolanic base course mixture has been constructed, the surface shall be kept continuously moist until the bituminous curing cover is applied. The bituminous curing cover shall be applied no later than 24 hours following final compaction unless in the judgement of the Engineer, it should be delayed. The materials and application of the curing cover shall be in accordance with the requirements of Article 303.14 for bituminous protective cover.

Surface course paving may proceed after the curing cover has been applied and cured to the satisfaction of the Engineer. At least 14 hours shall elapse between the time the curing cover material is applied and paving begins.

CONSTRUCTION JOINTS AND MAINTENANCE. At the end of each day's construction, a straight transverse construction joint shall be formed by cutting back into the completed work to form a vertical face. Damage to completed work shall be avoided. The pozzolanic base course mixture shall be constructed and finished full width each day without longitudinal joints.

The Contractor shall maintain, at his own expense, the entire base course in a manner satisfactory to the Engineer until the pavement has been completed. Maintenance shall include immediate repairs of any defective or damaged portions of the base course. Repairs or replacements shall be made in such a manner as to insure restoration of a uniform surface and durability of the portion repaired or replaced. The Contractor shall also remove and replace at his own expense any pozzolanic base course mixture which is unsatisfactory due to its being placed over excessively wet or otherwise unstable subgrade; damaged by rain, freezing or other climatic conditions; damaged by traffic; or which is unsatisfactory due to failure to comply with any of the requirements specified herein.

FINISHING OF POZZOLANIC BASE COURSE. Prior to constructing the next layer of pavement the entire width of base course shall be brought to true shape by mechanical means and shall be tested for crown and elevation by means of a template.

The Contractor shall have at all times enough base course prepared ahead of the paving location so that paving will be a continuous operation.

If required by the Engineer, the base course shall be sprinkled with water ahead of placing the surface.

COMPENSATION

TOLERANCE IN THICKNESS. It is the intent that the base course shall be constructed to the nominal thickness shown on the plans. Thickness determinations shall be made at such points as the Engineer may select. When the constructed thickness is less than 90 percent of the nominal thickness, it shall be brought to nominal thickness by the addition of the applicable mixture or by removal and replacement with new mixture at no additional cost. However, the surface elevation of the completed base course shall not exceed by more than 1/4 inch the surface elevation shown on the plans or authorized by the Engineer.

METHOD OF MEASUREMENT.

- (a) Contract Quantities. When work is constructed essentially to the lines, grades or dimension shown on the plans and the Contractor and the Engineer have agreed in writing that the plan quantities are accurate, no further measurement will be required and payment will be made for the quantities shown in the contract for the various items involved except that if errors are discovered after the work has been started, appropriate adjustments will be made.

When the plans have been altered or when disagreement exists between the Contractor and the Engineer as to the accuracy of the plan quantities, either party shall, before any work is started which would affect the measurement, have the right to request in writing and thereby cause the quantities involved to be measured as hereinafter specified.

- (b) Measured Quantities. Stabilized base course of the thickness specified will be measured in place and the area computed in square yards completed in accordance with this specification. The width for measurement will be from outside to outside of the top of the final layer of the completed work as shown on the plans or as directed by the Engineer. The liquid asphalt for the curing coat and any sand cover required will not be measured for payment, but shall be considered as incidental to the contract.

BASIS OF PAYMENT. This work will be paid for at the contract unit price per square yard for POZZOLANIC BASE COURSE of the thickness specified.

POZZOLANIC-AGGREGATE MIXTURE (PAM)
LABORATORY EVALUATION/DESIGN PROCEDURE

MATERIALS

The material components used in Pozzolan Aggregate Mixtures (PAM) evaluation/acceptance shall be representative of those intended for use on all projects for either base or subbase construction. For the purpose of this specification, pozzolan (fly ash) is a siliceous or alumina siliceous material that in itself possesses little or no cementitious value but that in finely divided form and in the presence of moisture will chemically react with alkali and alkaline earth hydroxides at ordinary temperatures to form or assist in forming compounds possessing cementitious properties. Fly ash is the finely divided residue that results from the combustion of ground or powdered coal and is transported from the boiler by flue gases. Each of the components shall be tested for conformance with the requirements of Standard Specifications for Road and Bridge Construction.

MIX DESIGN/EVALUATION

The objective of these mix design procedures is to determine those proportions of lime, flyash and aggregate which when incorporated in a mixture with water will provide a workable, durable, support for, or element of pavement structure at economical cost. To this extent, a producer may at his own expense, evaluate trial mixes under criteria established by the Standard Specifications and propose a mix design. However, this in no manner shall be construed as to imply acceptance by the Department without its written consent or laboratory evaluation of the mix.

GENERAL APPROACH

For a given set of component materials the significant factors which may be varied are the ratio of lime to flyash and the ratio of the lime plus flyash to the aggregate. The lime to flyash ratio affects primarily the quality of the "matrix", and the ratio of lime plus flyash to aggregate, primarily determines the quantity of matrix available to fill the voids of the aggregate and thus assuring that the matrix-aggregate particle contact is maximized.

The concept of providing sufficient matrix to fill the voids in the aggregate is applicable primarily to aggregates containing sufficient amounts of coarse (+ No. 4) aggregate to create large void spaces, and may be measured in a laboratory by adding incremental amounts of a fixed lime plus flyash ratio to an aggregate, until the compacted dry density decreases slightly. However, in the event that the aggregate contains a high fraction of fine material (- No. 4) the concern should shift to not only providing sufficient matrix but to the ability of the resultant mixture to compact and remain stable during construction. Thus, it may be necessary to reduce the amount of matrix in the mixture or otherwise, reduce the overall fineness of the aggregate through blending.

PRELIMINARY TESTING

In addition to the testing of components required by the Specifications for PAM mixtures, it may be desirable to perform preliminary evaluations of lime and flyash, in order to select the lime-flyash ratio which provides the greatest strength development. This may be accomplished by procedures outlined in ASTM C593, "Fly-ash And Other Pozzolans for Use With Lime," Section 7.

PREPARATION OF AGGREGATE/FLYASH

1. Sieve and discard if any, the aggregate retained on the 3/4 inch sieve.
2. Determine the moisture content and absorption of the aggregate (- No. 4) and the moisture content of the flyash.

In the event that the aggregate fraction between the 3/4 inch and the No. 4 sieve does not contain free surface moisture, that fraction shall be soaked 24 hours, and towel dried to obtain a saturated surface dry condition. Fly ash which has agglomerated due to drying, shall be crumbled with the fingers until the overall size is reduced to comply with the Specifications.

PROPORTIONING

Proportioning of components in PAM mixtures shall be on a dry weight basis, considering the total dry weight as 100% of the batch. Preliminary proportions for graded coarse aggregate mixtures are determined from a grain size distribution curve for the coarse aggregate. The amount of lime plus pozzolan plus the minus No. 4 material is estimated from Table A below.

Table A

<u>Maximum Nominal Particle Size</u>	<u>Minimum % Passing No. 4 Sieve</u> (Lime + Pozzolan + Minus No. 4 Sieve Aggregate)
1"	45%
3/4"	50%
1/2"	60%

Using an approximate 3 to 1 flyash to lime ratio and a minimum of 3 percent lime by weight, mixtures are blended with the estimated preliminary proportions at the amount from Table A and, 2 percent above, and 2 percent below the preliminary proportions. If the densities increase with increasing pozzolan contents (holding the lime content constant), the mix is deficient in fines; a new series of mixes should be compacted with higher pozzolan contents. When the unit weight of three mixes are equal or decrease slightly with the higher pozzolan contents, the optimum pozzolan content has been determined. The pozzolan content to be used in further testing should be the amount which produced the maximum dry density plus an allowance for segregation and construction variability, based on the Engineer's judgement.

The compacted density of each mixture shall be determined by AASHTO T180, the test for "Moisture-Density Relations of Soils, Using 10-lb Rammer and 18-inch Drop", except that the 5-lift requirement is replaced with three lifts, and Note 2 is not to be used. In determining the moisture-density relationship, dry materials should be mixed for 1 minute, or until the mixture is uniform in color and texture, in a Lancaster PC Mixer or its equivalent, plus an additional 3 minutes after the water is added, in order to obtain the first point on the moisture-density curve. The original sample may be re-used for subsequent trials. The batch shall be mixed for an additional minute after the water has been added for each subsequent trial.

MIXING AND MOLDING TEST SPECIMENS

After the optimum moisture content is obtained by the above procedure a batch large enough to make six (6) each 4.0 by 4.6-inch (102 by 117 mm) cylinders, shall be mixed in the following manner: Mix the dry materials for 1 minute or until the mixture is uniform in color and texture in a Lancaster PC Mixer or its equivalent. Add enough water to bring the mixture to optimum moisture content (corrected for the hygroscopic moisture of the minus No. 4 material). Mix an additional 3 minutes. Mold the specimens immediately in accordance with AASHTO T180 Method C except as previously noted. Each layer should be scarified to a depth of $\frac{1}{4}$ inch (6 mm) before the next layer is compacted in order to assure a good bond between the layers. Weigh a representative sample of the mixture to determine the moisture content (use a container with a tight lid to prevent loss of moisture). Then carefully remove from the specimen from the mold by the use of a sample extruder such as a jack or lever frame.

Curing of Test Specimens - Immediately after the specimens are removed from the mold, re-weigh the specimens and place in a sealed container to prevent loss of moisture. The sealed container may be either a can with a friction lid, or double sealed plastic bags. Place three of the specimens in the sealed containers carefully in a room or cabinet with forced air circulation maintained at $50^{\circ}\text{F} \pm 2^{\circ}\text{F}$ ($10^{\circ}\text{C} \pm 1^{\circ}\text{C}$) for a 7-day period. Place the remaining three (3) specimens in a sealed container

in a room or cabinet with forced-air circulation maintained at $72^{\circ}\text{ F} \pm 2^{\circ}$ ($22^{\circ}\text{ C} \pm 1^{\circ}\text{ C}$) for a fourteen day period, re-weigh, and allow to cool to room temperature. After the required period, remove the specimens from the container, and cap the specimens for compressive strength testing. Soak the specimens in water for 4 hours, remove, allow to drain on a nonabsorbent surface and test within 1 hour of the time of removal from the water.

Number of Test Specimens - Six (6) specimens shall be tested in accordance with ASTM Method C 39, Test for Compressive Strength of Cylindrical Concrete Specimens; no 1/d correction will be considered in the computation of the compressive strength.

VACUUM SATURATION

If, in addition the Vacuum Saturated Compressive strength is specified or otherwise required, the procedures outlined in ASTM C593, Section 9 shall be followed.

REPORT - Report of the compressive strength and/or vacuum saturation strength tests shall include the following:

- (a) Identification of each material used in the preparation of the specimens,
- (b) Percentage by dry weight of each of the constituents,
- (c) Actual as compacted percentage moisture content of mixture,
- (d) Actual dry unit weight of each specimen, nearest lb/ft^3 or g/cm^3 ,
- (e) Percentage of maximum dry unit weight of each specimen,
- (f) Cross-sectional area of each specimen, inches^2 or centimeters^2 ,
- (g) Maximum failure stress of each specimen, to nearest 5 psi or 35 kPa, and/or
- (h) Vacuum saturation strength of each specimen, to nearest 5 psi or 35 kPa.

The average compressive strength of three specimens tested at each curing condition shall be designated as the test value for evaluation by this specification. The average vacuum saturation strength (if required) of the three specimens tested shall be designated as the test value for evaluation by this specification. Co-efficients of variation within groups at each curing condition which exceed 10% for 50° F (10° C) and 10% for 72° F (22° C) shall be considered as cause for rejection of the samples, and a fresh batch shall be formulated, compacted and tested as per procedures previously defined. The corrected standard deviation will be estimated from Table B. The co-efficient of variation is computed by dividing the corrected standard deviation by the mean strength.

Table B.

ESTIMATING STANDARD DEVIATION.--If the number of values are not large (say, less than 10), the standard deviation can be estimated by either of the following equations:

$$s_e = \frac{R}{d} \text{ or } s_e = Rm$$

where: s_e = estimated standard deviation

R = range of values; i.e., the difference between the greatest value and the smallest value

d = factor (see Table C)

m = factor (see Table C)

TABLE C--FACTORS FOR ESTIMATING
STANDARD DEVIATION

Number of Values, n	Factor, d	Factor, m
2	1.1284	0.8862
3	1.6926	0.5908
4	2.0588	0.4857
5	2.3259	0.4299
6	2.5344	0.3946
7	2.7044	0.3698
8	2.8472	0.3512
9	2.9700	0.3369
10	3.0775	0.3249

PLOTTING OF DEGREE DAY (\overline{DD}) VS. CURED COMPRESSIVE STRENGTH (CS) CHARACTERISTIC CURVE

In order to evaluate the effect of curing at low to moderate temperatures it is necessary to plot the best fit straight line relationship of the average cured compressive strength (PSI) obtained herein at both curing temperatures, versus the curing degree days (40° F base) representative of each average strength.

Plots are to be arranged on 20x20/division graph-paper, at a convenient scale, with the number of degree-days along the x-axis and the cured strength (in PSI) along the y-axis. Degree-days (40° F base) are calculated as follows: (Curing temperature - 40) x number of days = \overline{DD} . Plots will be appropriately labeled as to: producer, month and year of analysis and proportions of each component ingredient.

The Department will analyze design test data and develop appropriate construction cut-off dates.

State of Illinois
Department of Transportation

SUPPLEMENTAL SPECIFICATION
FOR
SECTION 804. POZZOLANIC AGGREGATE MIXTURE EQUIPMENT

Effective April 1, 1980

This Supplemental Specification amends the provisions of the Standard Specifications for Road and Bridge Construction, adopted October 1, 1979 and shall be construed to be a part thereof, superseding any conflicting provisions thereof applicable to the work under the contract.

804.01 The pozzolanic aggregate mixture plant shall be a batch or continuous type mixing plant. The plant units shall be so designed, coordinated, and operated that they will produce mixtures within the tolerances specified. The plant units shall meet the following requirements:

- (a) General Requirements. The plant shall be approved before production begins. It shall be equipped with adequate and safe stairways to the mixer platform and sampling points. The plant shall be equipped with a room of approximately 200 square feet for performing the necessary tests for control of the mixture. The room shall be provided with sufficient heat, and air conditioning, natural and artificial light, and be equipped with a desk, chair, work bench 3'x10'x36" and 110 volt outlets. First aid equipment, telephone, fire extinguisher having a minimum underwriters laboratory rating of 2A10BC and sanitary facilities shall be available. When approved by the Engineer a room with sufficient space for performing the necessary tests for control of the mixture, either in a building occupied by the operator or in a separate building satisfactory to the Engineer, may be substituted for the aforementioned facility.

Guarded ladders shall be placed at all points where accessibility to plant operations is required. Accessibility to the top of truck bodies shall be provided by a platform or other suitable device to enable the Engineer to obtain samples. A hoist or pulley system, if required by the Engineer, shall be provided to raise scale calibration equipment, sampling equipment and other similar equipment from the ground to the mixer platform and return. All gears, pulleys, chain sprockets, and other dangerous moving parts shall be thoroughly guarded and protected. Ample and unobstructed space shall be provided on the mixing platform. A clear and unobstructed passage shall be maintained at all times in and around the truck loading area. This area shall be kept from drippings from the mixing platform.

(b) Storage Facilities. The plant used in the preparation of the PAM mixtures shall be located where it will have adequate storage and transportation facilities. Sufficient space shall be provided for separate stock piles of each material type. If necessary to prevent the intermixing of the different materials, or if stock piles join together, suitable partitions shall be used between adjacent stock piles. All aggregates shall be kept separated until they are fed in their proper proportions onto a belt conveyor. The aggregates shall be handled in such a manner as to prevent contamination and degradation.

(c) Crane or End Loader. The crane used in stock-piling the aggregates or conveying the aggregates to the aggregate feeders shall be in first-class mechanical condition. When compartment aggregate bins are used, the width of the crane bucket shall be not more than 1/2 the minimum width of the top of the bin compartments, and the maximum length of the bucket when fully open shall be at least 1 foot less than the length of the top of the bin compartment.

When an end loader is used to charge adjacent hoppers containing different materials, the maximum discharge width of the bucket shall be 2 feet less than the width of the top of the bin compartment surcharge.

(d) Aggregate Feeder. The plant shall be provided with accurate mechanical means for uniformly feeding aggregate in its proper proportion onto the main belt so that uniform production will be obtained. The controls of the lime and fly ash fed to the pug mill shall be by a variable speed system. Other methods may be approved by the Engineer. All gates shall be capable of being locked or bolted securely in the required position.

(e) Material Control. The plant shall provide means for accurately proportioning lime and fly ash within specified tolerances. Charts shall be provided showing the rate of feed of aggregate per minute for the aggregate being used.

(f) Weight Calibration of Lime, Fly Ash and Aggregate Feeds. The plant shall include a means for calibration by weighing test samples. Provision shall be made so that the lime and fly ash fed out of the feeder can be collected in an individual test container. The plant shall be equipped to conveniently handle individual test samples weighing not more than 200 pounds. Accurate scales shall be provided by the Contractor to weigh such test samples.

Adequate means must be provided to collect the individual or combined aggregates or fly ash into a truck after the aggregates or fly ash pass over the weigh belt or other proportioning device.

(g) Synchronization of Lime, Fly Ash and Aggregate. Means shall be provided to afford positive interlocking control along the flow of aggregate, fly ash, lime and water satisfactory to the Engineer.

- (h) Mixer. The plant shall include a continuous or batch mixer of an approved type, and capable of producing a uniform mixture within the job-mix tolerances. Continuous mixers shall be equipped with a discharge hopper with dump gates which will permit rapid and complete discharge of the mixture. The paddles shall be adjustable to advance or retard aggregate flow. The spray bar of the mixer shall be equipped with a pressure gauge. An adjustable baffle or dam which can be locked or bolted in position shall be placed at the discharge end of the pug mill. The mixer shall have a nominal capacity, as determined by the Engineer, of not less than 200 tons per hour and shall have a manufacturer's plate giving the net volumetric contents of the mixer at the several heights inscribed on a permanent gauge.
- (i) Platform Scale for Weighing Pozzolanic Aggregate Mixtures. The scales shall be accurate to 0.4 percent of the maximum load that may be required. The scales shall be calibrated at the beginning of each construction season and as often as the Engineer may deem necessary to assure their continued accuracy. The scales shall be inspected frequently for sensitivity, sluggishness or damage. They shall be checked for accuracy at intervals of not more than one week by obtaining the net weight, on another truck scale, of a truck load of pozzolanic aggregate mixture.

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL SPECIFICATION 835
AGGREGATE LIME-FLY ASH BASE

January 13, 1977

835.01 Description. This item shall consist of a mixture of aggregate, hydrated lime and fly ash mixed, placed and compacted in accordance with the requirements hereinafter set forth and in conformity with the lines, grades and cross sections shown on the plans.

This construction may involve patents and if so the provisions of 107.03, Patented Devices, Materials and Processes of the Construction and Material Specifications of the Ohio Department of Transportation will govern.

835.02 Materials. (a) Hydrated lime shall meet the requirements of 712.04(b).

(b) Fly ash shall meet the requirements of ASTM C 593, with the exception of Section 7 for plastic mixes. The maximum loss on ignition shall be 10 percent as determined in accordance with ASTM C 311.

(c) Aggregate. Aggregate for this course shall be sound and durable limestone, air-cooled blast furnace slag, or gravel which shall meet the grading requirements of 301.02 except that a minimum of 35 percent shall pass the No. 4 sieve.

When tested for soundness in accordance with Method of Test for Soundness of Aggregates by use of Sodium Sulphate, AASHTO T 104, the weighted loss of the aggregate shall not exceed 15 percent except in case of an aggregate where the major portion of the unsound materials acquires a mudlike condition during the test, the soundness shall not exceed 5 percent.

835.03 Composition. Samples of the materials proposed for use shall be submitted to the Laboratory at least 90 days before the planned construction of this item for evaluation, approval and proportioning.

Cylinders prepared from the submitted material samples will be tested for compressive strength and freeze-thaw loss according to ASTM C 593. The average compressive strength shall be not less than 400 psi with no individual cylinder being lower than 300 psi. The loss in weight shall be not more than 10 percent after 12 cycles of freezing and thawing.

835.04 Construction Methods. The aggregate, hydrated lime and fly ash shall be accurately proportioned and thoroughly mixed in a mechanical mixer of the pugmill or other approved type. The exact material proportions shall be fixed by the Engineer and shall be maintained within the following tolerances in percent by weight of the total mix.

Lime	± 0.3
Fly ash	± 1.5
Aggregate	± 2.0

Means shall be provided for checking the accuracy of the proportioning. Water shall be added if necessary to insure that the mixture will be at optimum moisture content when compacted. The mixing operation shall be continued until all the materials are distributed evenly throughout the mixture. The mixture shall then be discharged without undue segregation. A sample of batched lime-fly ash base material shall be obtained daily and compression specimens prepared for testing according to ASTM C 593. The average strength for each sample shall be not less than 400 psi with no individual test being lower than 300 psi. The Engineer reserves the right to make such changes in mix proportioning during the progress of the work as he may consider necessary.

The aggregate lime-fly ash base, within an increment of work, shall be placed and compacted within 48 hours of mixing. Where multiple layers are placed, each layer shall be placed and compacted the same day as the first layer.

The maximum compacted layer thickness shall be 4 inches except where vibratory equipment is used in conjunction with other methods of compaction, the maximum compacted layer thickness shall be 8 inches. Where the total thickness specified is more than 8 inches, the mixture shall be placed in two or more layers approximately equal in thickness.

Each layer shall be placed in full lane widths using a mechanical spreader of a type approved by the Engineer. When placed, the mixture shall be free from segregation and when compacted the surface shall require a minimum of finish grading to meet surface tolerances.

Each layer shall be compacted using rollers or vibratory equipment and rollers. Compaction requirements shall be as specified in 304.04 of the Construction and Material Specifications.

After a layer has been compacted, tested for density and approved by the Engineer, water shall be applied as required to maintain the moisture content of the mixture near the optimum until either a succeeding layer of lime-fly ash material or the bituminous curing coat is placed. The equipment used for applying the water and bituminous curing coat shall be such that will not displace or otherwise damage the surface.

Prior to placing a layer on a previously placed layer, the surface of the previously placed layer shall be loosened to assure interlocking of the aggregate between the layers.

In constructing the top layer, the grade shall be kept at sufficient height so that the top surface, when compacted, will be at or slightly above grade, rather than below grade. Finish grading shall be accomplished by removing excess material followed by recompaction by rolling. In the event that low areas occur, they shall be loosened, dampened with water immediately before placing additional mixture, and then rolled to the satisfaction of the Engineer. When this item is used as a subbase for 451 pavement, the surface tolerance shall not exceed 1/4 inch in 10 feet.

The Contractor shall remove and dispose of any mixture that has not been compacted in place within 48 hours from the time it was mixed. Any mixture that has become contaminated with subgrade material or otherwise damaged by rain, freezing, traffic, or construction operations shall be removed and discarded.

The Engineer may restrict hauling over partially completed work when such hauling causes excessive deflection, cracking, displacement, or other damage to the aggregate lime-fly ash base.

A bituminous curing coat shall be applied to the surface of the completed aggregate lime-fly ash base. At the time the curing coat is applied, the surface shall be tightly knit and free of all loose or extraneous material. The bituminous curing coat, 702.02 RC-250, 702.04 RS-1, 702.09 RT-9 or RT-10, shall be applied uniformly to the surface with a pressure distributor at a rate of approximately 0.15 gallons per square yard. The exact rate of application and temperature shall be specified by the Engineer. Cover aggregate conforming to 703.06 shall be applied in accordance with 407.06.

The Contractor shall maintain, at his own expense, the entire base in a manner satisfactory to the Engineer until the pavement has been completed. Maintenance shall include repairs of any defective or damaged portions of the base and shall be made in such a manner as to insure restoration of a uniform surface and durability of the portion repaired or replaced.

835.05 Construction Joints. At the end of a day's work, a short tapered construction joint shall be made at the end of the compacted base in a straight line normal to the center line of the roadway.

Where additional base course construction is to be joined to the previous work, the end of the existing base course shall be scarified and moistened, blended with new mixture, and compacted to form a continuous section without a joint.

835.06 Seasonal Limits. Lime-fly ash base shall be constructed between April 15 and September 15 on pavements which are to be opened to traffic during the summer, fall, or winter months of the construction year. On pavements which are to be opened the following spring, lime-fly ash base may be placed later than September 15 but, after this date, a bituminous curing coat and a minimum of one overlying pavement course shall be constructed within 72 hours of final base compaction. In no case shall lime-fly ash material be placed during rain or when the atmospheric temperature is below 40F in the shade nor shall this material be allowed to remain uncovered during the winter months.

835.07 Method of Measurement. The quantity of aggregate lime-fly ash base course to be paid for shall be the actual number of cubic yards, computed from plan lines, of approved aggregate lime-fly ash base course material compacted in conformity with the lines, grades and cross sections shown on the plans.

835.08 Basis of Payment. The quantity measured as provided above shall be paid for at the contract unit price per cubic yard bid for Item 835, Aggregate Lime-Fly Ash Base Course, which price and payment shall constitute full compensation for furnishing all materials for the aggregate lime-fly ash base, including hauling, incorporating admixture, water, placing, compacting and curing, and for all labor, tools, equipment and incidentals necessary to complete this item.

State of Pennsylvania
Department of Transportation

322.1 *Aggregate-Lime-Pozzolan* 322.2(f)
 Base Course

SECTION 322.
AGGREGATE-LIME-POZZOLAN
BASE COURSE

322.1 DESCRIPTION—This work shall consist of constructing an aggregate, lime, and pozzolan base course in accordance with these specifications and within reasonably close conformity to the lines, grades, width, and depth shown on the drawings and as specified.

322.2 MATERIALS—

(a) **Aggregate.** The aggregate shall be stone, gravel, or slag, meeting the requirements of Section 703.3 for Type C, or better, No. 2A material, except that a maximum of 15% may pass the No. 100 sieve, or the requirements of Section 321.2(a).

(b) **Lime.** Lime shall meet the requirements of Section 723 and ASTM Designation C 207, Type N, Sections 2, 3(a), 6, and 7(a), and shall be capable of producing a mixture meeting the requirements of Subsection (g).

(c) **Pozzolan.** Pozzolan shall meet the requirements of Section 724, and shall be capable of producing a mixture meeting the requirements of Subsection (g).

(d) **Water.** Section 720.

(e) **Bituminous Material.** Bituminous material for protection and curing shall meet the requirements of Bulletin No. 25, and shall be one of the following:

Class RT-2-C or RT-2-W
Class E-1
Class MC-30

(f) **Testing.** . It shall be the responsibility of the contractor to do the preliminary testing required to determine the compatibility and the quality of the respective materials, the proportions required, and that the proposed mixture meets the requirements of Subsection (g).

322.2(f)

*Aggregate-Lime-Pozzolan
Base Course*

322.3(b)

The testing shall be performed in accordance with the requirements of Sections 320.2(c)1. and 2.

(g) **Mixture.** The aggregate-lime-pozzolan mixture shall meet the following requirements:

1. **Liquid Limit and Plasticity Index.** The liquid limit of the mixture determined in accordance with AASHTO Designation T 89 shall not exceed 25 and the plasticity index determined in accordance with AASHTO Designation T 90 shall not exceed 6.

2. **Durability.** The proposed mixture shall be tested in accordance with PTM, No. 110.

322.3 CONSTRUCTION REQUIREMENTS—

(a) **Equipment.** Equipment shall conform to the requirements of Section 320.3(a).

(b) **Mixing.**

1. **Central Plant Mixing.** For central plant mixing, the materials shall be mixed in an approved continuous flow or batch-type mixer equipped with batching or metering devices designed to measure the specified quantities of the respective materials. Mixing shall be continued until a thorough and uniform mixture is obtained.

The mixture shall be transported from central mix plants in clean, tight vehicles and shall be deposited on the moistened prepared area by means of approved mechanical spreaders in a uniform loose condition for the full depth of layer being place. Protective covers for the vehicles may be required by the engineer.

2. **In-Place Mixing.** For in-place mixing the required quantity of aggregate shall be spread on the prepared area in a uniform loose layer. The specified quantity of pozzolan shall then be applied in a uniform spread to the aggregate in place and be blended until the pozzolan is uniformly distributed through the aggregate. At the time of application of the pozzolan, the moisture content of the aggregate shall not exceed the quantity which will permit uniform blending of the materials.

322.3(b)

*Aggregate-Lime-Pozzolan
Base Course*

322.3(b)

The specified quantity of lime shall then be applied in a uniform spread and be blended until the lime is uniformly distributed through the pozzolan and aggregate.

After the aggregate, lime, and pozzolan have been thoroughly blended, water shall be applied and incorporated into the mixture. The application of water shall be so controlled that there is no excessive concentration on or near the surface of the mixture. An adequate water supply and sufficient pressure distributing equipment shall be provided to insure that the mixing operation is continuous. After all required water has been applied, mixing shall be continued until a thorough and uniform mixture is obtained.

On projects where the application of lime and/or pozzolan creates a critical dust condition, the contractor may, with the approval of the engineer, moisten the pozzolan and/or lime, or may pre-blend the specified quantities of pozzolan and lime (with or without a portion of the aggregate) with water prior to application to the spread aggregate or addition to the mixer.

Water added to pozzolan and/or lime or to a pre-blend to eliminate excessive dust shall not exceed the quantity required in the final mix.

3. General. The moisture content at the time of final mixing shall not vary from the optimum moisture determined in the field by more than 2 percentage points, except that in no case shall the moisture content in the mix exceed the quantity which will permit uniform blending or cause the base course to become unstable during the compacting or finishing operations.

Bulk lime and bulk pozzolan may be used provided approved equipment and handling methods are used.

Pozzolan and/or lime shall not be spread nor shall mixture be placed when the aggregate or the base course area is excessively wet, frozen, or is at a temperature of 40 F or less. No material shall be spread nor mixture placed unless the air temperature is 40 F and rising and these operations shall be discontinued when the descending air temperature falls below 40 F.

322.3(b)

*Aggregate-Lime-Pozzolan
Base Course*

322.3(h)

The placing of Aggregate-Lime-Pozzolan Base Course shall terminate August 15 and shall not be resumed prior to May 1, unless otherwise approved in writing by the engineer.

Only the necessary shaping and processing equipment shall be permitted to travel over the spread materials and any lime, pozzolan, or mixture that becomes displaced or contaminated in any manner shall be removed and satisfactorily replaced at no expense to the Department.

(c) **Compaction.** Compaction shall conform to the requirements of Section 321.3(c), except that PTM No. 106, Method B shall be used for optimum moisture content and maximum dry weight density determination.

(d) **Finishing.** Finishing shall be performed in accordance with the requirements of Section 321.3(d), except that the finishing operation need not be limited to 3 hours.

(e) **Construction Joints.** Where additional base course construction is to be joined to the previous day's work, the end of the existing base course shall be scarified and moistened, blended with new mixture, and compacted to form a continuous section without a joint.

(f) **Protection and Curing.** Protection and curing shall conform to the requirements of Section 321.3(f). If the contractor so elects he may begin paving of binder and/or surface courses immediately after placing the prime coat without waiting for the completion of the 7 day curing period.

(g) **Density.** The density will be determined in accordance with PTM No. 112, or PTM No. 402. One density determination shall be made for each 3000 square yards, or less, of completed base course. No tolerance in density below that specified will be allowed.

(h) **Surface Tolerance.** The surface smoothness shall be checked transversely with approved templates and longitudinally with straightedges in accordance with the requirements of Section 310.3(d). Any surface irregularity that

322.3(h)

*Aggregate-Lime-Pozzolan
Base Course*

322.5

exceeds ½ inch under a template or straightedge shall be remedied to the satisfaction of the engineer.

(i) **Tests for Depth of Finished Base Course.** The depth of the finished base course shall meet the requirements of Section 320.3(i).

(j) **Maintenance and Traffic.** The completed base course shall be maintained and traffic controlled in accordance with the requirements of Section 310.3(f).

322.4 METHOD OF MEASUREMENT—This work will be measured on the surface using the two-dimensional method and include all areas shown on the drawings or otherwise approved by the engineer.

322.5 BASIS OF PAYMENT—Aggregate-Lime-Pozzolan Base Course will be paid for at the contract unit price per square yard, complete in place, as specified.

When this construction involves patent rights, it is mutually understood and agreed that without exception the bid price is to include all royalties, costs, and/or license fees arising from patents, trademarks, and copyrights in any way involved in the work and that the requirements of Section 107.03 will govern.

Federal Aviation Administration
Newark Airport Project

41. LIME-CEMENT FLYASH STABILIZED FILL SAND BASE.

The lime-cement flyash stabilized fill sand base shall be plant mixed, and consist of a mixture of in-place fill sand, hydrated lime, Portland cement, flyash, and coarse aggregate if specified, and shall be mixed, placed and compacted on a prepared subgrade in accordance with these Specifications and to the lines, grades and cross-sections shown on the Contract Drawings.

The Consolidated Edison Company of New York, Inc. (hereinafter referred to as the "Company") has agreed with the Authority to furnish flyash free of charge to contractors requiring flyash in the performance of their work under Authority contracts. The Agreement between the Authority and the Company is substantially in the form attached hereto.

The Contractor shall comply with the terms of the Agreement between the Authority and the Company and shall assume all the risks, duties and obligations of the Authority under said Agreement. The Contractor and the Company shall mutually agree as to the times, places and conveyances to be used in the removal of flyash. The flyash must be in accordance with the requirements for Lime-Cement Flyash Stabilized Fill Sand Base specified below.

Materials

The coarse aggregate, called "Aggregate" on the Contract Drawings, shall be crushed trap rock and shall consist of hard, durable particles, free of an excess of soft or disintegrated pieces, dirt, or other objectionable material. The coarse aggregate shall conform to the following gradation requirements:

<u>Sieve Sizes</u>	<u>Total Passing Per Cent by Weight</u>
1½"	100
1"	90 - 100
¾"	60 - 80
No. 4	0 - 5

Lime-cement as specified herein shall be a mixture of one part Portland cement and four parts hydrated lime, by weight. The cement shall be Type I conforming to the requirements of the Standard Specifications for Portland Cement (A.S.T.M. C150), and the lime shall be Type N conforming to the requirements of the Standard Specifications for Hydrated Lime for Masonry Purposes (A.S.T.M. C207) and the modified requirements specified herein:

1. Total oxide content ($\text{CaO} + \text{MgO}$) on a non-volatile basis shall not be less than 86% by weight.
2. A minimum of 75% shall pass a No. 200 sieve.
3. Substitution of high oxide lime (dolomitic hydrate) may be made provided that:
 - a. The total oxide in the mix shall not be less than the specified hydrate lime assuming an oxide content on a non-volatile basis of 92% and the combined H_2O is 25% (i.e. assuming a 3.2% lime mix, the total oxide content will be $3.2 \text{ parts} \times .75 \times .92 = 2.2 \text{ parts}$).
 - b. The total amount of substituted lime in any mix shall not be less than 2.8% by weight.
 - c. Quicklime shall be used only when the mixing, performance and safety provisions of the slaking mechanism are approved by the Engineer.

Flyash shall conform to the requirements of the Tentative Specifications for Flyash for Use as a Pozzolanic Material with Lime (A.S.T.M. Designation: C379) and the applicable testing procedures) and the following modified requirements:

1. Loss of ignition shall not be more than 10%.
2. Combined content of silica (SiO_2) and aluminum oxide (Al_2O_3) shall not be less than 50%.
3. Lime-pozzolan strength, minimum compressive strength shall be 600 psi at 7 days, $130^\circ \pm 3^\circ \text{ F}$.
4. Storage bins shall be provided when dry powder fly-ash is used.
5. Moisture content of wet flyash shall be determined prior to placing in mix.
6. A shredding machine shall be used to pulverize the conditioned (moistened) flyash prior to its use in the mix.

Fill sand to be used in the LCF mixes shall be the suitable material from the excavation and any deficiency in supply shall be supplemented from the stockpile as directed by the Engineer. The suitable fill material shall consist of sand or a sand and gravel mixture with fines not more than 10% by weight passing No. 200 sieve and shall have no particle size exceeding two inches in largest dimension.

Water for use in mixing the lime-cement flyash stabilized fill sand base courses shall be clean water without objectionable organic content.

Proportions

The materials in the lime-cement flyash stabilized fill sand base courses shall be proportioned by weight in the percentages shown herein. The Engineer, however, may at his sole option vary the percentage of materials. The Contractor will be reimbursed for the actual net cost delivery purchase price to him of any additional materials ordered by the Engineer. The amount of water used in the mix shall be determined by tests for the optimum density and compaction as specified herein in the subclause entitled "Compaction".

Composition of Lime-Cement-Flyash (LCF) Mixes

Percent by Weight

Type	Hydrated Lime ASTM Type N	Portland Cement ASTM Type I	Flyash	Aggregate ½" - ¾" Size	In-place Fill Sand
A	3.6	0.9	12-14	30	51.5-53.5
B	3.2	0.8	14-16	--	80.0-82.0
C	2.8	0.7	14-16	--	80.5-82.5

Any ingredient of the mix shall not deviate more than 1/20 of the figures shown above.

Change in Proportions

If the Contractor elects to place lime-cement flyash stabilized fill sand base courses during the months of September and October, the cement content shall be twice the amount shown in the table above at no additional compensation.

Between November 1 and March 1, half of the cement shall be deleted and an equivalent amount by weight of hydrated lime shall be substituted in lieu thereof.

Mixing

The lime-cement flyash stabilized fill sand base course materials shall be mixed in a stationary continuous flow or batch type mixer equipped with batching or metering devices to measure the specified quantities. Mixing shall be continued until a thorough and uniform mixture of all materials incorporated in the mix is obtained. The minimum mixing time determined from trial runs of the central mixing plant shall be as directed by the Engineer. For the batch type mixer, prior to the introduction of water, the dry mix of lime-cement flyash and fill sand shall be blended uniformly for a period of not less than 15 seconds per cubic yard or three revolutions of the mixing drum. For a continuous flow type mixer, adequate devices shall be installed to detect the changes in the flow materials. The moisture content of the flyash, aggregate and fill sand as well as all metering devices shall be daily tested and recalibrated.

The Contractor shall submit in detail his anticipated plant operation and layout for the approval of the Engineer. As a guide for the Contractor in selecting his equipment, the central mixing plant shall be equipped with the following:

1. Three separate storage bins, one each for the lime, cement and powder flyash, with a minimum capacity of each equal to the quantity requirements of a day's operations.
2. Three separate feeding belts, one each for coarse aggregate, fill sand and bulk volume moist flyash.
3. An additional measuring device if quicklime in slurry form is used.
4. The mixer charging conveyor shall be long enough to hold the volume of a single batch at idle.
5. The minimum capacity of the mixing plant shall be 100 cubic yards, approximately 200 tons, per hour.
6. The water system shall be adequate for the mixing plant and its requirements shall be determined from the optimum moisture in the mix, which ranges from 8 to 10% by weight.
7. A bar-screen having opening less than 2"x2" shall be installed on the sand hopper and the Contractor shall remove all material retained on the screening as "unsuitable".

Transporting

The mixture shall be transported from the central plant mix operation in vehicles that will maintain the moisture content and prevent the loss of fine materials in the mix during the transit. The location of the central mixing plant shall be shown on the Contract Drawings unless the Engineer directs that it is to be located elsewhere.

Preparation of Subgrade

Prior to placement of pavement materials and after grading, the subgrade shall be compacted the same as specified for backfill in the clause herein entitled "Backfill".

In the event that during or after compacting the subgrade, the Engineer determines that the material below such depths is unsuitable to properly support the permanent construction, the Contractor shall excavate to such further depths and within such limits as the Engineer may order and backfill and recompact to the extent ordered by the Engineer in accordance with the clause entitled "Over-Excavation".

If, in the opinion of the Engineer, the material below such depths is rendered unsuitable by the Contractor's operations, the Contractor shall receive no additional compensation whatever for such removal or backfill.

Placing of First Lift

The prepared subgrade on which the mixture is to be placed shall be thoroughly and evenly moistened, as directed by the Engineer immediately prior to placing of the mixture. The mixture shall be deposited on the moistened subgrade in a uniform loose condition for a depth that will provide the compacted depth specified on the Contract Drawings or as set forth in the Specifications.

Compaction

The roller used for the first two passes of initial compaction shall be a vibratory roller as specified for backfill in the clause herein entitled "Backfill". The final compaction shall be done with two self-propelled pneumatic-tired rollers equipped for rapid adjustment of tire inflation pressure. Each of these rollers shall have a minimum gross weight of 35 tons, and have a tire inflation pressure variable from 30 to 150 psi (minimum) and shall be Bros. SP-10000 self-propelled pneumatic-tired rollers with air on the run, as manufactured by Bros. Inc. or approved equal.

The number of passes of the pneumatic tired roller shall be determined by the Engineer when the deposited base courses reach a field density at trial run at least 100 per cent of the maximum density in accordance with AASHTO Designation T-180 Method "D" Density Test. The density of compacted base courses in actual installation shall be determined by the Engineer from in-place density tests or from undisturbed samples cut from the base courses. During the course of placement construction, the Engineer may increase or decrease the number of passes of the pneumatic-tired roller as frequently as required to obtain the best density of the compaction.

The Contractor shall furnish the necessary labor and materials to obtain these samples and to patch areas from which samples are taken.

During the checking of density of base courses, the Engineer will also check the thickness of the compacted base course. Before proceeding with succeeding courses, the Contractor will be required to correct any portions of the base course that do not meet the above density requirements or that do not meet in thickness the requirements shown below.

A reasonably rippled surface with no loose material, is tolerable for the integration of the subsequent base courses and asphalt concrete top course, as long as the following tolerances are maintained:

Tolerances in Thickness of Lifts

First Lift	LCF Mix "C"	± 1.0 inch
Subsequent Lifts	LCF Mix "B"	$\pm 1/2$ inch
Top Lift	LCF Mix "A"	$\pm 1/4$ inch
Total Thickness of All LCF Lifts		- $1/2$ inch + 1.0 inch

Subsequent lifts shall be placed by means of approved mechanical spreaders similar or equal to an auto-grader as manufactured by Construction Machinery Incorporated and other equipment that shall not damage the courses previously placed. In placing and compacting the subsequent lifts, the top surface of the previous lift shall be dampened with water immediately before placing additional base material.

The normal curing period for the top layer (LCF "A") shall be two weeks. If a top layer (LCF "A") is placed during September 1 through October 31, the curing period shall be two weeks only if additional cement is added to the mix in accordance with the subclause herein entitled "Change in Proportions". Any top layer (LCF "A") placed during September 1 through October 31 without change in proportions or placed after November 1 shall not be topped with asphalt concrete top course until April 1st. The exposed top layer (LCF "A") shall be protected as specified herein in the subclause entitled "Weather Restrictions".

Wet Load

In case a load of lime-cement flyash contains more moisture than that specified for the optimum content, the mixed material shall not be compacted but shall be spread to a thickness of 2 to 3 inches and left undisturbed to dry to the optimum moisture content. Upon the approval of the Engineer, additional material can be placed on top of the said load or said load can be blended and worked.

Finishing

In placing and compacting the mixture, the surface of the top lift when compacted, shall not deviate more than 1/4 inch from the theoretical grade level when tested with a ten-foot straight edge in any direction. Finished grading and shaping shall be accomplished by removing excess material followed by recompaction by rolling. In the event that low areas occur, they shall be scarified to a depth of one inch, dampened with water immediately before placing additional base material and then rolled to the satisfaction of the Engineer.

Construction Joints

At the end of each day's construction, a straight transverse construction joint shall be formed by installing a temporary wooden bulkhead or by cutting back into the completed Work to form a true vertical face. The construction joints shall be located in the area shown on the Contract Drawings or designated by the Engineer.

Placement of Electrical Ducts in Lime-Cement Flyash Courses

Any excavation for the placement of electrical ducts in lime-cement flyash courses shall be replaced with Class D concrete conforming to the requirements of the clause herein entitled "Concrete". The bottom and sides of duct trenches in LCF shall be heavily moistened just prior to placing concrete. A minimum of 48 hours shall be allowed to cure the concrete before any subsequent work is performed on the flyash courses in the vicinity of the ducts.

Rehandling of Material

Within three days after the mixing, the lime-cement flyash stabilized sand may be regarded, reshaped and reused in the work provided that the moisture of the mixture is within the range of optimum percentage +2% to -1%. However, no lime-cement flyash mixture may be stockpiled for future use.

During the construction period, the Contractor shall exercise all necessary precautions to prevent air pollutions due to wind-blown flyash and in-place fill sand while these materials are being transported to the batching plant.

Weather Restrictions

No lime-cement flyash stabilized fill sand base course shall be placed during periods of heavy or extended rainfall. Base course or courses shall be placed and compacted only if the day or night temperature is not anticipated to be below 32° F. in the next twenty-four hours after placement. All exposed lime-cement flyash courses of Mix "A" placed after November 1 and surfaces that will not receive an asphalt concrete top course until April 1, shall be protected by an asphaltic seal applied within two weeks after placement in accordance with the provisions of the subclause hereof entitled "Tack Coat". All exposed lime-cement flyash courses of Mix "B" or Mix "C" placed without cover after November 1 to April 1, the Contractor shall remove the top 2" of exposed lime-cement flyash in March or April by scraping or cutting prior to continuing paving construction, and the replacement of the 2" of lime-cement flyash cut away shall be added to the thickness of the subsequent lift. At the resumption of pavement operations in March or April, the base course or courses shall be recompacted immediately prior to the placement of new lifts using the equipment and number of passes specified in the sub-clause entitled "Compaction".

Protection and Maintenance

After the base course has been completed as specified to the required lines, grades and typical section as shown on the Contract Drawings, no traffic, other than light personnel vehicle as approved by the Engineer shall be allowed on the course. Any damage caused by equipment used in the construction of an adjoining section shall be the responsibility of the Contractor and shall be immediately repaired.

The Contractor shall maintain the entire base course in a condition considered satisfactory by the Engineer. Said maintenance shall include the repair of any defects that may occur.

Water Curing

The Contractor will be required, after placement to apply moisture to the lime-cement flyash stabilized sand base. The determination of said requirement shall be at the sole judgment of the Engineer.

Tack Coat

The Contractor shall apply tack coat to the compacted top lime-cement flyash layer (LCF "A") within two weeks after its placement and to surfaces called for in the subclause herein entitled "Weather Restrictions".

The tack coat shall consist of an 85 to 100 penetration grade hot asphalt cement or MC-70 which shall be placed by approved means at a rate of 0.25 gallons per square yard.

In addition, if the compacted top layer (LCF "A") is left uncovered of asphalt concrete top course over the winter months, it shall receive a tack coat of 0.10 gallon per square yard after recompaction, prior to the placement of the asphaltic top course.

Pavement Joint and Cushion Material

The preformed joint filler cushions shall be a closed-cell polyethylene foam of the sizes and dimensions shown on the Contract Drawings. The Contractor shall submit a sample of material he plans to use for the Engineer's approval.

Joint sealer shall be "Sikaflex T-68" as manufactured by the Sika Chemical Corp. or approved equal and shall be applied in accordance with the manufacturer's recommendations.

Any oversized cut for the installation of joint filler shall be backfilled with cement mortar consisting of one portion of Type 1 portland cement and 5 portions of LCF mix and not more than 5 gallons of water per sack of cement.

Inspection of Cement

Portland cement will be inspected by the Authority at the manufacturer's plant. For all cement designated for this Contract and inspected by the Authority at the manufacturer's plant, the Contractor shall pay to the Authority the amount of fifteen cents per barrel of cement for cement delivered in carload lots, the amount of thirty cents per barrel of cement delivered in truckload lots and forty cents per barrel of cement when re-handled thru a local distribution plant. These charges will be made on total amount of cement inspected even though the quantity shipped for the Contract be greater than the amount of concrete incorporated in the permanent structure. The operation of loading at plants and unloading at destination will be performed during the daytime only. The Authority shall, from time to time, render to the Contractor statements of the amounts to be paid to the Authority under this numbered clause and within fifteen days after receipt of each such statements, the Contractor shall pay the amount thereof. The Contractor, however, authorizes the Authority to, and the Authority may at its option, collect such amounts out of any sum payable under this Contract.

Federal Aviation Administration
Toledo Airport Project

ITEM P-305 AGGREGATE-LIME-
FLY ASH SUBBASE OR BASE COURSE
(CENTRAL PLANT MIXED)

305-1.1 DESCRIPTION. This work shall consist of the construction of a stabilized subbase or base course on a prepared and accepted underlying surface. The stabilized subbase or base course shall be prepared by mixing, hauling, spreading, shaping, or compacting, and curing mineral aggregate, lime, fly ash and water in accordance with the requirements of this specification. The stabilized course shall be constructed in reasonably close conformity to the lines, grades, thicknesses and typical sections shown on the plans or established by the engineer.

This construction may involve patents and, if so, GENERAL PROVISIONS 70-03, Patented Devices, Materials and Processes shall govern.

305-2.1 LIME-FLY ASH CEMENTITIOUS FILLER MATERIAL. The lime and fly ash shall be supplied either separately or as a manufactured blend. The lime, fly ash or blend may contain admixtures such as water reducing agents, portland cement, or other materials which are known to provide supplementary properties to the final mix. When admixtures are to be included, they are to be used in the laboratory design as required in Section 305.3.

(a). LIME shall meet ASTM Specification C-207, Type N, Sections 2 and 3(a) when sampled and tested in accordance with Sections 6 and 7 and shall be capable of producing a mixture which will meet the requirements of Section 305.3. A minimum of 85% shall pass a No. 200 sieve when tested by wet sieving as per ASTM C110.

(b). FLYASH shall meet the requirements of ASTM C-593 for fly ash for use with lime in non-plastic mixtures. If ordered by the engineer, a shredding machine shall be used to pulverize the conditioned (moistened) fly ash prior to its use in the mix.

(c). PORTLAND CEMENT, if used as an admixture, shall conform to the requirements of ASTM C-150, Type 1 of ASTM C-595, Type 1P.

305-2.2 WATER. Water known to be of potable quality may be used without test.

305-2.3 AGGREGATE. The aggregate shall be either stone, slag or sand, 100% crushed. In addition to the fine aggregate naturally contained in the coarse material, supplementary fly ash may be used as a mineral filler to provide the desired fines content.

The 100% crushed aggregate shall consist of hard, durable particles, having the gradation specified, and free from an excess of flat, elongated, soft or disintegrated pieces, dirt or other deleterious materials.

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The methods used in processing such as crushing, screening, and blending shall be such that the finished product shall be as uniform as practicable. If necessary to meet this requirement or to eliminate an excess of fine particles, the materials shall be screened before and during processing, and all stones, rocks, boulders, and other source material of inferior quality shall be wasted.

The aggregate shall show no evidence of general disintegration nor show a total loss of more than 12 percent when subjected to five cycles of the sodium sulfate accelerated soundness test specified in ASTM C-88. Aggregates failing the sodium sulfate test may be approved by the engineer, providing they are from a source that has proven satisfactory service records of being used in cement or asphaltic concrete pavement construction in the same locality.

All material passing the No. 4 sieve produced during crushing or other processing may be incorporated in the base material to the extent permitted by the gradation requirements, unless it is known to contain disintegrated deleterious material, such as clay lumps, shale, coal or other soft particles. The aggregate shall meet the gradation requirements given in Table 1 when tested in accordance with ASTM C-117 and ASTM C-136.

Sieve Designation	Percentage by Weight Passing Sieve
2 inch	100
1 inch	75-100
$\frac{1}{2}$ inch	50-85
No. 4	35-60
No. 8	15-45
No. 16	10-35
No. 50	3-18
No. 200	1-12

Table 1. Acceptable Gradation of Aggregates
for Aggregate-Lime-Fly Ash Base
and Subbase Courses.

The gradation in Table 1 sets limits which shall determine the general suitability of the aggregate from a source of supply. The final gradations selected for use shall be within the limits designated in the table, and shall also be well graded from fine to coarse and shall not vary from high to low limits on subsequent sieves.

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In addition to the gradations given in the table, clean sands and sand-sized materials such as boiler slags can be used. Also, if the aggregate has a substantial portion passing the No. 4 mesh sieve (75 percent), the gradations in the above table can be waived and the aggregate gradation adjusted with the fly ash and fines contents to produce the maximum dry density in the compacted mixture.

The portion of the base material including any blended material passing the No. 40 mesh sieve shall have a liquid limit of less than 25 and a plasticity index of less than 6 when tested in accordance with AASHTO T 89 and AASHTO T 90.

305-2.4 BITUMINOUS MATERIAL. The types, grades, controlling specifications and application temperatures for the bituminous materials used for curing the aggregate-fly ash treated base/subbase course are given below. The engineer shall designate the specific material to be used.

Type and Grade	Specification	Application Temperature
Cutback Asphalt RC-70 or MC-30	AASHTO M 81 & M 82	120°-160°F.
Emulsified Asphalt RS-1, RS-2K	Fed. Spec. SS-A-674	75°-130°F.

Laboratory Tests

305-3.1 LIME CONTENT. The quantity of lime approximately 2 to 5 percent by weight to be used with the aggregate, fly ash, and water, shall be determined by tests for the materials submitted by the contractor, at his own expense, and in a manner satisfactory to the engineer.

305-3.2 FLY ASH CONTENT. The quantity of fly ash approximately 9 to 15 percent by weight to be used with the aggregate, lime, and water, shall be determined by tests for the materials submitted by the contractor, at his own expense, and in a manner satisfactory to the engineer.

305-3.3 MANUFACTURED BLEND CONTENT. The quantity of manufactured blend to be used with the aggregate and water (and any supplemental fly ash), shall be determined by tests for the materials submitted by the contractor, at his own expense, and in a manner satisfactory to the engineer.

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305-3.4 LABORATORY TESTS. Specimens of the aggregate lime-fly ash base/subbase course material shall develop a minimum compressive strength of 400 psi and demonstrate freeze-thaw resistance of a maximum of 14% weight loss as specified in ASTM Specification C 593, Section 3.2, when tested in accordance with Section 9 of that specification except that all compaction shall be done in accordance with FAA T 611, Section 2.2 (a) and (b) for aircraft weighing more than 30,000 pounds.

Construction Methods

305-4.1 WEATHER LIMITATIONS. The fly ash treated base/subbase shall not be mixed or placed while the atmospheric temperature is below 40°F. or when conditions indicate that the temperature may fall below 40°F. within 24 hours. Temperature requirements may be waived but only when so directed by the engineer.

305-4.2 SOURCES OF SUPPLY. All materials shall be obtained from approved sources.

305-4.3 EQUIPMENT. All methods employed in performing the work and all equipment, tools, other plans and machinery used for handling materials and executing any part of the work shall be subject to the approval of the engineer before the work is started. If unsatisfactory equipment is found, it shall be changed and improved. All equipment, tools, machinery, and plants must be maintained in a satisfactory working condition.

305-4.4 PREPARING UNDERLYING COURSE. The underlying course shall be checked and accepted by the engineer before placing and spreading operations are started. Any ruts or soft, yielding places caused by improper drainage conditions, hauling, or any other cause, shall be corrected and rolled to the required compaction before the base course is placed thereon. Grade control between the edges of the pavement shall be accomplished by grade stakes, steel pins, or forms placed in lanes parallel to the centerline of the runway and at intervals sufficiently close that string lines or check boards may be placed between the stakes, pins or forms. To protect the underlying course and to insure proper drainage, the spreading of the base shall begin along the centerline of the pavement on a crowned section or on the high side of the pavement with one-way slope. However, it shall be the responsibility of the contractor to construct adequate drainage to maintain the specified subgrade densities.

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Fly Ash Subbase or Base Course

305-4.5 MIXING.

(a). General Requirements Fly ash treated base/subbase shall be mixed at a central mixing plant by either batch or continuous mixing. The capacity of the mixing plant should not be less than 50 tons per hour. The aggregates, lime, and fly ash may be proportioned either by weight or by volume. The exact material proportions shall be fixed by the Engineer and shall be maintained within the following tolerances in percent by weight of the total mix.

Lime	± 0.3
Fly ash	± 1.5
Aggregate	± 2.0

In all plants, water shall be proportioned by weight or volume, and there shall be means by which the engineer may readily verify the amount of water per batch or the rate of flow for continuous mixing. The discharge of the water into the mixer shall not be started before part of the aggregates are placed into the mixer. The inside of the mixer shall be kept free from any hardened mix.

In all plants, lime and fly ash (and portland cement when used in the mix) shall be added in such a manner that it is uniformly distributed throughout the aggregates during the mixing operation.

The charge in a batch mixer, or the rate of feed into a continuous mixer shall not exceed that which will permit complete mixing of all the material. Dead areas in the mixer, in which the material does not move or is not sufficiently agitated, shall be corrected either by a reduction in the volume of material or by other adjustments.

Means shall be provided for checking the accuracy of the proportioning. Water shall be added if necessary to insure that the mixture will be at optimum moisture content when compacted. The mixing operation shall be continued until all the materials are distributed evenly throughout the mixture. The mixture shall then be discharged without undue segregation. A sample of batched lime-fly ash base material shall be obtained periodically and compression specimens prepared for testing according to ASTM C 593. The average strength for each sample shall be not less than 400 psi with no individual test being lower than 300 psi. The Engineer reserves the right to make such changes in mix proportions during the progress of the work as he may consider necessary.

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Fly Ash Subbase or Base Course

(b). Batch Mixing. In addition to the "General Requirements" as provided in 305-4.5(a), batch mixing of the materials shall conform to the following requirements:

The mixer shall be equipped with a sufficient number of paddles of a type and arrangement to produce a uniformly mixed batch.

The mixer platform shall be of ample size to provide safe and convenient access to the mixer and other equipment. The mixer and batch-box housing shall be provided with hinged gates of ample size to permit easy sampling of the discharge of aggregate from each of the plant bins and of the mixture from each end of the mixer.

The mixer shall be equipped with a timing device which will indicate by a definite audible or visual signal the expiration of the mixing period. The device shall be accurate to within two seconds. The plant shall be equipped with suitable automatic device for counting the number of batches.

The mixing time of a batch shall begin after all ingredients are in the mixer and shall end when the mixer is half emptied. Mixing shall continue until a homogeneous mixture of uniformly distributed and properly coated aggregates of unchanging appearance is produced. In general, the time of mixing shall be not less than 30 seconds, except that the time may be reduced when tests indicate that the requirement for lime-fly ash content and compressive strength can be consistently met.

(1). Weight Proportioning. When weight proportioning is used, the discharge gate of the weigh box shall be arranged to blend the different aggregates as they enter the mixer.

(2). Volumetric Proportioning. When volumetric proportioning is used for batch mixing, the volumetric proportioning device for the aggregate shall be equipped with separate bins, adjustable in size, for the various sizes of aggregates. Each bin shall have an accurately controlled gate or other device designed so that each bin shall be completely filled and accurately struck-off in measuring the volume of aggregate to be used in the mix. Means shall be provided for accurately calibrating the amount of material in each measuring bin.

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(c). Continuous Mixing. In addition to the "General Requirements" as provided in 305-4.5(a), continuous mixing of the materials shall conform to the following requirements:

The correct proportions of each aggregate size introduced into the mixer shall be drawn from the storage bins by a continuous feeder, which will supply the correct amount of aggregate in proportion to the lime-fly ash and will be so arranged that the proportion of each material can be separately adjusted. The bins shall be equipped with a vibrating unit which will effectively vibrate the side walls of the bins and prevent any "hang up" of material while the plant is operating. A positive signal system shall be provided to indicate the level of material in each bin, and as the level of material in any one bin approaches the strike-off capacity of the feed gate, the device shall automatically and instantly close down the plant. The plant shall not be permitted to operate unless this automatic signal is in good working condition.

The drive shaft on the aggregate feeder shall be equipped with a revolution counter accurate to 1/100 of a revolution and of sufficient capacity to register the total number of revolutions in a day's run.

The continuous feeder for the aggregate may be mechanically or electrically driven. Aggregate feeders that are mechanically driven shall be directly connected with the drive on the lime feeder.

The pugmill for the continuous mixer shall be equipped with a surge hopper containing sufficient baffles and gates to prevent segregation of material discharged into the truck and to allow for closing of the hopper between trucks without requiring shut down of the plant.

305-4.6 PLACING, SPREADING, AND COMPACTING. The use of mixers having a chute delivery shall not be permitted except as approved. In all such cases the arrangement of chutes, baffle plates, etc., shall insure the placing of the fly ash treated base without segregation.

The prepared underlying course shall be free of all ruts or soft yielding places. The surface, if dry, shall be moistened but not to the extent of producing a muddy condition at the time the base mixture is placed.

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Trucks for transporting the mixed base material shall be provided with protective covers. The material shall be spread on the prepared underlying course to such depth that, when thoroughly compacted, it will conform to the grade and dimensions shown on the plans. The aggregate lime-fly ash base, within an increment of work, shall be placed and compacted within 24 hours of mixing. Where multiple layers are placed, each layer shall be placed and compacted the same day as the first layer.

The maximum compacted layer thickness shall be 4 inches except where vibratory equipment is used in conjunction with other methods of compaction, the maximum compacted layer thickness shall be 8 inches. Where the total thickness specified is more than 8 inches, the mixture shall be placed in two or more layers approximately equal in thickness, or as specified on the plans.

The materials shall be spread by a spreader box, self-propelled spreading machine or other method approved by the engineer. It shall not be placed in piles or windows without the approval of the engineer. If spreader boxes or other spreading machines are used that do not spread the material the full width of the lane or the width being placed in one construction operation, care shall be taken to join the previous pass with the last pass of the spreading machine. The machine shall be moved back approximately every 600 feet, when staggered spreading machines are not used. The first pass shall not be compacted to the edge and, if necessary, the loose material may be dampened just prior to joining the next pass. If portland cement is used in the mixture and the temperatures are more than 70°F., the materials shall be spread within 4 hours and worked into the adjacent material. When portland cement is used in the mixture and the temperatures are less than 70°F., the materials must be spread within 8 hours and worked into the adjacent material. Additional moisture may be required during the reworking operations as directed by the engineer.

The equipment and methods employed in spreading the base material shall insure accuracy and uniformity of depth and width. If conditions arise where such uniformity in the spreading is not being obtained, the engineer may require additional equipment or modification in the spreading procedure to obtain satisfactory results. Spreading equipment shall be no more than 30 feet nor less than 9 feet in width, unless approved by the engineer.

After spreading, the material shall be thoroughly compacted by rolling. The rolling shall progress gradually from one side toward previously placed material by uniformly lapping each preceding rear-wheel track by one-half the width of such track. Rolling shall continue until the base material has been uniformly compacted for its full depth to not less than 100% density, as determined by the compaction-control tests specified in FAA T 611. Blading and rolling shall be done alternately, as required or directed, to obtain a smooth, even, and uniformly compacted base. Finishing operations shall continue until the surface is true to the specified cross section and until the surface shows no variations of more than 3/8 of an inch from a 16-foot straight-edge laid in any location parallel with, or at right angles to the longitudinal axis of the pavement.

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After a layer has been compacted, tested for density and approved by the Engineer, water shall be applied as required to maintain the moisture content of the mixture near the optimum until either a succeeding layer of lime-fly ash material or the bituminous curing coat is placed. The equipment used for applying the water and bituminous curing coat shall be such that will not displace or otherwise damage the surface.

Prior to placing a layer on a previously placed layer, the surface of the previously placed layer shall be loosened to assure interlocking of the aggregate between the layers.

In constructing the top layer, the grade shall be kept at sufficient height so that the top surface, when compacted, will be at or slightly above grade, rather than below grade. Finish grading shall be accomplished by removing excess material followed by recompaction by rolling. In the event that low areas occur, they shall be loosened, dampened with water immediately before placing additional mixture, and then rolled to the satisfaction of the Engineer.

Any dusting or surface ravelling caused by traffic on the sealed base course material shall be the responsibility of the contractor and shall be taken care of as directed by the engineer.

305-4.7 CONSTRUCTION JOINTS. The protection provided for construction joints shall permit the placing, spreading, and compacting of base material without injury to the work previously laid. Care shall be exercised to insure the specified density of the base material immediately adjacent to all construction joints, existing pavements, structures and unsupported pavement or lane edges.

305-4.8 PROTECTION AND CURING. After the base course has been finished as specified herein and approved by the engineer, it shall be protected against drying until the surface course is applied by the application of the specified bituminous material.

The bituminous material specified shall be uniformly applied to the surface of the completed base course at the rate of approximately 0.20 gallons per square yard using approved heating and distributing equipment in accordance to Specification P-602. The exact rate and temperature of application to give complete coverage without excessive runoff shall be as directed by the engineer.

At the time the bituminous material is applied, the surface shall be dense, free of all loose and extraneous material, and shall contain sufficient moisture to prevent penetration of the bituminous material. All surfaces shall be cleaned of all dust and unsound materials to the satisfaction of the engineer. Cleaning shall be done with rotary brooms and/or blowing the surface with compressed air, with the surface reasonably moistened to prevent air pollution. Water shall be applied in sufficient quantity to fill the surface voids immediately before the bituminous curing material is applied.

Item P-305 Aggregate-Lime-
Fly Ash Subbase or Base Course

Should it be necessary for construction equipment or other traffic to use the bituminous-covered surface before the bituminous material has dried sufficiently to prevent pickup, sufficient granular cover shall be applied before such use.

No traffic shall be allowed on the fly ash base/subbase course other than that developing from the operation of essential construction equipment, unless otherwise directed by the engineer. Any defects which may develop in the construction of the base course or any other damage caused by the operation of the job equipment is the responsibility of the contractor and shall be immediately repaired or replaced to the satisfaction of the engineer, at no expense to the sponsor.

305-4.9 COLD WEATHER PROTECTION. During cold weather if the air temperature unexpectedly drops below 40°F. and remains there for a period of several days or more, the completed base course shall be protected from freezing by a method approved by the engineer prior to the application of the bituminous surface course. Any light surface frost caused by overnight below freezing temperatures shall be treated by rolling the surface with a light steel wheel roller as directed by the engineer.

* 305-4.11 TOLERANCE IN BASE/SUBBASE THICKNESS.
See General Notes on the Plans. **

Method of Measurement

305-5.1 The quantity of aggregate-lime-fly ash base course to be paid for shall be the actual number of cubic yards (computed from plan lines, within the actual width of the existing underpavements) of approved aggregate lime-fly ash base course material compacted in conformity with the lines, grades and typical sections shown on the plans.

Basis of Payment

305-6.1 Payment shall be made at the contract unit price per cubic yard for aggregate-lime-fly ash base/subbase course. This price shall be full compensation for furnishing all materials and for all preparation, manipulation, and placing of these materials and for all labor, equipment, tools and incidentals necessary to complete the item.

Payment will be made under:

Item P-305-6.10 Aggregate-Lime-Fly Ash Base Course
per cubic yard.

4. THE ROAD RESEARCH LABORATORY FROST TEST

The test adopted at the Laboratory is based on one originally developed by Taber in the United States.⁽⁴⁾ Compacted cylindrical samples of the material under test are frozen from one end while the other end is in contact with free water maintained at a temperature slightly above freezing point. The heave is recorded over a period of 10 days.

4.1 Preparation of samples

The samples tested are 4 in diameter and 6 in long. They are compacted in a cylindrical mould provided with a slight taper for easy extrusion. Details of the mould and the extruders are shown in Fig. 6 and Plate 1.

For cohesive soils the usual level of compaction adopted corresponds to 5 per cent of air voids at the natural moisture content or, if the latter is not known, at a moisture content of 2 per cent above the plastic limit.

Non-cohesive soils and other granular materials of maximum size less than 1 in are normally tested at the maximum dry density and optimum moisture content of the British Standard compaction test using normal compaction.⁽⁵⁾ For coarser granular materials the fraction retained on the 2 in sieve is removed prior to the preparation of the freezing samples. The selection of the appropriate moisture content and dry density for the compaction of such coarse materials presents some difficulty. A.E.S. compaction test carried out on material finer than $\frac{3}{4}$ in gives a useful guide, but some adjustment to the dry density may be necessary to achieve a sample which is sufficiently stable but at the same time is not subject to crushing of the particles when compacted by the procedure described below. This adjustment must be made by trial and error at the time of compaction.

For all materials, tests at several dry densities can be carried out to investigate the effect of dry density, but in granular materials care should be taken to avoid crushing the particles during compaction.

Classification tests adopted include liquid and plastic limits, particle size distribution and particle specific gravity. For aggregates of porous structure the saturation moisture content of the particles greater than the $\frac{1}{2}$ in sieve size is determined. From a kilogram of the material not less than ten particles in this size range are selected at random. The particles are immersed in water for at least 24 hours after which they are surface-dried and the wet weight of each is measured. From the oven-dry weights subsequently determined, the moisture content of each particle and the average moisture content are quoted.

4.2 Compaction of samples

The mould is assembled in the vertical position with the lower ram in the bore but held half to one inch from its innermost position by suitable spacers. The weighed amount of material necessary to give the required dry density in the compacted sample is placed slowly into the mould accompanied by continuous dynamic compaction with a flat-ended wooden rod of about $1\frac{1}{2}$ in diameter. When all the weighed material has been tamped into the mould the upper ram is placed in the bore and the complete mould transferred to a compression type testing machine of maximum capacity 30 tons (Plate 2). The spacers are removed from the lower ram and the sample is compressed statically using a rate of strain not exceeding 2 in per minute. During compression the side of the mould is struck periodically with a rawhide mallet. This compaction procedure is adopted to reduce density gradients within the specimens to a minimum.

The sample is extruded from the wide end of the mould using the short extruder mounted in the testing machine to start the extrusion process. Final extrusion is affected by hand using the full-length extruder.

Immediately after extrusion a waxed paper sheet 14 in long and 8 in wide is wrapped round the curved face of the sample and secured with adhesive tape, to give a 2 in upstand at the upper face. A waxed cardboard disc $3\frac{1}{4}$ in in diameter and provided with a central dimple to accommodate a $3/16$ in diameter push rod is placed on the top of the sample. Finally the sample is placed on a ceramic plate, $\frac{1}{2}$ in thick and 4 in in diameter, of average pore size 100 microns (Grade 1), located in a spun copper collar (specimen carrier) of the dimensions given in Fig. 7. An extruded sample ready for wrapping and mounting is shown in Plate 3.

4.3 Freezing cabinet

The freezing cabinet (Plate 4), which is designed to take nine specimens, is shown in cross-section in Fig. 8. A removable wooden specimen container is located in a lagged cabinet provided with wheels to facilitate movement into and out of the refrigeration room. The base of the specimen container is provided with nine recessed holes into which the copper specimen carriers fit. The space between the samples is filled with a coarse dry sand to a level slightly higher than the top of the samples. Vertical push rods $3/16$ in in diameter, supported by transverse metal bars in which they are free to slide, are located with their lower ends in the dimples provided in the sample cover discs (Plate 5).

When the specimen container is in position in the lagged cabinet, the upper faces of the ceramic discs are in the surface of the water in a thermostatically-controlled electrically-heated water bath in the bottom of the cabinet. An overflow pipe prevents water rising above the level of the plates and water can be added to maintain this level through a stand-pipe passing through the base of the specimen container. The adjustable thermostat for controlling the temperature of the bath is fixed to the outside of the cabinet.

4.4 Test procedure

The compacted specimens are placed in the cabinet, and the sand filling added. The transverse bars and push rods are put in position and water added to the bath until overflow occurs. After 24 hours at room temperature further water is added to replace any absorbed by the samples. The push rods are pressed firmly in contact with the sample covers and the distance between the top of each rod and the transverse bar is recorded. With the thermostat set to $+4^{\circ}\text{C}$ the equipment is wheeled into a refrigeration room operating at -17°C and the bath heating circuit is connected to the appropriate mains supply.

After 24 hours the push rods are again firmly pressed in contact with the specimen covers and the protrusion of the rods above the transverse bars is again measured, any heave which has occurred being deduced by subtraction. Water at $+4^{\circ}\text{C}$ is added until overflow occurs. This process is repeated until the specimens have been in the refrigeration room for 10 days.

At the conclusion of the test the cabinet is taken from the cold room and the frozen samples are removed from the specimen container and their copper rings. The waxed paper is removed and the samples are photographed, while still frozen, together with an unfrozen specimen for comparison.

4.5 Temperature conditions in the specimens during test

The temperature distribution in the test specimens once equilibrium conditions have become established varies slightly with the material under test. The average temperature distribution measured in several materials not susceptible to appreciable frost heave is shown in Fig. 9(a) and the suction distribution imposed by this temperature gradient (assuming no moisture flow) is given in Fig. 9(b). Under the conditions of the test the equilibrium temperature distribution is established after about 6 days of freezing.

The effect of heave on the temperature distribution is to elongate the depth scale approximately in proportion to the heave which occurs.

Comparison of Fig. 9(a) with the distribution of temperature with depth in the ground during severe winter conditions, Fig. 4(a), shows that the temperature gradients with depth in the vicinity of the zero isotherm are greater in the test than in practice. This means that the suction gradient is also greater. Both figures show, however, that once the zero isotherm has penetrated into a moist soil or granular material a considerable suction gradient is present at the depth of penetration. It is probable that the precise magnitude of this gradient is of secondary importance in determining frost heave. A more important factor is likely to be the high water-table used in the laboratory test. In soils other than unfissured heavy clays the height of the water-table has a profound effect on the ability of the unfrozen soil to transmit water. If it be assumed that the depth of the zero isotherm below a road surface during a prolonged cold spell is 18 in, the test would represent a water-table about 3 in lower than the depth i.e. at 21 in below road surface. This would represent a high water-table condition for a modern motorway or trunk road provided with an effective drainage system, although this would not necessarily be the case on older roads with ditch drainage. The test is therefore a rather severe one in relation to the conditions likely to prevail in practice in Britain during a very cold winter.

It is important to appreciate that the test conditions give a freezing front which is continuously descending in relation to the top of the sample. This is because the sample is allowed to heave above the level of the surrounding sand. Once the position of the zero isotherm has become stable with relation to the bottom of the sample, the addition of more sand packing to bring the level up to the top of the sample stabilizes the position of the zero isotherm relative to the top of the sample and completely inhibits further heave.

4.6 Criteria adopted to assess frost susceptibility

Most road materials heave to some extent when subjected to the Road Research Laboratory freezing test. It is therefore necessary to establish heave criteria from which the frost susceptibility can be judged. Experience during the severe frosts of 1940 and 1947 was used to develop these criteria. Subgrade materials from sites where frost failures had occurred were subjected to the test together with other materials which had apparently been satisfactory under similar conditions. From this work it was concluded that materials which heaved 0.5 in or less during the 10-day period of the test were satisfactory, materials which heaved between 0.5 and 0.7 in were marginally frost-susceptible and those which heaved more than 0.7 in were classified as very frost-susceptible. Since a main function of a sub-base is to replace frost-susceptible soil the same criteria were subsequently applied to sub-base and base materials.

Criteria such as these can clearly only distinguish broadly between the actual performance of the materials in a road structure, which will depend not only on the drainage conditions but also on the type of pavement used. The early experience was based largely on the performance of roads with relatively weak pavements consisting of crushed stone or pitched bases surfaced with the open-textured bituminous materials widely used at that time. The load-spreading ability of such a pavement would be much smaller than, for example, that of an asphalt surfacing on a bound base, and the danger of failure during the thaw period consequently greater. It is felt, however, that there is not sufficient information to permit the use of different criteria depending on the type of pavement used. Apart from the question of actual failure following the thaw, it is clear that the inevitable weakening of frost-susceptible foundations will impose additional stresses on the upper layers of the pavements, the effect of which may be long-term and not necessarily immediately apparent. This is particularly likely to apply to pavements with lean concrete bases and possibly to concrete roads generally, where the tensile stresses at the bottom of the concrete are known to be influenced by changes in the effective elastic moduli of the foundation.

: A further point to be considered in relation to frost-susceptibility criteria is the need to avoid significant differential heave even on pavements unlikely to suffer any serious structural weakening following the thaw. Such differential heave where pavements join structures or at edge-beams and hard shoulders gives rise to the opening of cracks and joints which subsequently present a maintenance problem if the ingress of water and its attendant difficulties are to be avoided.

APPENDIX VII: PERMEABILITY TESTS

1. DARCY'S LAW FOR FLOW OF WATER THROUGH SOIL. The flow of water through a soil medium is assumed to follow Darcy's law:

$$q = k i A$$

where q = rate of discharge through a soil of cross-sectional area A
 k = coefficient of permeability
 i = hydraulic gradient: the loss of hydraulic head per unit distance of flow

The application of Darcy's law to a specimen of soil in the laboratory is illustrated in Figure 1. The coefficient of permeability, k (often termed

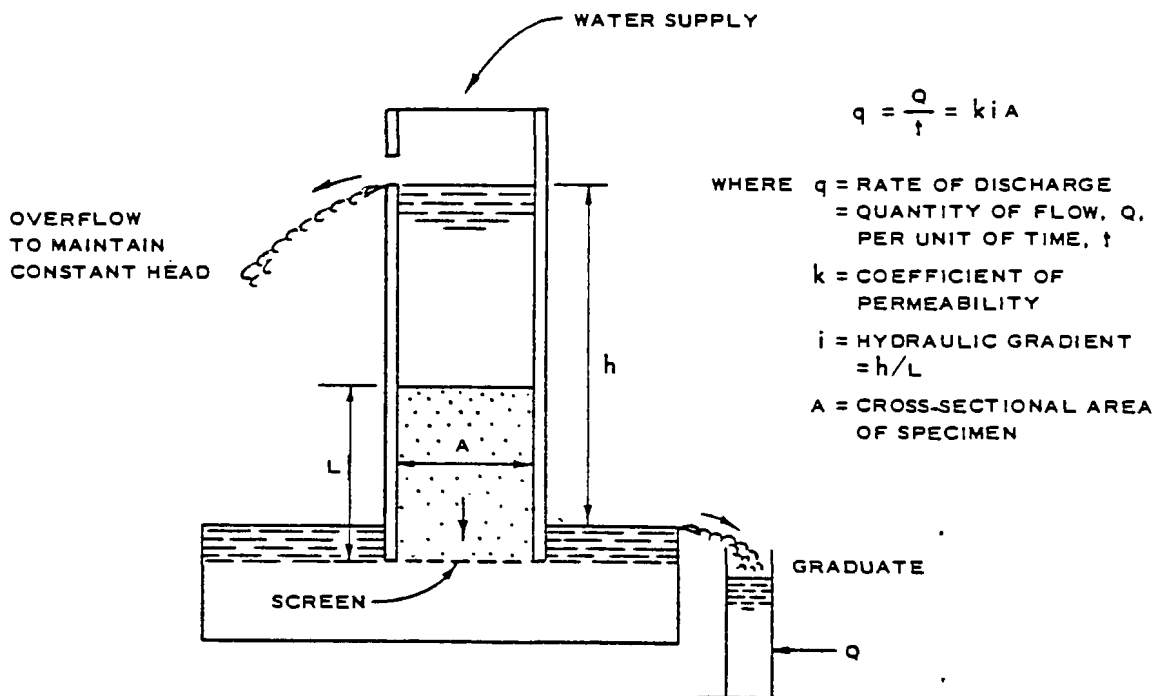


Figure 1. Flow of water through soil

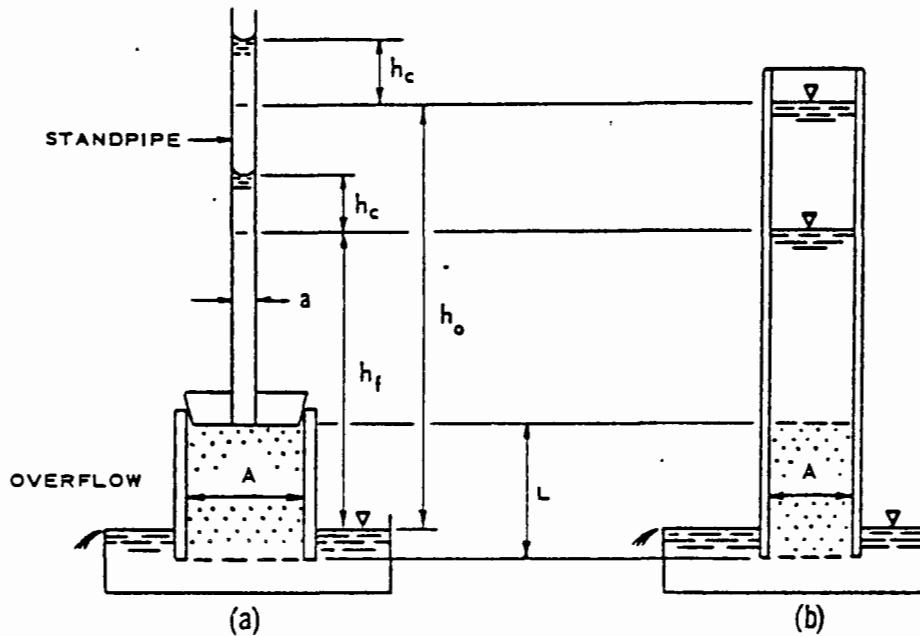
"permeability"), is defined as the rate of discharge of water at a temperature of 20 C under conditions of laminar flow through a unit cross-sectional area of a soil medium under a unit hydraulic gradient. The coefficient of permeability has the dimensions of a velocity and is usually expressed in centimeters per second. The permeability of a soil depends primarily on the size and shape of the soil grains, the void ratio of the soil, the shape and arrangement of the voids, and the degree of saturation.

Permeability computed on the basis of Darcy's law is limited to the conditions of laminar flow and complete saturation of the voids. In turbulent flow, the flow is no longer proportional to the first power of the hydraulic gradient. Under conditions of incomplete saturation, the flow is in a transient state and is time-dependent. The laboratory procedures presented herein for determining the coefficient of permeability are based on the Darcy conditions of flow. Unless otherwise required, the coefficient of permeability shall be determined for a condition of complete saturation of the specimen. Departure from the Darcy flow conditions to simulate natural conditions is sometimes necessary; however, the effects of turbulent flow and incomplete saturation on the permeability should be recognized and taken into consideration.

2. TYPES OF TESTS AND EQUIPMENT. a. Types of Tests. (1) Constant-head test. The simplest of all methods for determining the coefficient of permeability is the constant-head type of test illustrated in Figure 1. This test is performed by measuring the quantity of water, Q , flowing through the soil specimen, the length of the soil specimen, L , the head of water, h , and the elapsed time, t . The head of water is kept constant throughout the test. For fine-grained soils, Q is small and may be difficult to measure accurately. Therefore, the constant-head test is used principally for coarse-grained soils (clean sands and gravels) with k values greater than about 10×10^{-4} cm per sec.

(2) Falling-head test. The principle of the falling-head test is illustrated in Figure 2. This test is conducted in the same manner as

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USING SETUP SHOWN IN (a), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{La}{At} \ln \frac{h_o}{h_f} = 2.303 \frac{La}{At} \log_{10} \frac{h_o}{h_f}$$

USING SETUP SHOWN IN (b), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{L}{t} \ln \frac{h_o}{h_f} = 2.303 \frac{L}{t} \log_{10} \frac{h_o}{h_f}$$

WHERE: h_c = HEIGHT OF CAPILLARY RISE
 a = INSIDE AREA OF STANDPIPE
 A = CROSS-SECTIONAL AREA OF SPECIMEN
 L = LENGTH OF SPECIMEN
 h_o = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_o
 h_f = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_f
 t = ELAPSED TIME, $t_f - t_o$

Figure 2. Principle of falling-head test

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the constant-head test, except that the head of water is not maintained constant but is permitted to fall within the upper part of the specimen container or in a standpipe directly connected to the specimen. The quantity of water flowing through the specimen is determined indirectly by computation. The falling-head test is generally used for less pervious soils (fine sands to fat clays) with k values less than 10×10^{-4} cm per sec.

b. Equipment. The apparatus used for permeability testing may vary considerably in detail depending primarily on the condition and character of the sample to be tested. Whether the sample is fine-grained or coarse-grained, undisturbed, remolded, or compacted, saturated or nonsaturated will influence the type of apparatus to be employed. The basic types of apparatus, grouped according to the type of specimen container (permeameter), are as follows:

- (1) Permeameter cylinders
- (2) Sampling tubes
- (3) Pressure cylinders
- (4) Consolidometers

The permeability of remolded cohesionless soils is determined in permeameter cylinders, while the permeability of undisturbed cohesionless soils in a vertical direction can be determined using the sampling tube as a permeameter. The permeability of remolded cohesionless soils is generally used to approximate the permeability of undisturbed cohesionless soils in a horizontal direction. Pressure cylinders and consolidometers are used for fine-grained soils in the remolded, undisturbed, or compacted state. Fine-grained soils can be tested with the specimen oriented to obtain the permeability in either the vertical or horizontal direction. The above-listed devices are described in detail under the individual test procedures. Permeability tests utilizing the different types of apparatus, together with recommendations regarding their use, are discussed in the following paragraphs.

4. FALLING-HEAD PERMEABILITY TEST WITH PERMEAMETER CYLINDER.

a. Use. The falling-head test with the permeameter cylinder should in general be used for determining the permeability of remolded samples of cohesionless soils having a permeability less than about 10×10^{-4} cm per sec.

b. Apparatus. The apparatus and accessory equipment should consist of the following:

(1) A permeameter cylinder similar to that shown schematically in Figure 3b, or modified versions thereof. The permeameter cylinder should be constructed of a transparent plastic material. The inside diameter of the cylinder should be not less than about 10 times the diameter of the largest soil particles. The use of two piezometer taps, as shown by Figure 3b, connected to a standpipe and discharge level tube eliminates the necessity for taking into account the height of capillary rise which would be necessary in the case of a single standpipe of small size. The height of capillary rise for a given tube and condition can be measured simply by standing the tube upright in a beaker full of water. The size of standpipe to be used is generally based on experience with the equipment used and soils tested. In order to accelerate testing, air pressure may be applied to the standpipe to increase the hydraulic gradient.

(2) Perforated metal or plastic disks and circular wire screens, 35 to 100 mesh, cut for a close fit inside the permeameter.

(3) Glass tubing, rubber or plastic tubing, stoppers, screw clamps, etc., necessary to make connections as shown in Figure 3b.

(4) Filter materials such as Ottawa sand, coarse sand, and gravel of various gradations.

(5) Deaired distilled water, prepared according to paragraph 3b(6).

(6) Manometer board or suitable scales for measuring levels in piezometers or standpipe.

(7) Timing device, a watch or clock with second hand.

(8) Centigrade thermometer, range 0 to 50 C, accurate to 0.1 C

(9) Balance, sensitive to 0.1 g.

- (10) Oven (see Appendix I, WATER CONTENT - GENERAL).
(11) Scale, graduated in centimeters.

c. Placement and Saturation of Specimen. Placement and saturation of the specimen shall be done as described in paragraph 3c. Identifying information for the sample and test data shall be entered on a data sheet similar to Plate VII-2.

d. Procedure. The procedure shall consist of the following steps:

- (1) Measure and record the height of the specimen, L , and the cross-sectional area of the specimen, A .
- (2) With valve B open (see Fig. 3b), crack valve A and slowly bring the water level up to the discharge level of the permeameter.
- (3) Raise the head of water in the standpipe above the discharge level of the permeameter. The difference in head should not result in an excessively high hydraulic gradient during the test. Close valves A and B.
- (4) Begin the test by opening valve B. Start the timer. As the water flows through the specimen, measure and record the height of water in the standpipe above the discharge level, h_o , in centimeters, at time t_o , and the height of water above the discharge level, h_f , in centimeters, at time t_f .
- (5) Observe and record the temperature of the water in the permeameter.
- (6) Repeat the determination of permeability, and if the computed values differ by an appreciable amount, repeat the test until consistent values of permeability are obtained.

e. Computations. The computations consist of the following steps:

- (1) Compute the test void ratios as outlined in paragraph 3e(1).
- (2) Compute the coefficient of permeability, k , by means of the following equation:

$$k = 2.303 \frac{a}{A} \frac{L}{t} \log \frac{h_o}{h_f} \times R_T$$

where a = inside area of standpipe, sq cm
 A = cross-sectional area of specimen, sq cm
 L = length of specimen, cm
 t = elapsed time ($t_f - t_o$), sec
 h_o = height of water in standpipe above discharge level at time t_o , cm
 h_f = height of water in standpipe above discharge level at time t_f , cm
 R_T = temperature correction factor for viscosity of water obtained from Table VII-1, degrees C

If a single standpipe of small diameter is used as shown in Figure 2, the height of capillary rise, h_c , should be subtracted from the standpipe readings to obtain h_o and h_f .

f. Presentation of Results. The results of the falling-head permeability test shall be reported as described in paragraph 3f.

5. PERMEABILITY TESTS WITH SAMPLING TUBES. Permeability tests may be performed directly on undisturbed samples without removing them from the sampling tubes. The sampling tube serves as the permeameter cylinder. The method is applicable primarily to cohesionless soils which cannot be removed from the sampling tube without excessive disturbance. The permeability obtained is in the direction in which the sample was taken, i.e. generally vertical. The permeability obtained in a vertical direction may be substantially less than that obtained in a horizontal direction.

Permeability tests with sampling tubes may be performed under constant-head or falling-head conditions of flow, depending on the estimated permeability of the sample (see paragraph 2a). The equipment should be capable of reproducing the conditions of flow in the constant-head or falling-head tests. It is important that all disturbed material or material containing drilling mud be removed from the top and bottom of the sample. The ends of the sample should be protected by screens held in place by perforated packers. The test procedure and computations are

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the same as those described previously for each test.

6. PERMEABILITY TEST WITH PRESSURE CHAMBER. In the permeability test with a pressure chamber, see Figure 7, a cylindrical specimen is confined in a rubber membrane and subjected to an external hydrostatic pressure during the permeability test. The advantages of this type of test are: (a) leakage along the sides of the specimen, which would occur if the specimen were tested in a permeameter, is prevented, and (b) the specimen can be tested under conditions of loading expected in the field. The test is applicable primarily to cohesive soils in the undisturbed, remolded, or compacted state. Complete saturation of the specimen, if it is not fully saturated initially, is practically impossible. Consequently, this test should be used only for soils that are fully saturated, unless values of permeability are purposely desired for soils in an unsaturated condition. The permeability test with the pressure chamber is usually performed as a falling-head test.

The permeability specimens for use in the pressure chamber generally should be 2.8 in. in diameter, as rubber membranes and equipment for cutting and trimming specimens of this size are available for triaxial testing apparatus (see Appendix X, TRIAXIAL COMPRESSION TESTS). A specimen length of about 4 in. is adequate. (The dimensions of a test specimen may be varied if equipment and supplies are available to make a suitable test setup.) The pressure in the chamber should not be less than the maximum head on the specimen during the test. The other test procedure and computations are the same as those described for the falling-head test. The linear relation between permeability and void ratio on a semilogarithmic plot as shown in Figure 6 is usually not applicable to fine-grained soils, particularly when compacted. Other methods of presenting permeability-void ratio data may be desirable.

7. PERMEABILITY TESTS WITH BACK PRESSURE. Gas bubbles in the pores of a compacted or undisturbed specimen of fine-grained soil will invalidate the results of the permeability tests described in the preceding

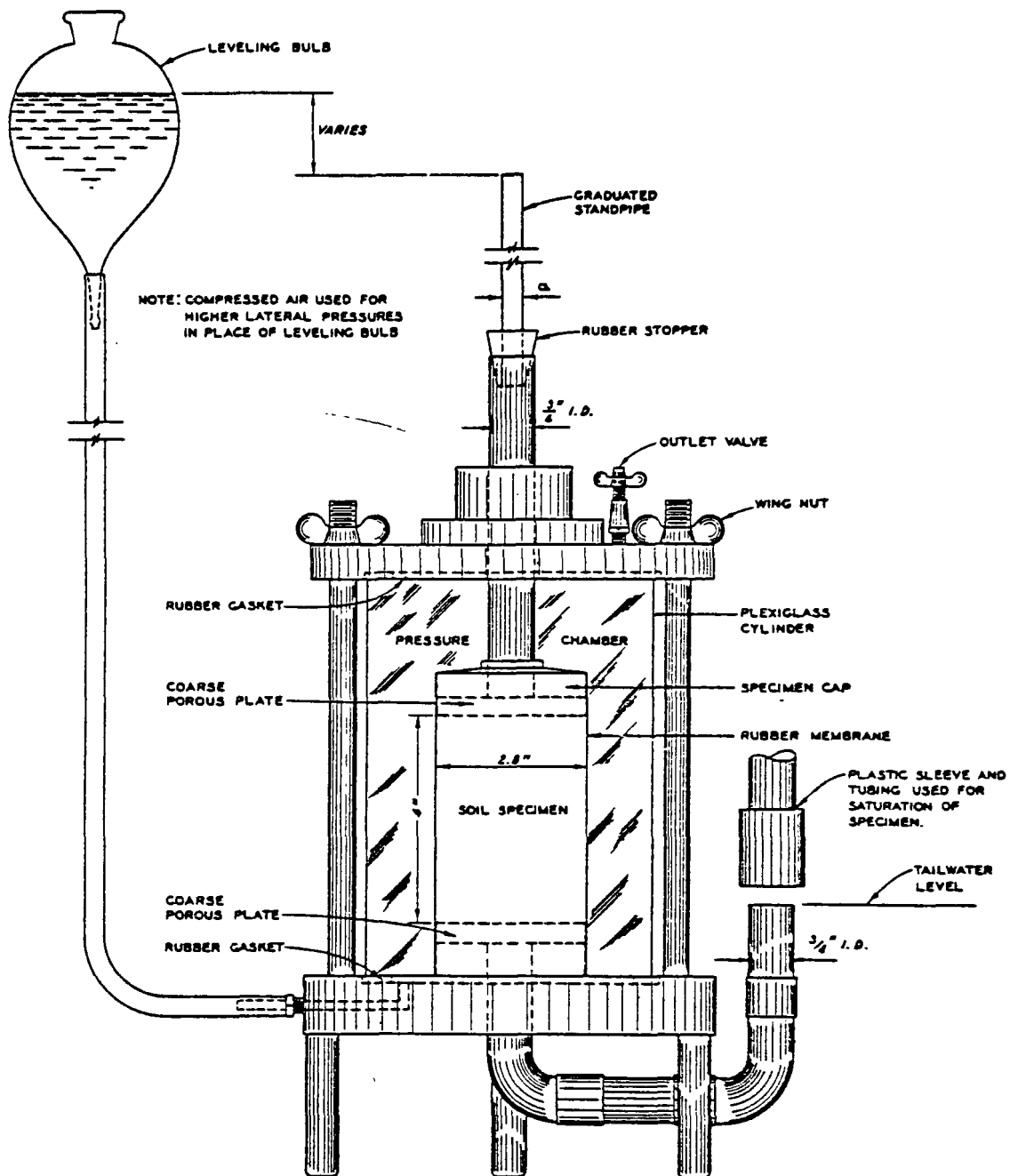


Figure 7. Pressure chamber for permeability test

paragraphs. It is known that an increase in pressure will cause a reduction in volume of gas bubbles and also an increased weight of gas dissolved in water. To each degree of saturation there corresponds a certain additional pressure (back pressure) which, if applied to the pore fluid of the specimen, will cause complete saturation. The permeability test with back pressure is performed in a pressure chamber such as that shown in Figure 7, utilizing equipment that permits increasing the chamber pressure and pore pressure simultaneously, maintaining their difference constant. The method is applicable to fine-grained soils which are not fully saturated. An apparatus which has been used for permeability tests with back pressure has been described by Bjerrum and Huder.†

8. PERMEABILITY TESTS WITH CONSOLIDOMETER. A permeability test in a consolidometer (see Appendix VIII, CONSOLIDATION TEST) is essentially similar to that conducted in a pressure chamber, except that the specimen is placed within a relatively rigid ring and is loaded vertically. The test can be used as an alternate to the permeability test in the pressure chamber. The test is applicable primarily to cohesive soils in a fully saturated condition. Testing is usually performed under falling-head conditions.

A schematic diagram of the consolidation apparatus set up for a falling-head permeability test is shown in Figure 8. Identifying information for the specimen and subsequent test data are entered on a data sheet (Plate VII-3 is a suggested form). The specimen should be placed in the specimen ring and the apparatus assembled as outlined under Appendix VIII, CONSOLIDATION TEST. The specimen is consolidated under the desired load and the falling-head test is performed as previously described. The

† L. Bjerrum and J. Huder, "Measurement of the permeability of compacted clays," Proceedings, Fourth International Conference on Soil Mechanics and Foundation Engineering (London, August 1957), vol. 1, pp. 6-8.

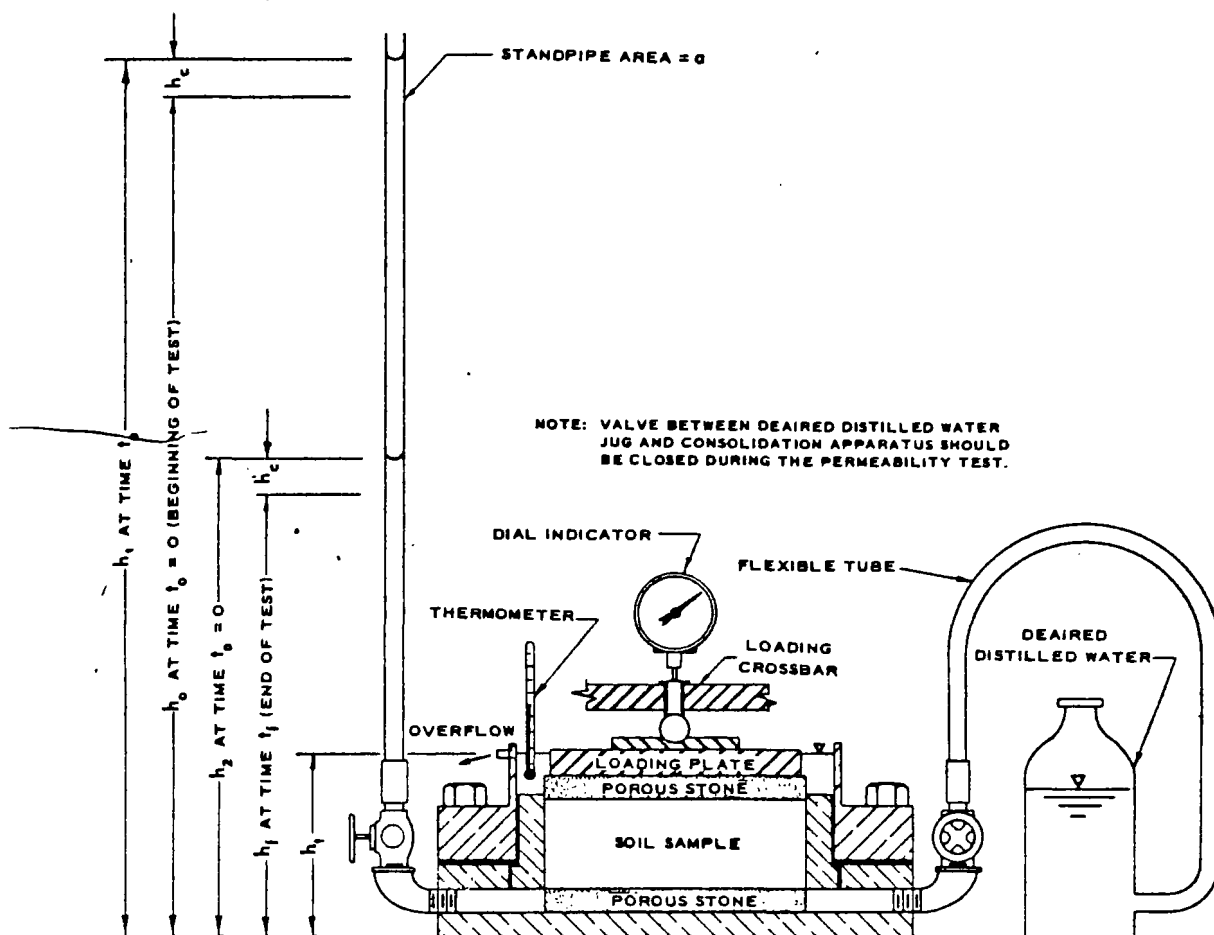


Figure 8. Schematic diagram of falling-head device for permeability test in consolidometer

net head on the specimen may be increased by use of air pressure; however, the pressure on the pore water should not exceed 25 to 30 percent of the vertical pressure under which the specimen has consolidated. Dial indicator readings are observed before and after consolidation to permit computation of void ratios. The determination of the coefficient of permeability may be made in conjunction with the consolidation test, in which case the test is performed at the end of the consolidation phase under each load increment. Computations are similar to those described for the

falling-head test with the permeameter cylinder.

The permeability may also be determined indirectly from computations using data obtained during the consolidation test; however the assumptions on which the method is based are seldom satisfied, and consequently, the direct determination of permeability should be employed where reliable values of permeability are required.

9. POSSIBLE ERRORS. Following are possible errors that would cause inaccurate determinations of the coefficient of permeability:

a. Stratification or nonuniform compaction of cohesionless soils. If the specimen is compacted in layers, any accumulation of fines at the surface of the layers will reduce the measured coefficient of permeability.

b. Incomplete initial saturation of specimen.

c. Excessive hydraulic gradient. Darcy's law is applicable only to conditions of laminar flow.

d. Air dissolved in water. No other source of error is as troublesome as the accumulation of air in the specimen from the flowing water. As water enters the specimen, small quantities of air dissolved in the water will tend to collect as fine bubbles at the soil-water interface and reduce the permeability at this interface with increasing time. The method for detecting and avoiding this problem is described in paragraph 3d(6). (It should be noted that air accumulation will not affect the coefficient of permeability determined by the constant-head test if piezometer taps along the side of the specimen are used to measure the head loss.)

e. Leakage along side of specimen in permeameter. One major advantage to the use of the triaxial compression chamber for permeability tests (see paragraphs 6 and 7) is that the specimen is confined by a flexible membrane which is pressed tightly against the specimen by the chamber pressure.

<u>FALLING-HEAD PERMEABILITY TEST</u>									
								DATE _____	
PROJECT _____									
BORING NO. _____									
Sample or Specimen No. _____									
Wt in grams	Tare plus dry soil			Diameter of specimen, cm		D			
	Tare			Area of specimen, sq cm		A			
	Dry Soil	W_s		Initial height of specimen, cm		L			
Specific gravity		G		Initial vol of spec, cc = AL		V			
Vol of solids, cc = $W_s + G$		V_s		Initial void ratio = $(V - V_s) + V_s$		e			
Area of standpipe, sq cm		a		Constant = $(2.303 \times a) + A$		C			
Test No.			1		2		3		
Height of specimen, cm		L							
Void ratio = $(AL - V_s) + V_s$		e							
			1a	1b	2a	2b	3a	3b	
Initial time		t_o							
Final time		t_f							
Elapsed time, sec = $t_f - t_o$		t							
Initial head, cm		h_o							
Final head, cm		h_f							
$\log(h_o + h_f)$									
Water temperature, °C		T							
Viscosity correction factor ⁽¹⁾		R_T							
Coefficient of permeability, ⁽²⁾ cm/sec		k_{20}							
		Avg							
<p>(1) Correction factor for viscosity of water at 20 C obtained from table VII-1.</p> <p>(2) $k_{20} = 2.303 \frac{a}{A} \frac{L}{t} \log \frac{h_o}{h_f} \times R_T = \frac{C}{t} \log \frac{h_o}{h_f} \times R_T$.</p>									
Remarks _____									
Technician _____ Computed by _____ Checked by _____									

<u>FALLING-HEAD PERMEABILITY TEST</u> <u>WITH CONSOLIDOMETER</u>									
								DATE _____	
PROJECT _____									
BORING NO. _____									
Sample or Specimen No. _____									
Wt in grams	Tare plus dry soil				Diameter of specimen, cm		D		
	Tare				Area of specimen, sq cm		A		
	Dry soil	W_s			Initial height of specimen, cm		L		
Specific gravity		G_s			Initial vol of spec, cc = AL		V		
Vol of solids, cc = $W_s + G_s$		V_s			Initial void ratio = $(V - V_s) + V_s$		e		
Area of standpipe, sq cm		a			Constant = $(2.303 \times a) + A$		C		
Capillary rise, cm		h_c			Initial dial reading, in.		D_o		
Height of tailwater, cm		h_t			Corrected tailwater, cm, $h_t + h_c$		Δh		
Test No.			1		2		3		
Load increment, T/sq ft			P						
Dial reading at start, in.			D_1						
Change in ht of spec, in. = $D_o - D_1$			ΔD						
Ht of spec, cm $L - 2.54 \Delta D$			L						
Void ratio = $(AL - V_s) + V_s$			e						
			1a	1b	2a	2b	3a	3b	
Initial time			t_o						
Final time			t_f						
Elapsed time, sec = $t_f - t_o$			t						
Initial height, cm			h_1						
Final height, cm			h_2						
Water temperature, °C			T						
Viscosity correction factor ⁽¹⁾			R_T						
Coefficient of permeability ⁽²⁾ cm/sec			k_{20}						
			Avg						
(1) Correction factor for viscosity of water at 20 C obtained from table VII-1. (2) $k_{20} = 2.303 \frac{a}{A} \frac{L}{t} \log \frac{h_1 - \Delta h}{h_2 - \Delta h} \times R_T = \frac{C L}{t} \log \frac{h_1 - \Delta h}{h_2 - \Delta h} \times R_T$									
Remarks _____									
Technician _____ Computed by _____ Checked by _____									

PATENTS

UNITED STATES PATENT OFFICE

2,564,690

HYDRATED LIME-FLY ASH-FINE
AGGREGATE CEMENTJules E. Havelin, Havertown, and Frank Kahn,
Philadelphia, Pa.

Application June 30, 1948, Serial No. 36,048

4 Claims. (CL 106—120)

1

This invention relates to novel hydrated lime-fly ash-fine aggregate cements especially useful for masonry mortar, protective coating, soil stabilization and grouting compositions and particularly to hydrated lime-fly ash-fine aggregate compositions of this type having early compressive strengths exceeding the corresponding early compressive strengths of the lime-fine aggregate mortar compositions of the prior art.

For many years the masonry mortar and protective coating art has operated on the supposition that the compressive strength of lime mortars is increased by adding lime and is decreased by a reduction in the proportion of lime to fine aggregate. This decrease in compressive strength with reduction in lime and the extent thereof is well known in this art and the various attempts to reduce the lime proportion without loss in compressive strength have been unsuccessful. In its broad aspect the present invention is directed to the provision of hydrated lime fly ash-fine aggregate cements useful as masonry mortars, protective coatings such as plaster, soil stabilization and construction filling materials such as groutings having compressive strengths exceeding those of the prior art lime mortars of corresponding lime proportion. For some applications the magnitude of improvement in early compressive strength need not be large, since a relatively small increase in early compressive strength will provide a cement having characteristics equal to or better than a prior art lime mortar of very much higher lime content. However, for other applications, particularly in the field of industrial construction, a mortar of very much higher early compressive strength is required and in these fields lime mortars have been largely displaced because early compressive strengths of the magnitude required are not obtainable in a lime-fine aggregate mortar even with very large proportions of lime. This characteristic of low compressive strength has been considered by the art as inherent in lime-fine aggregate mortars and consequently the art has turned to Portland cement mortars and the like.

As used throughout this specification and claims the terms "hydrated lime" and lime are used interchangeably to indicate a dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration. It consists essentially of calcium hydrate or a mixture of calcium hydrate and magnesium oxide and magnesium hydroxide. In the above definition quicklime is used to indicate a calcined material the major portion of which is calcium oxide or calcium oxide in natu-

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ral association with a lesser amount of magnesium oxide capable of slaking with water.

As defined above and as used throughout the present specification and claims, the term "hydrated lime" or "lime" is not intended to include hydraulic lime or the free lime made available in the hydration of Portland cement, natural cements and the like. Lime from such sources differs from the hydrated lime of the present invention and does not give the results hereinafter described.

The term "fly ash" as used in the present specification is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. The fly ash so obtained is in a finely divided state such that at least about 70% passes through a 200 mesh sieve.

The term "fine aggregate" as used throughout this specification and the claims hereof is intended to indicate natural or artificial substantially chemically inert inorganic materials such as natural sand, sand prepared from stone, blast-furnace slag, gravel, or other inert materials having similar characteristics, substantially as defined in A. S. T. M. Tentative Standard Specifications for Concrete Aggregates, Designation C33—37T, and having a fineness modulus of at least substantially 1.7, substantially all of which will pass a $\frac{3}{8}$ inch sieve, substantially 95% or more of which will pass a No. 4 sieve, substantially 45% or more of which will pass a No. 16 sieve, and substantially 5% or more of which will pass a No. 50 sieve.

So far as we are aware no lime mortars have been made available to the art which have set under normal conditions to a compressive strength of the order of about 225 pounds per square inch and above in a period of seven days. As used in the present specification and claims the term "high compressive strength" is intended to cover the range from about 225 pounds per square inch and above after 7 days and the term "low compressive strength" is intended to cover the range from about 225 pounds per square inch and below after 7 days.

The principal object of the present invention is to provide hydrated lime-fly ash-fine aggregate cement compositions having greater early compressive strengths than the lime mortar compositions of the prior art having comparable lime content.

A further object of the present invention is to

provide hydrated lime-fly ash-fine aggregate cement compositions having high early compressive strengths of the order of 225 pounds per square inch and above.

A further object of the present invention is to provide a hydrated lime-fly ash-fine aggregate cement comparable in early compressive strength to the known cement mortars.

Heretofore, the addition of fly ash to Portland cements has been investigated and certain advantageous results based upon the so-called "puzzolanic" effect have been referred to in the art. While the reaction underlying the puzzolanic effect is not entirely understood it is said to involve a chemical reaction between the lime content of the cement and the silica content of the fly ash. However, this reaction does not involve hydrated lime and fly ash and should not be confused with the present invention. So far as we are aware the prior art has not successfully combined hydrated lime and fly ash in the making of a useful hydrated lime cement, capable of developing practical high early strengths when allowed to set under ambient conditions within the range of normally occurring atmospheric temperatures and humidities. Moreover, in the Portland cement art the addition of fly ash has not produced particularly significant increases in early compressive strength which is one of the principal advantages of the present invention.

The effect of puzzolanic materials in Portland cement concretes is evidenced by their producing an increase in long-time compressive strength, and it is indicated that their use may result in decreased early compressive strength.

In contrast with the low early strength characteristic of the puzzolanic effect, applicants' invention produces a high early compressive strength. In fact, the high early strength feature of applicants' invention can be used to increase substantially the early strength characteristic of Portland cement mixes.

We attain the objects of the present invention by means of a dry mix comprising hydrated lime, fly ash and a suitable fine aggregate to which water is added in suitable proportion in making up the final working composition.

In the drawings Fig. 1 shows in the curve marked A a plot of the compositions specifically set forth in Table I which follows. Curve B represents a hypothetical curve which is the relationship that would be normally expected from knowledge of the prior art.

In Fig. 2 the curve marked A is the same as curve A of Fig. 1 but plotted on a different scale. Curve C is a plot of the compositions specifically set forth in Table II.

The data set forth in the following tables taken in conjunction with the curves of Fig. 1 and Fig. 2 will serve to illustrate the present invention as hereinafter described.

Table I (parts by volume)

Hydrated Lime	Fly Ash	Sand	Per Cent Fly Ash (of Fly Ash and Lime)	Ratio of 7 Day Compressive Strength
50	0	50	0	1.00
40	10	50	20	1.00
30	20	50	40	1.08
20	30	50	60	1.13
10	40	50	80	1.13
5	45	50	90	1.30
2.5	47.5	50	95	0.79
1.25	48.75	50	97.5	0.38

Table II (parts by volume)

Hydrated Lime	Fly Ash	Sand	Per Cent Fly Ash (of Fly Ash and Lime)	Ratio of 7 Day Compressive Strength
5	0	95	0	1.00
5	19	76	79.2	3.12
5	38	57	82.4	10.50
5	47.5	47.5	90.4	8.01
5	57	38	92.0	7.01
5	76	19	93.7	6.05
6.25	0	93.75	0	1.00
6.25	37.5	56.25	85.9	10.7
6.25	46.875	46.875	88.0	15.4

Table III (parts by volume)

Lime	Fly Ash	Sand	Lime/Fly Ash and Sand	7 Day Compressive Strength (in p. s. l.)
3.84	48.08	48.08	1 part lime to 25 parts fly ash and sand.	230
6.0	38.0	57.0	1 part lime to 19 parts fly ash and sand.	427
6.2	37.5	56.3	1 part lime to 15 parts fly ash and sand.	273

It will be noted from the curves of Figs. 1 and 2 that the optimum 7 day compressive strengths occur in the range from one part hydrated lime to about 5 parts fly ash to one part hydrated lime to about 15 parts fly ash which values correspond to about 83% fly ash and 93.7% fly ash respectively calculated on the sum of the hydrated lime and fly ash. In obtaining the novel hydrated lime-fly ash-fine aggregate cements of the present invention within this range a suitable proportion of fine aggregate must be used. High early compressive strengths are obtained in the particular range lying between one part hydrated lime to about 15 parts fly ash and sand by volume and one part lime to about 25 parts fly ash and sand by volume as indicated in the data listed in Table III. The data plotted in curve C is devoted almost entirely to a high compressive strength type mixture having a lime to fly ash and sand ratio of one to 19, there being one point lying directly above the peak which represents a composition in which the ratio of lime to fly ash and sand is one to 15 and a second point corresponding to the next to the last composition of Table II in which the ratio of lime to fly ash and sand is one to 15. The optimum ratio of hydrated lime to fly ash is not materially changed by variations in the amount of water used in preparing the final cement mix although the absolute compressive strength values will be stronger where the amount of water is not greater than that required to give the desired flow of 100 on a standard flow table.

The proportions given in the tables and in the examples which follow are based upon the following weights per cubic foot for the solid ingredients:

Pounds per cubic foot

Lime ----- 45
Fly ash ----- 60
Sand ----- 80

It will be apparent to those skilled in the art that in the tables and in the examples parts by volume can easily be converted to parts by weight and that parts by weight can easily be converted to parts by volume using the above weight per cubic foot values in calculating the conversions.

In preparing the compositions set forth in the

above tables, several mixing procedures were followed. For example, the compositions of Tables II and III were prepared by following the general procedure for mixing test specimens as outlined in A. S. T. M. C109—44. Specimens of each mix were prepared in cubes measuring 2 inches in each dimension and these cubes were stored in molds in laboratory air for seven days after which they were removed and tested for compressive strength following the standard A. S. T. M. compressive strength procedure. In each case water was added to give a flow of 100 as measured on an A. S. T. M. standard flow table. In order to obtain optimum results in the practice of the present invention the amount of water added to the dry mix should be the minimum amount required to obtain the desired flow but as pointed out above the optimum ratio of fly ash to hydrated lime is not changed by using more or less water. We have found that other mixing procedures produce results following the same general curve which gives the relative compressive strengths although the absolute values may differ and in fact may be materially increased by intimate intermixture as described in detail in the examples below.

As preferred examples for obtaining hydrated lime-fly ash-fine aggregate cements having high early compressive strengths, we direct attention to the following examples:

EXAMPLE I

Hydrated lime.....parts by volume..	5
Fly ash.....do.....	38
Sand (fineness modulus, 1.7).....do.....	57
Water to lime ratio (by weight).....	5.40 to 1
Compressive strength (7 days).....p. s. i..	427

The dry mix of the above example was prepared by following the procedure outlined in A. S. T. M. C109—44 referred to above and the compressive strength was measured on the two inch test cubes using the A. S. T. M. standard compressive strength test procedure.

EXAMPLE II

Hydrated lime.....parts by volume..	5
Fly ash.....do.....	38
Sand (fineness modulus, 1.7).....do.....	57
Water to lime ratio (by weight).....	4.17 to 1
Compressive strength (7 days).....	652

The dry mix of Example II was prepared by intimately mixing the hydrated lime and the fly ash in a ball mill for 15 minutes after which these ingredients were thoroughly mixed, while dry, with the sand. The dry mix thus obtained was converted to a masonry mortar having a desired consistency by the addition of water as indicated. The 7 day compressive strength of Example II was about 650 lbs. per square inch. It will be noted that this example has a higher compressive strength and requires a smaller proportion of water than the earlier example which is attributable to the ball milling step in place of the hand mixing step of the A. S. T. M. procedure.

EXAMPLE III

Hydrated lime.....parts by volume..	3.84
Fly ash.....do.....	48.08
Sand (fineness modulus, 1.7).....do.....	48.08
Water to lime ratio (by weight).....	8.1 to 1
Compressive strength (7 days).....	230

The mixing procedure followed for Example III was the A. S. T. M. procedure given above.

It will be noted that the compressive strength is lower than that of Example I although it still exceeds 225 pounds per square inch. This comparative decrease in compressive strength probably results from the increased amount of sand in Example III where the ratio of lime to fly ash and sand by volume is 1 to 25. In this case we have found that where the ratio of lime to fly ash is selected in the range between about one to 5 and about one to 15 high early compressive strength results are obtained by using the amount of fine aggregate calculated to hold the ratio of lime to fly ash plus fine aggregate between one to 15 by volume to one to 25 by volume, provided, however, that the ratio of fine aggregate to fly ash plus fine aggregate is maintained in the range from about 1 to 1.5 to about 1 to 2.5.

From the above it will be apparent, particularly to those skilled in the art, that we have provided a new hydrated lime cement having wholly unexpected properties and in certain cases surprisingly large early compressive strength values. We have pointed out above the sharp increase in compressive strength which occurs in a relatively narrow range in which the ratio of fly ash to hydrated lime is very high. The degree of improvement is likewise partly dependent on the manner of mixing and on the proportion of hydrated lime and of fine aggregate to fly ash plus fine aggregate. In the prior art the proportion of hydrated lime to aggregate has covered the range (in parts by volume) from one part of hydrated lime to from about 2½ parts to about 4 parts aggregate. For many years the art has considered that any substantial decrease in hydrated lime relative to aggregate material would result in mortars and plasters having undesirable characteristics including low early compressive strengths. From the foregoing detailed description of the present invention, it will be noted that the ratio of hydrated lime to other solid ingredients of the mix employed in the practice of the present invention where high early compressive strengths are required is of the order of from one part hydrated lime to about 15 parts of other solid ingredients to one part hydrated lime to about 25 parts of other solid ingredients. So far as we are aware, these proportions are not only unknown in the lime mortar art but are contrary to the previously held teachings thereof.

It will be seen that the present invention provides a choice of hydrated lime-fly ash-fine aggregate cement compositions which may vary depending upon the particular requirements of the specific use to which the cement is to be put. Where relatively low early compressive strength is all that is required, the prior art lime to other solid ingredient ratios may be employed, in which case the resulting hydrated lime-fly ash-fine aggregate cement will have improved characteristics as compared to prior art lime mortars of comparable lime content. Compositions such as shown in Examples I, II and III may be employed where a cement of high early compressive strength is required. So far as we are aware hydrated lime mortars having the characteristics of the embodiments referred to above have not been available to the art prior to our invention which therefore represents a new development in the hydrated lime mortar art and particularly provides a novel hydrated lime-fly ash-fine aggregate cement composition suitable for masonry mortar, protective coatings

such as plaster, soil stabilization and filling materials such as grouting.

It will be understood that the basic ingredients comprising hydrated lime, fly ash and sand may vary as to specific volume from the values given but it is intended that such variations shall be included within the scope of the present invention as hereinafter claimed. It will likewise be understood that various additive ingredients may be used in addition to the basic ingredients referred to without departing from the present invention as hereinafter claimed.

This application is a continuation in part of our prior application Serial No. 546,208, filed July 22, 1944, and now abandoned.

Having thus described our invention, we claim:

1. A hydrated lime-fly ash-fine aggregate cement having high early compressive strength when mixed with water in suitable amount and allowed to set, consisting essentially of hydrated lime, fly ash and an aggregate of substantially chemically inert inorganic material having a fineness modulus of at least substantially 1.7, substantially all of which will pass a $\frac{3}{8}$ inch sieve, substantially 95% or more of which will pass a No. 4 sieve, substantially 45% or more of which will pass a No. 16 sieve, and substantially 5% or more of which will pass a No. 50 sieve, the ratio of hydrated lime to fly ash being from about 1 to 5 to about 1 to 15 by volume, the ratio of hydrated lime to fly ash plus fine aggregate being from about 1 to 15 to about 1 to 25 by volume and the ratio of fine aggregate to fly ash plus fine aggregate being from about 1 to 1.5 to about 1 to 2.5 by volume.

2. A cement and protective coating composition having high early compressive strength when mixed with water in suitable amount and allowed to set, consisting essentially of hydrated lime about 1 part by volume, fly ash from about 7.5 to about 12.5 parts by volume and from about 7.5 to about 12.5 parts by volume of an aggregate of substantially chemically inert inorganic material having a fineness modulus of at least substantially 1.7, substantially all of which will pass a $\frac{3}{8}$ inch sieve, substantially 95% or more of which will pass a No. 4 sieve, substantially 45% or more of which will pass a No. 16 sieve, and substantially 5% or more of which will pass a No. 50 sieve.

3. A cement and protective coating composition having high early compressive strength when mixed with water in suitable amount and allowed to set, consisting essentially of hydrated lime about 5 parts by volume, fly ash about 38 parts by volume and an aggregate of substantially chemically inert inorganic material having a fineness modulus of at least substantially 1.7, substantially all of which will pass a $\frac{3}{8}$ inch sieve, substantially 95% or more of which will pass a No. 4 sieve, substantially 45% or more of which will pass a No. 16 sieve, and substantially 5% or more of which will pass a No. 50 sieve.

4. A structural material possessing high early compressive strength, produced by mixing hydrated lime, fly ash, an aggregate of substantially chemically inert inorganic material having a fineness modulus of at least substantially 1.7, substantially all of which will pass a $\frac{3}{8}$ inch sieve, substantially 95% or more of which will pass a No. 4 sieve, substantially 45% or more of which will pass a No. 16 sieve, and substantially 5% or more of which will pass a No. 50 sieve, and a suitable amount of water, the ratio of hydrated lime to fly ash being from about 1 to 5 to about 1 to 15 by volume, the ratio of hydrated lime to fly ash plus aggregate being from about 1 to 15 to about 1 to 25 by volume and the ratio of aggregate to fly ash plus aggregate being from about 1 to 1.5 to about 1 to 2.5 by volume, the mixture being subjected for a suitable time to ambient conditions within the range of normally occurring atmospheric temperatures and humidities.

JULES E. HAVELIN.
FRANK KAHN.

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Number	Country	Date
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Aug. 21, 1951

J. E. HAVELIN ET AL

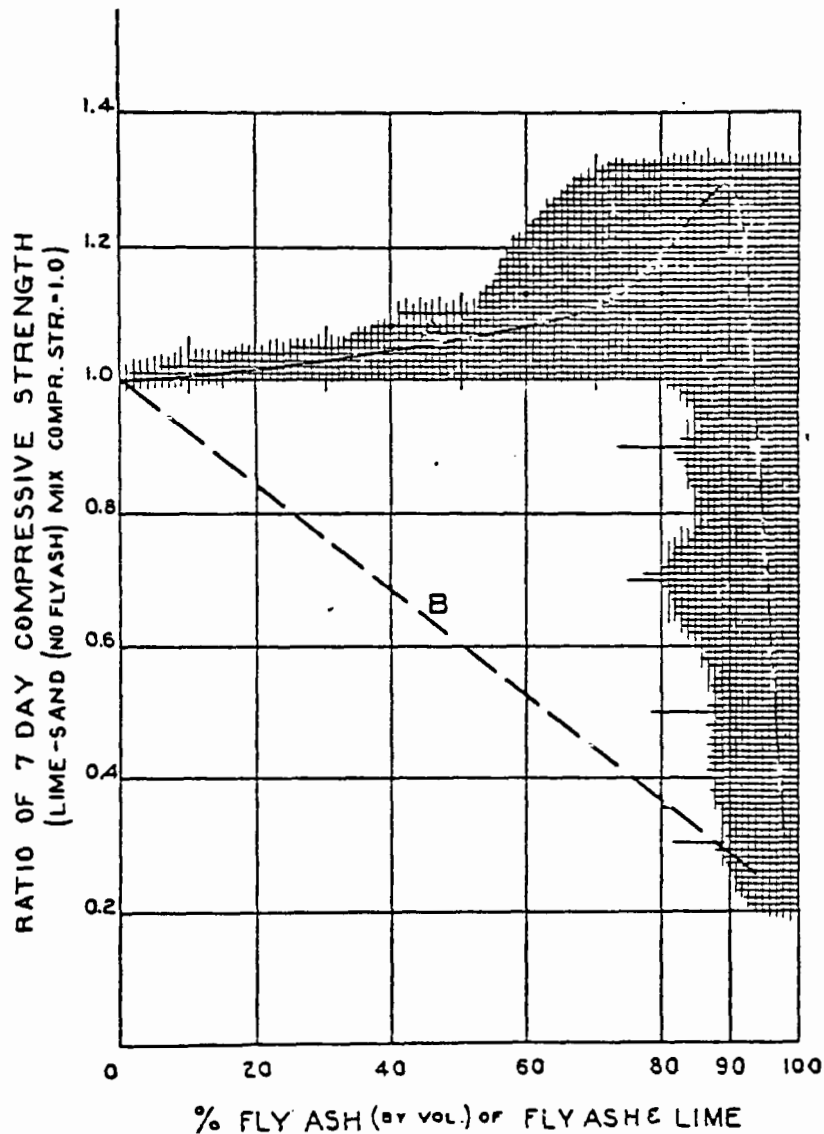
2,564,690

HYDRATED LIME-FLY ASH-FINE AGGREGATE CEMENT

Filed June 30, 1948

2 Sheets-Sheet 1

FIG. 1.



WITNESSES

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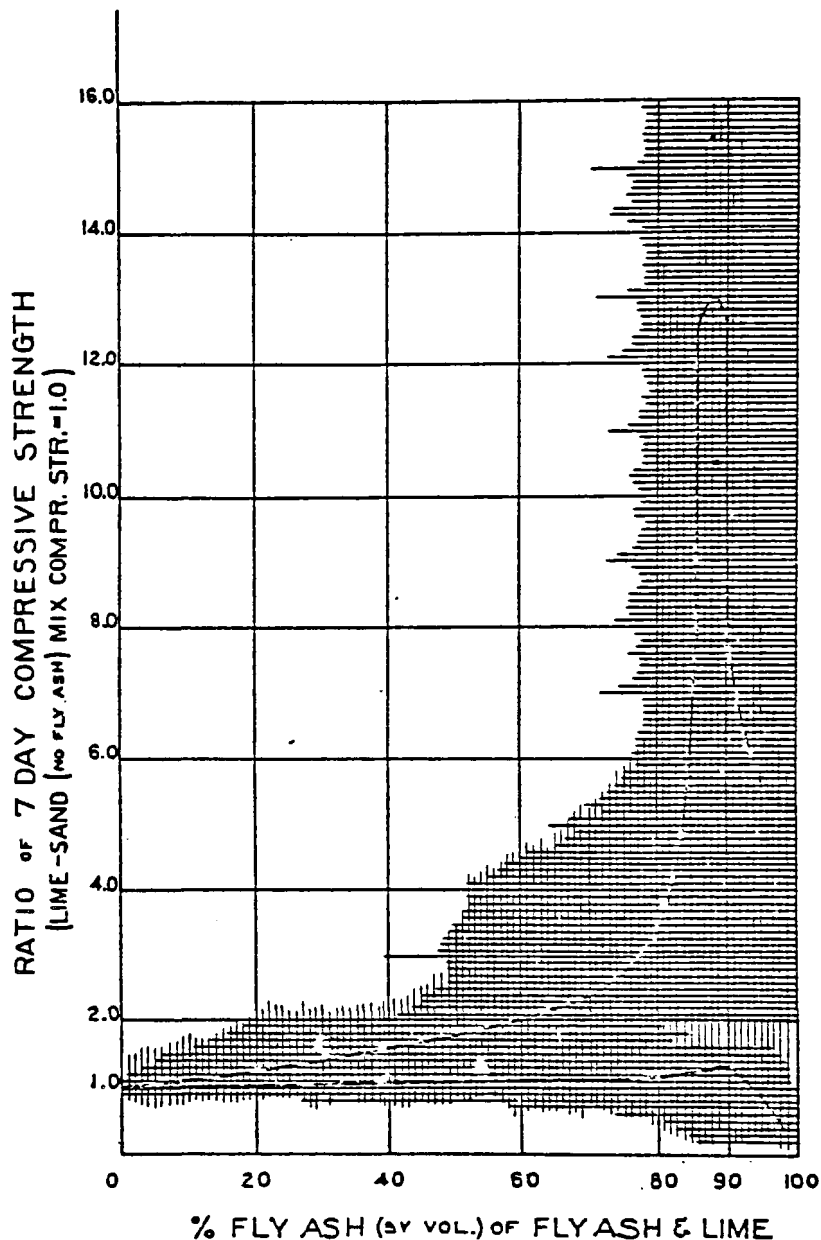
2,564,690

HYDRATED LIME-FLY ASH-FINE AGGREGATE CEMENT

Filed June 30, 1948

2 Sheets-Sheet 2

FIG. 2.



WITNESSES

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2,698,252

LIME-FLY ASH COMPOSITIONS FOR STABILIZING
FINELY DIVIDED MATERIALS SUCH AS SOILSJules E. Havetta, Havertown, and Frank Kahn,
Philadelphia, Pa.No Drawing. Application August 18, 1951,
Serial No. 245,652

7 Claims. (Cl. 106—120)

This invention relates to compositions for effecting the stabilization of finely divided materials such as soils and the like, and more particularly relates to compositions whereby substantially chemically inert fine mineral materials are stabilized by treatment with lime and fly ash.

This application is a continuation-in-part of our co-pending application, Ser. No. 36,048, filed June 30, 1948, entitled "Hydrated Lime Fly Ash Fine Aggregate," now U. S. Patent No. 2,564,690, issued October 21, 1951. In the aforesaid co-pending application we have disclosed cementitious compositions useful as mortars and the like which contain fine aggregate in the form of finely divided sand or other chemically inert aggregate having a fineness modulus of 1.7 or above. Repeated experiments in the laboratory as well as practical applications in the field have demonstrated that, within specific ranges of relative proportions of those ingredients, a mixture having unexpectedly high early compressive strength was obtained.

We have now discovered that unexpected advantages are attained by mixing lime and fly ash in controlled proportions with a finely divided soil having a fineness modulus less than 1.7. We have further found that, for certain soils of fineness modulus below 1.7, certain optimum relative proportions of lime and fly ash give unexpected peaks when soil characteristics relating to durability and bearing power of the soil are plotted against percentage. For example, the plasticity index, shrinkage characteristics, water retentivity and capillary potential of uncured samples as well as modulus of elasticity, unconfined compressive strength and resistance to alternate cycles of freezing and thawing and wetting and drying of cured specimens vary critically within definite ranges for definite soils. These materials are of such fineness that they are outside the class of materials usually referred to as aggregates. The compositions of this invention are extremely useful for many purposes and are found particularly useful in the field of soil stabilization for building load-supporting surfaces such as air field runways, roads, highways or the like.

Certain materials which have previously been suggested for other purposes wholly unrelated to soil stabilization involve the incorporation of lime with fly ash, as exemplified by the U. S. patent to Peffer, No. 1,942,769, issued January 9, 1934. Peffer's compositions do not include finely divided materials such as soils or the like and are necessarily indurated, or subjected to the action of heat, in order to cause a chemical interaction between the lime and the fly ash. Such induration ordinarily involves intimate contact with steam, which would be difficult if not impossible to accomplish in building roads or highways. Moreover any process involving induration would be excessively costly and of no practical merit whatsoever in road or highway building operations.

Another prior patent, issued to Jones and Swezey (U. S. Patent No. 2,382,154, August 14, 1945), discloses a building block or brick comprising lime, fly ash, and certain aluminosilicic acid materials such as shales, slates and clays. However, substantial proportions of lime, on the order of 40% lime, far in excess of the proportions of lime in applicants' compositions, are included in the Jones and Swezey composition, and this has a profound effect on the properties and character of the final composition as well as its cost.

The development of the field of soil stabilization is of increasing importance in construction of roads, highways

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and the like. Such stabilized soils are effectively utilized to form load-supporting bases, by which we mean base courses under highways and roads, and for road shoulders, secondary roads, parking areas, airport runways and the like. Several different compositions are being developed for stabilization of roads and highways, the construction of which is one of the largest industries in the United States. One soil stabilization composition involves the admixture of bituminous materials such as road oils, tars, emulsions and the like with the soil. Certain soils have been stabilized by mixing with lime, or with bitumin-hydrated lime compositions. Portland cement, has also been employed for soil stabilization, as well as various other materials such as organic resins, calcium chloride and various proprietary materials. However, these materials have not exhibited certain advantageous properties peculiar to this invention, and in most instances are relatively expensive as compared with our compositions. A further disadvantage in connection with the use of Portland cement is that the cement component of the soil mixture sets quite rapidly and it is therefore necessary for persons using the mixture to adhere closely to time schedules in forming the soil mixtures and in finishing the stabilized mixture.

The surfacing of airport runways has presented difficulties in that the jets of jet propelled airplanes using the runways are frequently directed against the runway surface. The surface temperature is almost instantly brought to a value sufficient to cause spalling of concrete and cement-like surfacing materials. On the other hand, bituminous materials such as asphalt and oil-treated aggregates are inadequate surfacing materials for airport use since the bituminous content of the surface immediately burns under the intense heat of the jet.

The primary object of the invention is to provide economical compositions for stabilizing soil to convert it to a composition well suited as a construction material for use in roads, highways and the like.

Another object of the present invention is to provide stabilized fine mineral material having high compressive strength. Still another object of the invention is to provide a stabilized soil or equivalent fine material having superior durability, wetting and drying resistance, freezing and thawing resistance, and weathering resistance.

Another object is to provide compositions for converting soils which have high plasticity, excessive shrinkage and poor drainage characteristics to composition having low plasticity index and improved dimensional stability and drainage properties.

Still another object of the invention is to provide a composition of matter for incorporation into a finely divided inert material with capacity to form a stabilized mixture having modified and improved engineering characteristics.

Still another object of the invention is to provide a relatively inexpensive solid mixture which, when incorporated into finely divided soil or equivalent mineral having a fineness modulus less than 1.7, in the presence of moisture, will form a stabilized mixture having resistance to intense heat and other radically modified and improved engineering characteristics.

Further objects and advantages of the invention will further become apparent hereinafter.

The foregoing and other objects are attained in accordance with this invention by providing a mix comprising lime, fly ash, and a finely divided soil, said soil having a fineness modulus less than 1.7.

As used throughout this specification and claims the term "lime" is used to indicate quicklime, hydrated lime, and slaked lime. The term "hydrated lime" indicates a dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration. It consists essentially of calcium hydrate or a mixture of calcium hydrate and/or magnesium oxide and/or magnesium hydroxide. In the above definition quicklime is used to indicate a calcined material the major portion of which is calcium oxide (or calcium oxide in natural association with a lesser amount of magnesium oxide) capable of slaking with water. The term "slaked lime" is used interchangeably with "hydrated

lime." Both hydrated lime and slaked lime may be associated with excess water, resulting in a moist or slurred state or condition.

The term "fly ash" as used in the present specification is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal, which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. The fly ash so obtained is in a finely divided state such that at least about 70% passes through a 200 mesh sieve. The fly ash collected from the exhaust gases is hereinafter referred to as crude fly ash.

The term "soil" is used throughout this specification and the claims hereof is intended to indicate natural or artificial substantially inorganic materials having a fineness modulus below 1.7. While we designate these materials as "inorganic," the presence of minor proportions of organic materials is not excluded, provided the fine material is predominantly inorganic.

By "fineness modulus" we refer to a standard particle size designation determined by sieve analysis. The standard sieves employed are $\frac{1}{8}$ inch, No. 4 sieve (4760 micron), No. 8 sieve (2380 micron), No. 16 sieve (1190 micron), No. 30 sieve (590 micron), No. 50 sieve (297 micron), and No. 100 sieve (149 micron). Fineness modulus of a material is determined by adding the total percentages retained on each of the specified sieves and dividing the sum by 100.

Our invention embraces a wide variety of naturally occurring soils which have a fineness modulus below 1.7. Such soils are well classified in accordance with the Public Roads Administration classification into seven groups identified as Group A-1 through A-7, with sub-grouping under A-1, A-2 and A-4. The principal groups covered in accordance with this invention, and as defined in Bulletin 39 of the Commonwealth of Pennsylvania Department of Highways, June 1948, are Groups A-4 through A-7, and A-2-4 through A-2-7, as well as certain A-3 soils having fineness modulus below 1.7. Group A-4 soils are non-plastic or moderately plastic silty soils usually having a high percentage passing the No. 200 sieve. The group includes also mixtures of fine silty soil and up to 24% sand and gravel retained on the No. 200 sieve. These soils ordinarily contain small amounts of colloidal clay. In performance as sub-grade material, Group A-4 soils of themselves are subject to objection in that they are difficult to compact, are subject to frost heaving, and have undesirable elasticity (or poor compressibility) and volumetric shrinkage characteristics.

Group A-5 soils are micaceous and diatomaceous materials, are finely divided, and are subject to the principal objections noted above in connection with A-4 soils. They are particularly objectionable as sub-grade materials by reason of their elasticity and instability.

Group A-6 soils are essentially plastic clay soils usually having 75% or more passing the No. 200 sieve. Similarly Group A-7 soils are clayey materials and exhibit undesirable elasticity as well as volumetric shrinkage. A-6 and A-7 soils are generally regarded as poor sub-grade materials for road and highway construction. The aforementioned Bulletin 39, on page 9 thereof, indicates that the A-4, A-5, A-6, and A-7 soils are silty and clayey, all being characterized by the fact that at least 36% by weight of the soil passes a standard No. 200 sieve.

Sub-groups A-2-4 and A-2-5 include gravels or coarse sands having fineness moduli above 1.7 but also include fine sands having fineness moduli below 1.7 which are effectively stabilized in accordance with this invention. The aforementioned Bulletin 39, on pages 7 and 9 thereof indicates that the A-2-4 and A-2-5 soils are gravels or sands containing a plastic component of clay or silt, and that the A-2-4 soils are characterized by the fact that a maximum of 35% by weight passes a standard No. 200 sieve, and that portion of the soil which passes a standard No. 40 sieve has a maximum liquid limit of 40 and has a maximum plasticity index of 10. The same bulletin similarly identifies A-2-5 soils, with the exception that the minimum liquid limit of the fraction passing a standard No. 40 sieve is 41. Sub-groups A-2-6 and A-2-7 contain sand and gravel together with a clayey binder component and many of these soils have fineness moduli below 1.7 and are advantageously treated in accordance

with this invention. On page 9, the aforementioned Bulletin 39 specifies that A-2-6 and A-2-7 soils are characterized by the fact that they are silty and clayey, and that portion of the soil passing a standard No. 40 sieve has a minimum plasticity index of 11. A-3 soils are essentially very fine sands, and those A-3 soils having fineness moduli below 1.7 are within the scope of this invention. Natural A-3 soils, though occasionally considered satisfactory as sub-grade materials in confined spaces, are generally too mobile or lacking in cementitious materials for average use. The aforementioned Bulletin 39, on pages 7 and 9 thereof, indicates that A-3 soils are fine sands having no binder content, at least 51% by weight passing a standard No. 40 sieve, and a maximum of 10% by weight passing a standard No. 200 sieve.

Finely divided materials other than natural soils, which are equivalent to the soils falling within the above defined soil classifications, nevertheless are included within the scope of this invention. These materials include fine sand, stone screenings, slags, gravel screenings, mineral deposits, fine screenings from quarry operations and the like, having fineness modulus below 1.7, as well as other similar soil-like materials all of which are included within the meaning of the term "soils" as used herein.

The relative proportions of the three principal components of the compositions are important, in that a wholly unexpected peak is attained, when certain soil characteristics are plotted against the relative proportions of fly ash and lime in the mix, such peak being of the same general character as that represented in Fig. 2 of our aforementioned pending application. Moreover, optimum results are attained for soils of different types by providing lime-fly ash compositions within critical ranges of different scopes. Thus, while the lime, fly ash and soil of our composition may advantageously be present in amounts by weight within the ranges of about lime 2-9, fly ash about 10-30 and soil about 70-90, very advantageous results are attained in different ranges for different soils, as indicated in the following table:

Optimum proportions

Soil Class	Parts By Weight		
	Lime	Fly Ash	Soil
A-3	2-7	10-20	70-90
A-2-4	2-7	10-20	80-90
A-2-5	2-8	10-20	80-90
A-2-6	2-8	10-20	80-90
A-2-7	2-4	10-20	80-90
A-4	2-8	10-20	80-90
A-5	2-8	10-20	80-90
A-6	2-8	10-20	80-90
A-7	2-8	10-20	80-90

In the ranges shown above, very advantageous results are obtained, with pronounced optimums occurring particularly with respect to the relative percentages of fly ash. Preferably the parts fly ash and soil, as expressed above, total 100.

The advantages and characteristics of these compositions are readily determined by testing samples thereof for plasticity index, resistance to penetration by standard needle, shrinkage characteristics, water retentivity and capillary potential, for example, such characteristics being measurable immediately after the mixture is formed. The stabilized soil mixes which show optimum performance as tested by the above characteristics are found to have the most advantageous properties upon aging or curing as reflected by tests for modulus of elasticity, freezing and thawing resistance, wetting and drying resistance, and unconfined compressive strength.

The plasticity index of soil is conventionally defined as the numerical difference between the liquid limit and the plastic limit of a soil. It indicates the range of moisture content in which the soil is in the plastic, or semi-solid state. The liquid limit is conventionally defined as the water content at which the soil passes from the plastic state to the liquid state, while the plastic limit of a soil is the lowest water content at which the soil becomes plastic, or the content at which a soil changes from a solid state to a semi-solid state. These tests may be carried out in accordance with AASHTO Designations T-89-49, T-90-49, and T-91-49.

The volumetric shrinkage of a soil is tested by mea-

uring the volume loss of a soil sample on drying, and may be determined in accordance with AASHTO Designation T-92-42.

The water retentivity of a soil is its ability to hold water, and may be determined by applying standard suction to a soil sample of standard size, and measuring the time required for removal of a unit amount of water.

The capillary potential of a soil is the direct measure of the property of the soil to raise water above the free ground water level by capillary action. It is determined by placing a wet soil sample of definite size in the top of a funnel the stem of which contains water. The open bottom of the stem is submerged in a mercury reservoir. Water is permitted to evaporate from the soil surface, the height of the mercury column thus drawn up is measured. Capillary potential is usually expressed in terms of feet of water.

Another important characteristic of stabilized soil, which is measurable after a curing or aging period, is its modulus of elasticity, which is often determined by a conventional dynamic method based upon resonance. The test for modulus of elasticity, or ratio of stress to strain, is of particular importance because many of the other important characteristics of stabilized soil are related to its modulus of elasticity.

The aged or cured stabilized soil specimens may also be tested for capacity to resist alternate cycles of freezing and thawing and/or wetting and drying. The specimen is subjected to successive cycles and the condition of the specimen is observed at the end of each cycle. After each cycle the surface of the specimen is brushed with a wire brush to remove loose particles. The loss in weight is recorded as an indication of the durability and quality of the soil composition.

Another important test which constitutes a definite factor, specifically relating to the proportions of our materials, is the test for unconfined compressive strength. Unconfined compressive strength is measured on unconfined cured and dried samples using conventional testing equipment such as that used for mortars, concrete, and the like. This test conveniently demonstrates the improvement in bearing capacity which is developed by the use of this invention as contrasted with the very low, and in many instances negligible bearing capacity of untreated soil expressed in terms of unconfined compressive strength. In fact, the superior strength developed by this invention improves it beyond the range measurable by the conventional test which involves measurement of deflection under load.

Ingredients of our compositions may be prepared in any conventional manner, such as by simple mixing of the solid components, preferably in the presence of water. However the mixing is preferably carried into effect by breaking up the soil and mixing the soil with lime and fly ash in predetermined proportions, utilizing suitable soil-breaking and mixing equipment such as that conventionally used for farm and construction purposes, with water added to the mixture in an amount substantially equal to that proportion of water known and defined as the optimum moisture content. Optimum moisture content is determined by the well known modified Proctor test.

Optimum moisture content of a soil or stabilized soil mixture is that moisture content at which the soil-moisture mix has the maximum dry density, or maximum dry weight of solids per unit volume. In practice, the optimum water content varies with each particular soil and stabilized soil mixture, ordinarily within the range of 8-25% moisture by weight, based on the total dry weight of lime, fly ash, and soil. Preferably, in incorporating moisture into our stabilized soil mixes, the water content should be controlled within the range of 70%-130% of the optimum water content. Thus the water content of the stabilized road base may vary from about 5%-32% by weight, based on the weight of total lime, fly ash, and soil, for different soils.

After mixing, the soil may be formed to the desired shape, which may be of any desired character. After curing for several weeks it will develop considerable compressive strength, but the cementitious bond of the mix develops so slowly that even after a week, the formed mix can readily be deformed and re-shaped.

The following examples are illustrative of the invention:

Example 1

A soil was selected comprising a clayey sand, fineness modulus below 1.7, secured from the southern part of Maryland, having a relatively high plasticity index of 11.4%. Its Highway Research Board classification was A-2-6. The soil was mixed with lime, fly ash and optimum water, the proportions of solids being as follows:

Parts by weight	
A-2-6 soil	90
Lime	9
Fly ash	10

The resulting material at once showed the following properties as contrasted to those of the natural A-2-6 soil:

The plasticity index of 11.4% for the natural soil was reduced to 3.5% for the stabilized soil.

The water retentivity of 8.4 seconds for the natural soil was reduced to 1.5 seconds for the stabilized soil.

The resistance to penetration was increased. A standard needle penetrated the natural soil a depth of .07 mm., while under the same test conditions it penetrated the stabilized soil to a depth of only .025 mm.

Specimens were prepared from the above mixture utilizing moisture at optimum moisture content and compacted and cured for 28 days. These specimens showed an unconfined compressive strength of 300 p. s. i. as contrasted to 20 p. s. i. for the natural soil. Resistance to freezing and thawing and wetting and drying was also radically improved as indicated by a standard wire brush test which showed that the stabilized material stands up after numerous cycles as contrasted to the native soil which fails to stand up for one cycle.

Example 2

Soil description: Plastic clay soil secured from a location north of Hagerstown, Maryland.

Highway Research Board classification: A-7.

Proportions of mixture:

Parts by weight	
A-7 soil	90
Lime	9
Fly ash	10

The resulting material at once showed the following properties as contrasted to those of the natural A-7 soil.

The plasticity index of 38.5% for the natural soil was reduced to 4.0% for the stabilized soil.

The volumetric shrinkage of 89% for the natural soil was reduced to 15% for the stabilized soil.

The capillary potential of 17 feet for the natural soil was reduced to 10.2 feet for the stabilized soil.

Specimens of the above mixture, combined with optimum water and compacted and cured for 28 days, showed an unconfined compressive strength of 2000 p. s. i. as contrasted to 700 p. s. i. for the natural soil, and a resistance to alternate cycles of freezing and thawing and wetting and drying for numerous cycles as contrasted to the natural soil which failed in the first cycle.

The dynamic modulus of the cured specimen expressed as the product of the weight of the specimen times the square of the natural frequency was 5.1×10^6 pounds/sec.² while that of the natural soil was below 0.1×10^6 pounds/sec.².

Example 3

Separate samples were compounded with varying proportions by weight of lime, fly ash, and A-2-6 soils as follows:

	Lime	Fly Ash	Soil (A-2-6)
75	10	10	80
80	10	10	80
	20	20	60
	20	20	60
	20	20	60

In the stabilized soil samples as above prepared, the

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engineering characteristics of the soil were improved as follows, the range being a function of the composition:

	Natural Soil	Stabilized Soil
Plasticity Index.....	11.4%.....	0-3.5%.....
Compressive Strength (28 days).....	85 p. s. i.....	200-300 p. s. i.....
Water retentivity.....	8.4 sec.....	1.5 sec. (all samples).....
Penetration.....	.07 mm.....	.025-.08 mm.....
Dynamic Modulus.....	2.0-4.8×10 ⁶ lbs./sec. ²	Less than 0.1×10 ⁶ lbs./sec. ²

Example 4

Separate samples were prepared in the manner described in Example 3, using an A-7 soil of fineness modulus below 1.7. The soil was effectively stabilized by the action of lime and fly ash, in proportions by weight as follows:

Lime	Fly Ash	Soil (A-7)
3.....	10.....	90.....
6.....	10.....	90.....
9.....	10.....	90.....
3.....	20.....	80.....
6.....	20.....	80.....
9.....	20.....	80.....

The comparative engineering characteristics of the natural soil and stabilized soils were as follows:

	Natural Soil	Stabilized Soil
Plasticity Index.....	22.6%.....	4-12%.....
Unconfined compressive strength (28 days).....	700 p. s. i.....	1,850-2,000 p. s. i.....
Volumetric shrinkage.....	22.5%.....	12.4-14%.....
Capillary potential.....	17 feet.....	10.2-4.1 feet.....

A corresponding mixture was prepared comprising 90 parts of same A-7 soil, 10 parts fly ash, and 9 parts Portland cement. The plasticity index of this corresponding mixture was 28; thus the incorporation of Portland cement into the soil reduced the plasticity index from 38.5 only to 28, a value which is still considered unsatisfactory.

Example 5

Various samples were prepared and tested as in Examples 3 and 4, using an A-3 soil having a fineness modulus below 1.7. The proportions of ingredients by weight were as follows:

Lime	Fly Ash	Soil (A-3)
3.....	10.....	90.....
6.....	10.....	90.....
9.....	10.....	90.....
3.....	15.....	85.....
6.....	15.....	85.....
9.....	20.....	80.....
6.....	20.....	80.....

The resulting compositions show compressive strengths in the range of 400-600 p. s. i. after aging for 28 days, a marked improvement over the natural soil. The stabilized soils also showed ability satisfactorily to resist 12 cycles of alternate freezing and thawing or wetting and drying, while the sandy A-3 soil alone fails in the first cycle.

Example 6

An A-3 soil similar to that of Example 5 was stabilized by the formation of a mix consisting essentially by weight of 3 parts lime, 16 parts fly ash, and 84 parts A-3 soil. This stabilized soil had a compressive strength after aging 28 days of 450 p. s. i., and resisted 12 cycles of wetting and drying with a 3.5% weight loss on surface brushing.

Example 7

Ingredient:	Parts by weight
Lime.....	5.....
Fly ash.....	10.....
A-2-4 soil (from Southern New Jersey).....	90.....

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The stabilized soil had a 7-day compressive strength of 770 p. s. i., as compared to 175 p. s. i. for the natural soil.

The following examples represent specific combinations of particular advantage in connection with soils of different types. All the following examples represent highly useful stabilized soils having improved properties for highway construction as compared to the soil prior to stabilization.

Example 8

	Parts by weight
A-4 soil.....	84.....
Lime.....	3.....
Fly ash.....	16.....

Example 9

A-5 soil.....	85.....
Lime.....	6.....
Fly ash.....	15.....

Example 10

A-6 soil.....	88.....
Lime.....	8.....
Fly ash.....	12.....

Example 11

A-3 soil.....	88.....
Lime.....	2.....
Fly ash.....	12.....

Example 12

A-3 soil.....	70.....
Lime.....	2.....
Fly ash.....	30.....

Example 13

The following example illustrates advantageous compositions in accordance with this invention wherein the finely divided material is an artificial material equivalent to natural soil, and herein defined as soil, parts being by weight:

Fine Material	Proportions		
	Fine Material	Lime	Fly Ash
Sand.....	90	3	10
	90	4	10
	90	5	10
	80	3	20
	80	6	20
	80	9	20
Crushed limestone screenings (through 10 mesh, fineness modulus 1.6).....	90	3	10
	90	4	10
	90	5	10
	80	3	20
	80	6	20
	80	9	20
Pulverized blast furnace slag (fineness modulus 1.6).....	90	3	10
	90	4	10
	90	5	10
	80	3	20
	80	6	20
	80	9	20
Crushed trap rock (fineness modulus 1.6)....	90	3	10
	90	4	10
	90	5	10
	80	3	20
	80	6	20
	80	9	20

All of the foregoing compositions of Example 13 have compressive strengths in the range of 400-600 p. s. i. after aging for 28 days, and show ability to resist about 12 cycles of alternate freezing and thawing or wetting and drying in accordance with conventional tests.

From the foregoing description and examples it will be appreciated that our lime-fly ash-soil compositions are novel generally and applicable to a wide variety of uses. They are of great advantage by reason of their relatively low cost, engineering properties and strength characteristics. The stabilized, uncured soil product is particularly advantageous in that considerable time (on the order of a week or more) elapses before the mixture sets up more or less completely. During this period the mix is readily handled, spread and compacted, and yet due to the immediate changes in soil properties which are produced, the compacted mixture has a surprisingly great load-bearing capacity during this period, even before complete

setting. In our experience the load-bearing characteristic of this newly formed composition has been sufficient to permit the use of a road or highway, for example, before setting is complete. The addition of the lime and fly ash, in the proportions disclosed, immediately converts a natural soil which is relatively poor as a load-supporting base to a composition having structural characteristics ideally suited for the purpose.

The property of our compositions to set slowly is of prime importance in road and highway construction, in that construction schedules need not necessarily be adhered to rigidly. Moreover, work may be discontinued or postponed due to rain and resumed at a later date without harm to the stabilized soil due to setting or erosion during the intervening period. By contrast, soils stabilized with Portland cement set up rapidly under such conditions.

Another advantage of our stabilized lime-fly ash-soil compositions is that they may be recompacted after several weeks, while soils treated with Portland cement are found to set up quickly and can not satisfactorily be recompacted several weeks after they are first compacted. Our material is also an ideal patching material, which is an additional advantage over Portland cement.

While lime alone or fly ash alone, when mixed with soil, may in certain cases improve certain characteristics of a soil, for use as a load-supporting base, the combination of lime with fly ash produces radically changed characteristics far beyond any results that might be predicted from the behavior of lime alone, or of fly ash alone. The beneficial effects achieved are far in excess of the sum of those attributable to the presence of either lime or fly ash.

Additional materials such as Portland cement, special grades of clay soils and aluminosilicates and the like may be incorporated into soil stabilized in accordance with our invention without detrimental effect to certain of the advantages of the invention. However, the novel stabilized soil road bases themselves consist essentially of the ingredients set forth in the appended claims.

The above description and examples are presented as illustrations of preferred embodiments of the invention. All modifications and variations which conform to the spirit of the invention, including the substitution of equivalents and other changes in the particular form of the method and product, as well as the use of certain advantageous features of the invention without the use of other features, are within the scope of the invention as defined in the appended claims.

Having thus defined our invention, we claim:

1. A stabilized soil composition of matter consisting essentially by weight of about 10% to about 30% inclusive of crude fly ash, about 70% to about 90% inclusive of soil having a fineness modulus below 1.7, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 2% to about 9% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

2. A stabilized soil composition of matter consisting essentially by weight of about 15% to about 30% inclusive of crude fly ash, about 70% to about 85% inclusive of soil having a fineness modulus below 1.7, said soil comprising fine sand having substantially no binder content, at least 51% by weight of which passes a standard No. 40 sieve, and a maximum of 10% by weight of which passes a standard No. 200 sieve, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 2% to about 7% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

3. A stabilized soil composition of matter consisting essentially by weight of about 10% to about 20% inclusive of crude fly ash, about 80% to about 90% inclusive of soil having a fineness modulus below 1.7, said soil

comprising a granular material selected from the group consisting of gravel and sand containing a plastic component which is selected from the group consisting of clay and silt, a maximum of 35% by weight of soil passing a standard No. 200 sieve, and that portion of the soil which passes a standard No. 40 sieve having a maximum liquid limit of 40 and having a maximum plasticity index of 10, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 2% to about 7% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

4. A stabilized soil composition of matter consisting essentially by weight of about 10% to about 20% inclusive of crude fly ash, about 80% to about 90% inclusive of soil having a fineness modulus below 1.7, said soil comprising a granular material selected from the group consisting of gravel and sand containing a plastic component which is selected from the group consisting of clay and silt, a maximum of 35% by weight of said soil passing a standard No. 200 sieve, that portion of said soil which passes a standard No. 40 sieve having a minimum liquid limit of 41 and having a maximum plasticity index of 10, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 2% to about 9% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

5. A stabilized soil composition of matter consisting essentially by weight of about 10% to about 20% inclusive of crude fly ash, about 80% to about 90% inclusive of soil selected from the group which consists of the silty and clayey soils having a fineness modulus below 1.7, at least 36% by weight of said soil passing a standard No. 200 sieve, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 3% to about 9% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

6. A stabilized soil composition of matter consisting essentially by weight of about 10% to about 20% inclusive of crude fly ash, about 80% to about 90% inclusive of soil selected from the group consisting of the clayey and silty soils having a fineness modulus below 1.7, that portion of said soil which passes a standard No. 40 sieve having a minimum plasticity index of 11, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, and about 3% to about 9% inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil.

7. A stabilized compact load-supporting course for a road, highway or the like, characterized by strength sufficient to support heavy loads and pliability sufficient for recompacting, consisting essentially of about 10% to 30% by weight inclusive of crude fly ash, about 70% to about 90% by weight inclusive of soil having a fineness modulus below 1.7, the sum of the percentages of crude fly ash plus soil being substantially equal to 100, about 2% to about 9% by weight inclusive of lime, the percent lime being based on the weight of crude fly ash plus soil, and about 5% to about 32% by weight inclusive of water, the percent water being based on the total weight of lime, fly ash and soil.

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STABILIZED SOIL

Jules F. Havelin, Havertown, and Frank Kahn,
Philadelphia, Pa.No Drawing. Application December 22, 1954,
Serial No. 477,122

6 Claims. (Cl. 106-118)

This invention relates to the stabilization of fine, plastic silts or clay soils.

This application is a continuation-in-part of our copending applications Serial Nos. 245,651 and 245,652, now U. S. Patent No. 2,698,252, both filed August 18, 1951, wherein we disclose stabilized soil compositions including lime and fly ash which are incorporated into the soil. Various soils, even including highly plastic soils, can be successfully stabilized by reacting them with lime and fly ash causing the product to set in accordance with the inventions disclosed in the aforementioned copending applications. Although the compositions set relatively slowly, they have good compressive strength even during the early stages of the setting period. After setting for a sufficient time, the compositions develop excellent compressive strength and have sufficient stability as load supporting bases for road building and other operations.

However, it has now been found that certain of the more plastic soils, when stabilized in accordance with the disclosures of the aforementioned copending applications, are lacking in durability under certain adverse weather conditions during the early stages of the setting period. It is desirable to provide a road base which has good stability immediately after the road base is laid down, and such base must have the property of retaining its stability even when it is exposed to severe weather conditions, such as alternate cycles of wetting and drying, frost action, or freezing and thawing, for example. The ability of a stabilized soil mixture to stand up under severe weather conditions during the early stages of the setting period, while said mixture is also subjected to heavy engineering loading, is referred to hereinafter as the durability of the soil mixture.

Attempts to improve the early durability characteristics of plastic soils, by adding lime and fly ash, are not successful. In fact, when an A-6 or A-7 clayey soil is combined with fly ash, for example, the progressive addition of lime decreases the water retentivity of the composition, which indicates that the lime is not acting in cooperation with the other components of the mixture to improve its early durability.

It is accordingly an object of this invention to provide an improved soil stabilization composition for stabilizing plastic soils. Still another object of this invention is to provide a stabilized soil composition including plastic soil, which composition has capacity to support heavy loads during the early stages of the setting period. Still another object of this invention is to provide an inexpensive means for stabilizing very plastic soils in such manner that the stabilized soil composition has sufficient pliability during the early stages of the setting period to permit compacting and re-shaping after compacting, but which composition has sufficient durability during the early stages of the setting period to support heavy loads without excessive deformation, even when subjected to severe weather conditions such as repeated wetting and drying or freezing and thawing, for example.

It is still another object of this invention to provide a means for stabilizing plastic silts or clay soils to provide compositions having excellent early load-bearing and durability properties, and without adversely affecting the

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compressive strength or other engineering properties of the final product after setting.

Other objects and advantages of this invention will further become apparent hereinafter.

We have now discovered that very plastic soils, when stabilized with specific proportions of lime, aggregate particles and fly ash, have remarkably improved durability during the early stages of the setting period.

The relative proportions of the ingredients are critical, as will further become apparent. We have found that the water retentivity of the composition decreases with lime addition when a small proportion of aggregate is incorporated into the composition, but surprisingly, the water retentivity increases with lime addition when the proportion of aggregate is in the range of about 20%-50% by weight, based on the total weight of fly ash plus soil plus aggregate.

As used throughout this specification and claims, the term "lime" is used to indicate quicklime, hydrated lime, and slaked lime. The term "hydrated lime" indicates a dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration. Hydrated lime consists essentially of calcium hydrate or a mixture of calcium hydrate and/or magnesium oxide and/or magnesium hydroxide. In the above definition quicklime is used to indicate a calcined material the major portion of which is calcium oxide (or calcium oxide in natural association with a lesser amount of magnesium oxide) capable of slaking with water. The term "slaked lime" is used interchangeably with "hydrated lime." Both hydrated lime and slaked lime may be associated with excess water, resulting in a moist or slurried state or condition.

The term "fly ash" as used in the present specification is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal, which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. The fly ash so obtained is in a finely divided state such that at least about 70% passes through a 200 mesh sieve.

The term "plastic soil" as used throughout this specification and the claims hereof is intended to indicate natural substantially inorganic material of the type of clay, loam or silt, which soil is so fine that the normal method of soil evaluation does not include fineness modulus determination. The majority of the soil passes through a standard 100-mesh sieve. While we designate this material as "inorganic," the presence of minor proportions of organic materials is not excluded, provided the fine material is predominantly inorganic.

Plastic soil, within the meaning of the term as applied to this invention, includes all soils which have a plasticity index of more than 15, all soils which have a plasticity index of about 9-15 when more than about 15% by weight of the soil passes a standard 200-mesh sieve, and all soils which have a plasticity index of less than about 9 when more than about 35% by weight of the soil passes a standard 200-mesh sieve.

The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit of the soil.

The liquid limit of a soil is that water content at which the soil passes from the plastic or semi-solid state to a liquid state. The plastic limit of the soil is the lowest water content at which the soil becomes plastic or the content at which the soil changes from a solid to a semi-solid state. Tests for liquid limit and plastic limit are standard in the art. ASTM specifications D423-54T and D424-54T as well as AASHTO designations T-89-49, T-90-49 and T-91-49, which are incorporated herein

by reference, define standard procedures for determining the liquid limit and plastic limit of a soil, and hence its plasticity index.

The term "aggregate" in accordance with this invention refers to natural or artificial inorganic materials which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water, such as limestone screenings, natural sand, sand prepared from stone, blast furnace slag, gravel, or other equivalent materials having similar characteristics. In accordance with this invention a relatively coarse aggregate is included, as well as fine aggregate. An aggregate, within the meaning of the term as used in this specification, is a mixture of finely divided particles which may include limited amounts of relatively coarse particles, and may even include particles up to about $\frac{1}{2}$ inch in size. Approximately the majority of the aggregate preferably consists of particles ranging in size from about 40 mesh to about $\frac{1}{2}$ inch. Preferably, the sizing of the aggregate falls within the following range:

Screen size	Percent by weight passing
$\frac{1}{2}$ "	90-100
#4	75-100
#10	40-90
#40	5-35
#200	0-15

The relative proportions of the principal components of the compositions are important. When the proportions are maintained within a limited range, surprising durability improvement is obtained in the early stages of the setting period. The preferable proportions are as follows, percentages being by weight:

Material	Percent (based on total of fly ash, soil, and aggregate)
Fly Ash	5-25
Soil	35-75
Aggregate	20-60
Lime	2-9

As expressed above, the sum of the percentages of fly ash plus soil plus aggregate are substantially equal to 100. This is the basis used throughout the specification and claims in specifying proportions of the components of our compositions.

The durability characteristics of these compositions are readily determined by testing samples thereof for underwater disintegration. One such method consists of forming a standard test block of the composition under investigation, allowing the block to set for a relatively short period, such as three days for example, under substantially dry conditions, and then submerging the block for several hours under still water. A sample having relatively poor durability tends to disintegrate, and a rough measure of its value is obtained by weighing the block after removing it from the water, to determine the loss of weight due to underwater disintegration. In accordance with this invention, even very plastic soils are converted to products having such excellent durability that in some cases the weight loss due to disintegration under water is substantially zero.

Underwater disintegration tests illustrate that, at about 20% by weight of aggregate, the aggregate coacts with the lime, fly ash and soil in such manner that the four ingredients act as a mixture rather than separate, distinct materials. At proportions below about 20% by weight aggregate, the progressive addition of lime to the soil plus fly ash plus aggregate tends to decrease the water retentivity of the composition; however, when the proportion of aggregate is increased to a value above

20% by weight the progressive addition of lime to the soil plus fly ash plus aggregate increases the water retentivity. This was entirely unexpected, and probably explains why the compositions of this invention function as well as they do. Repeated tests have established the fact of the existence of this phenomenon, as well as its practical merit.

The ingredients of our compositions may be prepared in any conventional manner, such as by simple mixing of the solid components, preferably in the presence of water. However, the mixing is preferably carried into effect by breaking up the soil and mixing the soil with lime, fly ash and aggregate in predetermined proportions, utilizing suitable soil breaking and mixing equipment such as equipment conventionally used for farm and construction purposes. Water is added to the mixture in an amount substantially equal to that proportion of water known and defined as the optimum moisture content. Optimum moisture content is determined by the well known modified Proctor test.

Optimum moisture content of a soil or stabilized soil mixture is that moisture content at which the soil-moisture mix has the maximum dry density, or maximum dry weight of solids per unit volume. In practice, the optimum water content varies with each particular soil and stabilized soil mixture, ordinarily within the range of 8-25% moisture by weight, based on the total dry weight of solids. Preferably, in incorporating moisture into our stabilized soil mixes, the water content should be controlled within the range of 70%-130% of the optimum water content. Thus the water content of the stabilized road base may vary from about 5%-32% by weight, based on the weight of total lime, fly ash, soil and aggregate, for different soils.

After mixing, the stabilized soil product may be formed to the desired shape. After curing for a very short period of time, for example two to five days, it develops considerable stability even when wet, but the cementitious bond of the mix develops so slowly that even after a week, the formed mix can readily be deformed and reshaped. After setting for a considerable period, such as one month for example, the mix has a very substantial compressive strength and after one year the product is exceedingly strong.

The following examples are illustrative of the invention:

EXAMPLE 1

A soil was selected comprising a plastic A-6 clay, located in Southeast Pennsylvania. The soil had the following sieve analysis:

Screen No.	Percent by weight passing
$\frac{1}{2}$ "	100.0
#4	99.0
#10	98.0
#40	97.6
#60	97.2
#200	97.0
	96.5

The soil had a plasticity index of 14 and a liquid limit of 32. The soil was mixed with hydrated lime, fly ash, and dolomitic limestone screenings, in the presence of optimum water, the proportions of solids being as follows:

	Percent by weight (based on total soil, fly ash, and limestone screenings)
A-6 soil	70
Lime (hydrated) (dolomitic)	9
Fly ash	10
Limestone screenings	20

The resulting material, after compaction, was allowed to set under natural ambient conditions for three days. Samples (compacted cubes) of the stabilized product were submerged in water for three hours and showed substantially zero weight loss. In addition, the mix had sufficient durability to support heavy trucks which were driven over it, even when subjected to repeated cycles of alternate wetting and drying, as contrasted to the very poor stability of the natural A-6 soil. Test cubes of the natural A-6 soil, when tested for underwater disintegration after exposure for three days under natural ambient conditions, substantially completely disintegrated within a few minutes when submerged in water.

After setting for twenty eight days under natural ambient conditions, the stabilized product showed excellent compressive strength on the order of about 300 lbs. per square inch, as contrasted to substantially zero compressive strength for the natural soil. The stabilized product also had radically improved resistance to freezing and thawing and wetting and drying as indicated by a standard wire brush test which showed that the stabilized material stands up after numerous cycles, as contrasted to the natural soil which fails to stand up after one cycle.

EXAMPLE 2

The following compositions further illustrate compositions within the scope of this invention which have high early stability (3 days) and have excellent engineering properties after setting for twenty eight days:

Table I

Type Aggregate	Soil		Percent by wt. Lime	Percent by wt. Fly Ash	Percent by wt. Soil	Percent by wt. Aggregate
	PI	Percent Passing 20 Mesh				
Limestone Screenings	2.0	47	8	10	70	30
Do.	2.0	47	8	8	78	30
Do.	2.0	47	8	25	55	20
Do.	3.0	37	8	10	60	25
Do.	3.0	37	6	15	45	40
Gravel	3.3	40	4	10	65	25
Do.	3.3	40	3	25	40	35
Limestone Screenings	3.9	37	8	10	60	30
Do.	3.9	37	6	20	60	20
Boiler Slag	3.1	19	3	10	65	25
Do.	3.1	19	7	25	55	20
Do.	3.9	35	8	10	55	35
Do.	3.9	35	3	5	45	50
Limestone Screenings	10.0	53	5	10	50	40
Do.	11.0	21	8	10	60	30
Do.	14.0	96	5	10	45	45
Do.	14.0	96	9	15	35	50
Gravel	17.0	23	5	10	55	35
Boiler Slag	24.0	45	5	10	50	40
Do.	24.0	45	9	15	35	50

EXAMPLE 3

A mixture was prepared consisting of 90% by weight plastic A-7 soil, 10% by weight fly ash and 5% by weight lime. After mixing with optimum water and setting under natural ambient conditions for three days, it was tested for durability by submerging standard test cubes in water. The test cubes disintegrated so rapidly that no quantitative measurement of loss was obtainable.

A composition was prepared consisting of 60% by weight of the same A-7 soil, 10% by weight fly ash, 5%

by weight lime and 30% by weight limestone screenings. After mixing with optimum water and setting under natural ambient conditions for three days, test cubes of the resulting mix were submerged in water and tested for disintegration. Substantially no weight loss was observed after submerging the cubes for three hours.

EXAMPLE 4

In a series of tests, a plastic kaolin (A-7) was stabilized with varying quantities of lime, fly ash and limestone screenings. The samples were allowed to set for a short time, water was added, and each sample was tested for water retentivity. According to this test, each soil sample was placed on top of a piece of filter paper supported on the flat perforated ceramic bottom of a Buchner funnel, and a standard suction was applied. After a certain time, the filter paper or ceramic support became wet, and this fact was visually observed. Increments of time were measured and reported as water retentivity count. The following results were obtained.

Table II.—Effect of lime on water retentivity count of stabilized kaolin

Wt. Kaolin	Wt. Fly Ash	Wt. Aggregate (Screenings)	Wt. Lime	Water Retentivity Count
90	10	0	0	33
90	10	0	3	31
90	10	0	6	29
90	10	0	9	27
70	10	20	0	23
70	10	20	3	24
70	10	20	6	19
70	10	20	9	20
50	10	40	0	20
50	10	40	3	20
50	10	40	6	21
50	10	40	9	23
30	10	60	0	15
30	10	60	3	17
30	10	60	6	20
30	10	60	9	19

The above example illustrates that, although the water retentivity count of the composition decreases with lime addition when a small proportion of aggregate is present, this effect is reversed and the water retentivity count of the composition increases with lime addition when the proportion of aggregate is in the range of about 20%–50% by weight. This effect indicates that an interaction takes place among the lime, fly ash, soil and aggregate.

EXAMPLE 5

A series of underwater disintegration tests was run, using a Maryland A-7 clay. Various specimens were prepared, containing various proportions of limestone screenings as aggregate, and all specimens were submerged in water for 60 hours, after which they were checked for hardness and compressive strength as well as underwater disintegration. The results are tabulated in the following table:

Table III

Test No.	Percent by weight				Hardness	Compressive Strength	Percent Disintegration		
	Lime	Fly Ash	Soil	Aggregate			1½ hrs.	24 hrs.	60 hrs.
1	3	10	90	0	Very poor	Sample crumbled	15	35	Almost complete.
2	5	10	90	0	do	do	8	28	40.
3	5	10	80	10	Poor	do	2.5	15	20.
4	5	10	70	20	Very good	485 p. s. i.	0	1	2.
5	5	10	60	30	do	465 p. s. i.	0	0.5	1.
6	5	10	50	40	do	485 p. s. i.	0	0.2	0.5.

The foregoing table illustrates that the underwater disintegration is sharply reduced and almost entirely eliminated when the percentage aggregate approaches about 20% by weight, when lime and fly ash proportions are maintained constant. This indicates that an interaction takes place at about 20% by weight aggregate.

When a plastic soil, having high water retentivity, is mixed with aggregate in an effort to improve the soil to provide a road base, the results are unsatisfactory even though a very large proportion of aggregate is added. For example, when over 50% aggregate is added to a plastic silt or to a plastic clay, the product quickly fails when subjected to alternate cycles of wetting and drying or freezing and thawing, when also subjected to heavy loads. It is accordingly surprising that the same soil can be stabilized to form a product having excellent durability under the same conditions, when small proportions of lime and fly ash and as little as 20% by weight of aggregate are incorporated into the soil. While the straight addition of aggregate to plastic soil is very costly because of the large quantity of aggregate required to create a good road base, the same soils are efficiently and economically stabilized in accordance with this invention, which requires much less aggregate, together with small amounts of fly ash and lime, at a drastically reduced total cost.

It will be appreciated that large aggregate, as distinguished from the aggregate in accordance with this invention and hereinbefore referred to, such as ½ inch stones or even larger, may be incorporated into the stabilized soil mixture without departing from the scope of this invention. The expression "consisting essentially of" as used in the claims does not imply that the compositions of the invention must be free of other additives; it is intended as a definition of those components which must be present in order to obtain the benefits of the invention, and these benefits are obtained whether our components are present alone or mixed with one or more compatible additives.

Having thus described our invention, we claim:

1. A stabilized soil composition of matter consisting essentially of about 5% to about 25% by weight fly ash, about 35% to about 75% by weight plastic soil, about 20% to about 50% aggregate, the sum of the percentages of fly ash, soil and aggregate being substantially equal to 100%, and about 2% to about 9% lime, the percentage of lime being based on the total weight of fly ash, soil and aggregate, said aggregate comprising a plurality of discrete particles which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water, the majority of said particles ranging in size from about forty mesh to about one half inch.

2. The stabilized soil composition of matter defined in claim 1, wherein the soil is selected from the group consisting of clay, loam and silt.

3. The stabilized soil composition defined in claim 1, wherein the soil is limited to those soils having a plasticity index below about 9 when more than about 35% by weight of the soil passes a standard 200-mesh sieve, to

those soils having a plasticity index of about 9-15 when more than about 15% by weight of the soil passes a standard 200-mesh sieve, and to those soils having a plasticity index of above about 15.

4. The stabilized soil composition defined in claim 1, wherein the aggregate has the following screen analysis:

Standard screen size	Percent by weight passing
1/4"	90-100
1/2"	75-100
3/4"	40-90
1"	5-35
2"	0-15

5. A stabilized soil composition of matter consisting essentially of about 5 to about 25% by weight fly ash, about 35 to about 75% by weight soil, said soil being limited to those soils having a plasticity index below about 9 when more than about 35% by weight of the soil passes a standard 200-mesh sieve, to those soils having a plasticity index of about 9-15 when more than about 15% by weight of the soil passes a standard 200-mesh sieve, and to those soils having a plasticity index above about 15, about 20% to about 50% aggregate, said aggregate comprising discrete particles of predominantly inorganic mineral material selected from the group consisting of limestone, sand, gravel and slag particles of which about 90-100% by weight passes a standard 1/4" sieve, about 75-100% by weight passes a standard No. 4 sieve, about 40-90% by weight passes a standard No. 10 sieve, about 5-35% by weight passes a standard No. 40 sieve, and about 0-15% by weight passes a standard No. 200 sieve, the sum of the percentages of aggregate, fly ash and soil being substantially equal to 100%, and about 2% to about 9% by weight lime, the percentage of lime being based on the total weight of fly ash, soil and aggregate.

6. A stabilized compact supporting course for a road, highway or the like, characterized by early durability and pliability sufficient for re-compacting, consisting essentially of about 5% to about 25% by weight fly ash, about 35% to about 75% by weight plastic soil, about 20% to about 50% by weight aggregate, said aggregate comprising a plurality of discrete particles which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water, the majority of said particles ranging in size from about 40 mesh to about one-half inch, the sum of the percentages of fly ash, soil and aggregate being substantially equal to 100%, about 2% to about 9% by weight lime, the percentage of lime being based on the total weight of fly ash, soil and aggregate, and about 5% to 32% by weight of water, a percent water being based on the total weight of lime, fly ash, soil and aggregate.

References Cited in the file of this patent

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2,364,690 Havelin et al. Aug. 21, 1951

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2,937,581

ROAD BUILDING METHOD

Jules E. Havelin, 216 Walnut Place, Havertown, Pa., and
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No Drawing. Filed June 28, 1957, Ser. No. 668,627

6 Claims. (Cl. 94-22)

This invention relates to a method of making stabilized load-supporting bases, and more particularly relates to a method of improving a stabilized road base composed of lime, fly ash and finely divided soil.

This application is a continuation-in-part of our application, Ser. No. 36,048, filed June 30, 1948, entitled "Hydrated Lime Fly Ash Fine Aggregate," now U.S. Patent No. 2,564,690, issued August 21, 1951, and is also a continuation-in-part of our application Ser. No. 245,652, filed August 18, 1951, now U.S. Patent No. 2,698,252, and is also a continuation-in-part of our co-pending patent application Ser. No. 245,651, filed August 18, 1951, now abandoned. In the aforesaid patents and co-pending application we have disclosed cementitious compositions useful as structural materials, stabilized soils and the like which contain fine aggregate in the form of finely divided sand or other chemically inert aggregate, or soil. Repeated experiments in the laboratory as well as practical applications in the field have demonstrated that, within specific ranges of relative proportions of those ingredients, a mixture having unexpectedly high early compressive strength was obtained.

We have now discovered that unexpected advantages are attained by mixing lime and fly ash in controlled proportions with a finely divided soil having a fineness modulus less than 1.7, compacting the mix, partially setting, then re-working and recompacting the mix, and then setting it completely. Soils having fineness modulus below 1.7 are of such fineness that they are outside the class of material usually referred to as aggregates. The formation of our mixtures changes the engineering properties of the soil at once, converting it to an excellent stabilized material for building load-supporting surfaces such as roads, highways, airfield runways and the like. After curing for an appropriate time, this stabilized material develops advantageous strength characteristics for service as a load-supporting base, but these advantages are greatly enhanced by the method which comprises this invention.

It is an object of this invention to provide a method of improving the ultimate strength of a mixture composed of lime, fly ash and soil.

Another object is to provide a method of making an improved road or other load-supporting base.

Further objects and advantages of the invention will further become apparent hereinafter.

The foregoing and other objects are attained in accordance with this invention by incorporating lime and fly ash into a finely divided soil, said finely divided soil having a fineness modulus less than 1.7, in the presence of moisture, compacting the resulting composition, subjecting the compacted composition to partial setting, breaking the partially-set mix down into a plurality of separate and discrete particles, recompacting the separate and discrete particles, and then completing the setting of the resulting recompacted mix.

The words, "lime," "fly ash," "soil," and "fineness

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modulus" are expressions well known in the art and have been discussed in considerable detail in our aforementioned U.S. Patent No. 2,698,252.

Finely divided materials other than natural soils, which are equivalent to the soils falling within the above defined soil classifications, nevertheless are included with the scope of this invention. These materials include fine sand, stone screenings, slags, gravel screenings, mineral deposits, fine screenings from quarry operations and the like, having fineness modulus below 1.7, as well as other similar soil-like materials all of which are included within the meaning of the term "soils" as used herein.

The relative proportions of the three principal components of the compositions are important, in that a wholly unexpected peak is attained, when certain soil characteristics are plotted against the relative proportions of fly ash and lime in the mix, such peak being of the same general character as that represented in Fig. 2 of our aforementioned Patent No. 2,564,690.

Accordingly the relative proportions of the ingredients are substantially 10-30 parts fly ash and 2-10 parts lime (expressed as $\text{Ca}(\text{OH})_2$) for each 70-90 parts of fine inert material. However, greater proportions of lime may be employed for some soils without excessive detrimental effect for the stabilization of highly plastic soils such as clays and the like although as lime content is increased the desirable characteristics of the composition are rapidly lost. Lime contents of 20% or above are to be avoided since the advantages of our invention are not realized. For certain A-7 soils and other highly plastic soils, lime contents up to 15 parts lime per 100 parts soil plus fly ash may be employed to advantage. Preferably, the lime content of the mix is within the range of 2-10% lime per 100 parts soil plus fly ash.

This invention is also applicable to compositions included in our co-pending patent application Serial No. 477,122 filed December 22, 1954, now U.S. Patent No. 2,815,294, issued December 3, 1957, consisting essentially of about 5% to about 25% by weight fly ash, about 35% to about 75% by weight plastic soil, about 20% to about 50% aggregate, the sum of the percentages of fly ash, soil and aggregate being substantially equal to 100% and about 2% to about 9% lime, the percentage of lime being based on the total weight of fly ash, soil, and aggregate, said aggregate comprising a plurality of discrete particles which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water, the majority of said particles ranging in size from about forty mesh to about one half inch.

Ingredients of our compositions may be initially prepared in any conventional manner, such as by simple mixing of the solid components, preferably in the presence of water. However the mixing is preferably carried into effect by breaking up the soil and mixing the soil with lime and fly ash in predetermined proportions, utilizing suitable soil-breaking and mixing equipment such as that conventionally used for farm and construction purposes, with water added to the mixture in an amount substantially equal to that proportion of water known and defined as the optimum moisture content. Optimum moisture content is determined by the well known modified Proctor test.

Optimum moisture content of a soil or stabilized soil mixture is that moisture content at which the soil-moisture mix has the maximum dry density, or maximum dry weight of solids per unit volume. In practice, the optimum water content varies with each particular soil and stabilized soil mixture, ordinarily within the range of 8-25% moisture by weight, based on the total dry weight of lime, fly ash, and soil. Preferably, in incorporating moisture into our stabilized soil mixes, the water content should be controlled within the range of 70%-130% of the

optimum water content. Thus the water content of the stabilized road base may vary from about 5%–32% by weight, based on the weight of total lime, fly ash, and soil, for different soils.

After mixing, the treated soil is laid down in the desired location and compacted while unconfined, either as a single layer or, depending upon the depth, in several separate layers. Preferably the compacting is effected by moving a heavy roller along the surface of the stabilized soil while unconfined.

In practice, the initial preparation and compacting of the mixture may be carried out in a number of ways. For example, the lime and fly ash may be mixed with the soil in batch type mixing equipment. If desired, permanent or portable mixing plants may be set up either at a control point from which the composition is transported to the job or the mix plant may be placed directly at the job site depending on the condition existing for each construction project. Another acceptable practice involves the "mix-in-place" method where the lime and fly ash is placed on the road or construction area either directly over the existing soil or in conjunction with a soil brought in from a local gravel pit or the like. The lime and fly ash may be supplied in bulk form or if desired in paper or other containers. Regardless of the method used the proportioning of materials is preferably carried out so that the composition conforms quite closely to the optimum mixture established in the previously described tests of sample mixes.

Where the material is mixed in place, the use of a pulv-mixer or similar road construction equipment will result in a thorough and rapid blending of the materials to a depth of 6" to 8". Usually where depths greater than 8" are desired the application and mixing process is preferably carried out in layers. The depth of material used will depend to a considerable extent on the service to which the base will be subjected and on the surface cover placed over the base.

The composition should preferably contain the proper amount of water to develop adequate density after compaction. Where the composition is prepared in a mixing plant the water may conveniently be added to the mixer. For the "mix-in-place" procedure the water may be applied either by means of watering tanks or by addition of water to one or more of the ingredients prior to mixing, regardless of the method of addition of water. It is usually essential to check the water content prior to compaction of the base. If the water concentration is not close enough to the optimum value, an adjustment should be made—either by blading or mixing material too high in moisture content or by addition of water for further mixing for material too low in water.

Compaction of the base is accomplished by using conventional grading and rolling equipment for some of the more plastic type soils. A sheeps foot roller may be used to advantage. Flat steel rollers or rubber wheeled rollers such as wobble wheel rollers may be also used to develop the desired compaction. Where possible the compaction should be checked in the field to determine whether or not the compaction of the base is adequate. Preferably the compaction should be quite close to the value of density established in the tests for optimum mixture as set forth above.

In accordance with this invention, the compacted composition is subjected to setting until a partial interaction takes place, producing a corresponding partial growth of its pozzolanic strength bonds. Preferably the mixture is subjected to natural ambient conditions for a period of about one week to about one year, but in any event for a time which is materially less than (preferably no more than one-half) the time required for the ultimately complete growth of the pozzolanic strength bonds (complete setting). The time required for complete setting varies according to prevailing conditions. For example, cold or freezing weather retards setting, as does poor drainage

According to this invention, at or prior to the time when the mix attains a compressive strength of about one-half the compressive strength attainable after completion of the setting reaction in a single stage, the partially set mix is broken down into a plurality of separate and discrete particles (disintegrated), such separate and discrete particles are reshaped and recompact in the presence of water. The recompact step may be carried out in the same way as the initial compaction step heretofore described. The foregoing steps, comprising breaking down and re-shaping are referred to herein collectively as "reworking."

Accordingly, the multiple stage road building method involves the reaction of lime, fly ash and soil in at least two successive and related stages. In the first stage, a pozzolanic action begins, which involves the lime, fly ash and soil. This stage of the reaction includes a metamorphic change of state of soil components, changes of material grain size, density, water of immobility, and an alteration of the mineral placement. All of these changes are due to the interaction of lime, fly ash and soil, and they result in the formation of intermediates which are of particular advantage in connection with the reactions taking place in the second stage of the process.

In the second stage of the process, after the mix has been reworked and recompact, the pozzolanic reaction involves the intermediates produced in the reaction of the first stage, together with residual lime and fly ash present in the mix. The residual lime and fly ash react far better and more rapidly with the intermediates produced from the first reaction stage, than they would have reacted had there been no reworking and recompact. The reworking and recompact steps cause a redistribution of the components of the mixture, allowing the residual lime and fly ash to react with the intermediate compounds produced in the first reaction stage.

In accordance with this invention, the setting reaction in the first reaction stage is carried out for a period of about one week to about one year, such period being limited as a maximum to the time required to produce a compressive strength of about one-half the compressive strength that would be produced after completion of the setting reaction in a single stage.

It has been discovered that the interaction of lime, fly ash and soil in the first reaction stage differs radically from the interaction which takes place in the second reaction stage. This fact has been demonstrated by observations of the amount of water of immobility associated with the particles of the mix, and by observations in connection with the mineral placement within the mix.

Referring to the matter of water of immobility, it is a known fact that the particles of the soil in the mix are associated with outer layers of immobile water, and the presence of this immobile water is evidenced by the behavior of the mix on settling. The "water of immobility" of the mix is expressed as a percentage, and is the ratio of the volume of immobile water to the total volume of immobile water plus solid particles. A typical reaction in accordance with this invention would show, for example, a water of immobility at the beginning of the first reaction stage on the order of about 90%, with a drop to a value as low as about 20–25% at the end of the first reaction stage. In the second reaction stage, the water of immobility drops very little, for example, from about 20% to about 15%. This indicates that a series of entirely different types of reactions are taking place during the second reaction stage as compared to the first reaction stage.

A similar observation may be made with respect to the mineral placement in the mix. As the mineral placement reaction between lime, fly ash and soil takes place, an ion exchange reaction occurs. For example, calcium and magnesium ions replace sodium and potassium originally present in the soil. Then, a supplementary reorientation occurs within the molecular structure, and this happens

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relatively slowly but has usually been found to take place in the time period referred to above in connection with water of immobility. A substantial mineral placement change occurs in the first reaction stage, as compared to the change occurring in the second reaction stage.

After the base has been finally compacted, a final surface treatment may be applied. In some instances no surface treatment may be necessary if the base is to serve in an application where severe traffic or climatic conditions are not anticipated. Usually some form of wearing or seal coat is applied to the compacted base. This may consist of a coating of oil or tar with or without additions of stone chips. The composition may also be placed directly under bituminous or Portland cement pavements or in some types of road construction may act as the sub-base under other base compositions such as water bound macadam and the like.

The compositions may also be added to larger size aggregates such as ballast road stone to bind the coarse aggregate together and thereby develop greater strength and improved stability in the base. Many variations of the above are possible.

The method used in the construction of the base requires essentially conventional road building equipment and therefore the invention may be practiced in both a convenient and economical manner.

The following examples are illustrative of the invention:

Example 1

A street was constructed for a development, utilizing a mixture consisting essentially by weight of about 5% lime, about 10% fly ash and the balance soil having a fineness modulus below 1.7. After suitably mixing the ingredients of the composition together with water, the road was compacted in an unconfined condition and was subjected to ambient conditions for a period of 6 months. After 6 months a sample was removed from the road and disintegrated, then recompact and subjected to curing until it developed its final compressive strength. This produced a compressive strength of 1200 pounds per square inch. Another sample of the material which was used in building the road was taken and such sample was simply compacted and cured until it reached its final compressive strength. This produced a compressive strength of 758 pounds per square inch. The increase of compressive strength, from 758 to 1200 pounds per square inch, was caused by the disintegration and recompact steps.

Example 2

Another housing development construction project involved the application of a lime-fly ash-soil composition, containing by weight about 5% lime, about 10% fly ash, and the balance soil having a fineness modulus below 1.7. A procedure the same as that detailed in Example 1 above, was followed. The final (completely cured) compressive strength of the sample which was not recompact was 700 pounds per square inch, while a sample which was recompact after being subjected to natural ambient conditions for a period of 2 months, was found to have a final (completely cured) compressive strength of 1180 pounds per square inch. Again, the increase of compressive strength was caused by the two-stage process involving breaking up the mix and recompacting it.

Example 3

A base was laid for a storage area at a large refinery. The project consisted of a road supporting base consisting of about 5% by weight lime, about 10% by weight fly ash, and about 85% by weight of A-2-4 soil having a fineness modulus below 1.7. At the time the base was prepared and compacted, representative samples of the mixture were taken and these were compacted in the laboratory under controlled conditions accurately representative of the conditions in the field. The final compressive strength measured 452 pounds per square inch.

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After the base had been subjected to natural ambient conditions in the field for a period of 1 month, a sample of the base was taken and was disintegrated and recompact and tested for its final compressive strength. Such disintegration was accomplished as follows: the sample of base was broken down, according to standard procedures for preparing soil samples, to a point where it substantially met the gradation of the original soil used for construction of the base. The test after recompact was conducted under the same conditions as the test without recompact and indicated an improvement of final compressive strength from 452 pounds per square inch to 570 pounds per square inch.

One of the important advantages of our invention is that it provides a new concept in road building in which the road is initially installed in a temporary way in rough condition for immediate use as a construction road (usable even while installing it) and then at some convenient later period it is reworked and recompact in final form, to result in a road of ultimately higher strength than if not reworked and recompact.

It is within the scope of this invention to stop the interaction of lime, fly ash and soil at the end of the first reaction stage by disintegrating the mix while in a dry condition. The mix, in this condition, can readily be removed and redeposited at any other location, and recompact in the presence of moisture.

Additional materials such as Portland cement, special grades of clay soils and alumina silicates and the like may be incorporated into soil stabilized in accordance with our invention without detrimental effect to certain of the advantages of the invention. However, the novel stabilized soil road bases themselves consist essentially of the ingredients set forth in the appended claims.

Although in the specification and claims we refer to a method of building a road, it will be appreciated that the term "road" is used in its broad sense and is intended to include load-supporting bases such as roadways, secondary roads, road shoulders, highways, parking areas, airport runways, floors, load-supporting bases and the like.

The above description and examples are presented as illustrations of preferred embodiments of the invention. All modifications and variations which conform to the spirit of the invention, including the substitution of equivalents and other changes in the particular form of the method and product, as well as the use of certain advantageous features of the invention without the use of other features, are within the scope of the invention as defined in the appended claims.

Having thus described our invention, we claim:

1. In a method of building a road of a slow-setting composition consisting essentially of about 10%-30% by weight crude fly ash, about 70%-90% by weight soil having a fineness modulus below 1.7, the sum of the percentages of soil plus fly ash being substantially equal to 100, and about 2% to about 9% by weight inclusive of lime, said composition having an early bearing strength which is greater than the bearing strength of the soil, the steps which comprise mixing said lime, crude fly ash and water with the soil in relative quantities forming said composition, compacting said composition, subjecting said compacted composition to conditions within the range of natural ambient conditions for a limited period of time of about a week to a year until partial setting of said composition occurs and the bearing strength of the composition is substantially increased, disintegrating and re-mixing the partially-set composition and distributing it along a predetermined road course, recompact said partially-set composition *in situ*, and then subjecting said compacted partially-set composition to natural ambient conditions for a suitable time until reaction of said lime, fly ash and soil is complete.

2. In a method of building a road of a slow-setting composition consisting essentially of about 10%-30% by

weight crude fly ash, about 70%-90% by weight soil having a fineness modulus below 1.7, the sum of the percentages of soil plus fly ash being substantially equal to 100, and about 2% to about 9% by weight inclusive of lime, said composition having an early bearing strength which is much greater than the bearing strength of the soil, the steps which comprise loosening the soil along a predetermined course, mixing said lime, crude fly ash and water with the soil in relative quantities forming said composition, compacting said composition, subjecting the compacted composition to natural ambient conditions for a limited period of time of about a week to a year until substantial partial setting of said composition occurs and the bearing strength of the composition is increased while said composition is in a re-workable condition, loosening the partially-set compacted composition before said setting is complete, disintegrating and remixing the loosened partially-set composition, and then subjecting said re-compacted partially-set composition to natural ambient conditions for an extended period of time until reaction of said lime, fly ash and soil is complete.

3. The method defined in claim 2, wherein the original mix is compacted in an unconfined condition, by downwardly directed pressure only.

4. In a method of building a road of a composition consisting essentially of about 10%-30% by weight fly ash, about 70%-90% by weight soil having a fineness modulus below 1.7, the sum of the percentages of soil plus fly ash being substantially equal to 100, and about 2% to about 9% by weight inclusive of lime, and wherein said lime, fly ash and soil are compacted in the presence of moisture causing an interaction which develops strength bonds and ultimately produces a hard material when subjected to natural ambient conditions, the novel step which comprises interrupting said interaction by disintegrating the mix within a period of about a week to about a year after said compaction, such period being limited as a maximum to the time required to produce a compressive strength of about one-half the compressive strength that would be produced after completion of said interaction,

and such disintegration being followed by reshaping and re-compacting the mix in the presence of moisture.

5. The method defined in claim 4, wherein the partially-set material, after having been disintegrated, is reshaped and re-compacted in the presence of moisture and subjected to natural ambient conditions until said interaction is completed.

6. A two-stage method of building a road of a slow-setting composition consisting essentially of about 10%-30% by weight fly ash, about 70%-90% by weight soil having a fineness modulus below 1.7, the sum of the percentages of soil plus fly ash being substantially equal to 100, and about 2% to about 9% by weight inclusive of lime, said composition having an early bearing strength which is greater than the bearing strength of the soil, the steps which comprise mixing said lime, fly ash and water with the soil in relative quantities forming said composition, commencing the first setting stage by compacting said composition in the presence of moisture, subjecting said compacted composition to conditions, within the range of natural ambient conditions for a limited period of time until partial setting of said composition occurs and the bearing strength of the composition is substantially increased, terminating the first stage of said setting by disintegrating the partially set mix into a plurality of separate and discrete particles within a period of about a week to about a year after said compaction, such period being limited as a maximum to the time required to produce a compressive strength of about one-half the compressive strength that would be produced after completion of said setting, re-shaping the disintegrated mix, then commencing the second setting stage by re-compacting the disintegrated re-shaped mix in the presence of moisture, and subjecting the resulting mix to natural ambient conditions until the setting reaction between said lime, fly ash and soil is complete.

References Cited in the file of this patent:

UNITED STATES PATENTS

2,698,252 Havelin Dec. 26, 1954

ASTM STANDARD SPECIFICATIONS AND STANDARD TEST METHODS

The following is a list of ASTM standard specifications and test materials which are relevant to this study. The complete specifications can be found in the pertinent ASTM documents.

ANSI/ASTM C29-78	Unit Weight and Voids in Aggregate
ANSI/ASTM C88-76	Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
ANSI/ASTM C127-80	Specific Gravity and Absorption of Coarse Aggregates
ANSI/ASTM C128-79	Specific Gravity and Absorption of Coarse Aggregates
ANSI/ASTM C131-76	Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine
ANSI/ASTM C311-77	Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
ASTM C593-69	Fly Ash and Other Pozzolans for Use with Lime
ANSI/ASTM C593-76a	Fly Ash and Other Pozzolans for Use with Lime
ASTM D422-63	Particle-Size Analysis of Soils
ANSI/ASTM D558-57	Moisture Density Relations of Soil-Cement Mixtures
ANSI/ASTM D698-78	Moisture Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5 lb (2.49-kg) Rammer and 12-in. (305-mm) Drop
ANSI/ASTM D1557-78	Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop
ANSI/ASTM D1883-73	Bearing Ratio of Laboratory-Compacted Soils
ANSI/ASTM D2049-69	Relative Density of Cohesionless Soils
ANSI/ASTM D2435-70	One-Dimensional Consolidation Properties of Soils
ANSI/ASTM D2850-70	Unconsolidated, Undrained Strength of Cohesive Soils in Triaxial Compression
ANSI/ASTM D3080-72	Direct Shear Test of Soils Under Consolidated Drained Conditions
ANSI/ASTM D1074-76	Compressive Strength of Bituminous Mixtures
ANSI/ASTM D1075-76	Effect of Water on Cohesion of Compacted Bituminous Mixtures
ANSI/ASTM D1138-73	Resistance to Plastic Flow of Fine-Aggregate Bituminous Mixtures by Means of the Hubbard-Field Apparatus
ANSI/ASTM D1559-76	Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
	Recommended Practice for Use of Process Waste in Structural Fill

"POZ-O-BLEND" - THE SECOND GENERATION OF POZ-O-PAC®

L. John Minnick^{1/}

HISTORICAL BACKGROUND

The original efforts in the early forties of Havelin and Kahn^{2/} (engineers with the Philadelphia Electric Company) to develop lime-fly ash-"soil" mixtures for structural purposes has resulted in a major industry in the field of road construction. Since the compositions were first produced at the Plymouth Meeting plant of the G. & W. H. Corson company, approximately fifty million tons of Poz-O-Pac® have been placed. Licensees have produced material in twenty states, and roads and highways of all types have now been in service for many years (some in excess of twenty years). Major airports, parking lots, highway embankments, reservoirs, and dams all have used the Poz-O-Pac compositions. Specifications have been drafted by many state and federal agencies, the most recent being the specification issued by the Federal Aviation Administration covering this product.

The properties of the Poz-O-Pac compositions have been carefully studied in numerous laboratories and evaluation programs of field jobs have been reported many times in the literature.^{3/} The product competes with other types of stabilized base compositions, namely cement aggregate base and asphalt aggregate base. Figure 1 shows a recent photograph of a feeder road that was placed in Salem County, N. J. in 1954. Figures 2 and 3 show views of a state highway at the time of construction (1968) and after eight years of service. These jobs illustrate the serviceability and durability that can be expected from this type of construction.

^{1/} Executive Vice President, IU Conversion Systems, Inc., Philadelphia, Pa.

^{2/} Minnick, L.J., and J.E. Havelin. The Use of Lime-Fly Ash Compositions in Highway Construction. American Road Builders' Association Meeting, Cincinnati, Ohio, March 8, 1950.

^{3/} Minnick, L.J., and R. Williams. Field Evaluation of Lime-Fly Ash-Soil Compositions for Roads. Highway Research Board Bulletin 129, 1956, pp. 83-99.

One of the major developments over the years was the establishment of "plant mix" operation to supersede the original "mixed in-place" method that was used in the early periods of construction. Today there are a number of high production plants that are in operation which require very minimal maintenance. Figure 4 is a photograph of a recently constructed plant operating in Missouri.

In 1972 IU International Corporation acquired G. & W. H. Corson, Inc. and at that time decided to structure a separate company, IU Conversion Systems, Inc., which among other things is continuing the marketing of the Poz-O-Pac proprietary system. Since the acquisition it was decided that some of the new formulations developed at the Corson research center should be marketed as a complete blend to augment the Poz-O-Pac program in a number of significant ways. It is the primary purpose of this brief report to describe the new "Poz-O-Blend" development which now represents the second generation of Poz-O-Pac.

POZ-O-BLEND PRODUCT CONCEPT

The development of new fly ash formulas comprises a complete blend of ingredients produced at a centrally located blending plant which serves as a supply center of a cementitious material that is then shipped to the mixing plants producing the stabilized aggregate base mixture. The Poz-O-Blend composition is a pozzolanic fly ash cement and therefore replaces the use of separate sources of the lime and fly ash ingredients. Producing a blend at a central plant offers a number of very important advantages over traditional Poz-O-Pac mixes, among which are the following.

Quality Control: One of the main advantages that has been developed in the commercial utilization of Poz-O-Blend is control of the quality of the final composition. Variations in fly ash, while not as important as in the case where fly ash is used with portland cement, does influence performance of Poz-O-Pac. Climatic conditions have invariably been of concern because of the relatively slow strength gain at low temperatures which are experienced late in the construction season. Adjustment of the formula of a manufactured blend can advantageously control rate of set, durability, etc. such as is often done in portland cement concrete. Control of optimum density in the final mix can also be influenced by proper premixing and adjustment of the fly ash matrix.

Seasonal Considerations: Extensive investigations have been carried out over the last five years to develop a so-called "winter mix" Poz-O-Pac. The purpose of this is to allow for late season construction

and avoid problems caused by low temperature curing. The new concepts of "degree days" which have been reported in the literature^{4/} can be substantially modified by using the Poz-O-Blend formulations. In effect, this means that several classes of Poz-O-Pac can be designed instead of a single formulation as used in the past. This is analogous, for example, to the use of different types of portland cement in the design of concrete mixtures.

Environmental Properties: Poz-O-Blend is attractive since it does not use a significant quantity of energy sensitive materials. In view of the high cost of energy today, this results therefore in a Poz-O-Pac composition that is very competitive to the other products specified for road base use. In addition, the large quantities of ash used in the mixtures provides an outlet to assist in the disposal (and utilization) of power plant waste.

Technical Field Support: The Poz-O-Blend concept also uses highly trained technicians for field support purposes. This covers such areas as providing assistance in drafting specifications for the base material, establishment of suitable test procedures for quality control, and providing technical data to develop proper design of the road base. In this connection, it should be mentioned that in the state of Pennsylvania the merit factor for Poz-O-Pac has now been set at a value of 0.40 which places it on an equivalent design basis with portland cement or asphalt stabilized compositions.

FIELD ACTIVITIES

An important evaluation program was undertaken in 1973 in cooperation with the Pennsylvania Department of Transportation. A number of sections of roadway were designed and placed at two separate times of the year; the first section early in the month of September, and the second section late in the month of October. The highway department utilized a road rater as one of its evaluation methods. This device measures variations in the roadway surface caused by deflection under load and establishes in this manner the performance of the road base. Figure 5 shows the equipment used for this purpose. While it is not the intention of this paper to provide specific data of the tests, the results have clearly indicated that the Poz-O-Blend formulations gave superior results to some of the conventional mixtures. In addition, cores have been taken out of the roadway at various times and

^{4/} Thompson, M.R., and B. J. Dempsey. Final Report - Durability Testing of Stabilized Materials. Illinois Cooperative Highway Research Program Series No. 152, 1974.

measurements have been made on these cores and on laboratory prepared specimens. These data have been used to assist in the development of ultimate design criteria of Poz-O-Blend and Poz-O-Pac for future use.

During the year of 1975 a full scale plant has been constructed at Kansas City, Missouri which uses fly ash from Kansas City Power and Light Company. The plant is located adjacent to the Hawthorne Station and can therefore supply Poz-O-Blend for an area that can use considerable quantities of the Poz-O-Pac road base. Figures 6 and 7 show photographs of the plant at Kansas City. One interesting aspect of the Kansas City program is the use of some lignite fly ash which is a quite reactive material. The production of Poz-O-Blend with this fly ash provides a means of controlling this reactivity so that it will perform in the final composition in an optimal manner. Previous experience with this type of fly ash has shown that it is sometimes difficult to control the reactions in road base mixtures.

While it is not yet appropriate to refer to other plants that are now being proposed, it is anticipated that at least two more of these blending systems will become operational in 1976. Conversion Systems is cooperating with the utilities in constructing a complete system for utilizing fly ash in the manufacture of Poz-O-Blend. This includes the financing, construction, and operation of the plant by Conversion Systems who also serves as a supplier of the product to the local stabilized base producers. Marketing is also carried out using local Conversion Systems' organizations. This program therefore represents a major step forward in the development of a reputable financially strong alliance of pertinent groups in the marketing of the final Poz-O-Pac base.

SUMMARY

As a result of many years of experience and use of lime-fly ash aggregate mixtures known as Poz-O-Pac road base, a new concept has been formulated to assist in the growth of this important product. Poz-O-Blend cement is a quality controlled mixture of all ingredients exclusive of the aggregate. It is produced in a centrally located plant usually on or adjacent to the power plant. Conversion Systems is offering to the utilities an ash utilization program including financing, construction, and operation of the Poz-O-Blend plant. The company also provides marketing and technical services to assist in the production and placement of the final Poz-O-Pac composition.

Results to date show that the new generation of Poz-O-Pac produces a product with improved structural properties, durability, and quality control. The Poz-O-Pac road base, produced with Poz-O-Blend cement, is economically competitive with the leading base course materials.

Appendix B

SUPPORT DOCUMENTATION - KILN DUST

This appendix contains copies of three patents cited in Chapter 6 of Volume 1. They relate to the use of kiln dust in stabilized road bases.

MIXTURE FOR PAVEMENT BASES AND THE LIKE

This invention relates to materials which are capable of supporting surfacing such as pavement bases.

BACKGROUND OF THE INVENTION

In road paving, at one time it was thought that the base for the surfacing material should comprise a granular or gravel base. However, more recently, it has been concluded that there was a considerable difference in the performance between such bases and cement-aggregate or bituminous (asphalt)-aggregate bases. As reported in the Highway Research Board Special Report 61E, titled "The AASHO Road Test, Report 5, Pavement Research, publication 954 of National Academy of Sciences - National Research Council, there is a clear superiority of such treated bases over untreated bases. In recent years, treated bases have become commonly known as stabilized bases.

In subsequent work, for example, use of asphalt mixtures in all courses of pavement above the subgrade has been proposed, The Asphalt Institute, Information Series No. 146, June 1968. Asphalt stabilized bases have become the most dominant stabilized base utilized to support a flexible surfacing such as asphalt concrete. In addition, asphalt concrete has found extensive use as a resurfacing material for concrete pavement.

It has also been proposed that a lime-fly ash-aggregate stabilized base be used in road paving. Such a base consists of a mixture of proper quantities of lime, fly ash, and graded aggregate at optimum moisture content, in which the stability is greatly enhanced by the cementing action which results from complex chemical reactions between the lime and the fly ash in the presence of water.

Stabilized bases are usually employed as base courses under wearing surfaces such as hot mixed, hot laid asphaltic concrete. A wearing surface is necessary to resist the high shearing stresses which are caused by traction, but the stabilized base provides the required stability to support wheel loads.

A serious obstacle to the expanded use of stabilized bases is the high energy costs for making the materials.

For example, it is well known that the production of portland cement which is used in stabilizing bases requires substantial quantities of coal in manufacture. In fact, the United States Department of Transportation has suggested that fly ash be substituted for a portion of the portland cement utilized in concrete or cement-aggregate bases, Federal Highway Administration Notice N5080.4, Jan. 17, 1974.

The use of asphalt in asphalt-aggregate bases which is derived from petroleum processing not only utilizes petroleum which is in short supply but also requires high energy to produce them.

Similarly, the lime, fly ash and graded aggregate stabilized bases utilize lime which requires coal in produc-

tion. Such bases have been used in limited geographical areas of the United States where they can compete economically because of availability of lime and fly ash.

Thus, the predominantly used stabilized bases utilize materials that are in short supply and require substantial quantities of energy to produce them. The materials may be termed energy intensive. There is a need to avoid or minimize the use of such energy intensive materials in road paving.

Accordingly, among the objects of the invention are to provide a mixture of materials for producing a stabilized base comprising a hard, strong, durable mass capable of supporting surfacing which avoids or minimizes the use of materials which are energy intensive and, moreover, utilizes materials that normally are waste materials that are readily available.

SUMMARY OF THE INVENTION

Basically, the invention comprises a mixture consisting essentially of fly ash, cement kiln dust and aggregate which through pozzolanic reactions produces a hard, strong, durable mass capable of supporting surfacing.

DESCRIPTION OF THE DRAWINGS

FIGS. 1-3 are curves of compressive strength versus age at test for various compositions.

FIG. 4 is curves of energy requirements for various pavement materials.

DESCRIPTION

In accordance with the invention, the pozzolanic load supporting composition utilizes cement kiln dust.

The solid waste generated by cement manufacture is primarily kiln dust. This dust contains a mixture of raw kiln feed, partly calcined material, finely divided cement clinker and alkali sulfates (usually sulfates). There is economic value in returning the dust to the kiln, but when the alkali content of the returned dust is too high for the product clinker to meet specifications, the dust must be discarded. Up to about 15% of the raw materials processed may be collected as dust and of this about half may be low enough in alkalis to be returned to the kiln. The rest is usually stockpiled as a waste material which must be disposed and may be a nuisance and possibly a hazard.

Although the chemical reactions occurring in the resultant cement kiln dust are not well known, typical cement kiln dust has a chemical analysis as follows:

SiO₂
Al₂O₃
Fe₂O₃
CaO
MgO
SO₃
Na₂O
K₂O

Loss Ignition

More specifically, typical cement kiln dust may have the following analyses:

Ingredient	Source A	Source B	Source C	Source D	Source E	Source F	Source G	Source H	Source I	Mid-Range
SiO ₂	28.5%	6.0%	22.4%	11.2%	13.0%	23.5%	14.8%	14.6%	14.7%	17.2%
Al ₂ O ₃	9.6	3.4	4.71	3.2	4.0	3.77	3.4	3.4	3.7	6.4
Fe ₂ O ₃	3.9	0.8	1.77	1.4	5.0	1.71	2.2	2.2	3.0	3.4
CaO	50.1	16.0	65.0	48.8	47.2	61.3	47.3	46.3	46.5	40.5
MgO	3.4	0.8	2.60	2.1	1.2	4.83	2.1	2.0	2.0	2.8

-continued

Ingredient	Source A	Source B	Source C	Source D	Source E	Source F	Source G	Source H	Source I	Mid- Range
SiO ₂	26.3	0.7	1.12	2.4	13.6	1.48	4.8	3.0	8.2	13.3
Na ₂ O	3.18	0.08	0.24	0.2	0.45	0.24	0.9	0.9	0.8	1.6
K ₂ O	26.23	1.08	1.3	4.2	2.9	1.85	4.1	5.1	3.0	13.7
Loss on Ignition	32.0%	7.7%	2.50%	26.6%	12.9%	1.84%	21.1%	21.4%	18.2%	17.2%

RANGE

Ingredient	Low %	High %	Average %
SiO ₂	6.0	28.5	16.3
Al ₂ O ₃	3.3	9.6	4.33
Fe ₂ O ₃	0.8	3.9	2.66
CaO	16.0	65.0	47.6
MgO	0.8	4.83	2.34
SO ₂	0.7	26.3	7.07
Na ₂ O	0.08	3.18	0.78
K ₂ O	1.08	26.23	5.52
Loss on Ignition	2.50	32.0	16.0

When mixtures made in accordance with the invention and mixed with water to produce a pozzolanic reaction have been tested in accordance with the specifications given in ASTM C-593 for fly ash and other pozzolans for use with lime, it has been found that the compositions meet or exceed the specifications.

The term "fly ash" as used in connection with stabilized bases is well known and as used herein is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal or lignite, which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. Those finely pulverized ashes resulting from combustion of oil and from combustion of waste materials in a large incinerator or natural pozzolans can also be utilized in the methods described herein providing their chemical compositions are reasonably similar to pulverized coal fly ashes. The fly ash so obtained is in a finely divided state such that usually at least 70% by weight passes through a 200-mesh sieve, although incinerator ashes may be considerably coarser. Fly ash may be considered an "artificial pozzolan," as distinguished from a "natural pozzolan."

The term "aggregate" as used in connection with load supporting compositions is also well known and refers to natural or artificial inorganic materials most of which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water. Typically, aggregate may comprise limestones, sand, blast furnace slag, gravel, synthetic aggregate and other similar material.

Aggregates can comprise a wide range of types and gradations, including sands, gravels, crushed stones, and several types of slag. Aggregates should be of such gradation that, when mixed with cement kiln dust, fly ash and water, the resulting mixture is mechanically

stable under compaction equipment and capable of being compacted in the field to high density. The aggregate should be free from deleterious organic or chemical substances which may interfere with the desired chemical reaction between the cement kiln dust, fly ash and water. Further, the aggregate should preferably consist of hard, durable particles, free from soft or disintegrated pieces.

It has been found that a preferable mixture comprises:

	Percent by Dry Weight
Cement Kiln Dust	8.0%
Fly Ash	12.0%
Aggregate	80.0%
Total	100.0%

However, the mixture for use in road stabilizer bases may preferably vary as follows:

	Percent By Dry Weight
Cement Kiln Dust	4 - 16%
Fly Ash	6 - 24%
Aggregate	60 - 90%

As indicated above, tests were conducted in accordance with ASTM C-593. More specifically, the test specimens were molded using a mechanical compactor, having a 10 pound hammer with an 18 inch drop. The material was placed in the molds in three equal layers, and compacted by 25 blows per layer. The machine has a revolving turntable to evenly distribute the blows over the surface of the layer being compacted.

After molding, the samples were carefully removed from the molds, weighed, and sealed in plastic bag, labeled for identification, and placed in a constant temperature oven at 100° F to cure until tested. Two cylinders of each mix were marked for testing at 7, 14 and 28 days of curing. After removal from the oven, the samples are submerged in water for four hours, removed, and allowed to drain on a non-absorbant surface, capped, and tested within one hour after removal from the water. The capping compound used is "Hydro-Stone" a lime based, quick-hardening compound. Plate glass was used to obtain even, parallel caps on the test specimens.

Examples of various tests and compositions are as follows:

EXAMPLE I

		Percent	Weight of Batch					
Cement Kiln Dust		8.0%	2.4 lbs.					
Fly Ash		12.0%	3.6 lbs.					
Limestone		80.0%	24.0 lbs.					
Total		100.0%	30.0 lbs.					
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.8	4.73	141.9	128.1	12.57	10-16	13,140	1050
B	10.8	4.72	141.6	127.8	12.57	10-16	14,370	1140
C	10.8	4.73	141.9	128.1	12.57	10-23	15,780	1260
D	10.8	4.73	141.9	128.1	12.57	10-23	15,530	1240
E	10.8	4.73	141.9	128.1	12.57	11-06	17,800	1420
F	10.8	4.73	141.9	128.1	12.57	11-06	17,800	1420

Remarks:

Slight bleeding at bottom of mold.

EXAMPLE II

		Percent	Weight of Batch					
Cement Kiln Dust		8.0%	2.4 lbs.					
Fly Ash		12.0%	3.6 lbs.					
Limestone		80.0%	24.0 lbs.					
Retarder			0.96 oz					
Total		100.0%	30.0 lbs.					
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.1	4.73	141.9	128.9	12.57	10-16	—	—
B	10.1	4.73	141.9	128.9	12.57	10-16	—	—
C	10.2	4.73	141.9	128.8	12.57	10-23	1,650	130
D	10.2	4.73	141.9	128.8	12.57	10-23	1,930	150
E	10.3	4.73	141.9	128.6	12.57	11-06	2,300	180
F	10.3	4.73	141.9	128.6	12.57	11-06	2,100	170

Remarks:

Slight bleeding. Samples 2-A' and 2-B fell apart during the four (4) hour soaking. There was no intact sample to subject to compression test. Samples C, D, E, and F were not subjected to the four (4) hour soaking, prior to testing.

EXAMPLE III

		Percent	Weight of Batch					
Cement Kiln Dust		8.0%	2.4 lb					
Fly Ash		12.0%	3.6 lb					
Limestone		80.0%	24.0 lb					
Calcium Chloride Solution		—	(0.24 lb)					
Total		100.0%	30.0 lb					
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.4	4.77	143.1	129.6	12.57	10-16	15,160	1210
B	10.4	4.77	143.1	129.6	12.57	10-16	15,750	1250
C	10.0	4.73	141.9	129.0	12.57	10-23	17,250	1370
D	9.9	4.73	141.9	129.1	12.57	10-23	18,950	1510
E	9.8	4.73	141.9	129.2	12.57	11-06	20,600	1640
F	9.7	4.72	141.6	129.1	12.57	11-06	20,700	1650

Remarks:

Slight bleeding

EXAMPLE IV

		Percent	Weight of Batch					
Cement Kiln Dust		8.0%	2.4 lb					
Slack Dust		3.0%	0.9 lb					
Fly Ash		12.0%	3.6 lb					
Limestone		77.0%	23.1 lb					
Total		100.0%	30.0 lb					
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	8.5	4.53	135.9	125.3	12.57	10-17	8,200	652
B	8.5	4.54	136.2	125.5	12.57	10-17	8,900	708
C	8.7	4.58	137.4	126.4	12.57	10-24	10,950	871
D	8.8	4.56	136.8	125.7	12.57	10-24	11,775	937
E	9.0	4.58	137.4	126.1	12.57	11-07	16,050	1280

EXAMPLE IV-continued

	Percent	Weight of Batch
Cement Kiln Dust	8.0%	2.4 lb
Slack Dust	3.0%	0.9 lb
Fly Ash	12.0%	3.6 lb
Limestone	77.0%	23.1 lb
Total	100.0%	30.0 lb

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
F	9.0	4.56	136.8	125.5	12.57	11-07	14,850	1180

Remarks:
no bleeding.

EXAMPLE V

	Percent	Weight of Batch
Cement Kiln Dust	12.0%	3.6 lb
Fly Ash	88.0%	26.4 lb
Total	100.0%	30.0 lb

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	9.5	2.87	86.1	78.6	12.57	10-17	2,350	187
B	9.7	2.90	87.0	79.3	12.57	10-17	2,300	183
C	9.7	2.90	87.0	79.3	12.57	10-24	2,075	165
D	9.7	2.90	87.0	79.3	12.57	10-24	1,900	151
E	9.7	2.90	87.0	79.3	12.57	11-07	3,040	240
F	10.0	2.96	88.8	80.7	12.57	11-07	3,230	260

Remarks:
Had difficulty in reaching the desired moisture content because of the dust's extremely dry condition. Extremely "fluffy" material.

EXAMPLE VI

	Percent	Weight of Batch
Cement Kiln Dust	8.0%	2.4 lb
Fly Ash	8.0%	2.4 lb
Limestone	79.0%	23.7 lb
Limestone Fines	5.0%	1.5 lb
Total	100.0%	30.0 lb

Water added: $1158 + 126 = 1294$

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	9.8	4.85	145.5	132.5	12.57	10-20	13,900	1110
B	9.8	4.81	144.3	131.4	12.57	10-20	15,000	1190
C	9.8	4.79	143.7	130.9	12.57	10-27	17,350	1380
D	9.9	4.81	144.3	131.3	12.57	10-27	18,200	1448
E	9.9	4.81	144.3	131.3	12.57	11-10	17,050	1356
F	9.9	4.78	143.4	130.5	12.57	11-10	16,600	1321

Remarks:
Good compactability. Material was relatively easy to work with.

EXAMPLE VII

	Percent	Weight of Batch
Fly Ash	8.0%	2.40 lb
Kiln Dust	10.0%	3.00 lb
No. 304 Limestone (Screened over $\frac{1}{4}$ " screen)	82.0%	24.60 lb
Total	100.0%	30.00 lb

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	11.5	4.73	141.9	127.3	12.57	4-01	9350	745
2	11.1	4.71	141.3	127.2	12.57	4-01	8610	685
3	11.1	4.73	141.9	127.7	12.57	4-01	9290	740
4	11.1	4.74	142.2	128.1	12.57	4-22	14050	1120
5	11.0	4.75	142.5	128.4	12.57	4-22	13500	1075
6	10.7	4.74	142.3	128.5	12.57	4-22	13620	1085

A. Slight bleeding at bottom of mold during compaction.
 B. Material appeared deficient in limestone fines (=No. 4 material).
 C. Some free moisture noted, giving slight "gummy" appearance.
 D. Sample chipped, following extraction from molds.

EXAMPLE VIII

		Percent	Weight of Batch	
Fly Ash		10.0%	3.00 lb	
Kiln Dust		8.0%	2.40 lb	
No. 104 Limestone		82.0%	24.60 lb	
(Screened over 1/2" screen)				
Total		100.0%	30.00 lb	

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.3	4.72	141.6	129.6	12.57	4-01	8060	640
2	9.4	4.71	141.3	129.2	12.57	4-01	7730	615
3	9.4	4.71	141.3	129.2	12.57	4-01	8000	635
4	9.5	4.69	140.7	128.5	12.57	4-22	9730	775
5	9.6	4.68	140.4	128.1	12.57	4-22	10450	830
6	9.5	4.69	140.7	128.5	12.57	4-22	11490	915

A. Samples retained shape following extraction from molds.
 B. No free water noticed bleeding during compaction.

EXAMPLE IX

		Percent	Weight of Batch	
Fly Ash		8.0%	2.40 lb	
Kiln Dust		10.0%	3.00 lb	
Fill Sand		82.0%	24.60 lb	
Total		100.0%	30.00 lb	

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.8	4.09	122.7	111.7	12.57	3-31	1800	145
2	10.0	4.12	123.6	112.4	12.57	3-31	1700	135
3	9.9	4.10	123.0	111.9	12.57	3-31	1690	135
4	9.9	4.11	123.3	112.2	12.57	4-21	2810	225
5	10.0	4.10	123.0	111.8	12.57	4-21	2880	230
6	9.8	4.09	122.7	111.7	12.57	4-21	2670	210

A. No bleeding of sample during compaction.
 B. Material stayed in a ball when pushed by hand.
 C. Slight bulking noticed.
 D. Easily compacted.

EXAMPLE X

		Percent	Weight of Batch	
Fly Ash		8.0%	2.40 lb	
Kiln Dust		10.0%	3.00 lb	
Glass (Crushed to approx. 1/8" size)		32.0%	9.60 lb	
Fill Sand		50.0%	5.0 lb	
Total		100.0%	30.00 lb	

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.4	4.50	135.0	123.4	12.57	4-02	4390	350
2	9.4	4.50	135.0	123.4	12.57	4-02	4590	365
3	9.3	4.51	135.3	123.8	12.57	4-02	4200	335
4	9.2	4.52	135.6	124.2	12.57	4-23	6750	535
5	9.1	4.51	135.3	124.0	12.57	4-23	6870	545
6	9.1	4.47	134.1	122.9	12.57	4-23	6280	500

A. Material originally mixed to 10-15% moisture, baked wet, probably because non-stickiness of glass.
 B. As dried the mix out to approximately 9.4% moisture, did not bulk at this moisture content.
 C. Surprisingly good cohesion of mix, even with the smooth faces of glass particles.
 D. Strength of cylinders higher than expected, thought the mix would slip off the smooth glass faces, when put under compression.

EXAMPLE XI

		Percent	Weight of Batch	
Cement Kiln Dust		16.0	3.2 lb	
Fly Ash		24.0	4.8 lb	
No. 104 Crushed Limestone		60.0	12.0 lb	
Total		100.0	20.0 lb	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	16.6	4.50	135.0	115.8	12.57	12/22	5890	470
B	15.1	4.46	133.8	116.2	12.57	12/22	6000	480
C	15.0	4.46	133.8	116.3	12.57	12/22	6150	490

EXAMPLE XII

		Percent			Weight of Batch				
Cement Kiln Dust		4.0			0.8 No.				
Fly Ash		6.0			1.2 No.				
No. 304 Crushed Limestone		90.0			18.0 No.				
Total		100.0			20.0 No.				
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.	
A	11.1	4.94	148.2	133.4	12.57	12/22	2950	230	
B	11.2	4.93	147.9	133.0	12.57	12/22	3570	280	
C	11.2	4.93	147.9	133.0	12.57	12/22	3250	260	

EXAMPLE XIII

	Percent	Weight of Batch
Cement Kiln Dust	6.9%	140 lb
Fly Ash	11.8%	240 lb
Limestone Screenings	39.4%	800 lb
No. 57 Crushed Limestone	39.4%	800 lb
Water	2.5%	50 lb
Total	100.0%	2030 lb

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	5.6	4.49	134.7	127.6	12.57	11-22	8,950	712
B	5.1	4.51	135.3	128.7	12.57	11-22	8,225	654
C	5.3	4.51	135.3	128.2	12.57	11-22	9,050	720
D	5.4	4.50	135.0	128.1	12.57	11-29	9,610	760
E	5.5	4.49	134.7	127.7	12.57	11-29	8,080	640
F	4.9	4.50	135.0	128.7	12.57	11-29	9,630	770
G	5.1	4.46	133.8	127.3	12.57	12-13	8,820	700
H	5.3	4.51	135.3	128.5	12.57	12-13	9,380	750
I	5.4	4.50	135.0	128.1	12.57	12-13	9,400	750
J	5.3	4.46	133.8	127.1	12.57	02-03	For Durability Test For Durability Test For Durability Test	
K	5.1	4.51	135.3	128.7	12.57	02-03		
L	4.9	4.48	134.4	128.1	12.57	02-03		
M	5.0	4.54	136.2	129.7	12.57			
N	4.9	4.54	136.2	129.8	12.57			
O	4.8	4.47	134.1	128.0	12.57			

EXAMPLE XIV

	Percent	Weight of Batch						
Cement Type I	1.0%	20 lb						
Cement Kiln Dust	6.8%	140 lb						
Fly Ash	11.7%	240 lb						
Limestone Screenings	34.0%	800 lb						
No. 57 Crushed Limestone	39.0%	800 lb						
Water	2.5%	50 lb						
Total	100.0%	2050 lb						

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	5.4	4.58	137.4	130.4	12.57	11-21	10,030	800
B	5.4	4.58	137.4	130.4	12.57	11-21	11,780	940
C	5.4	4.58	137.4	130.4	12.57	11-21	14,120	1120
D	5.3	4.58	137.4	130.5	12.57	11-28	15,500	1230
E	5.0	4.58	137.4	130.9	12.57	11-28	18,500	1470
F	5.8	4.46	133.8	126.5	12.57	11-29	14,910	1190
G	5.8	4.46	133.8	126.5	12.57	12-13	17,900	1420
H	5.7	4.46	133.8	126.6	12.57	12-13	20,010	1590
I	5.7	4.46	133.8	126.6	12.57	12-13	14,980	1190
J	5.7	4.46	133.8	126.6	12.57	02-13	For Durability Test For Durability Test For Durability Test	
K	5.6	4.46	133.8	126.7	12.57	02-13		
L	5.6	4.46	133.8	126.7	12.57	02-13		
M	5.4	4.49	134.7	127.8	12.57			
N	5.4	4.49	134.7	127.8	12.57			
O	5.4	4.49	134.7	127.8	12.57			

EXAMPLE XV

		Percent	Weight of Batch					
Cement Kiln Dust		7.8%	160 lb					
Fly Ash		11.7%	240 lb					
Limestone Screenings		39.0%	800 lb					
No. 57 Crushed Limestone		39.0%	800 lb					
Water		2.5%	50 lb					
Total		100.0%	2050 lb					

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	8.1	4.24	127.2	117.7	12.57	11-22	4,650	370*
B	7.9	4.24	127.2	117.9	12.57	11-22	5,700	450
C	8.3	4.29	128.7	118.8	12.57	11-22	6,030	480
D	7.8	4.23	127.5	118.3	12.57	11-29	7,220	570
E	7.7	4.24	127.2	118.1	12.57	11-29	6,850	540
F	7.6	4.26	127.8	118.8	12.57	11-29	8,080	640
G	7.6	4.30	129.0	119.9	12.57	12-13	10,000	800
H	7.6	4.27	128.1	119.0	12.57	12-13	9,500	760
I	7.6	4.27	128.1	119.0	12.57	12-13	8,980	710
J	7.5	4.27	128.1	119.2	12.57	02-13		
K	7.3	4.28	128.4	119.7	12.57	02-13		
L	7.2	4.26	127.8	119.2	12.57	02-13		
M	7.2	4.27	128.1	119.5	12.57	For Durability Test		
N	7.1	4.24	127.2	118.8	12.57	For Durability Test		
O	7.2	4.25	127.5	118.9	12.57	For Durability Test		

*Sample fractured horizontally during capping.

Remarks:

This product was produced on November 6, and sampled on November 13. Materials are the same as in Example XIII. This example is a check to see if the age of the product, before use, has any effect on the strength results.

EXAMPLE XVI

		Percent	Weight of Batch					
Fly Ash		11.6%	232 lb					
Lime		3.4%	68 lb					
No. 104 Crushed Limestone		85.0%	1700 lb					
Water								
Total		100.0%	2000 lb					

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.4	4.60	138.0	125.0	12.57	11-28	10,325	820
B	10.4	4.70	141.0	127.7	12.57	11-28	11,950	950
C	10.2	4.62	138.6	125.8	12.57	11-28	10,650	850
D	10.2	4.67	140.1	127.1	12.57	12-05	19,600	1559
E	10.2	4.66	139.8	126.9	12.57	12-05	18,950	1508
F	11.1	4.65	139.5	125.6	12.57	12-05	19,825	1577
G	10.8	4.66	139.8	126.2	12.57	12-19	21,860	1740
H	10.8	4.66	139.8	126.2	12.57	12-19	20,790	1650
I	10.8	4.64	139.2	125.6	12.57	12-19	21,000	1670
J	10.8	4.70	141.0	127.3	12.57	02-19		
K	10.9	4.65	139.5	125.8	12.57	02-19		
L	10.9	4.68	140.4	126.6	12.57	02-19		
M	10.9	4.66	139.8	126.1	12.57	For Durability Test		
N	10.9	4.68	140.4	126.6	12.57	For Durability Test		
O	9.6	4.63	138.9	126.7	12.57	For Durability Test		

The results of the tests are summarized in FIGS. 1-3.

As shown in FIG. 1, mixtures containing cement kiln dust vary but in each instance produce a base that is stabilized.

As shown in FIG. 2, the addition of additives or admixtures generally do not affect the strength except that a retarder tends to prevent the early development of strength as might be expected.

As shown in FIG. 3, the strength of mixtures including cement kiln dust compare favorably with a lime, fly ash, aggregate mixture. In addition, even a mixture of cement kiln dust and fly ash produces a stabilized base.

Thus, the mixtures of the present invention result in a stabilized base that is comparable in strength and required performance characteristics to cement-aggregate or lime-fly ash-aggregate stabilized bases and yet are not energy intensive. The mixtures of the present invention cost less than the predominantly used asphalt-aggregate bases. Also, the use of mixtures of the

invention releases asphalt for use in resurfacing or as a heavy industrial fuel.

FIG. 4 is a curve showing the BTU's per mile versus thickness for various road paving materials taken from Highway Research Circular titled "Fuel Usage Factors for Highway Construction," Number 158, July, 1974. It can be seen that asphalt concrete and cement type mixtures require substantial energy and only granular base or sub-base of aggregate has minimal energy requirements in hauling, spreading, compacting and finishing. Since the mixtures of the present invention utilize waste materials, namely, cement kiln dust and fly ash, the energy requirements for making a stabilized base are only in hauling, spreading, compacting and finishing. As a result, the mixtures of the present invention have minimal energy requirements and thereby obviate the energy intensive materials of prior stabilized bases.

The mixtures of the present invention utilize cement kiln dust which is a waste product that is relatively

available from cement plants and fly ash which is readily available from power plants.

I claim:

1. A mixture consisting essentially of fly ash in an amount between about 6 and 24% by dry weight, ce-
ment kiln dust in an amount between about 4 and 16%
by dry weight, and aggregate in an amount between
about 60 and 90% by dry weight, which through reac-
tions produces a hard, strong, durable mass capable of
supporting surfacing.

2. The mixture set forth in claim 1 wherein said fly
ash comprises 12.0% by dry weight, said cement kiln
dust comprises 8.0% by dry weight, and said aggregate
comprises 80% by dry weight.

3. The mixture set forth in claim 1 including a small amount of calcium chloride.

4. The method of making a stabilized load bearing material which comprises mixing cement kiln dust, fly ash, aggregate and water, said fly ash being in an
amount between about 6 and 24% by dry weight, said
cement kiln dust being in an amount between about 4
and 16% by dry weight, and said aggregate being in an
amount between about 60 and 90% by dry weight,
compacting the mixture, and permitting the mixture to

react at ambient temperatures to produce a hard, strong, durable mass.

5. A mixture consisting essentially of pozzolan in an amount between about 6 and 24% by dry weight, cement kiln dust in an amount between about 4 and 16% by dry weight, and aggregate in an amount between about 60 and 90% by dry weight, which through reactions produces a hard, strong, durable mass capable of supporting surfacing.

6. The mixture set forth in claim 5 wherein said pozzolan comprises 12.0% by dry weight, said cement kiln dust comprises 8.0% by dry weight, and said aggregate comprises 80% by dry weight.

7. The mixture set forth in claim 5 including a small amount of calcium chloride.

8. The method of making a stabilized load bearing material which comprises mixing cement kiln dust, pozzolan, aggregate and water, said pozzolan being in
an amount between about 6 and 24% by dry weight,
said cement kiln dust being in an amount between
about 4 and 16% by dry weight, and said aggregate
being in an amount between about 60 and 90% by dry
weight, compacting the mixture, and permitting the
mixture to react to ambient temperatures to produce a
hard, strong, durable mass.

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[54] MIXTURE FOR PAVEMENT BASES AND
THE LIKE

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106/120; 106/DIG. 1

[51] Int. Cl.³ C04B 7/26

[58] Field of Search 106/100, 103, 118, 120,
106/DIG. 1, 85

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[57] ABSTRACT

A mixture consisting essentially of fly ash, cement kiln
dust and aggregate which through pozzolanic reactions
produces a hard, strong, durable mass capable of sup-
porting surfacing

8 Claims, 4 Drawing Figures

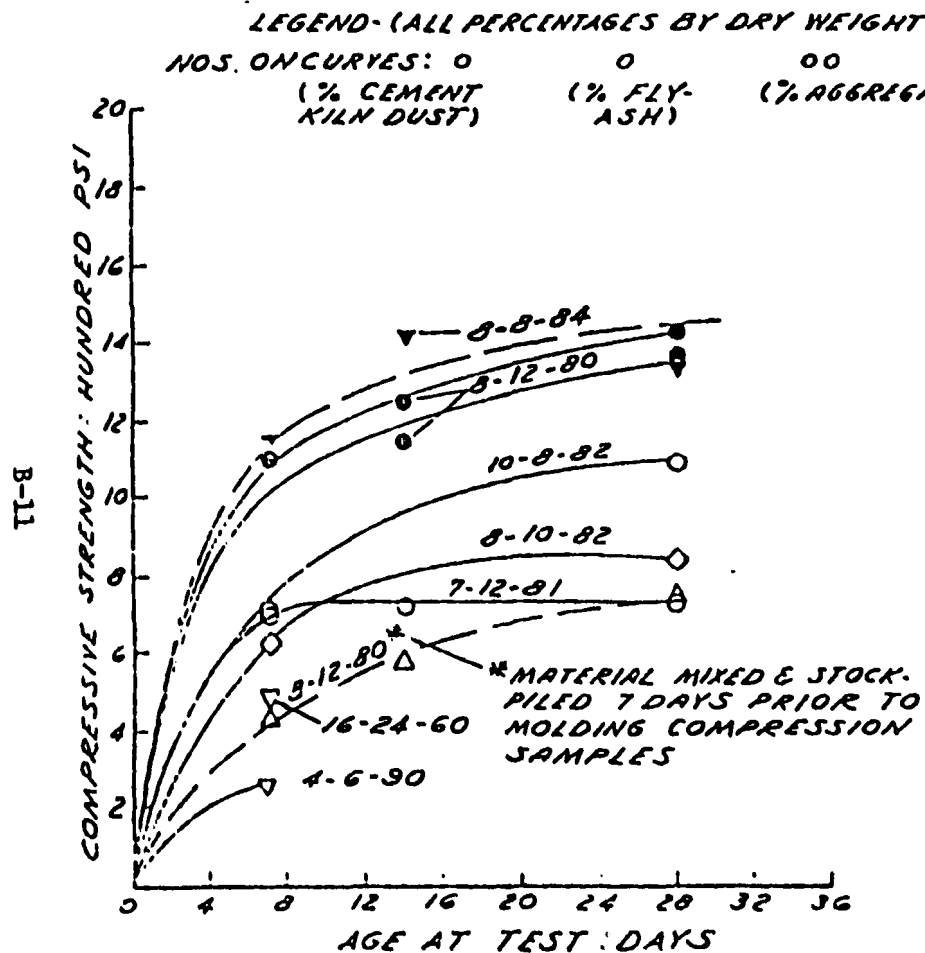
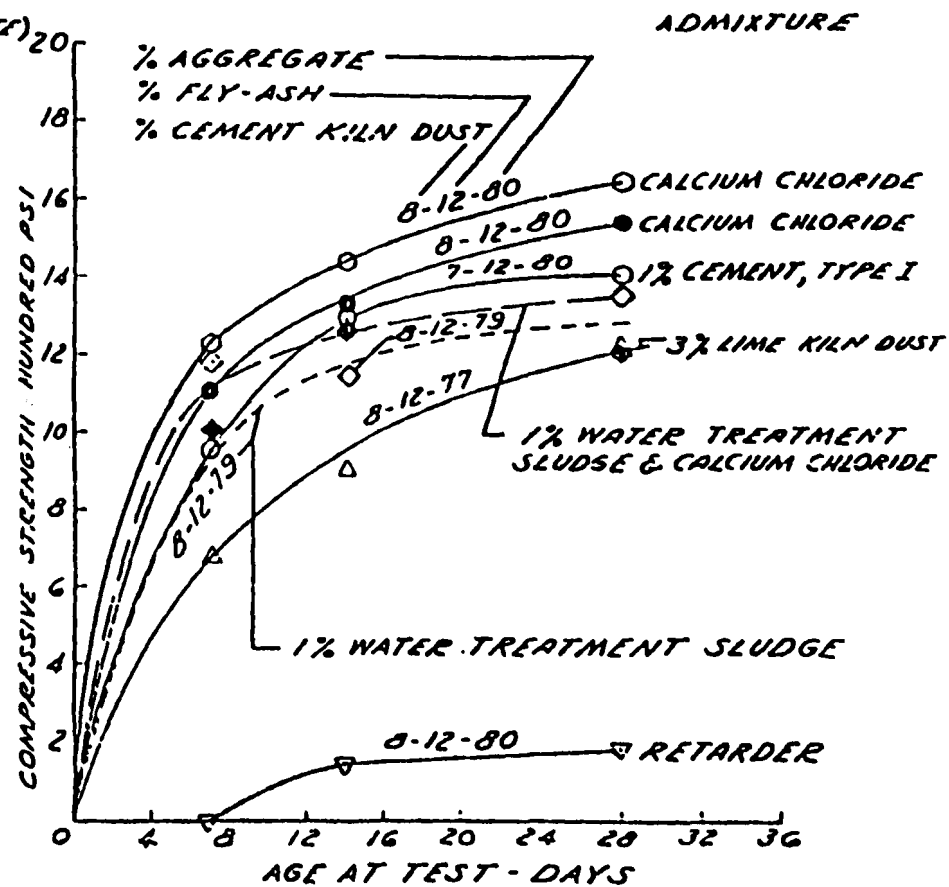
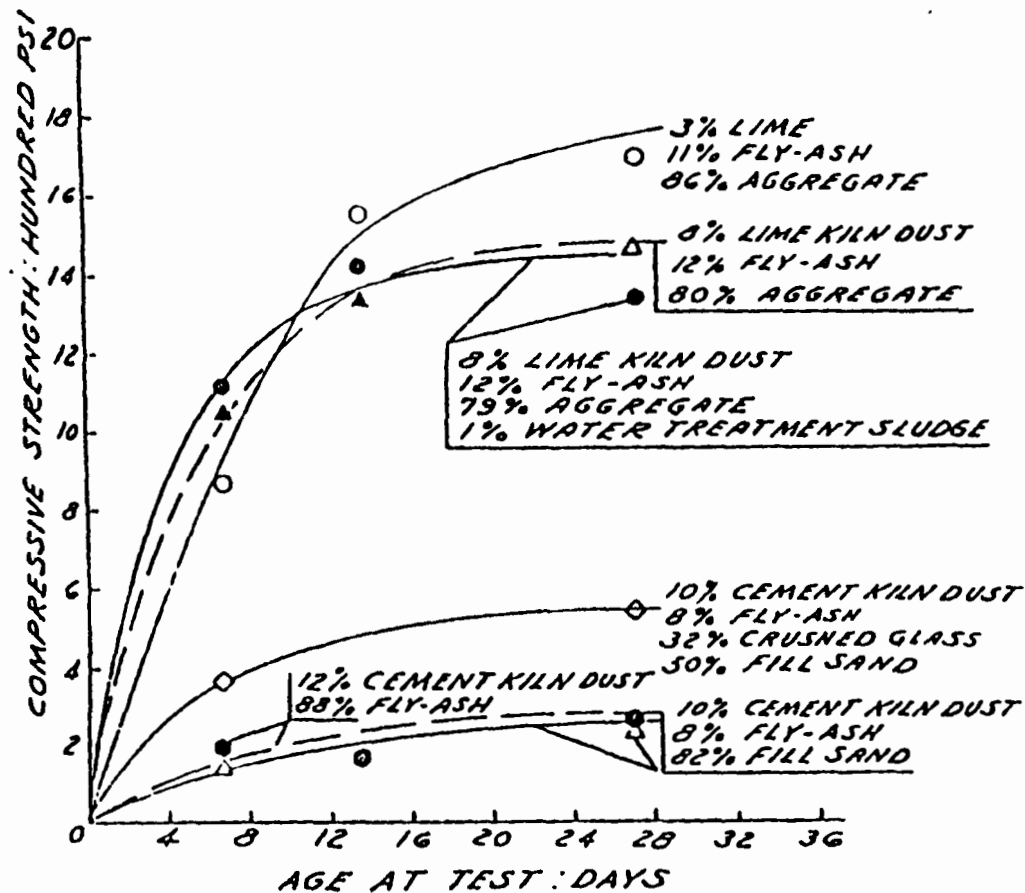
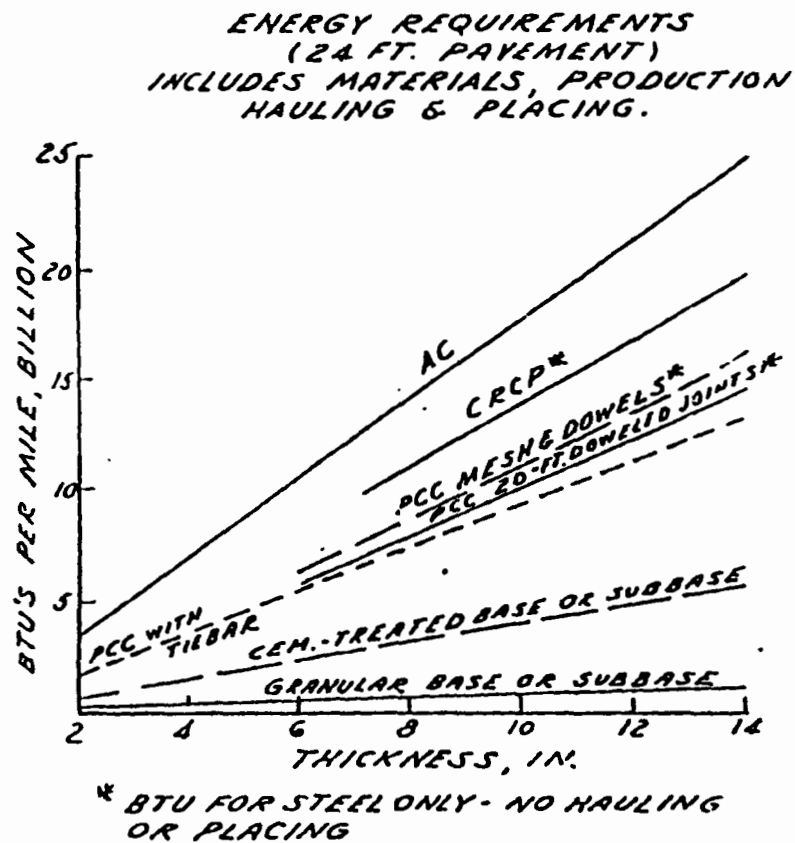
FIG. 1FIG. 2

FIG. 3FIG. 4

MIXTURE FOR PAVEMENT BASES AND THE LIKE

This invention relates to materials which are capable of supporting surfacing such as pavement bases.

BACKGROUND OF THE INVENTION

In road paving, at one time it was thought that the base for the surfacing material should comprise a granular or gravel base. However, more recently, it has been concluded that there was a considerable difference in the performance between such bases and cement-aggregate or bituminous (asphalt)-aggregate bases. As reported in the Highway Research Board Special Report 61E, titled The AASHO Road Test, Report 5, Pavement Research, publication 954 of National Academy of Sciences — National Research Council, there is a clear superiority of such treated bases over untreated bases. In recent years, treated bases have become commonly known as stabilized bases.

In subsequent work, for example, use of asphalt mixtures in all courses of pavement above the subgrade has been proposed, The Asphalt Institute, Information Series No. 146, June 1968. Asphalt stabilized bases have become the most dominant stabilized base utilized to support a flexible surfacing such as asphalt concrete. In addition, asphalt concrete has found extensive use as a resurfacing material for concrete pavement.

It has also been proposed that a lime-fly ash-aggregate stabilized base be used in road paving. Such a base consists of a mixture of proper quantities of lime, fly ash, and graded aggregate at optimum moisture content, in which the stability is greatly enhanced by the cementing action which results from complex chemical reactions between the lime and the fly ash in the presence of water.

Stabilized bases are usually employed as base courses under wearing surfaces such as hot mixed, hot laid asphaltic concrete. A wearing surface is necessary to resist the high shearing stresses which are caused by traction, but the stabilized base provides the required stability to support wheel loads.

A serious obstacle to the expanded use of stabilized bases is the high energy costs for making the materials.

For example, it is well known that the production of portland cement which is used in stabilizing bases requires substantial quantities of coal in manufacture. In fact, the United States Department of Transportation has suggested that fly ash be substituted for a portion of the portland cement utilized in concrete or cement-aggregate bases, Federal Highway Administration Notice N5080.4, Jan. 17, 1974.

The use of asphalt in asphalt-aggregate bases which is derived from petroleum processing not only utilizes petroleum which is in short supply but also requires high energy to produce them.

Similarly, the lime, fly ash and graded aggregate stabilized bases utilize lime which requires coal in production. Such bases have been used in limited geographical areas of the United States where they can compete economically because of availability of lime and fly ash.

Thus, the predominantly used stabilized bases utilize materials that are in short supply and require substantial quantities of energy to produce them. The materials may be termed energy intensive. There is a need to avoid or minimize the use of such energy intensive materials in road paving.

Accordingly, among the objects of the invention are to provide a mixture of materials for producing a stabilized base comprising a hard, strong, durable mass capable of supporting surfacing which avoids or minimizes the use of materials which are energy intensive and, moreover, utilizes materials that normally are waste materials that are readily available.

SUMMARY OF THE INVENTION

Basically, the invention comprises a mixture consisting essentially of fly ash, lime stack dust and aggregate which through pozzolanic reactions produces a hard, strong, durable mass capable of supporting surfacing.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a curve of compressive strength versus age at test for various compositions.

FIG. 2 is a curve of compressive strength versus age in a freeze-thaw test.

FIG. 3 is a curve of healed failure load versus original failure load in an autogenous healing test.

FIG. 4 is a curve of energy requirements for various pavement materials.

DESCRIPTION

In accordance with the invention, the pozzolanic load supporting composition utilizes lime stack dust.

The solid waste generated by lime manufacture is primarily lime stack dust. This dust contains a mixture of raw kiln feed, partly calcined material, and finely divided material. There is no value in returning the dust to the kiln, as it is too fine and passes directly through to the precipitator again. Up to about 15% of the raw materials processed may be collected as dust. It is usually stock-piled as a waste material which must be disposed and may be a nuisance and possibly a hazard.

Although the chemical reactions occurring in the resultant lime stack dust are not well known, typical lime stack dust has a chemical composition as follows:

CaO
MgO
S
CO₂
Loss on Ignition
Available Lime

More specifically, typical lime stack dust may have the following analyses:

Sample No.	CaO	MgO	S	CO ₂	Loss on Ignition	Available Lime	SO ₂
1	41.39	29.82	0.40	22.30	24.69	17.38	—
2	37.34	27.10	—	17.72	26.99	10.98	1.43
3	35.86	26.20	—	12.84	30.13	8.29	4.99
4	35.85	32.03	0.77	21.3	34.66	8.63	—
5	43.42	32.24	0.82	13.0	22.92	20.17	—
6	35.86	25.99	0.41	21.8	36.38	7.96	—
7	39.50	30.02	0.74	17.58	26.78	15.38	—
8	35.58	25.39	0.23	18.96	33.78	8.68	—
9	40.90	30.02	0.78	11.02	24.66	15.54	—
10	38.27	25.99	0.93	22.2	—	11.43	—
11	37.34	28.00	0.60	19.00	—	13.22	—
12	35.99	27.80	1.20	—	31.86	9.75	—
13	40.62	30.72	0.62	—	25.53	16.58	—
Mean	38.55	28.56	0.70	17.99	29.10	12.64	—
Max	43.42	32.24	1.02	22.30	36.38	20.17	—
Min	35.58	25.39	0.23	11.02	22.92	8.29	—
Range	7.84	6.85	0.79	11.28	13.46	11.88	—
Mid-Range	39.50	28.81	0.62	16.66	29.65	14.23	—

When mixtures made in accordance with the invention and mixed with water to produce a pozzolanic

reaction have been tested in accordance with the specifications given in ASTM C-593 for fly ash and other pozzolans for use with lime, it has been found that the compositions meet or exceed the specifications.

The term "fly ash" as used in connection with stabilized bases is well known and as used herein is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal or lignite, which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. Those finely pulverized ashes resulting from combustion of oil and from combustion of waste materials in a large incinerator or natural pozzolans can also be utilized in the methods described herein providing their chemical compositions are reasonably similar to pulverized coal fly ashes. The fly ash so obtained is in a finely divided state such that usually at least 70% by weight passes through a 200-mesh sieve, although incinerator ashes may be considerably coarser. Fly ash may be considered an "artificial pozzolan", as distinguished from a "natural pozzolan".

The term "aggregate" as used in connection with load supporting compositions is also well known and refers to natural or artificial inorganic materials most of which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water. Typically, aggregate may comprise limestone, sand, blast furnace slag, gravel, synthetic aggregate and other similar material.

Aggregates can comprise a wide range of types and gradations, including sands, gravels, crushed stones, and several types of slag. Aggregates should be of such gradation that, when mixed with lime stack dust, fly ash and water, the resulting mixture is mechanically stable under compaction equipment and capable of being compacted in the field to high density. The aggregate should be free from deleterious organic or chemical substances which may interfere with the desired chemical reaction between the lime stack dust, fly ash and water. Further, the aggregate should preferably consist of hard, durable particles, free from soft or disintegrated pieces.

It has been found that a preferable mixture comprises:

	Per Cent by Dry Weight
Lime Stack Dust	8%
Fly Ash	12%
Aggregate	80%
Total	100%

However, the mixture for use in road stabilizer bases may preferably vary as follows:

	Per Cent by Dry Weight
Lime Stack Dust	5 to 15%
Fly Ash	10 to 14%
Aggregate	71 to 85%

As indicated above, tests were conducted in accordance with ASTM C-593. More specifically, the test specimens were molded using a mechanical compactor, having a 10 pound hammer with an 18 inch drop. The material was placed in the molds in three equal layers,

and compacted by 25 blows per layer. The machine has a revolving turntable to evenly distribute the blows over the surface of the layer being compacted.

After molding, the samples were carefully removed from the molds, weighed, and sealed in plastic bag, labeled for identification, and placed in a constant temperature oven at 100° F to cure until tested. Two cylinders of each mix were marked for testing at 7, 14 and 28 days of curing. After removal from the oven, the samples are submerged in water for four hours, removed, and allowed to drain on a non-absorbant surface, capped, and tested within one hour after removal from the water. The capping compound used in "Hydro-Stone" a lime based, quick-hardening compound. Plate glass was used to obtain even, parallel caps on the test specimens.

Examples of various tests and compositions are as follows:

EXAMPLE I

Lime precipitator dust	5%
Fly ash	14%
Graded aggregate (1" maximum size)	77%
	100%

This group of cylinders was designated Batch 1.

Batch No.	Cylinder No.	Moisture (%)	Dry Weight (pcf)	% Max. Dry Weight	Failure Load (lbs)	Compressive Strength (psi)
1	11	7.6	128.8	99.3	4375	350
	12	7.6	129.0	99.7	7450	595
	13	7.6	128.5	99.3	7050	560
	14	7.8	128.6	99.4	"	"
	15	7.8	129.4	100.0	7800	620
	16	7.8	127.2	98.3	7875	625

*Specimen No. 4 destroyed prior to load reading

EXAMPLE II

	Batch No. 2	Batch No. 3
Lime precipitator dust	6%	5%
Fly ash	18%	12%
Graded aggregate (1" maximum size)	76%	83%
	100%	100%

This group of cylinders was designated as Batches 2 and 3.

Batch No.	Cylinder No.	Moisture (%)	Dry Weight (pcf)	% Max. Dry Weight	Failure Load (lbs)	Compressive Strength (psi)
2	21	7.5	127.3	99.7	3625	290
	22	7.5	127.8	100	8510	680
	23	7.5	126.4	98.9	12575	1000
3	31	9.5	131.2	99.9	2125	225
	32	9.5	132.1	99.1	3600	285
	33	9.5	132.4	99.3	3250	260

EXAMPLE III

Lime precipitator dust	6% by weight
Fly ash	6%
Graded aggregate (1" maximum size)	88%
	100%

This group of cylinders was designated as Batches 4 and 5.

Batch No.	Cylinder No.	Moisture (%)	Dry Weight (pcf)	% Max. Dry Weight	Failure Load (lbs)	Compressive Strength (psi)
4	41	8.8	135.9	99.9	4900	395
	42	8.8	135.1	99.3	5200	415
	43	8.8	135.4	99.6	4250	340
5	51	8.5	135.5	99.6	4800	380
	52	8.5	136.0	100	4675	370
	53	8.5	135.7	99.8	1775	300

As
range

3.5

EXAMPLE IV

Lime precipitator dust	1% by weight
Fly ash	12%
Graded aggregate (1" maximum size)	80%

In addition, freeze-thaw tests were conducted in accordance with ASTM Specifications C-593. A total of four batches were tested for twelve freeze-thaw cycles each. The data is set forth in the following table:

FREEZE-THAW TEST DATA

Cylinder No.	Aggregate No.	% Moisture	% "Lime"	% Flyash	Dry Density (pcf)	Compressive ⁽¹⁾ Strength (psi)	Original Dry Weight (lbs)	Weight Loss after 12 F-T Cycles (lbs)	% Weight Loss after 12 F-T Cycles	Compressive Strength after 12 F-T cycles (psi)	Compressive Strength ⁽²⁾ after Re-curing (psi)
81	1	8.7	8	10	132.7	688					
82	1	8.7	8	10	133.6	743					
83	1	8.7	8	10	133.3	760					
84	1	8.7	8	10	133.4		4.55	0.23	3		
85	1	8.7	8	10	133.1		4.53	0.19	4	806	
86	1	8.7	8	10	133.7		4.59	0.16	3	(3)	1180
91	2	9.2	8	10	129.6	653					
92	2	9.2	8	10	129.9	818					
93	2	9.2	8	10	129.6	703					
94	2	9.1	8	10	130.3		4.67	0.15	3		1075
95	2	9.1	8	10	130.6		4.69	0.15	3	396	
96	2	9.1	8	10	130.3		4.66	0.24	5		
101	1	8.9	8	12	129.2	768					
102	1	8.9	8	12	129.5	798					
103	1	8.9	8	12	128.9	621					
104	1	8.7	8	12	130.0		4.47	0.81	18		
105	1	8.7	8	12	129.2		4.41	0.76	17		
106	1	8.7	8	12	129.4		4.38	0.93	21		
111	2	8.7	8	12	130.0	860					
112	2	8.7	8	12	129.7	826					
113	2	8.7	8	12	129.7	999					
114	2	8.6	8	12	130.1		4.49	0.47	10		
115	2	8.6	8	12	129.8		4.58	1.36	30		
116	2	8.6	8	12	130.7		4.52	0.34	8		

⁽¹⁾Compressive strength after 7 days cure at 100° F per C593

⁽²⁾Cured 21 days at 100° F per C593, after undergoing 12 freeze-thaw cycles

⁽³⁾Specimens 83 and 86 are cured 3 days after completion of 12 freeze thaw cycles and before further testing

100%

This group of cylinders is designated Batch No. 6.

Batch No.	Cylinder No.	Moisture (%)	Dry Weight (pcf)	% Max. Dry Weight	Failure Load (lbs)	Compressive Strength (psi)
6	61	8.4	130.6	99.5	11,700	930
	62	8.4	130.0	99.1	11,925	950
	63	8.4	129.5	98.7	13,200	1050
	64	8.6	130.4	99.4	11,450	910
	65	8.6	129.8	98.9	10,800	860
	66	8.6	129.6	98.8	11,700	930
Average			129.98			940

The following table summarizes the results of the test:

Summary of Freeze-Thaw Test Results

35	Aggre- gate No.	% Flyash	Dry Density (pcf)		Mean % Weight loss After 12 Cycles	Mean Compressive Strength (psi)
			Mean	Std. Dev.		
40	1	10	133.3	0.36	4.0	698
	2	10	130.1	0.42	3.7	725
	1	12	129.4	0.37	18.7	729
	2	12	130.0	0.38	16.0	895

EXAMPLE V

Lime precipitator dust	1% by weight
Fly ash	10%
Graded aggregate (1" maximum size)	82%
	100%

This group of cylinders is designated Batch No. 7.

Batch No.	Cylinder No.	Moisture (%)	Dry Weight (pcf)	% Max. Dry Weight	Failure Load (lbs)	Compressive Strength (psi)
7	71	8.7	129.9	99.7	7900	630
	72	8.7	129.7	99.5	9150	730
	73	8.7	128.9	98.9	9500	755
	74	8.5	130.2	99.9	7300	575
	75	8.5	129.1	99.1	8750	700
	76	8.5	129.7	99.5	8000	640
Average			129.6			670

The results of the tests are summarized in FIG. 1 and the following table:

TABLE OF INGREDIENTS

Ingredient	% By Weight							
	1	2	3	4	5	6	7	8
Aggregate	16	16	16	16	11	10	79	69
Fly Ash	7.6	6.0	11.0	11.0	11.0	11.0	11.0	11.0
Precipitator Dust	6.4	8.0	—	—	8.0	9.0	10.0	20.0
Hydrated Lime	—	—	3.0	3.0	—	—	—	—

In addition, certain cylinders in Batch No. 6 containing 8% lime precipitator dust, 12% fly ash and 80% aggregate were tested for autogenous healing. Cylinder No. 66 was too badly damaged from the original compression test to be "healed", but the remaining five were utilized.

We are not aware of a standard test for autogenous healing. The five cylinders in question were soaked in water for 8 days and then over cured in closed cans for 7 days at 100° F. After completion of over curing, the five cylinders were inadvertently allowed to remain in air at room temperature for 4 more days before the compression tests were run.

All the cylinders were, of course, cracked from the original compression test and slightly deformed. But nothing was done to the cylinders other than the operations described in the previous paragraph. The original caps were left in place and re-used.

Results were as follows:

Cylinder No.	Failure Load (lbs)		Compressive Strength (psi)		Rank		"Healed" Original
	Original	"Healed"	Original	"Healed"	Original	"Healed"	
61	11,700	12,800	930	1013	3	4	1.09
62	11,925	13,850	950	1100	2	2	1.16
63	13,200	15,300	1050	1210	1	1	1.15

-continued

Cylinder No	Failure Load (lbs)		Compressive Strength (psi)		Rank		"Healed"
	Original	"Healed"	Original	"Healed"	Original	"Healed"	Original
64	11,450	13,250	910	1050	4	3	1.15
65	10,800	11,125	860	885	5	5	1.03
Average			940	1050			1.12

The results of these tests are set forth in FIG. 3.

Thus, the mixtures of the present invention result in a stabilized base that is comparable in strength and required performance characteristics to cement-aggregate or lime-fly ash-aggregate stabilized bases and yet are not energy intensive. The mixtures of the present invention cost less than the predominantly used asphalt-aggregate bases. Also, the use of mixtures of the invention releases asphalt for use in resurfacing or as a heavy industrial fuel.

FIG. 4 is a curve showing the BTU's per mile versus thickness for various road paving materials taken from Highway Research Circular titled "Fuel Usage Factors for Highway Construction", Number 158, July, 1974. It can be seen that asphalt concrete and cement type mixtures require substantial energy and only granular base or sub-base of aggregate has minimal energy requirements in hauling, spreading, compacting and finishing. Since the mixture of the present invention utilize waste materials, namely, lime stack dust and fly ash, the energy requirements for making a stabilized base are only in hauling, spreading, compacting and finishing. As a result, the mixtures of the present invention have minimal energy requirements and thereby obviate the energy intensive materials of prior stabilized bases.

I claim:

1. A mixture consisting essentially of fly ash, lime stack dust and aggregate which through pozzolanic reactions produces hard, strong, durable mass capable of supporting surfacing.

2. The mixture set forth in claim 1 wherein the aggregate comprises the major constituent.

3. The mixture set forth in claim 1 wherein said fly ash is in an amount between about 10% and 14% by dry weight, said lime stack dust is in an amount between about 5% and 15% by dry weight, and said aggregate is in an amount between about 71% and 85% by dry weight.

4. The mixture set forth in claim 1 wherein said fly ash comprises 12% by dry weight, said lime stack dust comprises 8% by dry weight, and said aggregate comprises 80% by dry weight.

5. The mixture set forth in claim 1 including a small amount of calcium chloride.

6. The method of making a stabilized load bearing material which comprises mixing lime stack dust, fly ash, aggregate and water, compacting the mixture, and permitting the mixture to react to ambient temperatures to produce a hard, strong, durable mass.

7. A mixture consisting essentially of pozzolan, lime stack dust and aggregate which through pozzolanic reactions produces a hard, strong, durable mass capable of supporting surfacing.

8. The method of making a stabilized load bearing material which comprises mixing lime stack dust, fly ash, aggregate and water, said fly ash being in an amount between about 10% and 14% by dry weight, said lime stack dust being in an amount between about 5% and 15% by dry weight, compacting the mixture, and permitting the mixture to react to ambient temperatures to produce a hard, strong, durable mass.

• • • • •

[54] MIXTURE FOR PAVEMENT BASES AND
TIE LIKE

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[21] Appl. No.: 685,430

[22] Filed: May 11, 1976

[51] Int. Cl.¹ C04B 1/00

[52] U.S. Cl. 106/118; 106/120;
106/DIG. 1

[58] Field of Search 106/118, 120, DIG. 1

[56]

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[57]

ABSTRACT

A mixture consisting essentially of fly ash, lime stack
dust and aggregate which through pozzolanic reactions
produces a hard, strong, durable mass capable of sup-
porting surfacing.

8 Claims, 4 Drawing Figures

FIG. 1

COMPRESSIVE STRENGTH
VS AGE AT TEST

MIXTURE CONTAINING LIME
PRECIPITATOR DUST.

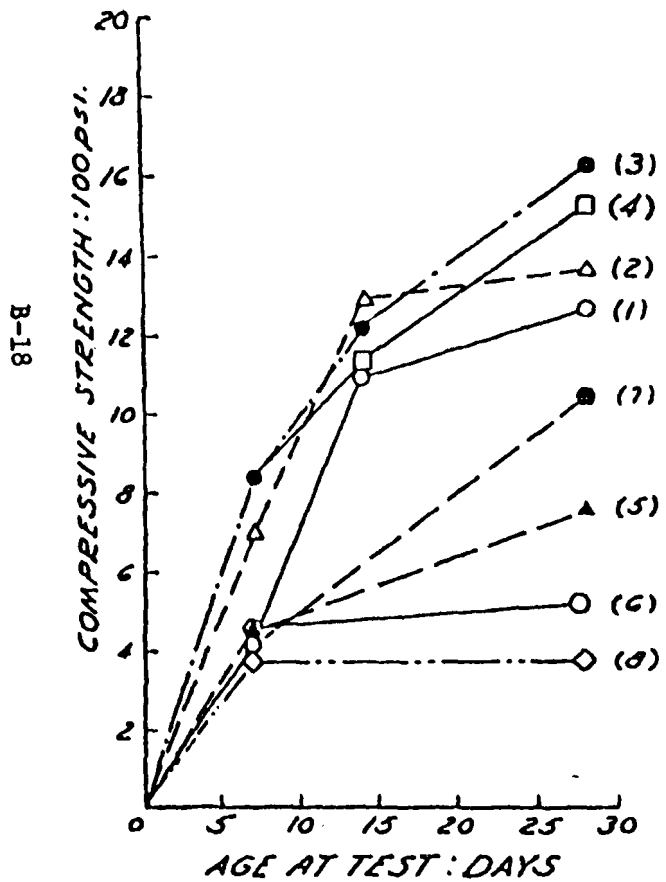
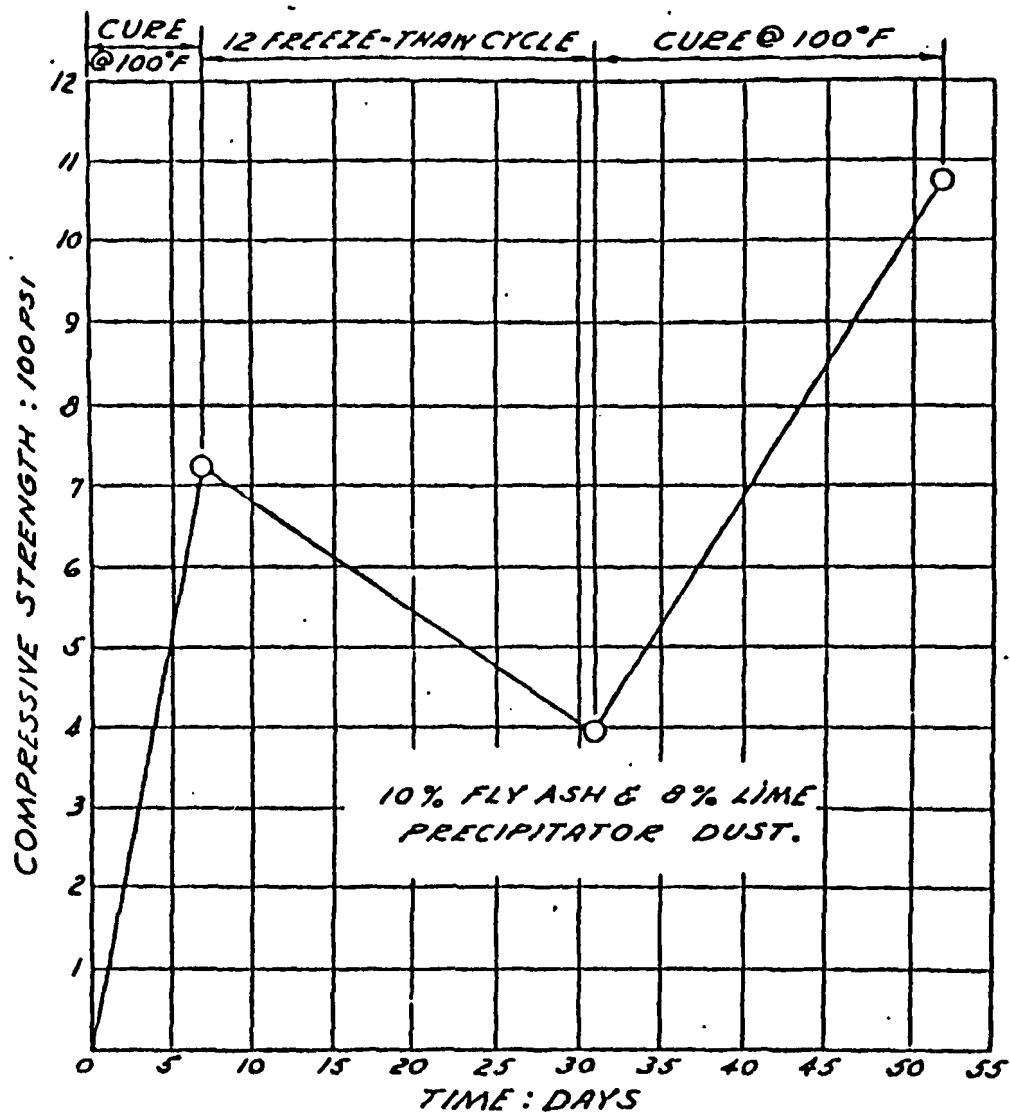
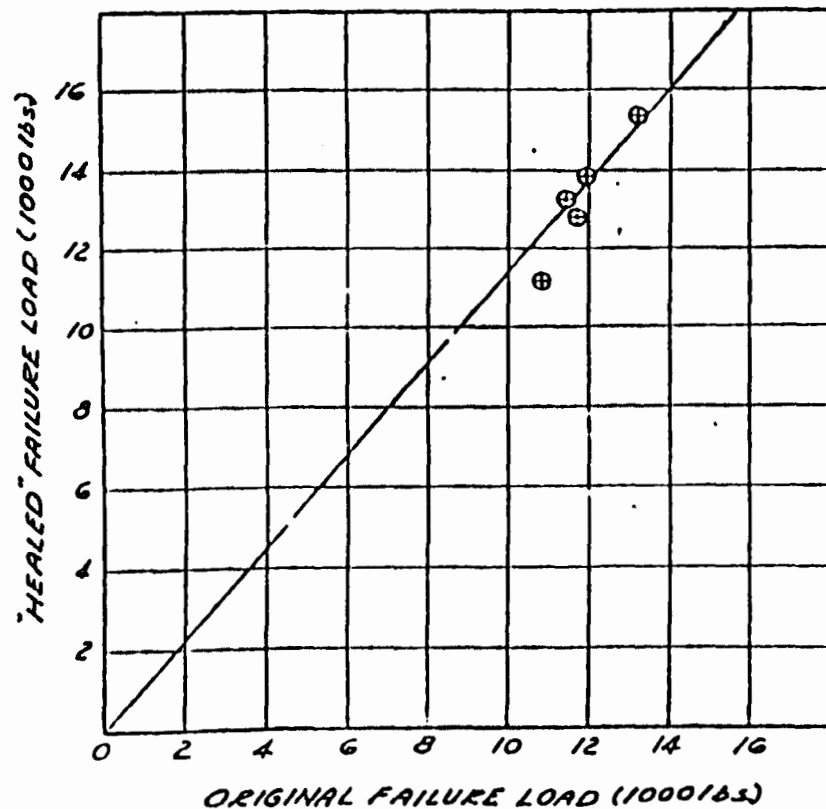
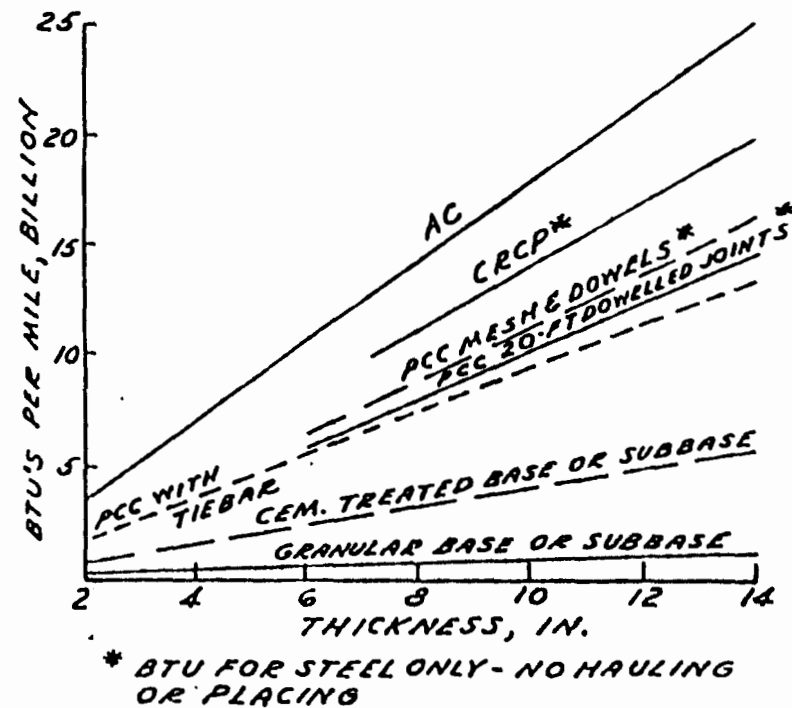
FIG. 2

FIG. 3

AUTOGENOUS HEALING TEST
BATCH NO. 6 WITH LIME PRECIPITATOR DUST

FIG. 4

ENERGY REQUIREMENTS
(24 FT. PAVEMENT)
INCLUDES MATERIALS, PRODUCTION
HAULING & PLACING.



STABILIZED MIXTURE

This application is a division of application Ser. No. 654,211, filed Feb. 2, 1976, now U.S. Pat. No. 4,018,617.

This invention relates to materials which are capable of supporting surfacing such as pavement bases.

BACKGROUND OF THE INVENTION

In road paving, at one time it was thought that the base for the surfacing material should comprise a granular or gravel base. However, more recently, it has been concluded that there was a considerable difference in the performance between such bases and cement-aggregate or bituminous (asphalt)-aggregate bases. As reported in the Highway Research Board Special Report 61E, titled The AASHO Road Test, Report 5, Pavement Research, publication 954 of National Academy of Sciences - National Research Council, there is a clear superiority of such treated bases over untreated bases. In recent years, treated bases have become commonly known as stabilized bases.

In subsequent work, for example, use of asphalt mixtures in all courses of pavement above the subgrade has been proposed, The Asphalt Institute, Information Series No. 146, June 1968. Asphalt stabilized bases have become the most dominant stabilized base utilized to support a flexible surfacing such as asphalt concrete. In addition, asphalt concrete has found extensive use as a resurfacing material for concrete pavement.

It has also been proposed that a lime-fly ash-aggregate stabilized base be used in road paving. Such a base consists of a mixture of proper quantities of lime, fly ash, and graded aggregate at optimum moisture content, in which the stability is greatly enhanced by the cementing action which results from complex chemical reactions between the lime and the fly ash in the presence of water.

Stabilized bases are usually employed as base courses under wearing surfaces such as hot mixed, hot laid asphaltic concrete. A wearing surface is necessary to resist the high shearing stresses which are caused by traction, but the stabilized base provides the required stability to support wheel loads.

A serious obstacle to the expanded use of stabilized bases is the high energy costs for making the materials.

For example, it is well known that the production of portland cement which is used in stabilizing bases requires substantial quantities of coal in manufacture. In fact, the United States Department of Transportation has suggested that fly ash be substituted for a portion of the portland cement utilized in concrete or cement-aggregate bases, Federal Highway Administration Notice N5080.4, Jan. 17, 1974.

The use of asphalt in asphalt-aggregate bases which is derived from petroleum processing not only utilizes petroleum which is in short supply but also requires high energy to produce them.

Similarly, the lime, fly ash and graded aggregate stabilized bases utilize lime which requires coal in pro-

duction. Such bases have been used in limited geographical areas of the United States where they can compete economically because of availability of lime and fly ash.

Thus, the predominantly used stabilized bases utilize materials that are in short supply and require substantial quantities of energy to produce them. The materials may be termed energy intensive. There is a need to avoid or minimize the use of such energy intensive materials in road paving.

Accordingly, among the objects of the invention are to provide a mixture of materials for producing a stabilized base comprising a hard, strong, durable mass capable of supporting surfacing which avoids or minimizes the use of materials which are energy intensive and, moreover, utilizes materials that normally are waste materials that are readily available.

SUMMARY OF THE INVENTION

In accordance with the invention, the mixture consists essentially of fly ash and cement kiln dust which reacts at ambient temperature with water to produce a durable mass.

DESCRIPTION OF THE DRAWINGS

FIGS. 1-3 are curves of compressive strength versus age at test for various compositions.

FIG. 4 is curves of energy requirements for various pavement materials.

DESCRIPTION

In accordance with the invention, the pozzolanic load supporting composition utilizes cement kiln dust.

The solid waste generated by cement manufacture is primarily kiln dust. This dust contains a mixture of raw kiln feed, partly calcined material, finely divided cement klinker and alkali sulfates (usually sulfates). There is economic value in returning the dust to the kiln, but when the alkali content of the returned dust is too high for the product klinker to meet specifications, the dust must be discarded. Up to about 15% of the raw materials processed may be collected as dust and of this about half may be low enough in alkalis to be returned to the kiln. The rest is usually stockpiled as a waste material which must be disposed and may be a nuisance and possibly a hazard.

Although the chemical reactions occurring in the resultant cement kiln dust are not well known, typical cement kiln dust has a chemical analysis as follows:

SiO₂
Al₂O₃
Fe₂O₃
CaO
MgO
SO₃
Na₂O
K₂O
Loss Ignition

More specifically, typical cement kiln dust may have the following analyses:

Ingredient	Source A	Source B	Source C	Source D	Source E	Source F	Source G	Source H	Source I	Mid-Range
SiO ₂	28.5%	6.0%	22.4%	11.2%	13.0%	23.5%	14.8%	14.6%	14.7%	17.2%
Al ₂ O ₃	9.6	3.4	4.71	1.2	4.0	3.77	3.4	3.4	3.7	6.4
Fe ₂ O ₃	5.9	0.8	1.77	1.4	5.0	1.71	2.2	2.2	3.0	3.4
CaO	50.1	16.0	65.0	44.8	47.2	61.3	47.3	46.3	46.5	40.5
MgO	3.4	0.8	2.60	2.1	1.2	4.83	2.1	2.0	2.0	2.8
SO ₃	26.3	0.7	1.12	2.4	13.6	7.48	4.8	5.0	8.2	13.5

-continued-

Ingredient	Source A	Source B	Source C	Source D	Source E	Source F	Source G	Source H	Source I	Multi-Range
Na ₂ O	1.18	0.08	0.24	0.2	0.45	0.24	0.9	0.9	0.8	1.6
K ₂ O	26.23	1.08	1.3	4.2	2.9	1.83	4.1	3.1	3.0	13.7
Loss on Ignition	32.0%	7.7%	2.50%	26.6%	12.9%	1.84%	21.1%	21.4%	18.2%	17.2%

Ingredient	RANGE		Average %
	Low %	High %	
SiO ₂	6.0	28.3	16.3
Al ₂ O ₃	3.2	9.6	4.35
Fe ₂ O ₃	0.8	3.9	2.66
CaO	16.0	65.0	47.6
MgO	0.8	4.83	2.34
SO ₃	0.7	26.3	7.07
Na ₂ O	0.08	1.18	0.78
K ₂ O	1.08	26.23	5.52
Loss on Ignition	2.50	32.0	16.0

When mixtures made in accordance with the invention and mixed with water to produce a pozzolanic reaction have been tested in accordance with the specifications given in ASTM C-593 for fly ash and other pozzolans for use with lime, it has been found that the compositions meet or exceed the specifications.

The term "fly ash" as used in connection with stabilized bases is well known and as used herein is intended to indicate the finely divided ash residue produced by the combustion of pulverized coal or lignite, which ash is carried off with the gases exhausted from the furnace in which the coal is burned and which is collected from these gases usually by means of suitable precipitation apparatus such as electrical precipitators. Those finely pulverized ashes resulting from combustion of oil and from combustion of waste materials in a large incinerator or natural pozzolans can also be utilized in the methods described herein providing their chemical compositions are reasonably similar to pulverized coal fly ashes. The fly ash so obtained is in a finely divided state such that usually at least 70% by weight passes through a 200-mesh sieve, although incinerator ashes may be considerably coarser. Fly ash may be considered an "artificial pozzolan", as distinguished from a "natural pozzolan".

The term "aggregate" as used in connection with load supporting compositions is also well known and refers to natural or artificial inorganic materials most of which are substantially chemically inert with respect to fly ash and lime, and substantially insoluble in water. Typically, aggregate may comprise limestone, sand, blast furnace slag, gravel, synthetic aggregate and other similar material.

Aggregates can comprise a wide range of types and gradations, including sands, gravels, crushed stones, and several types of slag. Aggregates should be of such gradation that, when mixed with cement kiln dust, fly ash and water, the resulting mixture is mechanically

stable under compaction equipment and capable of being compacted in the field to high density. The aggregate should be free from deleterious organic or chemical substances which may interfere with the desired chemical reaction between the cement kiln dust, fly ash and water. Further, the aggregate should preferably consist of hard, durable particles, free from soft or disintegrated pieces.

It has been found that a preferable mixture comprises:

	Per Cent by Dry Weight
Cement Kiln Dust	8.0%
Fly Ash	12.0%
Aggregate	80.0%
Total	100.0%

However, the mixture for use in road stabilizer bases may preferably vary as follows:

	Per Cent By Dry Weight
Cement Kiln Dust	4 - 16%
Fly Ash	6 - 24%
Aggregate	60 - 97%

As indicated above, tests were conducted in accordance with ASTM C-593. More specifically, the test specimens were molded using a mechanical compactor, having a 10 pound hammer with an 18 inch drop. The material was placed in the molds in three equal layers, and compacted by 25 blows per layer. The machine has a revolving turntable to evenly distribute the blows over the surface of the layer being compacted.

After molding, the samples were carefully removed from the molds, weighed, and sealed in plastic bag, labeled for identification, and placed in a constant temperature oven at 100° F to cure until tested. Two cylinders of each mix were marked for testing at 7, 14 and 28 days of curing. After removal from the oven, the samples are submerged in water for four hours, removed, and allowed to drain on a non-absorbant surface, capped, and tested within one hour after removal from the water. The capping compound used is "Hydro-Stone" a lime based, quick-hardening compound. Plate glass was used to obtain even, parallel caps on the test specimens.

Examples of various tests and compositions are as follows:

EXAMPLE I

		Percent	Weight of Batch
Cement Kiln Dust		8.0%	2.40
Fly Ash		12.0%	3.60
Limestone		80.0%	24.00
Total		100.0%	30.00

Specimen No.	Percent Water	Wt. As Moulded (lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. in.)	Date Tested	Mach. Load	P.S.I.
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A	10.8	4.73	141.9	128.1	12.57	10-16	13,140	1050
B	10.8	4.72	141.6	127.8	12.57	10-16	14,370	1140
C	10.8	4.73	141.9	128.1	12.57	10-23	15,780	1260
D	10.8	4.73	141.9	128.1	12.57	10-23	15,530	1240
E	10.8	4.73	141.9	128.1	12.57	11-06	17,800	1420
F	10.8	4.73	141.9	128.1	12.57	11-06	17,740	1420

Remarks: Slight bleeding at bottom of mold.

EXAMPLE II

							Weight of Batch	
							Percent	
Cement Kila Dust							8.0%	2.4#
Fly Ash							12.0%	3.6#
Limestone							80.0%	24.0#
Retarder							—	0.96 oz
Total							100.0%	30.0#
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.1	4.73	141.9	128.9	12.57	10-16	—	—
B	10.1	4.73	141.9	128.9	12.57	10-16	—	—
C	10.2	4.73	141.9	128.8	12.57	10-23	1,650	150
D	10.2	4.73	141.9	128.8	12.57	10-23	1,930	150
E	10.3	4.73	141.9	128.6	12.57	11-06	2,300	180
F	10.3	4.73	141.9	128.6	12.57	11-06	2,100	170

Remarks:

Slight bleeding.

Samples J-A and J-B fell apart during the four (4) hour soaking. There was no intact sample to subject to compression test. Samples C, D, E, and F were not subjected to the four (4) hour soaking, prior to testing.

EXAMPLE III

			Percent		Weight of Batch	
Cement Kila Dust			8.0%		2.4#	
Fly Ash			12.0%		3.6#	
Limestone			80.0%		24.0#	
Calcium Chloride Solution			—		(0.24#)	
Total			100.0%		30.0#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.4	4.77	143.1	129.6	12.57	10-16	15,160	1210
B	10.4	4.77	143.1	129.6	12.57	10-16	15,750	1250
C	10.0	4.73	141.9	129.0	12.57	10-23	17,250	1370
D	9.9	4.73	141.9	129.1	12.57	10-23	18,950	1510
E	9.8	4.73	141.9	129.2	12.57	11-06	20,600	1640
F	9.7	4.72	141.6	129.1	12.57	11-06	20,700	1650

Remarks: Slight bleeding.

EXAMPLE IV

						Weight of Batch		
						Percent		
Cement Kila Dust						8.0%	2.4#	
Stack Dust						3.0%	0.9#	
Fly Ash						12.0%	3.6#	
Limestone						77.0%	23.1#	
Total						100.0%	30.0#	
Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	8.3	4.53	135.9	125.3	12.57	10-17	8,200	652
B	8.3	4.54	136.2	125.5	12.57	10-17	8,900	708
C	8.7	4.58	137.4	126.4	12.57	10-24	10,950	871
D	8.8	4.56	136.8	125.7	12.57	10-24	11,775	937
E	9.0	4.58	137.4	126.1	12.57	11-07	16,050	1280
F	9.0	4.56	136.8	125.5	12.57	11-07	14,850	1180

Remarks: No bleeding.

EXAMPLE V

			Percent		Weight of Batch				
Cement Kila Dust			12.0%		3.6#				
Fly Ash			88.0%		26.4#				
Total			100.0%		30.0#				

-continued

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	9.5	2.87	86.1	78.6	12.57	10-17	2,350	187
B	9.7	2.90	87.0	79.3	12.57	10-17	2,441	183
C	9.7	2.90	87.0	79.3	12.57	10-24	2,075	165
D	9.7	2.90	87.0	79.3	12.57	10-24	1,900	151
E	9.7	2.90	87.0	79.3	12.57	11-07	3,040	240
F	10.0	2.96	88.8	80.7	12.57	11-07	3,230	260

Remarks.— Had difficulty in reaching the desired moisture content because of the dust's extremely dry condition. Extremely "fluffy" material.

EXAMPLE VI

	Percent	Weight of Batch
Cement Kiln Dust	8.0%	2.4#
Fly Ash	8.0%	2.4#
Limestone	79.0%	23.7#
Limestone Fines	5.0%	1.5#
Total	100.0%	30.0#
Water added: 1158 + 136 = 1294		

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	9.5	4.35	145.5	132.5	12.57	10-20	13,900	1110
B	9.6	4.81	144.3	131.4	12.57	10-20	15,000	1190
C	9.3	4.79	143.7	130.9	12.57	10-27	17,350	1380
D	9.9	4.81	144.3	131.3	12.57	10-27	18,200	1448
E	9.9	4.81	144.3	131.3	12.57	11-10	17,050	1356
F	9.9	4.78	143.4	130.5	12.57	11-10	16,600	1321

Remarks: Good compactability. Material was relatively easy to work with.

EXAMPLE VII

	Percent	Weight of Batch
Fly Ash	8.0%	2.40#
Kiln Dust	10.0%	3.00#
No. 304 Limestone	82.0%	24.60#
(Screened over 1" screen)		
Total	100.0%	30.00#

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	11.5	4.73	141.9	127.3	12.57	4-01	9150	745
2	11.1	4.71	141.3	127.2	12.57	4-01	8610	685
3	11.1	4.73	141.9	127.7	12.57	4-01	9290	740
4	11.1	4.74	142.2	128.1	12.57	4-22	14050	1120
5	11.0	4.75	142.5	128.4	12.57	4-22	13500	1075
6	10.7	4.74	142.2	128.5	12.57	4-22	13620	1085

- A. Slight bleeding at bottom of mold during compaction.
 B. Material appeared deficient in limestone fines (~ #4 material).
 C. Some free moisture noted, giving slight "gluey" appearance.
 D. Samples slumped, following extraction from molds.

EXAMPLE VIII

	Percent	Weight of Batch
Fly Ash	10.0%	3.00#
Kiln Dust	8.0%	2.40#
No. 304 Limestone	82.0%	24.60#
(Screened over 1" screen)		
Total	100.0%	30.00#

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.3	4.72	141.6	129.6	12.57	4-01	8060	640
2	9.4	4.71	141.3	129.2	12.57	4-01	7750	615
3	9.4	4.71	141.3	129.2	12.57	4-01	8000	635
4	9.5	4.69	140.7	128.5	12.57	4-22	9730	775
5	9.6	4.68	140.4	128.1	12.57	4-22	10450	830
6	9.3	4.69	140.7	128.5	12.57	4-22	11490	915

- A. Samples retained shape following extraction from molds
 B. No free water noticed bleeding during compaction

EXAMPLE IX

			Percent		Weight of Batch	
Fly Ash			8.0%		2.40#	
Kila Dust			10.0%		3.01#	
Fill Sand			82.0%		24.60#	
Total			100.0%		30.00#	

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.8	4.09	122.7	111.7	12.57	3-31	1800	145
2	10.0	4.12	123.6	112.4	12.57	3-31	1700	135
3	9.9	4.10	123.0	111.9	12.57	3-31	1690	135
4	9.9	4.11	123.3	112.2	12.57	4-21	2810	225
5	10.0	4.10	123.0	111.8	12.57	4-21	2180	230
6	9.8	4.09	122.7	111.7	12.57	4-21	2670	210

A. No bleeding of sample during compaction.

B. Material stayed in a ball when pacted by hand.

C. Slight bulging noticed.

D. Easily compacted.

EXAMPLE X

			Percent		Weight of Batch	
Fly Ash			8.0%		2.40#	
Kila Dust			10.0%		3.00#	
Glass (Crushed to approx. 1" size)			32.0%		9.60#	
Fill Sand			50.0%		15.00#	
Total			100.0%		30.00#	

Cyl. No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
1	9.4	4.50	133.0	123.4	12.57	4-02	4390	350
2	9.4	4.50	133.0	123.4	12.57	4-02	4590	365
3	9.3	4.51	133.3	123.8	12.57	4-02	4200	335
4	9.2	4.52	133.6	124.2	12.57	4-23	6750	535
5	9.1	4.51	133.3	124.0	12.57	4-23	6870	545
6	9.1	4.47	134.1	122.9	12.57	4-23	6280	500

A. Material originally mixed to 10.3% moisture, looked wet, probably because non-absorbency of glass.

B. As dried the mix out to approximately 9.4% moisture, did not ball at this moisture content.

C. Surprisingly good cohesion of mix, even with the smooth faces of glass particles.

D. Strength of cylinders higher than expected, thought the mix would slip off the smooth glass faces, when put under compression.

EXAMPLE XI

			Percent		Weight of Batch	
Cement Kila Dust			16.0		3.2#	
Fly Ash			24.0		4.8#	
No. 304 Crushed Limestone			60.0		12.0#	
Total			100.0		20.0#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	16.6	4.50	133.0	115.8	12.57	12/22	3890	470
B	15.1	4.46	133.8	116.2	12.57	12/22	4000	480
C	15.0	4.46	133.8	116.3	12.57	12/22	4150	490

EXAMPLE XII

			Percent		Weight of Batch	
Cement Kila Dust			4.0		0.8#	
Fly Ash			6.0		1.2#	
No. 304 Crushed Limestone			90.0		18.0#	
Total			100.0		20.0#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	11.1	4.94	148.2	133.4	12.57	12/22	2950	230
B	11.2	4.93	147.9	133.0	12.57	12/22	3570	280
C	11.2	4.93	147.9	133.0	12.57	12/22	3250	260

EXAMPLE XIII

		Percent		Weight of Batch	
Cement Kiln Dust		6.9%		140#	
Fly Ash		11.1%		240#	
Limestone Screenings		39.4%		877#	
No. 57 Crushed Limestone		39.4%		800#	
Water		2.5%		50#	
Total		100.0%		2050#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	5.6	4.49	134.7	127.6	12.57	11-22	8,950	712
B	5.1	4.51	135.3	128.7	12.57	11-22	8,225	654
C	5.3	4.51	135.3	128.2	12.57	11-22	9,050	720
D	5.4	4.50	135.0	128.1	12.57	11-29	9,610	760
E	5.3	4.49	134.7	127.7	12.57	11-29	8,080	640
F	4.9	4.50	135.0	128.7	12.57	11-29	9,630	770
G	5.1	4.46	133.8	127.3	12.57	12-13	8,820	700
H	5.3	4.51	135.3	128.5	12.57	12-13	9,380	750
I	5.4	4.50	135.0	128.1	12.57	12-13	9,420	750
J	5.3	4.46	133.8	127.1	12.57	02-03		
K	5.1	4.51	135.3	128.7	12.57	02-03		
L	4.9	4.48	134.4	128.1	12.57	02-03		
M	5.0	4.54	136.2	129.7	12.57	For Durability Test		
N	4.9	4.54	136.2	129.8	12.57	For Durability Test		
O	4.8	4.47	134.1	128.0	12.57	For Durability Test		

EXAMPLE XIV

		Percent		Weight of Batch	
Cement Type I		1.0%		20#	
Cement Kiln Dust		6.8%		140#	
Fly Ash		11.7%		240#	
Limestone Screenings		39.0%		800#	
No. 57 Crushed Limestone		39.0%		800#	
Water		2.5%		50#	
Total		100.0%		2050#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	5.4	4.58	137.4	130.4	12.57	11-21	10,030	800
B	5.4	4.58	137.4	130.4	12.57	11-21	11,780	940
C	5.4	4.58	137.4	130.4	12.57	11-21	14,120	1120
D	5.3	4.58	137.4	130.5	12.57	11-28	15,500	1230
E	5.0	4.58	137.4	130.9	12.57	11-28	18,560	1470
F	5.8	4.46	135.8	126.5	12.57	11-29	14,910	1190
G	5.8	4.46	135.8	126.5	12.57	12-13	17,940	1420
H	5.7	4.46	135.8	126.6	12.57	12-13	20,010	1590
I	5.7	4.46	135.8	126.6	12.57	12-13	14,980	1190
J	5.7	4.46	135.8	126.6	12.57	02-13		
K	5.6	4.46	135.8	126.7	12.57	02-13		
L	5.6	4.46	135.8	126.7	12.57	02-13		
M	5.4	4.49	134.7	127.8	12.57	For Durability Test		
N	5.4	4.49	134.7	127.8	12.57	For Durability Test		
O	5.4	4.49	134.7	127.8	12.57	For Durability Test		

EXAMPLE XV

		Percent		Weight of Batch	
Cement Kiln Dust		7.8%		160#	
Fly Ash		11.7%		240#	
Limestone Screenings		39.0%		800#	
No. 57 Crushed Limestone		39.0%		800#	
Water		2.5%		50#	
Total		100.0%		2050#	

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	8.1	4.24	127.2	117.7	12.57	11-22	4,650	370*
B	7.9	4.24	127.2	117.9	12.57	11-22	5,700	450
C	8.3	4.29	128.7	118.8	12.57	11-22	6,030	
D	7.8	4.25	127.5	118.3	12.57	11-29	7,200	570
E	7.7	4.24	127.2	118.1	12.57	11-29	6,850	540
F	7.6	4.26	127.8	118.8	12.57	11-29	8,080	640
G	7.6	4.30	129.0	119.9	12.57	12-13	10,000	800
H	7.6	4.27	128.1	119.0	12.57	12-13	9,500	760
I	7.6	4.27	128.1	119.0	12.57	12-13	8,950	710
J	7.5	4.27	128.1	119.2	12.57	02-13		
K	7.5	4.28	128.4	119.7	12.57	02-13		
L	7.2	4.26	127.8	119.2	12.57	02-13		
M	7.2	4.27	128.1	119.5	12.57	For Durability Test		

-continued-

N	7.1	4.24	127.2	118.8	12.57	For Durability Test
O	7.3	4.25	127.5	118.9	12.57	For Durability Test

*Sample fractured horizontally during capping

Remarks:

This product was produced on November 6, and sampled on November 13. Materials are the same as in Example XIII. This example is a check to see if the age of the product, before use, has any effect on the strength results.

EXAMPLE XVI

	Percent	Weight of Batch
Fly Ash	11.8%	232#
Lime	3.4%	68#
No. 304 Crushed Limestone	85.0%	1700#
Water	—	—
Total	100.0%	2000#

Specimen No.	Percent Water	Wt. As Molded (Lbs.)	Wet Wt. Per Cu. Ft.	Dry Wt. Per Cu. Ft.	Area (Sq. In.)	Date Tested	Mach. Load	P.S.I.
A	10.4	4.60	138.0	125.0	12.57	11-28	10,325	820
B	10.4	4.70	141.0	127.7	12.57	11-28	11,950	950
C	10.2	4.62	138.6	125.8	12.57	11-28	10,650	850
D	10.2	4.67	140.1	127.1	12.57	12-05	19,600	1559
E	10.2	4.66	139.8	126.9	12.57	12-05	18,950	1508
F	11.1	4.65	139.5	125.6	12.57	12-05	19,825	1577
G	10.8	4.66	139.8	126.2	12.57	12-19	21,860	1740
H	10.8	4.66	139.8	126.2	12.57	12-19	20,790	1650
I	10.8	4.64	139.2	125.6	12.57	12-19	21,010	1670
J	10.8	4.70	141.0	127.3	12.57	02-19		
K	10.9	4.65	139.5	125.8	12.57	02-19		
L	10.9	4.68	140.4	126.6	12.57	02-19		
M	10.9	4.66	139.8	126.1	12.57	For Durability Test		
N	10.9	4.68	140.4	126.6	12.57	For Durability Test		
O	9.6	4.63	138.9	126.7	12.57	For Durability Test		

The results of the tests are summarized in FIGS. 1-3.

As shown in FIG. 1, mixtures containing cement kiln dust vary but in each instance produce a base that is stabilized.

As shown in FIG. 2, the addition of additives or admixtures generally do not affect the strength except that a retarder tends to prevent the early development of strength as might be expected.

As shown in FIG. 3, the strength of mixtures including cement kiln dust compare favorably with a lime, fly ash, aggregate mixture. In addition, even a mixture of cement kiln dust and fly ash produces a stabilized base.

Thus, the mixtures of the present invention result in a stabilized base that is comparable in strength and required performance characteristics to cement-aggregate or lime-fly ash-aggregate stabilized bases and yet are not energy intensive. The mixtures of the present invention cost less than the predominantly used asphalt-aggregate bases. Also, the use of mixtures of the invention releases asphalt for use in resurfacing or as a heavy industrial fuel.

FIG. 4 is a curve showing the BTU's per mile versus thickness for various road paving materials taken from Highway Research Circular titled "Fuel Usage Factors for Highway Construction", Number 158, July, 1974. It can be seen that asphalt concrete and cement type mixtures require substantial energy and only granular base or sub-base of aggregate has minimal energy requirements in hauling, spreading, compacting and finishing. Since the mixtures of the present invention utilize waste materials, namely, cement kiln dust and fly ash, the energy requirements for making a stabilized base are only in hauling, spreading, compacting and finishing.

As a result, the mixtures of the present invention have minimal energy requirements and thereby obviate the energy intensive materials or prior stabilized bases.

The mixtures of the present invention utilize cement kiln dust which is a waste product that is relatively available from cement plants and fly ash which is readily available from power plants.

I claim:

1. A mixture consisting essentially of fly ash and cement kiln dust.

2. The mixture set forth in claim 1 including an amount of portland cement.

3. The mixture set forth in claim 1 wherein said cement kiln dust comprises about 12% by dry weight and said fly ash comprises about 88% by dry weight.

4. The method which comprises mixing fly ash, cement kiln dust and water and permitting the mixture to react at ambient temperatures to produce a durable mass.

5. The method set forth in claim 4 wherein said fly ash comprises about 12% by dry weight of the total of fly ash and cement kiln dust and the cement kiln dust comprises about 88% by dry weight of the total of fly ash and cement kiln dust.

6. The mixture set forth in claim 1 including about 1% portland cement.

7. The mixture set forth in claim 1 wherein the fly ash comprises the major constituent.

8. The method set forth in claim 4 including mixing about 1% portland cement with said fly ash and cement kiln dust.

• • • • •

[54] STABILIZED MIXTURE

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Ohio

[21] Appl. No.: 763,837

[22] Filed: Feb. 4, 1977

Related U.S. Application Data

[62] Division of Ser. No. 654,211, Feb. 2, 1976, Pat. No.
4,018,617.[51] Int. Cl.² C04B 7/26[52] U.S. Cl. 106/85; 106/97;
106/118; 106/DIG. 1

[58] Field of Search 106/85, 97, 118, DIG. 1

[56]

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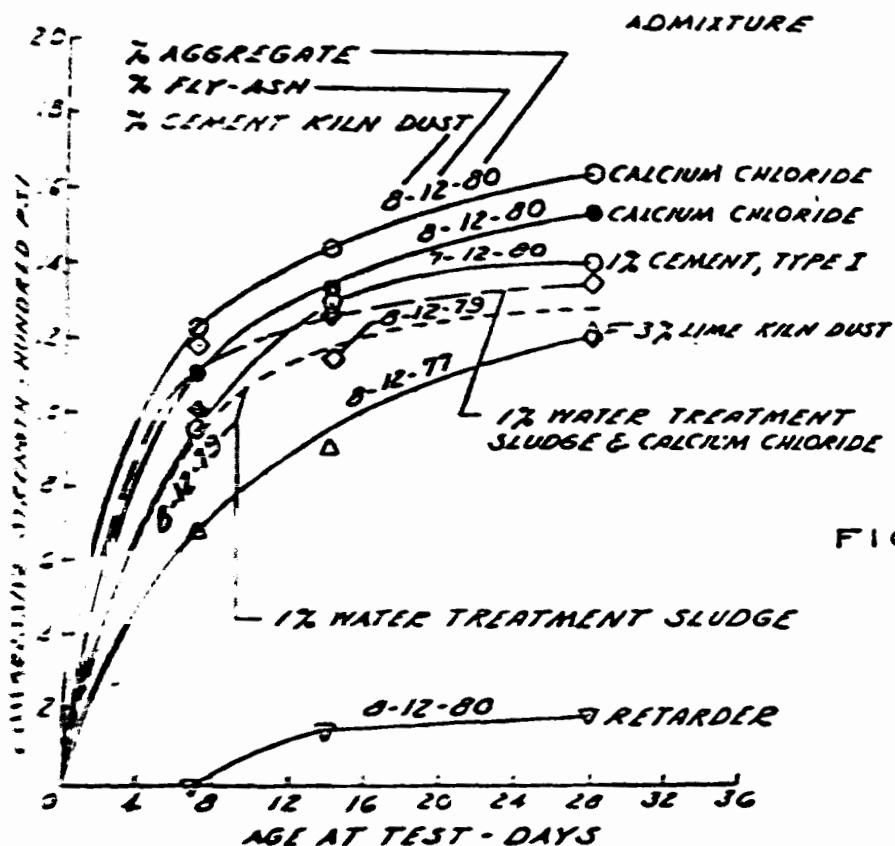
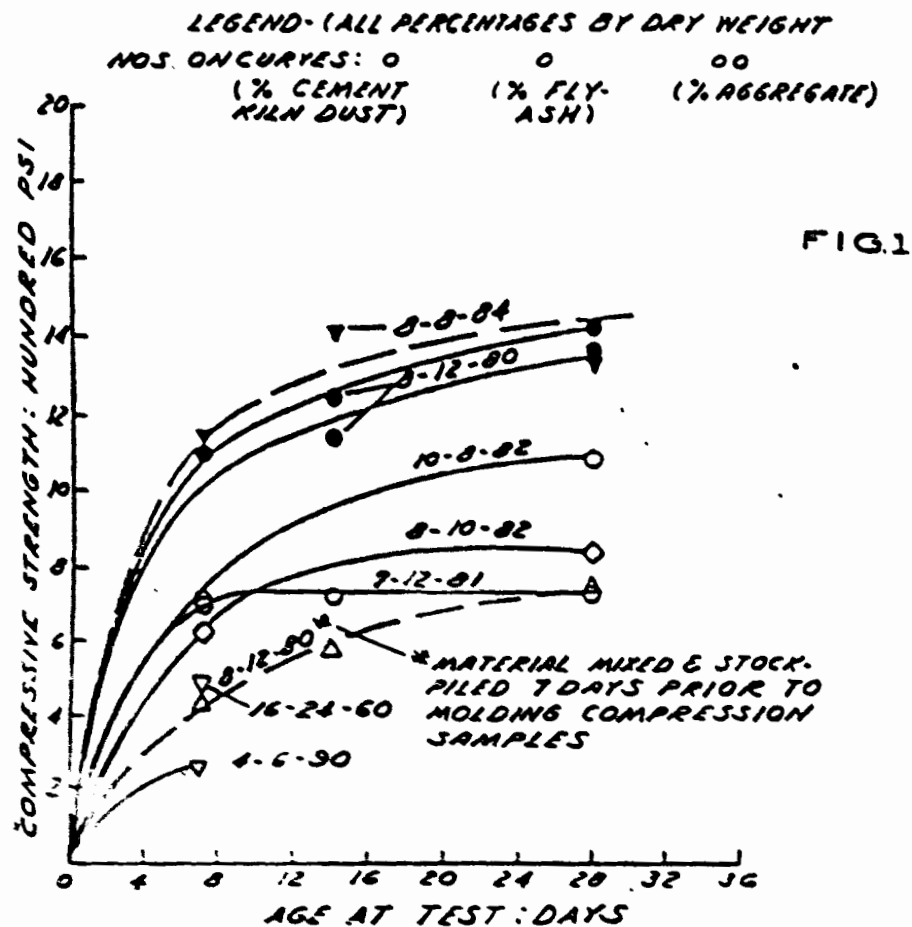
*Primary Examiner—J. Poes**Attorney, Agent, or Firm—Barnes, Kinselle, Raisch &
Choate*

[57]

ABSTRACT

A mixture consisting essentially of fly ash and cement
kiln dust which reacts at ambient temperature with
water to produce a durable mass.

8 Claims, 4 Drawing Figures



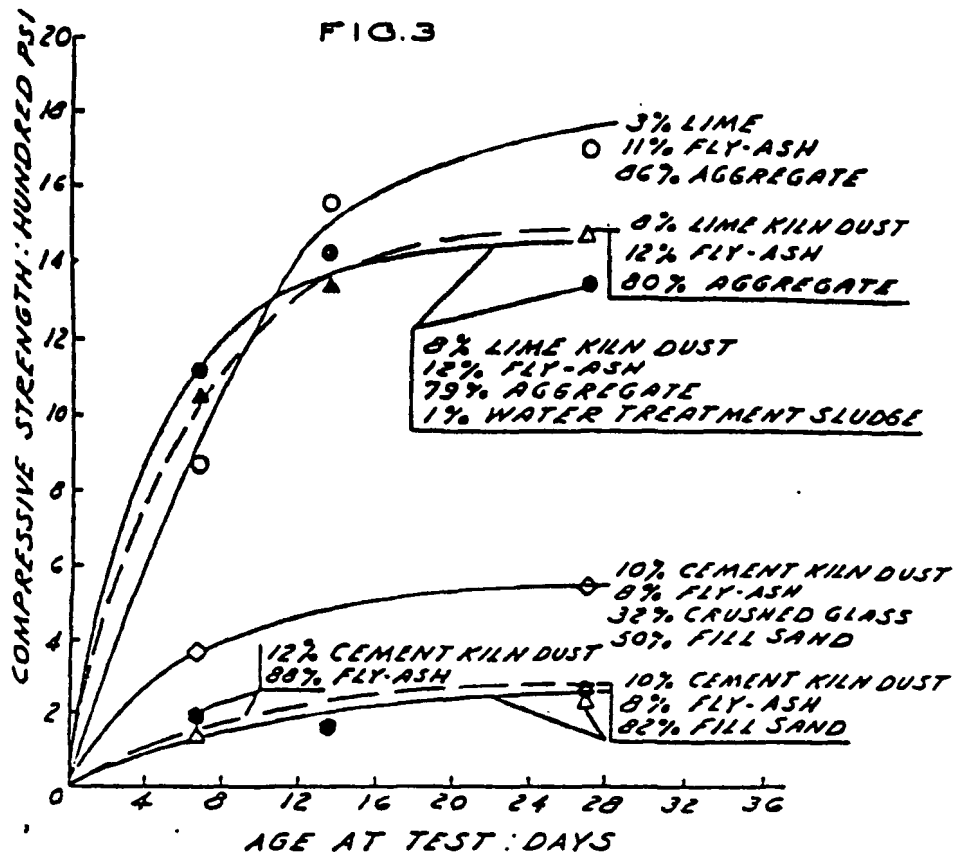
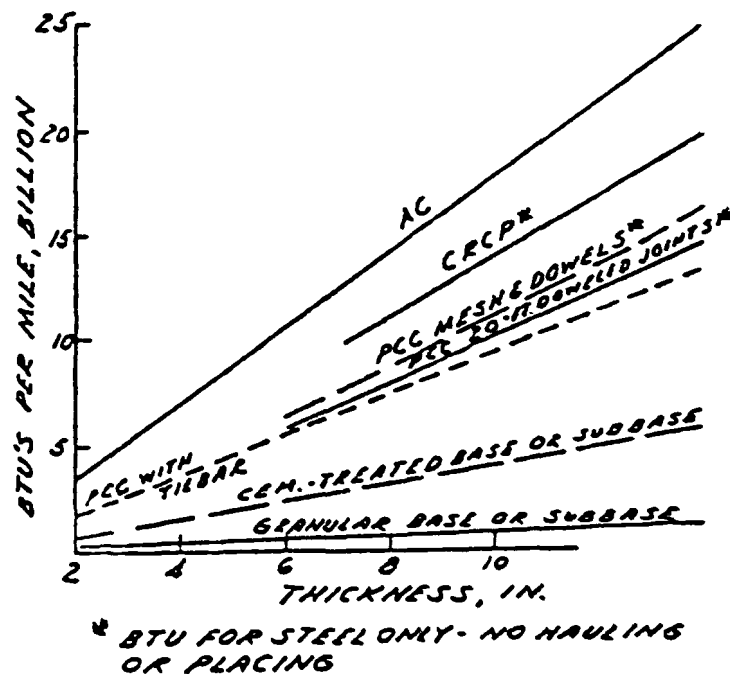


FIG. 4

ENERGY REQUIREMENTS
(24 FT. PAVEMENT)
INCLUDES MATERIALS, PRODUCTION
HAULING & PLACING.



Appendix C

SUPPORT DOCUMENTATION - ASPHALT RUBBER

This Appendix contains support documentation referred to in Chapter 7 of Volume 1. Included here are state specifications, company specifications, and certain other information submitted by companies. The company submissions may be in part promotional in nature, but are included here for the readers' information. Verification of the information contained in company submissions was not possible in all cases.

Arizona Department of Transportation

STORED: Spec 4010821 on 20

8-23-79

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STRESS-ABSORBING MEMBRANE (Seal):

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General:

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The Stress-Absorbing membrane seal shall consist of furnishing either asphalt-rubber (Vulcanized) or asphalt-rubber (Devulcanized) and applying it as a seal coat where shown on the plans.

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^{Project}

Construction Materials:

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Tack Coat:

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The asphalt for tack coat shall be either Paving Grade Asphalt Cement or Emulsified Asphalt, Grade CRS-3.

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The paving grade asphalt shall conform to the requirements of Table 705-1 of the Supplemental Specifications, for the grade specified for the asphaltic concrete or the contractor may utilize the asphalt cement in which the rubber material is to be incorporated.

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Emulsified asphalt, Grade CRS-3, shall conform to the requirements of Table 705-5 of the Supplemental Specifications.

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Asphalt - Rubber (Vulcanized):

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The Asphalt Cement shall conform to the requirements of Table 705-1 of the Supplemental Specifications for Asphalt Cement AR-1000, except that the absolute viscosity of the aged residue, AASHTO T-240, shall not exceed 1700 poises when tested in accordance with the requirements of AASHTO T-202.

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The granulated rubber shall meet the following requirements:

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Passing Sieve

Percent

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No. 8

100

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- No. 50

0- 15

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The sieves shall comply with the requirements of AASHTO M-92.

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The material shall have a specific gravity of 1.15 ± 0.02 and shall be free of fabric, wire or other contaminating materials, except that up to four percent of calcium carbonate may be included to prevent the particles from sticking together.

Asphalt-Rubber (Devulcanized):

The asphalt cement shall conform to the requirements of Table 705-1 of the Supplemental Specifications for Asphalt Cement AR-4000, except that the absolute viscosity of the aged residue, AASHTO T-240, shall not exceed 4700 poises when tested in accordance with the requirements of AASHTO T-202. The asphalt cement shall be fully compatible with the ground rubber to be used to produce the asphalt-rubber.

The extender oil shall be a resinous, high flash point aromatic hydrocarbon meeting the following test requirements:

Viscosity, SSU at 100 degrees F. (ASTM D-88)	2500 Min.	66
Flash Point, C.O.C., degrees F. (ASTM D-92)	392 min.	67
Molecular Analysis (ASTM D-2007)		68
Asphaltenes, percent by weight	0.1 max.	69
Aromatics, percent by weight	55 min.	70

The ground rubber shall meet the following physical and chemical requirements:

a. Composition:

The rubber shall be a dry, free flowing blend of 40 percent powdered reclaimed (i.e., devulcanized) rubber and 60 percent ground vulcanized rubber scrap selected to have a high natural rubber content. It shall be free from fabric, wire or other contaminants except that up to four percent calcium carbonate may be included to prevent the particles from sticking together.

b. Sieve Analysis: 87

Passing Sieve		Percent	90
No.	8	100	92
No.	30	60- 80	93
No.	50	15- 40	94
No.	100	0- 15	95

The sieves shall comply with the 97
requirements of AASHTO M-92. 98

c. Mill Test: 101

When 40 to 50 grams of rubber retained on the No. 30 sieve 103
are added to a tight set six-inch rubber mill, the material 104
shall band on the mill roll in one pass (Note: This test 105
is to establish that a sufficient quantity of reclaimed, 106
devulcanized rubber is present). 107

d. Natural Rubber content shall be a minimum of 30 percent, by 109
weight, when tested in accordance with ASTM D-297. 110Cover Material: 112

Cover material may be obtained from any source provided that the 115
material meets the requirements of the Specifications.

The cover material retained on the No. 8 sieve shall contain, by 118
weight, not more than 30 percent of limestone. Neither sandstone nor
synthetic materials shall be used in the production of cover material. 119
The aggregate shall be relatively free from clay balls, clay coating, 120
organic matter or foreign substances. 121

Cover material shall conform to the requirements of Table 704-1 124
for Type CM-11, except that the maximum percentage of wear at 100
revolutions shall be nine percent and the bulk specific gravity shall 125
be a maximum of 2.9 as determined in accordance with the requirements 126
of AASHTO T-85. The amount of material passing the No. 4 sieve shall 127
be within the limits of 0 and 25 percent. 128

Blotter Material: 131

Blotter material shall conform to the requirements of Subsection 134
706 (C) (2) of the Standard Specifications, except that the grading 135
shall be as follows:

Passing Sieve	Percent	138
3/8 inch	100	140
No. 4	80-100	141
No. 16	45- 80	142
No. 200	0- 5	143

No source of blotter material is designated. Commercial 146
sources or any source shall be allowed, providing the material 147
complies with the Specifications. 148

Construction Details: 150

Mixing Asphalt-Rubber Material: 152

General: 154

All equipment utilized in the mixing and application of the 156
asphalt-rubber material shall meet the requirements for equipment 157
specified for the placement of asphalt materials as called for in the 158
Standard Specifications. The equipment shall also be capable of 159
maintaining a uniform, homogeneous mixture throughout the sealing 160
operation. 161

The method and equipment for combining the asphalt and 163
rubber shall be so designed and accessible that the engineer can 164
readily determine the percentage, by weight, of each of the two 165
materials being incorporated into the mixture. 166

Asphalt-Rubber (Vulcanized): 168

The proportions of the asphalt and the granulated rubber, 170
by weight, shall be 78 percent +1 percent asphalt and 22 percent +1 171
percent granulated rubber. The weight of granulated rubber shall 172
equal 28 percent of the asphalt weight. 173

The materials shall be combined as rapidly as possible for such a time and at such a temperature that the consistency of the mix approaches that of a semi-fluid material. The temperature of the asphalt shall be between 350 degrees F. and 450 degrees F. The necessary reaction time required to achieve this semi-fluid state is a time-temperature relationship. The time may vary from a minimum of 10 minutes at 450 degrees F. to as much as one hour at 350 degrees F.

To obtain optimum spraying and wetting viscosity it may be necessary to add kerosene. A high boiling point kerosene shall be used in an amount not be exceed 7 1/2 percent, by volume, of the hot asphalt-rubber composition. The kerosene used shall have a boiling point of not less than 350 degrees F. and the temperature of the asphalt-rubber shall not exceed 350 degrees F. at the time the kerosene is added.

Asphalt-Rubber (Devulcanized):

The asphalt-rubber blend shall be a combination of the asphalt cement, extender oil and ground rubber mixed together at elevated temperatures in accordance with the following proportions and procedures:

Preparation of Asphalt Cement-Extender Oil Mix:

The asphalt cement shall be heated to between 250 and 400 degrees F. and combined with from two to six percent of the extender oil to reduce the viscosity of the asphalt cement to within the range of 600 to 1800 poises at 140 degrees F. when tested in accordance with AASHTO T-202. The mixture shall be thoroughly mixed by recirculation, stirring, air agitation, or other means.

Addition of Rubber:

The temperature of the asphalt cement-extender oil blend shall be increased to within the range of 350-425 degrees F. and an amount of ground rubber equal to 22 percent, plus or minus one percent by weight of the total asphalt-rubber blend shall be added. The rubber shall be added as rapidly as possible and the mixture shall be recirculated for a period of not less than 30 minutes after incorporation of all the rubber. Recirculation and stirring of the total combined material shall be maintained to provide good mixing and dispersion. Sufficient heat should be applied to keep the temperature of the total blend to between 350-425 degrees F.

Application of Tack Coat: 221

The asphalt cement shall be applied at the approximate rate of 223
0.05 of a gallon per square yard. If the emulsified asphalt is 224
 utilized, it shall be applied at the approximate rate of 0.07 of a 225
 gallon per square yard. Should the contractor utilize asphalt-rubber 226
 (devulcanized), no tack coat will be required. 227

Application of the Asphalt-Rubber Stress-Absorbing Membrane: 229

The asphalt - rubber shall be applied only between ///// and 232
/////.

The existing pavement shall be cleaned in accordance with the 235
 requirements of Subsection 4040-3.01 of the Standard Specifications.

After cleaning and prior to the application of the membrane 237
seal, the existing pavement surface shall be treated with a tack coat 238
as hereinbefore specified. 239

Placement of the asphalt rubber stress-absorbing membrane shall 242
 be made only when all of the following conditions can be met:

- (1) The ambient air temperature is above 65 245
 degrees F., 246
- (2) The pavement is absolutely dry, and 248
- (3) The wind conditions are such that a 250
 satisfactory membrane can be achieved. 251

The distributor shall be capable of spreading the asphalt - 255
 rubber mixture in accordance with the tolerances called for in 256
 Subsection 401-3.02 of the Standard Specifications, except that the 257
 maximum deviation from the specified rate shall not exceed 0.06 of a 258
 gallon per square yard.

After reaching the proper consistency, application of the 260
 material shall proceed immediately and in no case shall the material 261
be held at a temperature over 330 degrees F. for more than one and 262
one-half hours after reaching the proper consistency. 263

The hot asphalt-rubber mixture shall be applied at the rate of 267
0.55±0.05 of a gallon per square yard (based on 7 1/2 pounds per hot 268
gallon). Some adjustment in the application rate may be deemed 269
necessary by the engineer due to varied surface texture encountered. 270

All transverse joints shall be made by placing building paper 272
over the end of the previous application, and the joining application 273
shall start on the building paper. Once the application process has 274
progressed beyond the paper, the paper shall be disposed of as 275
directed by the engineer.

Transverse joints created by short stoppages (approximately five 278
minutes or less) such as changing chip or distributor trucks, can be 279
made by holding the chip application short of the end of the asphalt- 280
rubber application approximately 1-1/2 feet. The joining application 281
of asphalt-rubber can then proceed immediately with as little overlap 282
of the previous application as is necessary to insure a continuous 283
binder application.

All longitudinal joints shall be lapped approximately four 285
inches. Longitudinal joints shall be located at or near the 286
centerline of the roadway, or in the center of the travel lane. 287

Application of Cover Material: 289

Cover material shall be applied in accordance with the 291
requirements of Section 404 of the Supplemental Specifications at the 292
approximate rate of 30 pounds per square yard. However, the actual 293
rate will be determined by the engineer. 294

At the time of application to the roadway, cover material shall 296
be at least as dry as material dried in accordance with the 297
requirements of Section 4.2 of AASHTO T-85. 298

Rolling: 301

At least three pneumatic rollers conforming to the requirements 303
of SubSection 406-3.05(F)(2), of the Standard Specifications shall be 304
provided to accomplish the required rolling, except that the rollers 305
shall carry a minimum of 4,000 pounds on each wheel and a minimum air 306
pressure of 100 pounds per square inch in each tire. At some 307
locations or where production rates require, fewer rollers may be 308
utilized as directed by the engineer. 309

Sufficient rollers shall be furnished to cover the width of the 311
spread with one pass. It is imperative that the first pass be made 312
immediately behind the spreader and if the spreading is stopped for 313
any reason, the spreader shall be moved ahead so that all cover 314
material spread may be immediately rolled. The rolling shall continue 315
until a minimum of four complete coverages have been made. Final 316
rolling shall be completed within two hours after the application of 317
the cover material.

Application of Blotter Material: 319

Immediately behind the first pass of the rollers, dry blotter 321
sand shall be applied at the approximate rate of one pound per square 322
yard. Additional blotter sand may be required after opening the 323
roadway to traffic. However, the rate of application will be 324
determined by the engineer. 325

At the time of application to the roadway, blotter material 327
shall be at least as dry as material dried in accordance with the 328
requirements of Section 4.1 of AASHTO T-84. 329

Traffic on Chip Seal: 331

Traffic of all types shall be kept off the stress-absorbing 333
membrane until it has had time to set properly and the minimum traffic 334
free period shall not be less than three hours. However, when it is 335
absolutely necessary that hauling equipment or piloted traffic travel 336
on the newly applied stress-absorbing membrane, their speed shall not 337
exceed 15 M.P. H. Stress-absorbing membrane operations shall be so 338
scheduled that the normal flow of traffic will be resumed before 339
sunset.

<u>Removing Loose Cover Material:</u>	342
<u>The power broom used in removing loose cover material shall be a rotary sweeper type.</u>	344 345
<u>Sweeping shall be performed at daybreak of the day following placement, or at any time when it is required to remove loose cover material that is detrimental to the membrane or is an inconvenience to traffic.</u>	347 348 349 350
<u>If because of temperatures or other causes, there is displacement of the embedded cover material, sweeping shall be discontinued until such time as there will be a satisfactory retention of cover material. Additional final sweeping shall be done and all excess cover material removed prior to the opening of the roadway to traffic.</u>	352 353 354 355 356
<u>Method of Measurement and Basis of Payment:</u>	358
<u>The Bituminous Tack Coat will be measured in accordance with Section 401 and paid for under ITEM 4030005 - ASPHALT FOR TACK COAT (SAM).</u>	360 361 362
<u>The Asphalt-Rubber will be measured and paid for per ton of the mixture under ITEM 4010721 - ASPHALT CEMENT (For Membrane Seal) (Rubberized), in accordance with Section 401 of the Specifications and including asphalt, extender oil, granulated rubber, and any added kerosene.</u>	364 365 366 367 368
<u>Cover Material will be measured and paid for at the contract price per cubic yard for ITEM 4040122 - COVER MATERIAL (Type CM-11), which price shall be full compensation for the item complete, including rolling as herein described and specified.</u>	370 371 372 373
<u>Blotter Material will be measured and paid for under ITEM 4040501 - BLOTTER MATERIAL, which price shall be full compensation for the item complete, including brooming required, as described hereinbefore in these special provisions.</u>	375 376 377 378
<u>The Bidding Schedule reflects a quantity bases on the approximate rate for the one application as herein specified; however, more than one application may be required.</u>	380 381 382

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Rev.: 8/22/79 2

STRESS-ABSORBING MEMBRANE (Interlayer):

General:

The Stress-Absorbing membrane shall consist of furnishing either asphalt-rubber (Vulcanized) or asphalt-rubber (Devulcanized) and applying it where shown on the plans prior to placement of the asphaltic concrete. ^{project}

Construction Materials:

Tack Coat:

The asphalt for tack coat shall be either Paving Grade Asphalt Cement or Emulsified Asphalt, Grade CRS-3.

The paving grade asphalt shall conform to the requirements of Table 705-1 of the Supplemental Specifications, for the grade specified for the asphaltic concrete or the contractor may utilize the asphalt cement in which the rubber material is to be incorporated.

Emulsified asphalt, Grade CRS-3, shall conform to the requirements of Table 705-5 of the Supplemental Specifications.

Asphalt-Rubber (Vulcanized):

The Asphalt Cement shall conform to the requirements of Table 705-1 of the Supplemental Specifications for Asphalt Cement AR-1000, except that the absolute viscosity of the aged residue, AASHTO T-240, shall not exceed 1700 poises when tested in accordance with the requirements of AASHTO T-202.

The granulated rubber shall meet the following requirements:

Passing Sieve	Percent
No. 8	100
No. 50	0- 15

The sieves shall comply with the requirements of AASHTO M-92.

The material shall have a specific gravity of 1.15+0.02 and shall be free of fabric, wire or other contaminating materials, except that up to four percent of calcium carbonate may be included to prevent the particles from sticking together.

Asphalt-Rubber (Devulcanized):

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The asphalt cement shall conform to the requirements of Table 57
 705-1 of the Supplemental Specifications for Asphalt Cement AR-4000, 59
 except that the absolute viscosity of the aged residue, AASHTO T-240, 60
 shall not exceed 4700 poises when tested in accordance with the 61
 requirements of AASHTO T-202. The asphalt cement shall be fully
 compatible with the ground rubber to be used to produce the asphalt- 63
 rubber.

The extender oil shall be a resinous, high flash point aromatic 66
 hydrocarbon meeting the following test requirements:

Viscosity, SSU at 100 degrees F. (ASTM D-88)	2500 min.	69
Flash Point, C.O.C., degrees F. (ASTM D-92)	392 min.	70
Molecular Analysis (ASTM D-2007)		71
Asphaltenes, percent by weight	0.1 max.	72
Aromatics, percent by weight	55 min.	73

The ground rubber shall meet the following physical and chemical 76
 requirements: 77

a. Composition: 79

The rubber shall be a dry, free flowing blend of 40 percent 82
 powdered reclaimed (i.e., devulcanized) rubber and 60 83
 percent ground vulcanized rubber scrap selected to have a 94
 high natural rubber content. It shall be free from fabric, 85
 wire or other contaminants except that up to four percent 86
 calcium carbonate may be included to prevent the particles 88
 from sticking together.

b. Sieve Analysis: 90

Passing Sieve	Percent	93
No. 8	100	95
No. 30	60- 80	96
No. 50	15- 40	97
No. 100	0- 15	98

The sieves shall comply with the 102
 requirements of AASHTO M-92. 103

c. Mill Test: 106

When 40 to 50 grams of rubber retained on the No. 30 sieve 109
 are added to a tight set six-inch rubber mill, the material 110
 shall band on the mill roll in one pass (Note: This test 111
 is to establish that a sufficient quantity of reclaimed, 112
 devulcanized rubber is present). 113

- d. Natural Rubber content shall be a minimum of 30 percent, by weight, when tested in accordance with ASTM D-297. 117
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Cover Material: 121

Cover material may be obtained from any source provided that the material meets the requirements of the Specifications. 124

The material retained on the No. 8 sieve shall contain, by weight, not more than 30 percent of limestone. Neither sandstone nor synthetic materials shall be used in the production of cover material. The aggregate shall be relatively free from clay balls, clay coating, organic matter or foreign substances. 126
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Cover material shall conform to the requirements of Table 704-1 for Type CM-11, except that the maximum percentage of wear at 100 revolutions shall be nine percent and the bulk specific gravity shall be a maximum of 2.9 as determined in accordance with the requirements of AASHTO T-85. The amount of material passing the No. 4 sieve shall be within the limits of 0 and 25 percent. 133
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Cover material shall be applied at the approximate rate of 30 pounds per square yard; however, the actual rate of application will be determined by the engineer. 139
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Construction Details: 143

Mixing Asphalt-Rubber Material: 145

General: 147

All equipment utilized in the mixing and application of the asphalt-rubber material shall meet the requirements for equipment specified for the placement of asphalt materials as called for in the Standard Specifications. The equipment shall also be capable of maintaining a uniform, homogeneous mixture throughout the sealing operation. 149
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The method and equipment for combining the asphalt and rubber shall be so designed and accessible that the engineer can readily determine the percentage, by weight, of each of the two materials being incorporated into the mixture. 156
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Asphalt-Rubber (Vulcanized): 161

The proportions of the asphalt and the granulated rubber, by weight, shall be 78 percent +1 percent asphalt and 22 percent +1 percent granulated rubber. The weight of granulated rubber shall equal 23 percent of the asphalt weight. 163
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The materials shall be combined as rapidly as possible for such a time and at such a temperature that the consistency of the mix approaches that of a semi-fluid material. The temperature of the asphalt shall be between 350 degrees F. and 450 degrees F. The necessary reaction time required to achieve this semi-fluid state is a time-temperature relationship. The time may vary from a minimum of 10 minutes at 450 degrees F. to as much as one hour at 350 degrees F.

To obtain optimum spraying and wetting viscosity it may be necessary to add kerosene. A high boiling point kerosene may be used in an amount not to exceed 7 1/2 percent, by volume, of the hot asphalt-rubber composition. The kerosene used shall have a boiling point of not less than 350 degrees F. and the temperature of the asphalt-rubber shall not exceed 350 degrees F. at the time the kerosene is added.

Asphalt-Rubber (Devulcanized):

The asphalt-rubber blend shall be a combination of the asphalt cement, extender oil and ground rubber mixed together at elevated temperatures in accordance with the following proportions and procedures:

Preparation of Asphalt Cement-Extender Oil Mix:

The asphalt cement shall be heated to between 250 and 400 degrees F. and combined with from two to six percent of the rubber extender oil to reduce the viscosity of the asphalt cement to within the range of 500 to 1800 poises at 140 degrees F. when tested in accordance with AASHTO T-202. The mixture shall be thoroughly mixed by recirculation, stirring, air agitation, or other means.

Addition of Rubber:

The temperature of the asphalt cement-extender oil blend shall be increased to within the range of 350-425 degrees F. and an amount of ground rubber equal to 22 percent, plus or minus one percent by weight of the total asphalt-rubber blend shall be added. The rubber shall be added as rapidly as possible and the mixture shall be recirculated for a period of not less than 30 minutes after incorporation of all the rubber. Recirculation and stirring of the total combined material shall be maintained to provide good mixing and dispersion. Sufficient heat should be applied to keep the temperature of the total blend to between 350-425 degrees F.

<u>Application of Tack Coat:</u>	216
The asphalt cement shall be applied at the approximate rate of 0.05 of a gallon per square yard. If the emulsified asphalt is utilized, it shall be applied at the approximate rate of 0.07 of a gallon per square yard. If the contractor utilizes the asphalt rubber (devulcanized), no tack coat will be required on the existing bituminous surface.	218 219 220 221 222
If the stress-absorbing membrane has been subjected to traffic, the tack coat shall be applied at the approximate rate of 0.06 of a gallon per square yard prior to the placement of the asphaltic concrete.	224 225 226
<u>Application of the Asphalt-Rubber Stress-Absorbing Membrane:</u>	229
The existing pavement shall be cleaned in accordance with the requirements of subsection 404-3.01 of the Standard Specifications.	231 232
After cleaning and prior to the application of the membrane seal, the existing pavement surface shall be treated with a tack coat as hereinbefore specified.	234 235 236
Placement of the asphalt-rubber stress-absorbing membrane shall be made only when all of the following conditions can be met:	239
(1) The ambient air temperature is above 65 degrees F.,	242 243
(2) The pavement is absolutely dry, and	245
(3) The wind conditions are such that a satisfactory membrane can be achieved.	247 248
The distributor shall be capable of spreading the asphalt-rubber mixture in accordance with the tolerances called for in subsection 401-3.02 of the Standard Specifications, except that the maximum deviation from the specified rate shall not exceed 0.05 of a gallon per square yard.	251 253 254 255
After reaching the proper consistency, application of the material shall proceed immediately and in no case shall the material be held at a temperature over 330 degrees F. for more than one and one-half hours after reaching the proper consistency.	257 258 259 260
The hot asphalt-rubber mixture shall be applied at the rate of 0.55+0.05 of a gallon per square yard (based on 7 1/2 pounds per hot gallon). Some adjustment in the application rate may be deemed necessary by the engineer due to varied surface texture encountered.	263 264 265 266

All transverse joints shall be made by placing building paper over the end of the previous application, and the joining application shall start on the building paper. Once the application process has progressed beyond the paper, the paper shall be disposed of as directed by the engineer.

All longitudinal joints shall be lapped approximately four inches.

Application of Cover Material:

Cover material shall be applied in accordance with the requirements of Section 404 of the Supplemental Specifications at a rate specified by the engineer.

At the time of application to the roadway, cover material shall be at least as dry as material dried in accordance with the requirements of Section 4.2 of AASHTO T-85.

Rolling:

At least three pneumatic rollers conforming to the requirements of subsection 406-3.05(F)(2), of the Standard Specifications shall be provided to accomplish the required rolling, except that the rollers shall carry a minimum of 4,000 pounds on each wheel and a minimum air pressure of 100 pounds per square inch in each tire.

Sufficient rollers shall be furnished to cover the width of the spread with one pass. It is imperative that the first pass be made immediately behind the spreader and if the spreading is stopped for any reason, the spreader shall be moved ahead so that all cover material spread may be immediately rolled. The rolling shall continue until a minimum of four complete coverages have been made. Final rolling shall be completed within two hours after the application of the cover material.

Traffic on Chip Seal:

Traffic of all types shall be kept off the stress-absorbing membrane until it has had time to set properly and the minimum traffic free period shall not be less than three hours. However, when it is absolutely necessary that hauling equipment or piloted traffic travel on the newly applied stress-absorbing membrane, their speed shall not exceed 15 M.P.H. Stress-absorbing membrane operations shall be so scheduled that the normal flow of traffic will be resumed before sunset.

Removing Loose Cover Material: 319

Loose cover material shall be removed in accordance with 320
Subsection 404-3.02(E) of the Supplemental Specifications. Sweeping 321
shall be completed and all excess cover material removed prior to the 322
placement of the asphaltic concrete. 323

Placement of Asphaltic Concrete: 325

The first lift of the Asphaltic Concrete shall not be 327
 placed for at least forty-eight hours after the application of the 329
 Asphalt-Rubber Stress-Absorbing Membrane. Any blotting, patching with 330
 asphalt-rubber, additional sweeping or other means necessary and 331
 called for by the engineer to insure the integrity of the membrane 332
 during this period will be paid for in accordance with Subsection 333
 104.03 of the Standard Specifications.

Method of Measurement and Basis of Payment: 335

The Bituminous Tack Coat will be measured in accordance with 338
 Section 401 and paid for under ITEM 4030005 - ASPHALT FOR TACK COAT 339
 (SAM).

The Bidding Schedule reflects a quantity based on the 341
 approximate rate for the two applications of Emulsified Asphalt, Grade 342
 CRS-3, as herein specified; however, no adjustment in the contract 343
 unit price will be made because of an increase or decrease in the 344
 quantity utilized to complete the work under this item, as provided 345
 for in Subsection 109.03.

The Asphalt-Rubber will be measured and paid for per ton of the 349
 mixture under ITEM 4010721 - ASPHALT CEMENT (For Membrane Seal) 350
 (Rubberized), in accordance with Section 401 of the Specifications and 351
 including asphalt, extender oil, granulated rubber, and any added
 kerosene.

Cover Material will be measured and paid for at the contract 354
 price per ton for ITEM 4040120 - COVER MATERIAL (Type CM-11) which 355
 price shall be full compensation for the item complete, including 356
 rolling and brooming, as herein described and specified.

Pennsylvania Department of Transportation

York County

L.R. 127 Par. (302)

Item 2000-0002 - Open Graded Rubberized Asphalt Friction Course,
SRL-H (Reclaimed)

1. Description

This work shall consist of constructing a wearing course of hot-mixed, hotlaid, rubberized open-graded, asphalt friction course in accordance with these specifications and within reasonably close conformity to the lines, grades, width, and depth shown on the drawing and as specified.

2. Materials

The materials and their use shall conform to the requirements of Section 401.2.

(a) Asphalt Cement. The asphalt cement shall be Class AC 20 conforming to the requirements of Bulletin No. 25.

In addition, the asphalt shall be of such composition that when heated in a mixture containing 20% rubber by weight for one hour at 425 F under direct heat, it will produce a material with a ring and ball softening point greater than that of the untreated asphalt and a viscosity not exceeding 1000 cps at 420 F.

Samples shall be submitted and tested prior to use. Testing of the rubberized asphalt shall be in accordance with ASTM D-36.

(b) Powdered Devulcanized Rubber. The rubber shall be reclaimed and devulcanized tire tread rubber which has been milled so that 100% passes the No. 10 sieve and not more than 50% passes the No. 30 sieve.

The material shall be free from fabric, wire, cord, or other contaminating materials except dusting agents included to prevent the particles from sticking together.

(c) Aggregates.

(i) Fine Aggregate. The fine aggregate shall meet the quality of Section 703.2.

(ii) Coarse Aggregate. The coarse aggregate shall be Type A stone, gravel, or slag, meeting the quality requirements of Section 703.3.

The coarse aggregate used in the wearing course shall have an SRL letter of H, as defined, and be supplied from sources approved for this classification as listed in Bulletin No. 13.

(d) Composition of Mixture. The fine aggregate, coarse aggregate, and

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bitumen meeting the requirements herein specified shall be combined in such proportions that the total aggregate and bitumen in the wearing course shall conform to the percent by weight composition specified by the engineer, but within the limits of Table A of this specification.

✓✓ { The rubberized asphalt shall be mixed with aggregate having a temperature of 350-400 F in the conventional manner. The rubberized asphalt shall be used at its mixing temperature and not allowed to cool substantially before mixing with the aggregate.

✓✓ { (e) Preparation of Rubberized Asphalt. Bituminous distributors or heated tanks with circulating pumps will be required. The tank shall be equipped so as to assure even heating of the material to 425 F. have pump capacity to maintain up to 300 gallons per minute circulation in the tank, and to transfer material in bulk.

Asphalt cement shall be heated to 420 F and two pounds of powdered devulcanized rubber added per gallon of asphalt. Adequate circulation of the liquid shall be maintained to provide for dispersion and mixing. After addition of the rubber, heating shall be continued at 420 F for an additional thirty minutes to complete dispersion of the rubber.

REMOVE STRAINER

(f) Approval of Job-Mix Formula. The approval of the job-mix formula, the uniformity of the mixture, acceptance of aggregates, sampling and testing, and the design control and compaction of the mixture shall conform with Section 401.2 except that the Marshall control requirements in Sections 401.2(d)2. and 3 shall not apply. PennDOT's Bureau of Materials, Testing and Research shall be responsible for the design of the rubberized open-graded, asphalt friction course. One hundred pounds of aggregate, one gallon of asphalt, and two pounds of powdered devulcanized rubber shall be submitted to the Bureau 30 days prior to the anticipated starting date.

(g) Uniformity. The general composition limits prescribed in Table A are master ranges of tolerance to govern any mixtures made from raw materials meeting the specifications and are the maximum in all cases.

TABLE A

COMPOSITION OF MIXTURE

Rubberized, Open-Graded, Asphalt Friction Course

Total Percent by Weight Passing Square Openings
based on Laboratory Sieve Tests

<u>Sieve</u>	<u>Percent Passing</u>
1/2"	100

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3/8"	95 - 100
#4	30 - 50
#8	5 - 15
#200	2 - 5

Bitumen % by Weight

Stone or Crushed Gravel	6.0-8.0
Slag	7.0-10.5

As an initial guide, the following formula is suggested:

$$\text{Percent Asphalt} = 2.0 K_c + 4.0$$

Where K_c = value from CKE test = coarse aggregate absorption
of SAE 10 lubricating oil.

3. Construction Requirements

Construction shall conform to the requirements of Section 401.3 and the following additional provisions:

(a) Weather Limitations. The rubberized, open-graded, asphalt friction course shall not be placed in late fall or in cold weather or when the pavement surface is below 60 F.

(b) 4.c Mixing. The temperature of the aggregate shall be controlled so that the temperature of the completed mixture taken at the plant shall not exceed 400 F. The temperature of the asphalt shall not be more than 35 degrees F above the temperature of the aggregate.

(c) Hauling Equipment. Construction operations shall be closely coordinated to eliminate standing time for loaded trucks. Excess asphalt that drains to the bottom of the truck bed shall be removed immediately.

(f) Conditioning of Existing Surface. A tack coat conforming to Section 460 shall be applied to a concrete pavement surface at 0.05 gallons per square yard and to a bituminous concrete surface if the surface is excessively lean.

(g) Spreading and Finishing. The temperature of the asphalt friction course shall not be more than 75 degrees lower than the mixing temperature.

The operation shall be as continuous as possible. Paving shall be limited to a speed which produces a uniform surface texture free of tearing. Any irregularities that occur shall be removed prior to compaction. The minimum lay down temperature shall be 325 F.

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(h) Compaction. Due to the temperature of the mix, rolling shall be delayed until no pickup is produced. The contractor is cautioned that the asphalt friction course is likely to set-up more rapidly than conventional type mixes. Compaction shall be accomplished by one or two passes of a steel wheeled roller. Additional rolling is ineffective and harmful because of rapid heat loss and possible degradation of aggregate.

4. Method of Measurement

This work will be measured in accordance with Section 401.4(b).

5. Basis of Payment

The rubberized, open-graded, asphalt friction course will be paid for at the contract unit price per ton as specified in Section 401.5(b).

Utilities

There is no utility involvement on the project.

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Arizona Refining Company
Specification M 101-80

SPECIFICATION FOR ARM-R-SHIELDTM

1.0 DESCRIPTION

ARM-R-SHIELD is a mixture of asphalt cement, rubber extender oil and ground rubber blended together at an elevated temperature in the manner, proportions and sequence herein described. When hot-spray applied and allowed to cool to ambient temperatures, it forms a tough, durable and adhesive membrane suitable for use in the construction of:

- a. surface treatments for paved surfaces (chip seals)
- b. stress absorbing membrane interlayers (SAMI)
- c. bridge deck waterproofing membranes

When hot-poured into pavement joints and cracks, and allowed to cool, it is suitable for use as a joint and crack filler.

2.0 MATERIALS

2.1 Asphalt Cement

The asphalt cement shall be a grade meeting the general requirements of AASHTO Specification M-226 or ASTM Specification D-3381 as determined by prior laboratory testing of asphalts available in the respective project area. It shall be fully compatible with the ground rubber to be used in producing ARM-R-SHIELD.

2.2 Rubber Extender Oil

The extender oil shall be a resinous, high flash point aromatic

hydrocarbon meeting the following test requirements:

Viscosity, SSU at 100 ^o F (ASTM D-88)	2500 min.
Flash Point, C.O.C., ^o F (ASTM D-92)	392 min.
Molecular Analysis (ASTM D-2007)	
Asphaltenes, %W	0.1 max.
Aromatics, %W	55 min.

2.3 Ground Rubber

The rubber shall meet the following physical and chemical requirements:

a. Composition:

The rubber shall be a dry, free flowing blend of 40% powdered reclaimed (i.e. devulcanized) rubber and 60% ground vulcanized rubber scrap selected to have a high natural rubber content. It shall be free from fabric, wire, or other contaminants except that up to 4% of a dusting agent, such as calcium carbonate, may be included to prevent caking of the particles.

b. Sieve Analysis:

<u>Sieve No.</u>	<u>% Passing</u>
8	100
30	60 - 80
50	15 - 40
100	0 - 15

c. Mill Test:

When 40 to 50 grams of rubber retained on the No. 30 sieve are added to a tight set 6-inch rubber mill, the material shall band on the mill roll in one pass. (Note: This test is to establish that a sufficient quantity of reclaimed, devulcanized rubber

is present.)

d. Natural Rubber Content (ASTM D-297), ZW 30 min.

3.0 ASPHALT-RUBBER BLEND

The asphalt-rubber blend (ARM-R-SHIELD) shall be a combination of the asphalt cement, extender oil and ground rubber mixed together at elevated temperature in accordance with the following proportions and procedures:

3.1 Preparation of Asphalt-Extender Oil Mix

Blend together the preheated asphalt cement (250-400°F), and rubber extender oil (usually from 1% to 7% depending upon the type asphalt used). Mix thoroughly by recirculation, stirring, air agitation, or other appropriate means.

3.2 Addition of Rubber

Increase the temperature of the asphalt cement-extender oil blend with appropriate heat exchangers to within the range of 350-425°F and then add an amount of specified ground rubber equal to 22%, plus or minus 2% by weight of the total asphalt-rubber blend. Add the rubber as rapidly as possible and continue recirculating for a period of not less than 30 minutes after incorporation of all the rubber. Adequate recirculation and/or agitation of the total combined material shall be maintained to provide good mixing and dispersion. Sufficient heat should be applied to keep the temperature of the total blend between 350-425°F while mixing.

4.0 APPLICATION

The final rubber-asphalt blend (ARM-R-SHIELD) is ready for application immediately after mixing by either hot-spray application in a distributor truck or by hot-pour in various devices. In the event a delay occurs

when the product is ready to be applied, the heat shall be turned off until the job resumes.

The product may also be allowed to stand overnight and be applied the following day, provided the heat is turned off and restarted at a time interval prior to application sufficient to insure that the application temperature is again within the application temperature range of 350-425°F. Mixing by recirculation or stirring shall be maintained during reheating to obtain temperature uniformity and avoid localized overheating which may damage the product.



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Arizona Refining Company
Specification C 202-80

CONSTRUCTION SPECIFICATION

for

ARM-R-SHIELDTM STRESS ABSORBING MEMBRANE INTERLAYER

1.0 DESCRIPTION

This work shall consist of the placement of a one-course asphalt-rubber membrane (ARM-R-SHIELD) on an existing asphalt or Portland cement concrete surface prior to placing an asphalt concrete overlay.

2.0 GENERAL REQUIREMENTS

2.1 Preparation of Existing Surface

Prior to application of the asphalt-rubber membrane, the entire paved surface to be treated shall be cleaned by sweeping, blowing and other methods until free of dirt and loose particles. Pot holes, depressions and other irregularities shall be patched as required. No water shall be present on the surface.

2.2 Seasonal and Weather Limitations

Construction shall not proceed when the ambient temperature is below 50°F, when rain is falling, or when wind conditions are unfavorable to obtaining a uniform spread.

3.0 MATERIALS

3.1 Asphalt-Rubber Membrane

The asphalt-rubber membrane material shall be ARM-R-SHIELD meeting

the requirements of Arizona Refining Company Specification M 101-80.

3.2 Mineral Aggregate

Aggregate to be spread on the membrane to provide a working surface for construction equipment shall consist of a hard, clean aggregate such as crushed rock, dry pea gravel or sand. It shall be of uniform quality throughout and shall be free from dirt and other deleterious substances.

The aggregate shall conform to either of the following grading requirements:

<u>Sieve Size</u>	<u>Medium Grade % Passing</u>	<u>Fine Grade* % Passing</u>
1/2 in.	100	---
3/8 in.	85 - 100	100
No. 4	10 - 30	75 - 100
No. 8	0 - 10	30 - 80
No. 16	0 - 5	0 - 50
No. 200	0 - 2	0 - 5

*(Note: Should the interlayer be required to carry traffic longer than 24 hours prior to placing the overlay, it shall be necessary to place medium grade aggregate listed herein or the type called for in Arizona Refining Specification C 201-80 for "ARM-R-SHIELD Surface Treatment.")

3.3 Certification

Prior to application, the Contractor shall submit certifications of specification compliance for all materials.

4.0 EQUIPMENT

4.1 Distributor Truck

At least one pressure-type bituminous distributor truck in good

condition will be required. The distributor shall be equipped with an internal heating device capable of even heating of the material up to 425°F; have adequate pump capacity to maintain a high rate of circulation in the tank; have adequate pressure devices and suitable manifolds to provide constant positive cut-off to prevent dripping from the nozzles. The distribution bar on the distributor shall be fully circulating. Any distributor that produces a streaked or irregular distribution of the material shall be promptly repaired or removed from the project.

Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, and a thermometer for reading temperature of tank contents.

It shall be so constructed that uniform applications may be made at the specified rate per square yard within a tolerance of plus or minus 0.05 gal./sq. yd.

4.2 Aggregate

Any self-propelled aggregate spreader in good condition of sufficient capacity to apply the aggregate within the time period specified will be required. The spreader shall be so constructed that it can be adequately gauged and set to uniformly distribute the required amount of aggregate at regulated speed.

4.3 Brooms

Revolving brooms shall be so constructed as to sweep clean or redistribute aggregate without damage to the ARM-R-SHIELD membrane.

4.4 Pneumatic-Tired Roller

There shall be at least two multiple wheel self-propelled pneumatic-tired rollers with provisions for loading to eight to twelve tons as deemed necessary. Pneumatic-tired rollers shall have a total compacting width of at least 60 inches and shall have minimum tire pressure of 60 pounds per square inch.

4.5 Trucks

Trucks of sufficient number and size to adequately supply the material will be required.

5.0 CONSTRUCTION DETAILS

5.1 Application of ARM-R-SHIELD

The asphalt-rubber material shall be applied by pressure distributor truck within the temperature range of 375-425°F and at a minimum rate of 0.60 gallons (hot) per square yard. (For estimating purposes, use 7.6 pounds per hot gallon.) If a job delay occurs, the heater in the distributor should be turned off and restarted in sufficient time before start of spreading to reheat material to at least 350°F prior to resumption of spreading. No spread shall be in excess of a length which can be immediately covered with aggregate.

The application from the distributor shall be stopped before the tank is empty to be sure the application does not run light. At all startings, intersections, and junctions at transverse joints with previous spreads or other pavements, provision shall be made to insure that the distributor nozzles are operating at full force when the application begins. Building paper or other suitable devices shall be used to receive the initial application from the

nozzles before any material reaches the surface at the transverse joint. The paper or device shall be removed immediately after use without spilling surplus material on the surface.

Longitudinal joints shall be reasonably true to line and parallel to centerline. The overlap in application of asphalt-rubber material shall be the minimum to assure complete coverage. Where any construction joint occurs, the edges shall be broomed back and blended so there are no gaps and the elevations are the same, and free from ridges and depressions.

During application, adequate provision shall be made to prevent marring or discoloration of adjacent pavements, structures, vehicles, foliage or personal property.

5.2 Application of Aggregate

The application of the medium-sized aggregate shall follow as closely as possible behind the application of the hot asphalt-rubber material, which shall not be spread further in advance of the aggregate spread than can be immediately covered. The application of the fine-sized aggregate shall be delayed until the membrane has reached approximately the same temperature as the pavement. Construction equipment and other vehicles shall not drive on the uncovered asphalt-rubber material.

The dry aggregate shall be spread uniformly at the rate of spread directed by the engineer, generally between 10 and 40 pounds per

square yard. Any deficient areas shall be covered with additional material.

Only sufficient aggregate should be applied to provide a working surface for construction equipment needed to place the asphalt concrete overlay. Refer to the note on Mineral Aggregate, 3.2, under this Specification C 202-80.

5.3 Rolling

There shall be at least three complete coverages by the pneumatic-tired roller to embed the aggregate particles firmly into the asphalt-rubber membrane.

5.4 Sweeping

Prior to placing the overlay all loose material shall be swept or otherwise removed.

5.5 Tack Coat

A tack coat shall generally be required prior to the placement of the asphalt concrete overlay on the asphalt-rubber membrane, except when the fine grade aggregate is specified as cover material.

6.0 MEASUREMENT AND PAYMENT

6.1 Quantities

Quantities subject to payment are as follows:

- (1) ARM-R-SHIELD - per ton or gallon
- (2) Aggregate - per ton or cubic yard.

6.2 Basis of Payment

Payment for ARM-R-SHIELD shall be in full compensation for all

labor, use of equipment, and incidentals necessary in furnishing, hauling, heating and applying the material in accordance with these specifications.

Payment for aggregate shall be in full compensation for all labor, use of equipment, and incidentals necessary in preparation of surface; furnishing, hauling and spreading aggregate; and rolling and sweeping operations.

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Arizona Refining Company
Specification C 201-80

CONSTRUCTION SPECIFICATION

FOR

ARM-R-SHIELD_{TM} SURFACE TREATMENT

1.0 DESCRIPTION

This work shall consist of the application of a hot asphalt-rubber membrane (ARM-R-SHIELD) to a paved surface and immediately embedding aggregate therein, by spreading and rolling procedures as described below, to form a multilayered aggregate ARM-R-SHIELD surface treatment.

2.0 GENERAL REQUIREMENTS

2.1 Preparation of Existing Surface

Prior to application of the asphalt-rubber membrane, the entire paved surface to be treated shall be cleaned by sweeping, blowing and other methods until free of dirt and loose particles. Pot holes, depressions and other irregularities shall be patched as required. No water shall be present on the surface.

2.2 Seasonal and Weather Limitations

Construction shall not proceed when the ambient temperature is below 50°F, when rain is falling, or when wind conditions are unfavorable to obtaining a uniform spread. When hot (125-300°F) cover aggregate is used, the above temperature requirements may be waived.

3.0 MATERIALS

3.1 Asphalt-Rubber

The asphalt-rubber material shall be ARM-R-SHIELD meeting the requirements of Arizona Refining Specification M 101-80.

3.2 Mineral Aggregate

Aggregate to be embedded into the asphalt-rubber membrane shall consist of a hard, clean aggregate such as crushed rock, crushed gravel or crushed slag. It shall be of uniform quality throughout and shall be free from dirt and other deleterious substances. It shall also be essentially dry, with a water content less than 0.5 percent as determined by AASHTO T-142.

The aggregate shall also conform to the following requirements:

a. Gradation - either of the following:

<u>Sieve Size</u>	<u>Coarse Grade % Passing</u>	<u>Medium Grade % Passing</u>
3/4 in.	100	---
1/2 in.	70 - 100	100
3/8 in.	0 - 40	70 - 90
No. 4	0 - 10	0 - 10
No. 200	0 - 2	0 - 2

b. Wear Resistance

Loss in Los Angeles Rattler (after 100 revolutions) ASTM C-131	10 max.
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c. Crushed Faces

At least 75% by weight of the material retained on the No. 4 sieve shall have at least one rough, angular surface produced by crushing.

3.3 Certification

Prior to application, the Contractor shall submit certifications of specification compliance for all materials.

4.0 EQUIPMENT

4.1 Distributor Truck

At least one pressure-type bituminous distributor truck in good condition will be required. The distributor shall be equipped with an internal heating device capable of even heating of the material up to 425°F; have adequate pump capacity to maintain a high rate of circulation in the tank; have adequate pressure devices and suitable manifolds to provide constant positive cut-off to prevent dripping from the nozzles. The distribution bar on the distributor shall be fully circulating. Any distributor that produces a streaked or irregular distribution of the material shall be promptly repaired or removed from the project.

Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, and a thermometer for reading temperature of tank contents.

It shall be so constructed that uniform applications may be made at the specified rate per square yard within a tolerance of plus or minus 0.05 gal./sq. yd.

4.2 Chip Spreader

A self-propelled chip spreader in good condition of sufficient capacity to apply the aggregate within the time period specified will be required. The spreader shall be so constructed that it can

be accurately gauged and set to uniformly distribute the required amount of aggregate at regulated speed.

4.3 Brooms

Revolving brooms shall be so constructed as to sweep clean or re-distribute aggregate without damage to the asphalt-rubber membrane or surface treatment.

4.4 Pneumatic-Tired Roller

There shall be at least two multiple wheel self-propelled pneumatic-tired rollers with provisions for loading to eight to twelve tons as deemed necessary. Pneumatic-tired rollers shall have a total compacting width of at least 60 inches and shall have minimum tire pressure of 60 pounds per square inch.

4.6 Trucks

Trucks of sufficient number and size to adequately supply the material will be required.

5.0 CONSTRUCTION DETAILS

5.1 Application of ARM-R-SHIELD

The asphalt-rubber material shall be applied by pressure distributor truck within the temperature range of 375-425°F and at a rate of 0.45 to 0.70 hot gallons per square yard. (For estimating purposes, use 7.6 pounds per hot gallon.) If a job delay occurs, the heater in the distributor should be turned off and restarted sufficiently before start of spreading to reheat material to at least 350°F prior to resumption of spreading. No spread shall be in excess of a length which can be immediately covered with aggregate. Maximum distance between distributor truck and chip spreader should be 100 feet.

The application from the distributor shall be stopped before the tank is empty to be sure the application does not run light. At all startings, intersections, and junctions at transverse joints with spreads or other pavements, provision shall be made to insure that the distributor nozzles are operating at full force when the application begins. Building paper or other suitable devices shall be used to receive the initial application from the nozzles before any material reaches the surface at the transverse joint. The paper or device shall be removed immediately after use without spilling surplus material on the surface.

Longitudinal joints shall be reasonably true to line and parallel to centerline. The overlap in application of asphalt-rubber material shall be the minimum to assure complete coverage. Where any construction joint occurs, the edges shall be broomed back and blended so there are no gaps and the elevations are the same, and free from ridges and depressions.

During application, adequate provision shall be made to prevent marring or discoloration of adjacent pavements, structures, vehicles, foliage or personal property.

5.2 Application of Aggregate

The application of aggregate shall follow as closely as possible behind the application of the hot asphalt-rubber material, which shall not be spread further in advance of the aggregate spread than can be immediately covered. Construction equipment or other vehicles shall not drive on the uncovered asphalt-rubber material.

The dry aggregate shall be spread uniformly by a self-propelled spreader at the rate of spread directed by the engineer, generally between 30 and 50 pounds per square yard. Any deficient areas shall be covered with additional material.

Aggregate may be preheated before application but to a temperature not to exceed 300°F. Aggregate may also be precoated with 0.25 to 0.75 percent of asphalt, if required by the engineer.

5.3 Rolling

Rolling shall commence immediately following spread of aggregate and maintain a distance of not more than 100 feet behind the chip spreader on the first pass. There shall be at least three complete coverages by the pneumatic-tired rollers to embed the aggregate particles firmly into the asphalt-rubber membrane.

5.4 Curing

The rolled ARM-R-SHIELD surface treatment may be placed under traffic immediately provided vehicles are controlled to a speed not to exceed 25-miles per hour. Speed control should continue until sweeping is complete. At the conclusion of sweeping, the pavement may be returned to posted speed limit traffic.

5.5 Sweeping

When the maximum of aggregate has been embedded into the asphalt-rubber membrane, all loose material shall be swept or otherwise removed at such time and in such a manner as will not displace any embedded aggregate or damage the asphalt-rubber membrane. Generally 2 hours is sufficient elapsed time following rolling for setting to occur and sweeping to start.

6.0 MEASUREMENT AND PAYMENT

6.1 Quantities

Quantities subject to payment are as follows:

- (1) ARM-R-SHIELD - per ton or gallon
- (2) Aggregate - per ton or cubic yard.

6.2 Basis of Payment

Payment for ARM-R-SHIELD shall be in full compensation for all labor, use of equipment, and incidentals necessary in furnishing, hauling, heating and applying the material in accordance with these specifications.

Payment for aggregate shall be in full compensation for all labor, use of equipment, and incidentals necessary in preparation of surfaces; furnishing, hauling and spreading aggregate; and rolling and sweeping operations, in accordance with these specifications.

SAHUARO PETROLEUM & ASPHALT CO.
GUIDE SPECIFICATIONS

for

Asphalt Rubber for Stress Absorbing Treatments (SAM or SAMI)

1. SCOPE

1.1 This specification covers the materials, equipment and construction procedures for a stress absorbing _____*
(_____*)

2. MATERIALS

2.1 Asphalt

The grade of asphalt cement for the asphalt rubber mixture shall be specified by the engineer prior to letting of the contract. The specified material shall comply with the applicable requirements of _____* and shall also have a maximum penetration of 150 when tested in accordance with AASHTO T49 (ASTM D5).

Emulsified asphalt for tack coat shall be SS-1, SS-1h, CSS-1 or CSS-1h and shall comply with the requirements of _____*.

2.2 Rubber Material

The granulated crumb rubber shall be 100 percent vulcanized and meet the following gradation requirements:

<u>Sieve Size</u>	<u>Percent Passing</u>
No. 8	100
No. 10	98-100
No. 30	0-10
No. 40	0-4

The sieves shall comply with the requirements of AASHTO M92 (ASTM E11).

The specific gravity of the material shall be 1.15 ± 0.02 and shall be free from fabric, wire or other contaminating materials, except that up to 4 percent calcium carbonate may be included to prevent the rubber particles from sticking together.

Granulated crumb rubber shall be accepted by certification from the rubber supplier*.

The granulated rubber, irrespective of diameter, shall not be greater than 7mm (1/4 inch) in length and contain no more than 2 percent moisture.

*See "Notes to Engineer".

Guide Specifications
(Continued)

2.3 Diluent

The diluent shall be a solvent with an initial boiling point (IBP) of +350 and an end point (EP) not exceeding 420F when tested in accordance with ASTM D86.

2.4 Cover Material*

Aggregate for cover material shall consist of crushed rock, crushed gravel or crushed slag conforming to the requirements of AASHTO Specification M43-54 (ASTM D448-54). The aggregate shall meet one of the following gradation requirements:

<u>Sieve Size</u>	<u>Percent Passing</u>		
	<u>#6</u>	<u>#7</u>	<u>#8</u>
1 in.	100		
3/4 in.	90-100	100	-
1/2 in.	20-55	90-100	100
3/8 in.	0-15	40-70	85-100
No. 4	0-5	0-15	10-30
No. 8	-	0-5	0-10
No. 16	-	-	0-5

The sieves shall comply with the requirements of AASHTO M92 (ASTM E11).

The contractor shall submit a minimum 75 pound sample of cover material to the engineer for testing at least 10 calendar days prior to the spreading of this material.

2.5 Blotter Material

The blotter material shall be a fine aggregate (sand) conforming to the following gradation requirements:

<u>Sieve Size</u>	<u>Percent Passing</u>
3/8 in.	100
No. 4	80-100
No. 16	45-80
No. 50	10-30
No. 100	2-10

The sieves shall comply with the requirements of AASHTO M92 (ASTM E11).

*See "Notes to Engineer"

3. EQUIPMENT

3.1 General

The equipment used by the contractor shall include a self-propelled rotary power broom for pavement cleaning and excess cover material removal and a self-propelled pressure asphalt distributor capable of applying tack coat uniformly at the specified rate. If a blotter material (sand) is to be applied, a hopper or whirl-type tailgate spreader shall be required.

3.2 Asphalt-Rubber Equipment

All equipment utilized in processing and application of the asphalt-rubber material shall be as described below:

- (1) A truck or trailer mounted self-powered distributor equipped with a heating unit, a mixing unit capable of producing a homogeneous mixture of asphalt and rubber, pump(s) capable of spraying asphalt-rubber within ± 0.05 gallon per square yard of the specified rate, and a fully circulating spray bar capable of applying asphalt-rubber without a streaked or otherwise irregular pattern.
- (2) The distributor also shall include a tachometer, pressure gages, volume measuring devices, an on-board weighing device to aid in proportioning materials and a thermometer. A "bootman" shall accompany the distributor and ride in a position so that all spray bar nozzles are in his full view and readily accessible for unplugging.

3.3 Cover Material Spreader

The cover material (chip) spreader shall be a self-propelled machine with an aggregate receiving hopper in the rear, belt conveyors to carry the aggregate to the front, and a spreading hopper equipped with full-width distribution auger and spread roll. The spreader shall be in good mechanical condition and be capable of applying the cover material uniformly across the spread at the specified rate.

3.4 Rolling Equipment

Self-propelled pneumatic-tired rollers shall be used for the required rolling of the cover material. The pneumatic-tired rollers shall carry a minimum loading of * pounds on each wheel and an air pressure of 100-5 pounds per square inch in each tire.

*See "Notes to Engineer".

3.5 Hauling Equipment

Trucks for hauling cover material shall be tailgate discharge and shall be equipped with a device to lock onto the hitch at the rear of the aggregate spreader. Haul trucks shall also be compatible with the aggregate spreader so that the dump bed will not push down on the spreader when fully raised or have too short a bed which results in aggregate spillage while dumping into the receiving hopper.

4. CONSTRUCTION DETAILS

4.1 General

Holes and depressions in the old pavement surfacing shall be repaired by patching and transverse and longitudinal cracks $\pm 3/8$ inch repaired by cleaning and pouring with crack filler.

Immediately prior to application of a tack coat, the surface shall be thoroughly cleaned by sweeping.

4.2 Tack Coat*

A tack coat of diluted emulsified asphalt, of the type and grade designated in Section 2.1, shall be applied to the cleaned surface and allowed to fully cure before spreading of the asphalt rubber material. The emulsified asphalt shall be diluted 1 part water to 1 part emulsified asphalt by volume with from 0.10 to 0.15 gallon per square yard of the diluted material applied.

4.3 Asphalt-Rubber Material Mixing

The percentage of crumb vulcanized rubber shall be 33-1/3 ± 2 percent by weight of the asphalt cement.

The temperature of the asphalt shall be between 350 and 425 before addition of the crumb vulcanized rubber. The materials shall be carefully combined and mixed and reacted for a period of time as required by the engineer which shall be based on laboratory testing by the asphalt-rubber supplier or contracting agency. The temperature of the asphalt rubber mixture shall be above 325F during the reaction period.

After the reaction between asphalt and rubber has occurred, the viscosity of the hot asphalt-rubber mixture may be adjusted for spraying and/or better "wetting" of the cover material by the addition of a diluent. The diluent shall comply with the requirements of Section 2.3 and shall not exceed 7½ percent by volume of the hot asphalt rubber mixture.

*See "Notes to Engineer"

Guide Specifications (Continued)

If a job delay results after the full reaction has occurred, the material may be allowed to cool and be slowly reheated to an acceptable spraying temperature just prior to application. However, because of the polymer reversion that can occur when crumb rubber is held for prolonged high temperatures, the material shall not be reheated to temperatures above 325F. Additional diluent up to a maximum of 3 percent by volume of the hot asphalt-rubber mixture may be used after reheating of the material.

4.4 Application of Asphalt-Rubber Material

Placement of the asphalt-rubber shall be made only under the following conditions:

- (1) The pavement surface temperature is not less than * and rain is not imminent,
- (2) The pavement surface is clean and absolutely dry,
- (3) The wind conditions are such that excessive blowing of the spray bar fans is not occurring, and
- (4) All construction equipment such as asphalt-rubber distributor, aggregate spreader, haul trucks with cover material, and rollers are in position and ready to commence placement operations.

The asphalt-rubber mixture shall be applied at a temperature of 290 to 325F at a rate of * ± 0.05 gallon per square yard (based on $7\frac{1}{2}$ pounds per hot gallon). Transverse joints shall be constructed by placing building paper across and over the end of the previous asphalt-rubber application. Once the spraying has progressed beyond the paper, the paper shall be removed immediately and disposed of as directed by the engineer. All longitudinal joints shall be lapped a minimum of 4 inches.

4.5 Application of Cover Material

Cover material shall be applied immediately to the asphalt-rubber after spreading at a rate of * to * pounds per square yard.

At the time of application to the asphalt rubber, cover material shall be at least saturated surface dry in accordance with the requirements of Section 4.2 of AASHTO T-85.

*See "Notes to Engineer"

Guide Specifications (Continued)

4.6 Rolling*

At least 3 pneumatic-tired rollers complying with the requirements of Section 3.4 shall be provided to accomplish the required embedment of the cover material. At some project locations or where production rates dictate, fewer rollers may be utilized as directed by the engineer.

Sufficient rollers shall be used for the initial rolling to cover the width of the aggregate spread with one pass. The first pass shall be made immediately behind the aggregate spreader, and if the spreading is stopped for any reason, the spreader shall be moved ahead or off to the side so that all cover material may be immediately rolled. Four complete passes with rollers shall be made with all rolling completed within 2 hours after the application of the cover material.

4.7 Application of Blotter Material*

Blotter material meeting the requirements of Section 2.5 may be required immediately after the initial pass of the rollers (usually 4 to 6 pounds per square yard) or after opening to traffic and sweeping so as to prevent asphalt-rubber bleed through and pick-up. The use, rate and locations for blotter material shall be designed by the engineer. The blotter material shall be uniformly applied using equipment specified in Section 3.1.

At the time of application, the blotter material shall be at least saturated surface dry in accordance with the requirements of Section 4.1 of AASHTO T-84.

4.8 Traffic Control

Traffic shall be directed through the project with warning signs, cones and flagmen in a manner that provides maximum safety for the workmen and the least interruption of the work.

Except when it is necessary that hauling equipment must travel on the newly applied membrane, traffic of all types shall be kept off the membrane until it has had time to set properly. The speed of all hauling equipment shall not exceed 15 miles per hour when traveling over a membrane which is not adequately set. The minimum traffic free period shall not be less than two hours.

*See "Notes to Engineer".

4.9 Removing Loose Cover Material*

The sweeping shall be a multi-step operation following placement of the membrane. The initial sweeping shall be a light brooming at the end of the placement day with a second sweeping completed at daybreak of the day following membrane placement. If because of high temperatures or other causes there is dislodgment of cover material, sweeping shall be discontinued until such time as there will be satisfactory retention of cover material.

4.10 Placement of Asphalt Concrete*

The placement of the asphalt concrete overlay shall be delayed as directed by the engineer for sufficient time to allow for adequate evaporation of the diluent.

If the SAMI has been subjected to traffic, an emulsified asphalt tack coat shall be applied as described in Section 4.2 prior to overlaying.

4.11 Method of Measurement and Basis of Payment

The Asphalt-Rubber will be measured and paid for per ton of mixture in-place under ASPHALT CEMENT (Rubberized) which includes asphalt cement, granulated crumb rubber and diluent (based on 7½ pounds per hot gallon).

The Cover Material will be measured and paid for per ton under COVER MATERIAL, as hereinbefore specified.

The Blotter Material will be measured and paid for per ton under BLOTTER MATERIAL, as hereinbefore specified.

The Tack Coat will be measured and paid for per ton under ASPHALT FOR TACK COAT, as hereinbefore specified.

*See "Notes to Engineer"

NOTES TO ENGINEER

Section 1.1

For a stress absorbing membrane, the first blank should be "membrane" and the second "SAM". For a stress absorbing membrane interlayer, the first blank should be "membrane interlayer" and the second "SAMI".

Section 2.2

Requirements for asphalt cement may be AASHTO M226 or ASTM D3381 for viscosity graded materials, AASHTO M20 or ASTM D946 for penetration graded materials, or the local state highway department specification.

Requirements for emulsified asphalts may be AASHTO M140 and M208 or ASTM D977 and D2397 (indicate both AASHTO or ASTM specifications as this is necessary to cover anionic and cationic materials which are indicated.) Also, local state highway department specifications may be indicated in lieu of AASHTO or ASTM.

Section 2.2

Specific standards for sampling and testing of granulated crumb rubber have not yet been established. Until standards are established, it is recommended that the rubber be accepted if accompanied by a certificate of compliance from the rubber supplier that the material has been tested during the grinding process and meets the gradation and specific gravity as specified.

Section 2.4

Only one of the gradations shown in this Guide Specification should be indicated in the actual project specifications. Usually sizes #7 or #8 have been selected for SAM or SAMI treatments. However, size #6 might be used for a SAMI if regular traffic were not allowed over it prior to overlay.

When aggregate surface dustiness is a probability, a requirement for cover material washing or pre-coating with asphalt cement or emulsified asphalt (0.5 to 0.75 percent asphalt residue) should be included. Also, if cool weather during placement and/or high traffic volumes are involved, a requirement for pre-heating and/or pre-coating of the cover aggregate should be considered.

NOTES TO ENGINEER (Continued)

Section 3.4

Most SAMI construction has involved the use of large pneumatic-tired rollers ballasted so as to achieve a minimum 5,000 pound wheel load. However, successful SAM's and SAMI's have been achieved using smaller pneumatic-tired rollers of about 10 tons ballasted weight. Therefore, a change in roller requirements (3,000 pound minimum wheel load) could be considered for SAMI projects subjected to only construction traffic (closed to regular traffic) and for SAM's and SAMI's when placed during warm weather. If smaller rollers are allowed, however, it is critical to maintain a tight placement operation. Also, a tandem steel-wheeled roller has been used in some instances in lieu of a third pneumatic roller for final rolling (acceptable only if pavement transverse profile smooth, i.e. without noticeable wheel-path rutting).

Section 4.2

Elimination of the tack coat requirement should be considered if the pavement has free asphalt already on the surface (bleeding, tracked crack pouring material, etc.). Also, RS type emulsified asphalts (undiluted) and asphalt cement have been used successfully for tack coats and could be specified if SS emulsion products are not readily available. However, excess tack coat is a much greater possibility with these materials so close control of application is very necessary to achieve a residual asphalt rate of 0.03 to 0.05 gallon per square yard.

Section 4.4

The minimum pavement surface temperature shall be 70F for a SAM and 60F for a SAMI.

Asphalt rubber application rates generally have varied from 0.55 to 0.70 gsy with the quantity selected based on pavement surface condition (fatness, texture, etc.), cover material size, and the type of treatment (SAM or SAMI).

Section 4.5

Cover material quantities generally used have been 30 to 40 pounds per square yard. The actual amount selected within this range on the project has been based on the appearance of the SAM or SAMI after initial rolling. Tracking of the asphalt rubber binder by the aggregate spreader or hauling trucks is one indicator of the need for an increase in spreading rate. Adjustments from the 30 to 40 psy rate may be necessary for aggregates with unusual specific gravities such as for slags.

NOTES TO ENGINEER
(Continued)

Section 4.6

If a tandem steel-wheeled roller is permitted for final rolling, then the equipment requirements in Section 3.4 and the first sentence in paragraph one of this section will require rewriting so as to allow this modification from these Guide Specifications.

Section 4.7

In some instances, particularly for SAMI treatments, the application of a sand blotter material has not been necessary. Thus, consideration should be given to eliminating this requirement, especially when previous project experience has indicated no difficulties without a blotter application.

Section 4.9

When the treatment is a SAMI, a second paragraph is required as follows: "Final sweeping shall be done and all loose cover material removed just prior to the placement of the asphalt concrete overlay".

Section 4.10

This item only included for SAMI treatments. For SAM projects, this section eliminated and the "Method of Measurement and Basis of Payment" indicated as Section 4.10.

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SPECIFICATION FOR ARM-R-SHIELD-CF

ARM-R-SHIELD-CF crack sealing material shall be a blend of asphalt cement, aromatic rubber extender oil, and a minimum of 23% powdered rubber by weight, combined in such a manner as to produce a material with the following properties:

- I. WORKABILITY - The material shall pour readily and penetrate large cracks at temperatures below 400°F.
- II. CURING - The product shall contain no water or volatile solvents and shall cure immediately upon cooling to a sufficient viscosity to prevent tracking by traffic.
- III. LABORATORY EVALUATION - When a sample of the product has been heated at 350°F for one hour, it shall pass the following tests:
 - A. Softening Point (R & B) - 135°F minimum.
 - B. Flexibility - A 1/8"-thick specimen of the product conditioned to 0°F shall be capable of being bent to a 90° angle over a 1" mandrel without cracking.

The type rubber and asphalt used shall be at the discretion of the supplier to produce the desired finished product.

DESCRIPTION OF GENSTAR TIRE RECYCLING PROCESS

The Genstar plant is designed to handle all types of road tires; truck, bus, passenger, steel and fiber belted, in sizes up to 42 inches in diameter and weighing from 15 to 90 pounds each (excluding off-road farm tractor and construction types).

It is unique in design in that it is capable of processing and blending the shredded tires as required, to meet exacting specifications for synthetic or natural rubber content, and with further in-process blending of finished products, to an even more finite specification of particle sizes, comprised of both vulcanized and devulcanized materials.

All final product will be packaged in bags or semi-bulk sling bins (with future bulk handling as an option).

By designing the plant in this fashion, we have attempted to provide a certain flexibility to the asphalt/rubber technologist, as we proceed to find the best material and process solution to provide optimum pavement construction and maintenance performance characteristics, while ever expanding the recycling rate of 200 million waste tires each year.

As you proceed through the plant, you will observe several stages of processing.

YARD OPERATIONS

Tire Stockpiling & Handling
Tire Shredding
Metal Removal
Shredded Material and Storage

INSIDE THE PLANT

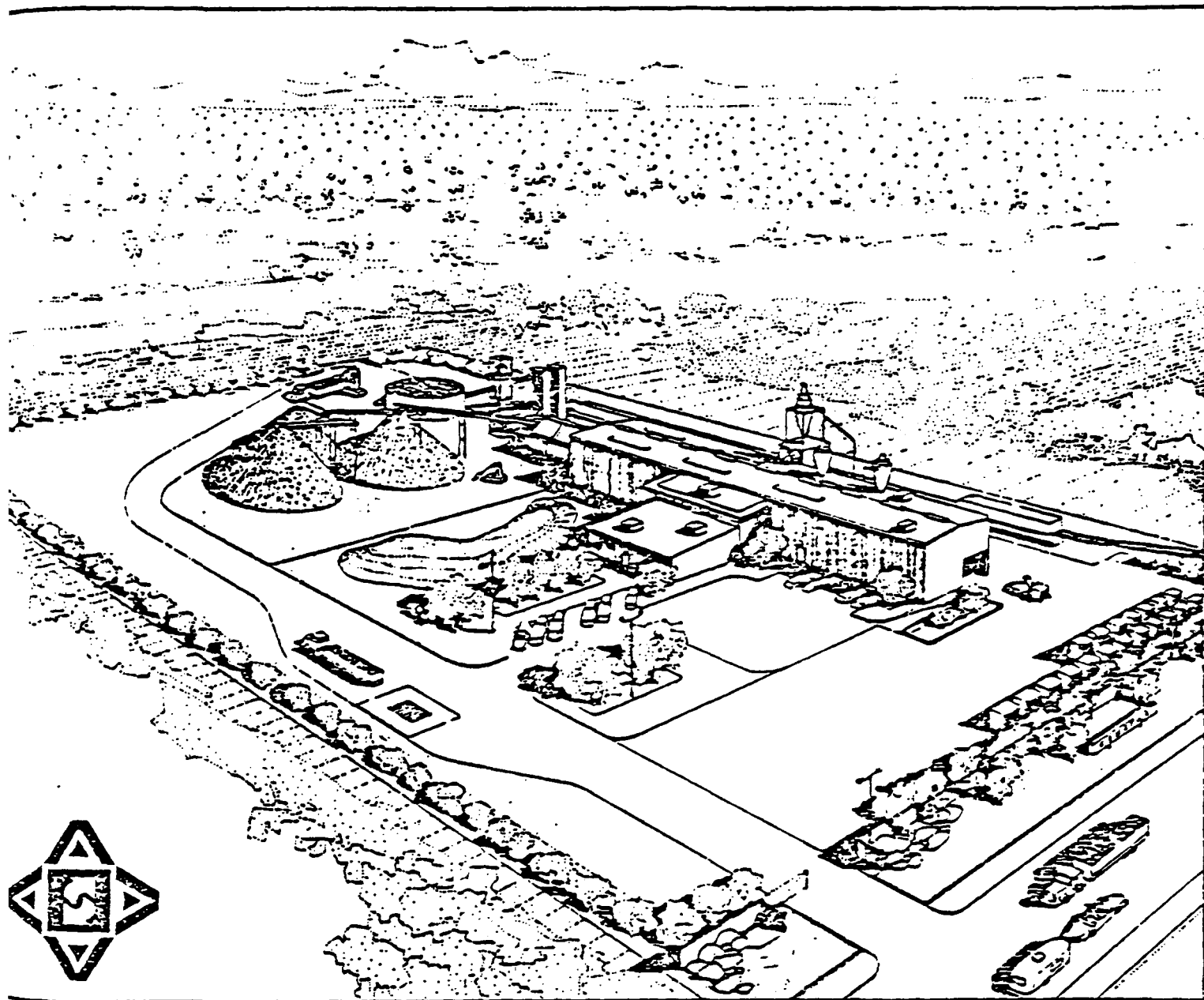
A. Primary	Primary Grinding Particle Sizing Metal Removal Fiber Removal
B. Secondary	Particle Sizing Metal Removal Fuzz Removal
C. Quality Control	Sampling Lab Tests
D. Final Packaging and Storage	

This is the newest and most modern plant of its type in the United States, and we believe it demonstrates three important objectives:

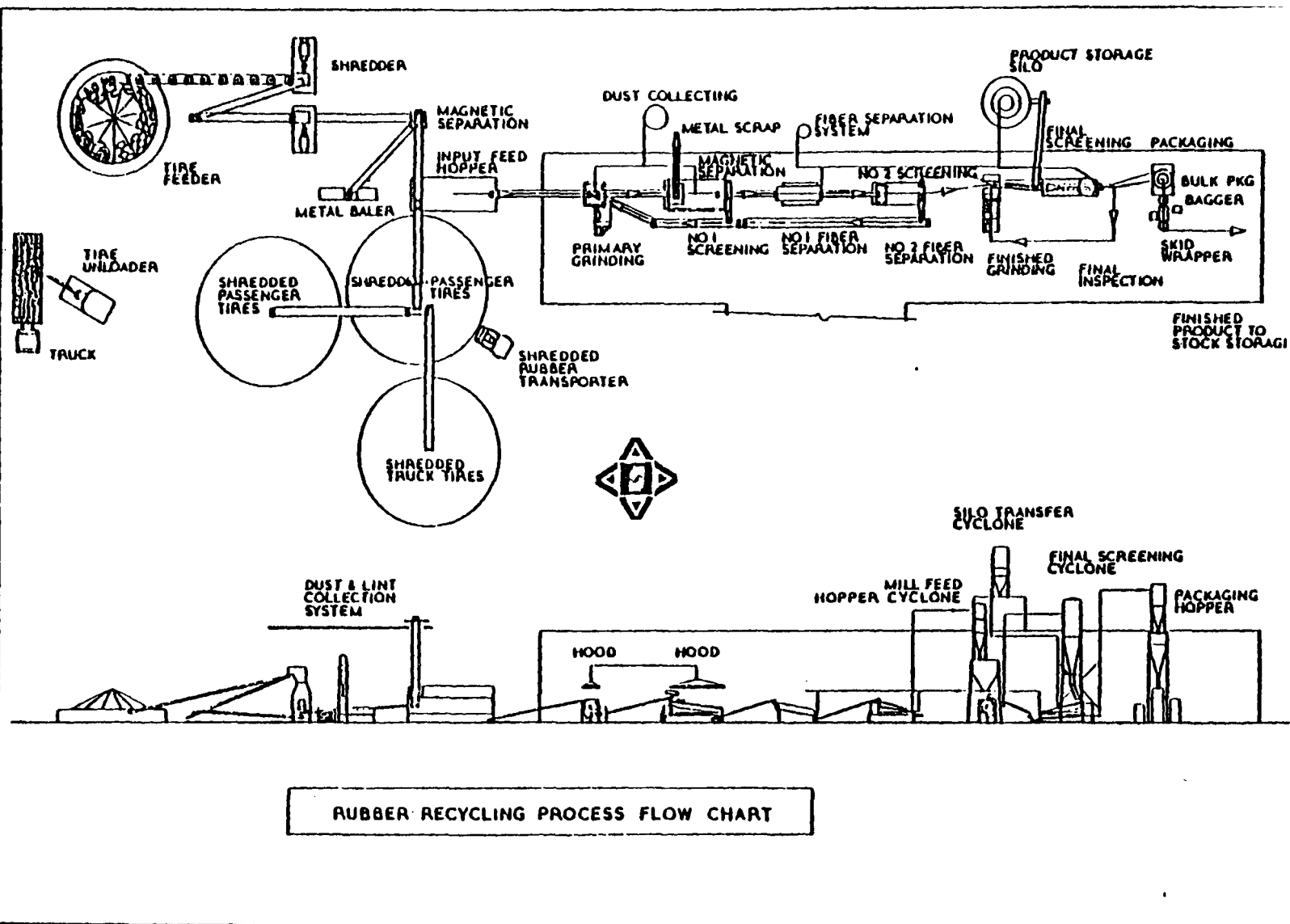
1. It is a clean, safe and cost-effective recycling facility that can be introduced throughout the United States and Canada without environmental concerns sometimes experienced;
2. It recycles nearly all waste tires and provides, in the process, for a wider range of product specifications to meet current and future asphalt/rubber technical requirements;
3. It is extremely energy effective, conserving nearly 90,000 BTUs for each pound of rubber placed in asphalt/rubber construction and/or maintenance.

GENSTAR Conservation Systems Inc.

RUBBER RECYCLING DIVISION



WASTE TIRE CONVERSION SYSTEM



ARM - R - SHIELD

CUTS RESURFACING COSTS IN HALF

SAVES ENERGY

CONSUMES OLD TIRES

/ / / / / / / / / / / / /

The key to such savings is in the design. A research study has shown that an Arm-R-Shield surface treatment, followed by a 3/4 inch thick conventional overlay, is as effective, and sometimes more effective, as four inches of regular asphalt concrete overlay when it comes to resisting reflective cracking. So, the thinner resultant structure reduces construction costs, even though Arm-R-Shield is more expensive than regular asphalt.

Cost savings using the Arm-R-Shield approach are recapped as follows:

	<u>Cost/S.Y.</u>	<u>Savings/S.Y.</u>	<u>% Savings</u>
Four-inch overlay	\$5.75	-	-
Arm-R-Shield Interlayer	2.59	\$3.16	55%

Note: Actual costs and savings may vary throughout the U. S.

Another plus is a construction energy savings equivalent to 8,200 gallons of diesel fuel per mile of pavement, 24 feet wide.

And, a disposal for about 1,280 old tires will be found per mile of pavement, 24 feet wide.

Even more money can be saved with the Arm-R-Shield approach because the thinner section ties into curb lines and utility holes in the pavement easier and has little effect on overhead clearances.

And, to top it all off, there should be additional savings due to the longer life of Arm-R-Shield.

Calculations for these claims are attached.

ESTIMATED COST COMPARISONS

ARM-R-SHIELD SAMI'S

vs.

OTHER ASPHALT HOT-MIX OVERLAYS

BASIC PREMISES -

1. Arm-R-Shield SAMI (stress absorbing membrane interlayer) applied at 0.6 hot gallons per square yard, plus 40 pounds of chips per square yard, plus a tack coat, plus a 3/4 inch thick 6% asphalt content open graded overlay, has the ability to resist reflective cracking (a) equal to a 4 inch thick hot-mix overlay placed in two lifts with two tack coat applications, and (b) far more effectively than a 2 inch thick hot-mix overlay placed in one lift with one tack coat application.
2. Arm-R-Shield SAMI applied at 0.6 hot gallons per square yard, plus 40 pounds of chips per square yard, plus a tack coat, plus a 3/4 inch thick open graded overlay using 7% Arm-R-Shield as a binder, is superior in ability to resist reflective cracking than a 4 inch thick hot-mix overlay placed in two lifts with two tack coat applications.

CONCLUSIONS -

1. The Arm-R-Shield approach, per Premise No. 1 above, will be about \$3.16 per square yard less than a 4 inch thick hot-mix overlay, and \$.29 per square yard less than a 2 inch thick hot-mix overlay.
2. The Arm-R-Shield approach, per Premise No. 2 above, will be about \$2.65 per square yard less than a 4 inch thick hot-mix overlay.

COSTS OF COMPONENTS USED IN COMPARISONS -

1. Arm-R-Shield SAMI applied at 0.6 gals./yd.², plus 40 lbs./yd.² of chips (Arizona Refining's experience) \$1.25/yd.²
2. SS or CSS Emulsion Tack Coat applied at 0.05 gals./yd.² (0.1 gals./yd.² undiluted) (\$300/ton) .06/yd.²

3. 3/4" thick open graded mix with 6% asphalt content (\$30/ton)	\$1.28/yd. ²
4. 3/4" thick open graded mix with 7% Arm-R-Shield as a binder (\$42/ton)	1.79/yd. ²
5. 4" thick hot-mix overlay (\$25/ton)	5.63/yd. ²
6. 2" thick hot-mix overlay (\$25/ton)	2.82/yd. ²

COST COMPARISONS -

<u>Premise No. 1</u>		<u>\$/Sq. Yd.</u>	
Arm-R-Shield SAMI with chips	-	\$1.25	
SS or CSS Tack Coat	-	.06	
3/4" thick open graded mix	-	<u>1.28</u>	
Total		\$2.59	
		<u>4" Overlay</u>	<u>2" Overlay</u>
Regular Overlays	-	\$5.63	\$2.82
SS or CSS Tack Coat(s)	-	<u>.12</u>	<u>.06</u>
Totals		\$5.75	\$2.88
Savings with Arm-R-Shield approach	-	\$3.16	\$.29

Premise No. 2

Arm-R-Shield SAMI with chips	-	\$1.25
SS or CSS Tack Coat	-	.06
3/4" thick open graded mix with Arm-R-Shield binder	-	<u>1.79</u>
Total		\$3.10
Total cost 4" overlay per Premise No. 1	-	\$5.75
Savings with Arm-R-Shield approach	-	\$2.65/sq. yd.

ESTIMATED ENERGY SAVINGS USING ARM-R-SHIELD

BASIC PREMISE -

Arm-R-Shield applied at 0.6 hot gallons per square yard, plus 40 pounds of chips per square yard, plus a tack coat, plus a 3/4 inch thick open graded overlay, is equivalent in ability to resist reflective cracking to a straight 4 inch thick hot-mix overlay, placed with 2 tack coats.

CONCLUSIONS -

	<u>BTU'S REQUIRED PER SQ. YD.</u>
Arm-R-Shield SAMI approach	30,601
Straight 4 inch thick overlay	111,412
BTU's savings per square yard	80,811
BTU's savings per mile of 24 foot wide road	1,137,819,000
Savings in diesel fuel per mile	8,200 gals.

C A L C U L A T I O N S

ARM-R-SHIELD SAMI PLUS 3/4 INCH THICK OPEN GRADED OVERLAY

BTU'S TO PRODUCE ASPHALT AND RUBBER - Asphalt Institute Publication MISC-75-3 estimates that it takes 587,000 BTU's to manufacture one ton of asphalt at a refinery. The energy consumption to produce one pound of rubber used in the Arm-R-Shield process is 843 BTU's per pound. For an average haul of 1,000 miles for the rubber to jobsite, an average of .009 gallons of diesel fuel per pound of rubber hauled will be consumed on the round trip, or at 1,251 BTU's per pound of rubber. The total rubber production and transportation will therefore consume about 2.094 BTU's per pound of rubber, or 4,188,000 BTU's per ton of rubber.

	<u>BTU'S/TON ARM-R-SHIELD</u>
78% asphalt @ 587,000 BTU's/ton	457,860
22% rubber @ 4,188,000 BTU's/ton	<u>921,360</u>
Total	1,379,220

Arm-R-Shield weighs about 7.75 pounds per hot gallon. At 0.6 hot gallons per square yard, there are about 4.65 pounds per square yard -

$$\frac{1,379,200 \text{ BTU's/ton}}{2,000 \text{ lbs.}} = 689 \text{ BTU's per pound}$$

$$689 \text{ BTU's/lb.} \times 4.65 \text{ lbs./yd.}^2 = 3,204 \text{ BTU's/yd.}^2$$

BTU'S TO MIX AND APPLY ARM-R-SHIELD - Arizona Refining's experience has been that one mixing tank plus two distributors will consume about 570 gallons of diesel fuel per day. Diesel fuel contains about 139,000 BTU's per gallon, so consumption is 79,230,000 BTU's per day. Average daily application is 100 tons, so consumption is 792,300 BTU's per ton. This is equal to 396 BTU's per pound. There are about 7.75 pounds per hot gallon for Arm-R-Shield x 0.6 hot gallons per square yard = 4.65 pounds per square yard. $396 \times 4.65 = 1,841$ BTU's per square yard.

COVER AGGREGATE AT 40 POUNDS PER SQUARE YARD - Asphalt Institute estimated a BTU consumption of 2,300 BTU's per square yard to produce, haul, apply and roll 20 pounds per square yard of chips. We are applying twice that amount, or 4,600 BTU's per square yard.

SS OR CSS EMULSIFIED ASPHALT TACK COAT - Asphalt Institute estimated that it takes 1,980 BTU's per gallon to manufacture these emulsions and 144 BTU's per gallon for distributor application for a total of 2,124 BTU's per gallon. Application of 0.05 gallons per square yard (0.1 gallons per square yard diluted) $\times 2124 = 106$ BTU's per square yard.

3/4 INCH THICK OPEN GRADED OVERLAY - Asphalt Institute estimated that it takes 27,800 BTU's per square yard per inch of thickness to manufacture all the components of hot mix, haul them to a plant, mix, haul to jobsite, lay and roll. $27,800 \times .75 = 20,850$ BTU's per square yard.

RECAP OF BTU CONSUMPTION FOR ARM-R-SHIELD SAMI
WITH 3/4 INCH THICK OPEN GRADED OVERLAY

	<u>BTU's/Sq. Yd.</u>
Manufacture of asphalt and rubber	3,204
Mixing and application of Arm-R-Shield	1,841
Manufacture and application of chips	4,600
Tack Coat	106
3/4" thick open-graded overlay	<u>20,850</u>
Total	30,601

FOUR INCH OVERLAY PLACED IN TWO LIFTS

Two Tack Coat Applications - Double the quantity in the above Arm-R-Shield SAMI calculation. $106 \times 2 = 212$ BTU's/yd.²

Four Inch Overlay - Asphalt Institute estimated that it takes 27,800 BTU's per square yard per inch thickness to manufacture all the mix components, haul them to a plant, mix, haul to jobsite, place and roll. $27,800 \times 4 = 111,200$ BTU's/yd.²

Recap of 4" Thick Overlay

	<u>BTU's/Sq. Yd.</u>
Tack Coat	212
4" thick overlay	<u>111,200</u>
Total	111,412

CONSUMPTION OF OLD TIRES WITH USE OF ARM-R-SHIELD

ARM-R-SHIELD MEMBRANE

Arm-R-Shield wt/hot gallon	-	7.75 lbs.
22% rubber content	-	1.71 lbs.
Arm-R-Shield application/hot gal.	-	0.6 gals./yd. ²
Rubber content/yd. ²	-	1,026 lbs.
Square yards in one mile road, 24' wide	-	14,080 yds. ²
Rubber used/mile of road - 24' wide	-	14,446 lbs.
Percent of tire rubber in rubber component	-	70%
Calculation of number of tires:		

$$\frac{40}{70} (20 \text{ lbs./tire} \times 80\%) + \frac{30}{70} (5 \text{ lb./tire}) = 11.29 \text{ lb/tire}$$

$$\frac{14,446 \text{ lbs.}}{11.29 \text{ lbs./tire}} = 1,280 \text{ tires per mile of 24' road.}$$

ARM-R-SHIELD IN OPEN GRADED MIX

Weight of 3/4" thick mix/yd. ²	-	84 lbs.
7% Arm-R-Shield content	-	5.88 lbs./yd. ²
Rubber content/yd. ²	-	1.29 lbs./yd. ²
Square yards in one mile road - 24' wide	-	14,080 yds. ²
Rubber used/mile of road - 24' wide	-	18,163 lbs.
Number of tires/mile of road - 24' wide:		

$$\frac{18,163 \text{ lbs.}}{11.29 \text{ lbs./tire}} = 1,609 \text{ tires per mile of 24' road.}$$

Appendix D

DATA AND CALCULATION - ESTIMATES OF ENERGY AND ENVIRONMENTAL IMPACTS OF SELECTED HIGHWAY CONSTRUCTION PRODUCTS MANUFACTURE AND INSTALLATION

INTRODUCTION

This summary is a brief compilation of the energy and environmental impacts of the manufacture and installation of selected highway construction products. A series of comparisons are presented whereby products of approximately equivalent quality and usefulness are compared. Three product categories treated quantitatively are common base course alternatives utilizing recovered materials as replacements for asphalt; asphalt bases using various recovered materials as replacements for aggregate; and asphalt rubber stress absorbing membranes as compared to conventional asphalt overlay. A qualitative analysis is included of fly ash used as a fill material, and asphalt rubber as a seal coat.

The impacts included here are for the manufacture and installation of the construction products. The possibility of pollutants leaching from the products after installation is a subject of experiments presently underway, and will be discussed later.

The basic methodology used was to analyze all steps in the manufacture and installation system for each product paying careful attention to each component. For example, the lime-fly ash-aggregate (LFA) system has three separate components--lime, fly ash, and aggregate. To analyze the lime system, the mining, processing, and transport of the limestone was included, as well as the manufacture and transport of the lime itself. Even the drilling of wells, transporting, and refining of fuels used in lime processing was included. Each other product component was also analyzed in detail.

In products that include asphalt, special consideration had to be made because of the fact that asphalt is made from a fuel resource. Contact with manufacturers revealed that asphalt is in fact a fuel resource. In fact,

when asphalt is not marketed for construction products, it is sold as a fuel. Thus, the placement of asphalt in a road causes a depletion of energy resources, just as if it had been burned. Thus, the fuel value of the asphalt was included as an energy impact in the subsequent calculations.

What follows is a brief summary of a set of comprehensive, lengthy, and complex calculations. However, the full details are discussed in the appendix, to which the interested reader is referred.

STABILIZED AND AGGREGATE BASE COURSE ALTERNATIVES

The two most common bases used under flexible pavements are aggregate bituminous (black base) and crushed stone (aggregate). To some extent portland cement stabilized bases are used, but they are more commonly used under rigid pavements and therefore frequently are not a viable alternative. Recently, recovered materials have been used in stabilized (or pozzolonic) bases. The most common application is a lime-fly ash-aggregate (LFA) base. However, other recovered materials can be used in LFA variations, such as boiler slag as a partial replacement for aggregate; cement or lime kiln dust as a replacement for lime; and incinerator residue as a replacement for aggregate.

For each of these options, a base of appropriate thickness was chosen for a typical pavement design, the details of which are in the appendix. The energy and environmental calculations were made for the materials needed to lay one mile of 2-lane highway. These calculations are summarized in Table D-1.

Table D-1

STABILIZED AND AGGREGATE BASE COURSE ALTERNATIVES
(One mile of 2-lane road)

	<u>Lime Fly Ash- Aggregate</u>	<u>Aggregate Bituminous</u>	<u>Crushed Stone</u>	<u>Aggregate Cement</u>	<u>Lime Fly Ash- Bottom Ash</u>	<u>Lime Fly Ash- Boiler Slag- Aggregate</u>	<u>Kiln Dust- Fly Ash- Aggregate</u>	<u>Kiln Dust- Incinerator Residue</u>
Thickness (inches)	9.0	6.7	12.9	9.0	9.0	9.0	9.0	10.5
Energy (10^9 Btu)	3.9	10.3	1.8	4.2	3.8	3.0	2.7	2.9
Air Pollution (10^3 lb)	123-160	60	117	116	43-72	72-102	104-166	18-38
Water Pollution (10^3 lb)	1.5	4.0	1.0	1.5	1.5	1.3	1.2	1.3
Processing Solid Waste (10^3 lb)	90.6	7.4	9.8	107	70.4	71.9	10.1	5.5
Materials Diverted from Waste (10^3 lb)	1,500	0	0	0	9,200	5,300	2,600	10,600

Source: Franklin Associates, Ltd.

There are many important conclusions which can be drawn from the table. It is clear that use of recovered materials can result in substantial energy savings as compared to the most widely used base--aggregate bituminous. The lowest energy use is for a crushed stone base, but this base type is not strictly competitive with the others listed as they are stabilized and develop strength with time whereas crushed stone does not. Thus, crushed stone is not always an alternative.

The first level of energy conservation is achieved when asphalt cement is replaced by lime and fly ash as the cementitious material. LFA, lime-fly ash-bottom ash and lime-fly ash-boiler slag-aggregate range in energy from 3.4 to 3.9×10^9 Btu, about one-third of the energy requirement of black base. Portland cement treated aggregate is also approximately in the same energy range as the bases using lime and fly ash.

Finally, the replacement of lime with another recovered material--kiln dust--results in still lower energy values of 2.7 to 2.9×10^9 Btu. This is only slightly more than one-quarter of the energy for black base.

Examining the air pollution category in Table D-1 shows that it is more complex to evaluate the use of recovered materials. Reference to the detailed appendix tables reveals that the dominant pollutant is particulates, primarily dusts from mining and crushing aggregates, and in the handling of fly ash. The use of recovered materials affects the use of aggregates, and therefore affects the amounts of particulates generated. In addition, dusting is a problem in the handling of fly ash, and varies greatly from situation to situation. Thus, the air pollution situation with respect to use of recovered materials is inconclusive.

Water pollution is generated in the systems studied primarily because of brines generated in oil field development. Thus, fuels or asphalt required generate indirect water pollution in this way. Because the black base requires substantially more petroleum-derived resources than the other bases, it results in the most water pollution.

The process solid wastes generated by the systems studied here are primarily solid residues from lime manufacture. Systems not requiring lime have relatively low solid waste. Thus, black base and the kiln dust bases result in less generation of solid waste.

In all cases where recovered material is used, the amount of material diverted from waste is much larger than processing wastes generated. The wastes diverted range from LFA and kiln dust-fly ash-aggregate where the recovered materials are only about 15 percent of the batch, to amounts as much as seven times as much where the base is entirely made from recovered materials. In any event, the use of recovered materials results in substantial amounts of diverted wastes.

In summary, it would appear that use of recovered materials for highway bases results in significantly less energy used as compared to the commonly used black base, but crushed stone bases require less energy than any other alternative. Also, less water pollution results from use of recovered materials and substantial diversion of materials from waste occurs. On the other hand, the processing solid wastes generated and the particulate air pollution may be either greater or less for recovered material use than for use of conventional materials, depending on particular applications.

ASPHALT BASE COURSE ALTERNATIVES

Previously, black base was considered in relation to alternative materials. But, recovered materials can be used in conjunction with asphalt as an aggregate replacement. However, in most cases the recovered materials have a higher surface area than conventional aggregates and are more absorptive, thus increasing the asphalt requirement. The result is that the use of recovered materials in conjunction with asphalt generally increases the energy and environmental impacts, as shown in Table D-2. The only possible exception is that recovered materials may result in marginally less particulate air pollution than conventional aggregates in some cases. Of course, the diversion from waste when recovered materials are used is a positive environmental factor for these options.

ASPHALT RUBBER AS STRESS ABSORBING MEMBRANE INTERLAYER (SAMI) OR SEAL COAT

Asphalt rubber is reported to be effective in absorbing stress and preventing crack reflection when used as a SAMI or as a seal coat. Table D-3 contains calculations based on a comparison suggested by an asphalt rubber supplier. The comparison is a three-quarter-inch SAMI to a conventional two-inch asphalt overlay. As shown, the asphalt rubber SAMI results in less impact in every category.

However, comparison of asphalt rubber to conventional asphalt is questionable. Most persons interviewed in the course of this study felt that asphalt rubber is a unique material, with characteristics quite different from conventional asphalt. Thus, the comparison in Table D-3 will not be valid in the majority of applications.

Table D-2

ASPHALT BASE COARSE ALTERNATIVES
(One mile of 2-lane road)

	<u>Asphalt Concrete</u>	<u>Asphalt- Incinerator- Residue- Aggregate</u>	<u>Asphalt- Boiler Slag- Aggregate</u>	<u>Asphalt- Bottom Ash</u>
Thickness (inches)	4.0	6.0	6.0	6.0
Energy (10^9 Btu)	7.1	13.1	15.8	16.2
Air Pollution (10^3 Btu)	37.3	34.2	41.4	4.9
Water Pollution (10^3 lb)	2.7	4.9	6.0	5.7
Processing Solid Wastes (10^3 lb)	4.8	5.4	6.6	5.5
Materials Diverted from Waste (10^3 lb)	0	3,100	4,100	7,600

Source: Franklin Associates, Ltd.

Table D-3

STRESS ABSORBING MEMBRANE INTERLAYER (SAMI) ALTERNATIVES
(One mile of 2-lane road)

	<u>Asphalt Concrete</u>	<u>Asphalt Rubber</u>
Energy (10^9 Btu)	9.1	5.9
Air Pollution (10^3 lb)	39.9	25.1
Water Pollution (10^3 lb)	3.5	2.3
Processing Solid Wastes (10^3 lb)	5.2	3.4
Materials Diverted from Waste (10^3 lb)	0	16

Source: Franklin Associates, Ltd.

FLY ASH AS A FILL MATERIAL

Fly ash may be used as a structural fill or embankment material as a replacement for dirt. In this application, fly ash is transported to the site and compacted in much the same way as dirt. The exception is that fly ash is less dense than dirt so that less fuel may be used in hauling. However, this may be easily offset by the fact that it may be hauled greater distances than would be dirt, and the fact that water must be added to achieve satisfactory compaction and for dust control. Also, care must be taken in the design and construction of the fill to ensure that there will be no problems from leaching. Encapsulating the fill with two feet or more of dirt is common to prevent any possible problem.

No data were found that indicated there would be any systematic process energy or environmental differences between fly ash and dirt. Thus, we conclude that any differences would be related to specific situations. However, the potential for diversion of fly ash from conventional disposal is quite significant. Even a moderate embankment or fill will use from one to three years of the total ash output of a typical power plant. In addition, the ash can be of variable quality which would make it unusable for other applications. Therefore, the potential for use is quite large, and subsequently the environmental benefits may be greater for this application than for any other application.

DATA AND CALCULATIONS

FOREWORD

The basic data for calculating the energy and environmental impacts associated with producing the different highway construction product mixtures, including data for the individual components which make up the mixtures, are presented in this report. The energy requirements and pollution factors used in this study include the handling, processing, transporting, and placing of the component materials and mix products. Many different sources of information were consulted for this study, in order to present an objective and accurate picture, though in some cases information was incomplete and assumptions had to be made. Nonetheless, all numbers and calculations are referenced or footnoted to enable examination or replication.

In order to present this detailed analysis in as simple a form as possible, it has been divided into two sections. First, the "Individual Components" section which describes the process and energy/environmental factors calculated for each specific material is presented, followed by the "Mixtures" section which contains information on the combinations of the individual components.

INDIVIDUAL COMPONENTS

The following 14 materials are discussed in this section:

- Limestone
- Lime
- Crushed stone
- Crude oil
- Asphalt cement
- Emulsified asphalt cement
- Asphalt aggregate
- Sand
- Portland cement
- Fly ash
- Bottom ash/boiler slag
- Lime and cement kiln dust
- Incinerator residue
- Waste rubber

A detailed breakdown of air and water pollution sources associated with the production of each of these materials is given at the conclusion of this section.

LIMESTONE MINING

Limestone is quarried primarily from open pits. The most economical method of recovering the stone has been blasting, followed by mechanical crushing and screening. According to the Bureau of Mines environmental problems plague these crushed stone producers more than any other mineral industry except sand and gravel. The reason for this is that limestone typically is mined quite close to the ultimate consumer, which frequently dictates that the mining operation be near, or even within, heavily populated areas. Hence, their environmental problems are accentuated by their high visibility.

The environmental consequences of limestone mining include: noise from heavy equipment and from blasting; dust from mining; crushing and screening; solid residues not properly disposed of; general unsightliness; and occasional contamination of streams. None of these problems is insurmountable and many quarries are presently operated in an acceptable fashion.

Data used to calculate the impacts are shown in Table D-4.

Table D-4

DATA FOR MINING 1,000 POUNDS LIMESTONE

		<u>Source*</u>
Energy		(15)
Coal	0.12 pound	
Distillate Oil	0.078 gallon	
Residual Oil	0.005 gallon	
Natural Gas	3.15 cubic feet	
Gasoline	0.021 gallon	
LPG	0.003 gallon	
Electricity	0.459 kwh	
Air Pollutants		(16, 19)
Particulates	6.55 pounds	
Nitrogen Oxides	0.15 pound	
Hydro Carbons	0.04 pound	
Sulfur Oxides	0.06 pound	
Carbon Monoxide	0.16 pound	
Other	0.01 pound	
Water Pollutants		(16, 19)
Dissolved Solids	0.05 pound	
Other	<0.01 pound	
Solid Waste	0.16 pound	(16, 19)
Transportation		(19)
Truck	21 ton-miles	
Rail	5 ton-miles	
Barge	13 ton-miles	

LIME MANUFACTURE

Lime is produced by calcining limestone. Limestone (calcium carbonate) is heated in a kiln to a high temperature so that any water present is driven off and the carbonate is broken up by the evolution of carbon dioxide. The product remaining is lime (calcium oxide). Significant environmental impacts occur due to fuel combustion and material losses. For 1,000 pounds of lime produced, approximately 800 pounds of carbon dioxide are released. An additional 200 pounds of material impacts the environment as solid waste and dust (particulate emission). The data are summarized in Table D-5.

* Sources are found in the Reference section at the end of this Appendix.

Table D-5

DATA FOR THE MANUFACTURE OF 1,000 POUNDS LIME

		<u>Source</u>
Energy		(15, 20)
Coal	113 pounds	
Distillate Oil	0.63 gallon	
Residual Oil	0.27 gallon	
Natural Gas	1,186 cubic feet	
Electricity	19.4 kwh	
Raw Materials		
Limestone	2,000 pounds	(19)
Air Pollutants		(16, 19)
Particulates	19.90 pounds	
Nitrogen Oxides	1.84 pounds	
Hydro Carbons	1.47 pounds	
Sulfur Oxides	3.87 pounds	
Carbon Monoxide	0.79 pound	
Other	0.03 pound	
Water Pollutants		(16, 19)
Dissolved Solids	0.39 pound	
Other	0.37 pound	
Solid Wastes	211.90 pounds	(16, 19)
Transportation		(19)
Rail	72 ton-miles	
Truck	27 ton-miles	

CRUSHED STONE

The initial step in the processing of crushed stone occurs at the quarry site. Rock and stone products are loosened by drilling and blasting from their deposit sites. Primary drilling, primary blasting, and secondary blasting or breakage comprise the principal steps in the quarry operation. The secondary blasting operation in many quarries is now either eliminated by better fragmentation during primary blasting, or by the use of "drop ball" cranes. Tractor-mounted air or hydraulic operated "rock-splitters" have proven satisfactory for some operations.

The broken rock or stone is transported from the quarry to the processing plant. Transport is usually by truck or heavy earth moving equipment. The processing of stone includes such operations as drying, crushing, pulverizing, screening, and conveying. Primary crushers will normally reduce stone to 1 to 3 inches in size. Secondary crushers are used to reduce stone to sizes below 1 inch. Following the processing operations, the stone or rock is loaded for shipment to the customer or sent to storage. Data used to calculate the impacts are shown in Table D-6.

Table D-6

DATA FOR PRODUCTION AND INSTALLATION OF 1,000 POUNDS OF CRUSHED STONE

		<u>Source</u>
Energy		(13)
Gasoline	0.015 gallon	
Diesel Fuel	0.043 gallon	
Electricity	2.33 kwh	
Air Pollutants <u>1/</u>		(10, 16)
Particulates	6.72 pounds	
Nitrogen Oxides	0.248 pound	
Hydrocarbons	0.062 pound	
Sulfur Oxides	0.084 pound	
Carbon Monoxide	0.11 pound	
Other	0.015 pound	
Water Pollutants <u>1/</u>		(10, 16)
Dissolved Solids	0.05 pound	
Other	0.01 pound	
Solid Waste	0.61 pound	(10, 16)
Transportation		
Truck	17.5 ton-miles	(13)
Spread and Compact		(13)
Diesel	0.06 gallon	

1/ Includes pollutants from mining, crushing, transportation, spreading, and compacting.

Crude Oil Production

Oil is produced by drilling holes into porous rock structures which contain oil. These rock strata are generally several thousand feet underground. Once an oil deposit is located, numerous holes are drilled and lined with steel casing. Some oil is brought to the surface by natural pressure in the rock structure, although most oil requires some energy to drive pumps which lift oil to the surface.

Once oil is on the surface, it is stored in tanks to await transportation to a refinery. Two significant impacts associated with the handling and storage of crude oil are the evaporation of hydrocarbons (air pollution) from the oil and the inappropriate disposal of "oil field brine" (water pollution) which accompanies crude oil from the ground and is separated at or near the well head.

Data for the production of crude oil are summarized in Table D-7. Transportation values are given for both foreign and domestically produced crude oil. It was assumed that 60 percent of the crude oil used will come from domestic sources and 40 percent from foreign sources.

Table D-7

DATA FOR THE PRODUCTION OF 1,000 POUNDS CRUDE OIL

		<u>Source</u>
Energy		(14)
Electricity	6.18 kwh	
Residual Oil	0.47 gallon	
Gasoline	0.02 gallon	
Natural Gas	287.2 cubic feet	
Air Pollutants		(14, 16)
Particulates	0.050 pound	
Nitrogen Oxides	0.355 pound	
Hydrocarbons	9.058 pounds	
Sulfur Oxides	0.284 pound	
Carbon Monoxide	0.152 pound	
Other	0.008 pound	
Water Pollutants		(14, 16)
Dissolved Solids	6.196 pounds	
Oil and Grease	0.110 pound	
Solid Wastes	2.181 pounds	
Transportation		(14)
Barge	28 ton-miles	
Truck	10 ton miles	
Pipeline	70.95 cubic feet	

Asphalt Cement Refining

Asphalt cement is refined from crude oil which contains approximately 4 percent asphalt. The asphalt and other heavy residuals remain behind after the lighter fractions are distilled off in the refining process. From here it receives further processing, depending upon specifications required, and handling and storage before being shipped out.

Estimates of overall energy consumption by refining process do exist, but can vary greatly from plant to plant. Many refineries do not measure fuel flow to individual processes, and those that do usually cannot pinpoint fuel consumption associated with each distillation process. However, according to two reliable sources (13, 25) the energy consumption attributed to asphalt cement refining is approximately 600,000 Btu per ton.

According to a number of refineries contacted, asphalt cement can be, and commonly is, mixed with diesel fuel or kerosene to produce a range of fuel oils from No. 2 to No. 6. Therefore, a fuel content equivalent to No. 2 fuel oil (diesel) has been assigned to all asphalt cement included in this report. Calculations are in reference 27. Table D-8 summarizes the asphalt cement refining data.

Table D-8

DATA FOR REFINING 1,000 POUNDS OF ASPHALT CEMENT

		<u>Source</u>
Energy		(9, 13, 14)
Electricity	4.05 kwh	
Natural Gas	234.8 cubic feet	
Air Pollutants		(14, 16)
Particulates	0.42 pound	
Nitrogen Oxides	0.526 pound	
Hydrocarbons	3.49 pounds	
Sulfur Oxides	3.66 pounds	
Carbon Monoxide	0.17 pound	
Other	0.20 pound	
Water Pollutants		(14, 16)
BOD	0.050 pound	
Phenol	0.014 pound	
Sulfides	0.018 pound	
Oil and Grease	0.03 pound	
COD	0.16 pound	
Suspended Solids	0.09 pound	
Dissolved Solids	0.11 pound	
Other	0.003 pound	
Solid Waste	1.07 pounds	(14, 16)
Transportation		
Truck	50 ton-miles	(13)
Energy Content	18.3×10^6 Btu	(27)

Emulsified Asphalt Cement Production

Emulsified asphalt is an emulsion of asphalt cement and water with a small amount of emulsifying agent. The asphalt content is generally between 55 and 65 percent by volume.

In an Asphalt Institute publication, the Asphalt Emulsion Manufacturers Association states that 1.2 to 3.6 kwh are required to make 1,000 pounds of emulsified asphalt. If the asphalt cement content is 60 percent, the energy to refine 600 pounds of asphalt must be added to this. Using these percentages along with information presented in Table D-8, Table D-9 was calculated.

Table D-9

DATA FOR 1,000 POUNDS OF EMULSIFIED ASPHALT CEMENT

		<u>Source</u>
Energy		(9, 13, 14)
Electricity	3.87 kwh	
Natural Gas	140.9 cubic feet	
Air Pollutants		(14, 16)
Particulates	0.244 pound	
Nitrogen Oxides	0.43 pound	
Hydrocarbons	2.065 pounds	
Sulfur Oxides	2.173 pounds	
Carbon Monoxide	0.162 pound	
Other	0.103 pound	
Water Pollutants		(14, 16)
BOD	0.030 pound	
Phenon	0.008 pound	
Sulfides	0.011 pound	
Oil and Grease	0.018 pound	
COD	0.096 pound	
Suspended Solids	0.054 pound	
Dissolved Solids	0.071 pound	
Other	0.002 pound	
Solid Wastes	1.625 pounds	(14, 16)
Transportation		
Truck	50 ton-miles	(13)
Energy Content	11.0 x 10 ⁶ Btu	(27)

ASPHALT AGGREGATE

Asphalt aggregate is generally a mixture of sand and gravel containing roughly 60 to 70 percent gravel. The process for producing the gravel component is the same as for crushed stone described on page D-13. Likewise, the data for mining sand can be found on this page. Table D-10 below represents a combination of the two separate components, 65 percent crushed stone and 35 percent sand.

Table D-10

DATA FOR PRODUCTION OF 1,000 POUNDS OF ASPHALT AGGREGATE

		<u>Source</u>
Energy		
Gasoline	0.013 gallon	(13)
Diesel	0.080 gallon	(13, 2)
Electricity	1.93 kwh	(13, 2)
Air Pollutants		(10, 16)
Particulates	4.387 pound	
Nitrogen Oxides	0.171 pound	
Hydrocarbons	0.028 pound	
Sulfur Oxides	0.064 pound	
Carbon Monoxide	0.075 pound	
Other	0.017 pound	
Water Pollutants		(16)
Dissolved Solids	0.032 pound	
Other	0.004 pound	
Solid Waste	0.497 pound	(16)
Transportation		
Truck	10 ton-miles	(13)

SAND MINING

Sand may be dredged from a river or quarried from deposits and then transferred by vehicle to the crushing and screening equipment. The material is frequently washed prior to processing to obtain a product which meets users' specifications. Following processing and classification, the material is loaded for shipment or stockpiled in storage areas.

In 1976, 6,162 sand deposits were being mined throughout the 50 states (1). Thus, everyone has relatively close access, keeping transportation impacts and costs low. Table D-11 summarizes the data.

Table D-11

DATA FOR MINING 1,000 POUNDS SAND

		<u>Source</u>
Energy		(2)
Diesel	0.052 gallon	
Electricity	1.217 kwh	
Air Pollutants		(11, 16)
Particulates	0.061 pound	
Nitrogen Oxides	0.142 pound	
Hydrocarbons	0.022 pound	
Sulfur Oxides	0.045 pound	
Carbon Monoxide	0.056 pound	
Other	0.002 pound	
Water Pollutants		(16)
Dissolved Solids	0.027 pound	
Other	0.002 pound	
Solid Waste	0.316 pound	(16)
Transportation		
Truck	10 ton-miles	(5)

PORTLAND CEMENT

Portland cement is made by mixing and calcining calcareous and argillaceous materials in the proper ratio. The principal minerals used for manufacturing cement are limestones, clays and shales, ferrous minerals, sand, and gypsum.

There are two methods used in producing portland cement, the wet process and the dry process. In the United States, 60 percent of the cement plants employ the wet process while the remaining 40 percent use the dry method (1, 10). In the wet process, the wet ground material is pumped in the form of a slurry containing about 40 percent water into a series of large mixing tanks and from these it is pumped into the kiln. In the dry process, the dry ground raw material is carried by a conveyor to the storage bins, and from the bins it is fed into the kiln. From the kiln to the finished product the cement making process is basically the same for the wet or dry process. There are differences in energy requirements for the two processes, but the figures presented in this report are based on the total energy consumption per ton of cement produced by the entire cement industry. Figure D-1 represents a materials and process flow diagram for the manufacture of portland cement. Table D-12 summarizes the energy and environmental factors for the national mixture of wet and dry cement.

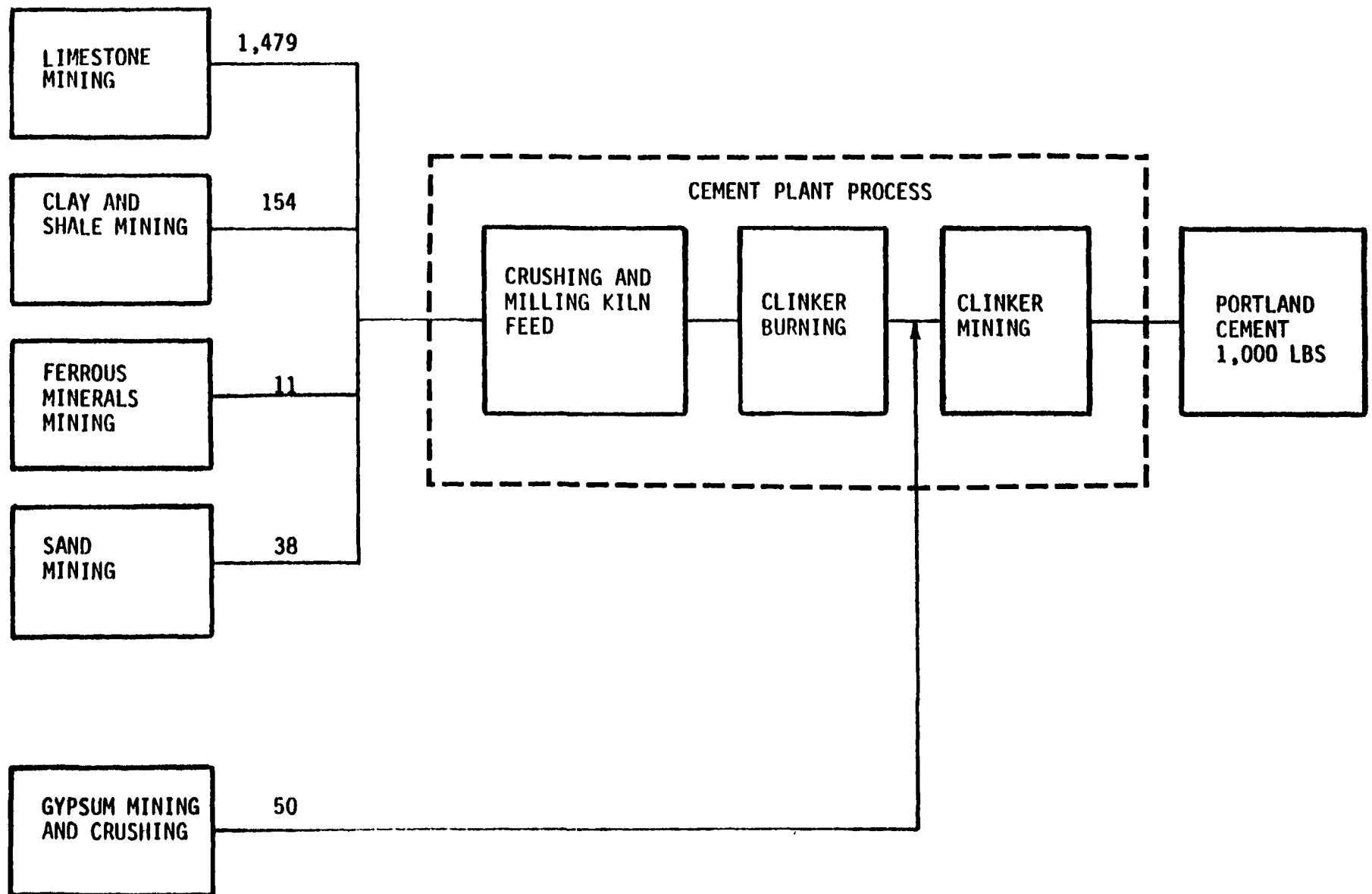


Figure D-1. Materials and process flow diagram for the manufacture of 1,000 pounds of portland cement.

Table D-12

DATA FOR PRODUCTION OF 1,000 POUNDS OF PORTLAND CEMENT

		<u>Source</u>
Energy		(1, 2)
Coal	135.4 pounds	
Natural Gas	964 cubic feet	
Residual Oil	2.3 gallons	
Electricity	70.7 kwh	
Air Pollutants		(10, 16)
Particulates	14.942 pounds	
Nitrogen Oxides	3.594 pounds	
Hydrocarbons	1.437 pounds	
Sulfur Oxides	10.317 pounds	
Carbon Monoxide	0.912 pound	
Other	0.029 pound	
Water Pollutants		(16)
Dissolved Solids	0.520 pound	
Others	0.507 pound	
Solid Waste	46.79 pounds	(16)
Kiln Dust	111 pounds	(23)
Transportation		
Truck	29 ton-miles	(18)
Rail	16 ton-miles	
Barge	16.5 ton-miles	

FLY ASH/BOTTOM ASH

The residual materials collected from the burning of coal at electric utility plants are referred to as power plant ash. These materials are produced in two forms: fly ash and bottom ash. Fly ash is the fine-grained dusty material from the combustion of ground or powdered coal that is recovered from boiler flue gases by means of electrostatic or mechanical collection systems. Bottom ash is the granular material, which, after coal combustion, collects in the ash hopper at the base of the boiler unit.

The relative amounts of fly ash and bottom ash produced at a particular power plant location are determined mainly by the design of the boiler units. However, as a general rule, 70 percent or more of all power plant ash is fly ash. According to statistics compiled by the National Ash Association, a total of 48.1 million tons of fly ash was collected in 1978.

Fly ash and bottom ash have been used in substantial quantities as highway construction materials. The applications for fly ash studied in this report are for structural fill and backfill and stabilization agent for highway and parking lot base courses. The applications studied for bottom ash are aggregate replacements in stabilized base course and asphalt base course mixtures.

In some cases, fly ash as generated by power plants, needs no further processing or preparation before being used in highway construction. However, it is common for fly ash with a high calcium content to set up and become hard, if stored as received. Therefore, in many cases fly ash is conditioned prior to storage. This involves dampening the fly ash and allowing a few days for the water to react with the pozzolanic components. Then the ash is processed through a pug mill, allowing it to be stored safely. Table D-13 summarizes the data for conditioning and transporting fly ash.

Table D-13

DATA FOR CONDITIONING AND TRANSPORTING
1,000 POUNDS OF FLY ASH

		<u>Source</u>
Energy		(21)
Electricity	1 kwh	
Handling		(13)
Gasoline	0.018 gallon	
Transportation		(24)
Truck	40 ton-miles	
Air Pollutants		(30)
Particulates	1-25 pounds	

Bottom ash, sometimes referred to as boiler slag, which is used as an aggregate replacement, is screened, sized, and separated similarly to a natural aggregate. Table D-14 summarizes the energy and environmental factors associated with processing 1,000 pounds of dry bottom ash or boiler slag.

Table D-14

DATA FOR PROCESSING 1,000 POUNDS DRY BOTTOM ASH OR BOILER SLAG

		<u>Source</u>
Energy		(2)
Conveying	0.75 kwh	
Screening	0.20 kwh	
Handling	0.018 gallon gasoline	(13)
Transportation	.	
Truck	40 ton-miles	(24)
Air Pollutants		(16)
Particulates	0.073 pound	
Nitrogen Oxides	0.482 pound	
Hydrocarbons	0.074 pound	
Sulfur Oxides	0.085 pound	
Carbon Monoxide	0.210 pound	
Other	0.009 pound	
Water Pollutants		(16)
Dissolved Solids	0.090 pound	
Other	0.004 pound	
Solid Waste	0.277 pound	(16)

LIME/CEMENT KILN DUST

Kiln dust is one of the major wastes of the cement and lime industries. The dust is generated in the kilns during the calcining process. In most plants the amount of dust is minimized in order to save energy and materials, but even under the best conditions with current technology, the dust produced is not likely to be less than 5 percent of production. Many plants, due to their particular equipment and raw materials, generate significantly more. A typical wet process plant produces from 150 to 250 tons of dust daily and often one-third of raw material is converted to dust, not clinker (23).

In this study, kiln dust is looked at as a pozzolonic binder for aggregate or incinerator residue base courses. Table D-15 summarizes the energy and environmental factors for delivering kiln dust.

Table D-15

DATA FOR DELIVERING 1,000 POUNDS OF LIME
OR CEMENT KILN DUST

		<u>Source</u>
Handling		(13)
Gasoline	0.018 gallon	
Transportation	.	
Truck	40 ton-miles	(24)
Air Pollutants		(16)
Particulates	1.25 pounds	
Nitrogen Oxides	0.472 pound	
Hydrocarbons	0.069 pound	
Sulfur Oxides	0.064 pound	
Carbon Monoxide	0.193 pound	
Other	0.008 pound	
Water Pollutants		(16).
Dissolved Solids	0.088 pound	
Other	0.003 pound	
Solid Waste	0.039 pound	(16)

INCINERATOR RESIDUE

Many municipalities throughout the United States employ incineration as a means for solving solid waste disposal problems. At the present time there are approximately 72 incinerator plants operating in this country, generating 10 to 12 million tons of residue yearly. An average of approximately 25 percent by weight of the original waste material still remains in the form of a non-combustible residue, after incineration. Therefore, some 2.5 to 3 million tons of this residue is available for use as base course aggregate. Like other aggregates, the incinerator residue must be screened, sized, and separated. The data for incinerator residue is summarized in Table D-16.

DATA FOR PROCESSING AND DELIVERING 1,000 POUNDS OF INCINERATOR RESIDUE

		<u>Source</u>
Energy		
Handling	0.018 gallon gasoline	(13)
Conveying	0.75 kwh	(2)
Screening	0.20 kwh	(2)
Transportation		
Truck	40 ton-miles	(24)
Air Pollutants		(16)
Particulates	0.028 pound	
Nitrogen Oxides	0.482 pound	
Hydrocarbons	0.074 pound	
Sulfur Oxides	0.085 pound	
Carbon Monoxide	0.210 pound	
Other	0.009 pound	
Water Pollutants		(16)
Dissolved Solids	0.090 pound	
Other	0.004 pound	
Solid Waste	0.277 pound	(16)

GROUND RUBBER

To produce the rubber component of asphalt-rubber mixtures from discarded truck and auto tires, the tires must go through a number of basic processes. These processes are shredding, metal and fabric removal, grinding, sizing, and packaging. The finished product consists of particles finer than 2mm and can be tailored to meet exacting specifications for synthetic or natural rubber content. Table D-17 summarizes the energy data for producing 1,000 pounds of ground rubber used in asphalt mixtures.

Table D-17

DATA FOR PRODUCING 1,000 POUNDS OF GRANULATED RUBBER

		<u>Source</u>
Energy		
Electricity	76.6 kwh	(26)
Air Pollutants		(16)
Particulates	0.635 pound	
Nitrogen Oxides	5.812 pounds	
Hydrocarbons	1.497 pounds	
Sulfur Oxides	2.496 pounds	
Carbon Monoxide	6.686 pounds	
Other	0.381 pound	
Water Pollutants		(16)
Dissolved Solids	1.398 pounds	
Other	0.168 pound	
Solid Waste	19.8 pounds	(16)
Transportation		
Truck	1,000 ton-miles	(28)

1/ Pollutants are the result of electricity generation and transportation.

Table D-18a

**DETAILED AIR AND WATER POLLUTANTS RESULTING FROM
THE PRODUCTION OF HIGHWAY ROAD CONSTRUCTION MATERIALS**
(All tables are based on 1,000 pounds of material)

		<u>Limestone Mining</u>				<u>Lime Manufacture</u>				<u>Portland Cement Concrete Batching</u>			
		<u>Process</u>				<u>Process</u>				<u>Process</u>			
		<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>
<u>Air Pollutants</u>													
Particulates	lbs	0.005	6.50	0.007	6.548	1.887	18.00	0.013	19.900	-	0.010	0.003	0.013
Nitrogen Oxides	lbs	0.015	-	0.135	0.150	1.541	-	0.303	1.844	0.003	-	0.177	0.180
Hydrocarbons	lbs	0.010	-	0.033	0.043	1.415	-	0.059	1.474	0.001	-	0.020	0.021
Sulfur Oxides	lbs	0.024	-	0.034	0.058	3.823	-	0.044	3.867	0.002	-	0.012	0.014
Carbon Monoxide	lbs	0.021	-	0.140	0.161	0.545	-	0.248	0.793	0.012	-	0.072	0.084
Other	lbs	0.001	-	0.008	0.009	0.014	-	0.014	0.028	0.001	-	0.006	0.007
<u>Water Pollutants</u>													
BOD	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Sulfides	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Grease	lbs	-	-	-	-	-	-	-	-	-	-	-	-
COD	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Suspended Solids	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Solids	lbs	0.010	-	0.036	0.046	0.328	-	0.065	0.393	0.001	-	0.020	0.021
Other	lbs	0.001	-	0.001	0.002	0.372	-	0.002	0.374	-	-	-	-
Solid Wastes	lbs	0.145	-	0.012	0.157	29.870	182.00	0.028	211.898	0.027	-	0.009	0.036

Source: Franklin Associates, Ltd.

Table D-18b

**DETAILED AIR AND WATER POLLUTANTS RESULTING FROM
THE PRODUCTION OF HIGHWAY ROAD CONSTRUCTION MATERIALS**
(All tables are based on 1,000 pounds of material)

		<u>Dry Bottom Ash</u>				<u>Emulsified Asphalt Cement</u>			
		<u>Process</u>				<u>Process</u>			
		<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>
<u>Air Pollutants</u>									
Particulates	lbs	0.004	0.050	0.019	0.073	0.021	0.210	0.013	0.244
Nitrogen Oxides	lbs	0.010	-	0.472	0.482	0.104	-	0.339	0.443
Hydrocarbons	lbs	0.005	-	0.069	0.074	0.155	1.860	0.050	2.065
Sulfur Oxides	lbs	0.021	-	0.064	0.085	0.087	2.040	0.046	2.173
Carbon Monoxide	lbs	0.017	-	0.193	0.210	0.023	-	0.139	0.162
Other	lbs	0.001	-	0.008	0.009	0.001	0.096	0.006	0.103
<u>Solid Wastes</u>	lbs	0.238	-	0.039	0.277	0.971	0.626	0.028	1.625
<u>Water Pollutants</u>									
BOD	lbs	-	-	-	-	-	0.030	-	0.030
Phenol	lbs	-	-	-	-	-	0.008	-	0.008
Sulfides	lbs	-	-	-	-	-	0.011	-	0.011
Oil and Grease	lbs	-	-	-	-	-	0.018	-	0.018
COD	lbs	-	-	-	-	-	0.096	-	0.096
Suspended Solids	lbs	-	-	-	-	-	0.054	-	0.054
Dissolved Solids	lbs	0.002	-	0.088	0.090	0.033	-	0.063	0.071
Other	lbs	0.001	-	0.003	0.004	0.006	-	0.002	0.002

Source: Franklin Associates, Ltd.

Table D-18c

**DETAILED AIR AND WATER POLLUTANTS RESULTING FROM
THE PRODUCTION OF HIGHWAY ROAD CONSTRUCTION MATERIALS**
(All tables based on 1,000 pounds of material)

		<u>Fly Ash</u>				<u>Lime-Fly Ash-Aggregate Batching</u>				<u>Sand Mining</u>			
		<u>Process</u>				<u>Process</u>				<u>Process</u>			
		<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>
<u>Air Pollutants</u>													
Particulates	lbs	0.005	1-25 lbs	0.019	1-25	0.006	1.55	0.004	1.560	0.007	0.050	0.004	0.061
Nitrogen Oxides	lbs	0.011	-	0.472	0.483	0.037	-	0.177	0.214	0.032	-	0.110	0.142
Hydrocarbons	lbs	0.005	-	0.069	0.074	0.009	-	0.019	0.028	0.006	-	0.016	0.022
Sulfur Oxides	lbs	0.022	-	0.064	0.086	0.025	-	0.012	0.037	0.030	-	0.015	0.045
Carbon Monoxide	lbs	0.017	-	0.193	0.210	0.028	-	0.072	0.100	0.011	-	0.045	0.056
Other	lbs	0.001	-	0.008	0.009	0.001	-	0.007	0.008	-	-	0.002	0.002
<u>Water Pollutants</u>													
Dissolved Solids	lbs	0.002	-	0.088	0.090	0.007	-	0.020	0.027	0.006	-	0.021	0.027
Other	lbs	0.001	-	0.003	0.004	0.001	-	0.001	0.002	0.002	-	-	0.002
<u>Solid Wastes</u>	lbs	0.251	-	0.039	0.290	0.253	-	0.009	0.262	0.307	-	0.009	0.316

Source: Franklin Associates, Ltd.

Table D-18d

DETAILED AIR AND WATER POLLUTANTS RESULTING FROM
THE PRODUCTION OF HIGHWAY ROAD CONSTRUCTION MATERIALS
 (All tables are based on 1,000 pounds of material)

		<u>Crushed Stone</u>				<u>Asphalt Cement Refining</u>				<u>Crude Oil Production</u>			
		<u>Process</u>				<u>Process</u>				<u>Process</u>			
		<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>
<u>Air Pollutants</u>													
Particulates	lbs	0.012	6.700	0.010	6.722	0.043	0.350	0.013	0.406	0.043	-	0.007	0.050
Nitrogen Oxides	lbs	0.041	-	0.207	0.248	0.187	-	0.339	0.526	0.237	-	0.118	0.355
Hydrocarbons	lbs	0.012	-	0.050	0.062	0.264	3.100	0.050	3.414	0.340	8.620	0.098	9.085
Sulfur Oxides	lbs	0.054	-	0.031	0.085	0.182	3.400	0.046	3.628	0.231	-	0.053	0.284
Carbon Monoxide	lbs	0.026	-	0.084	0.110	0.042	-	0.139	0.181	0.068	-	0.084	0.152
Other	lbs	0.001	-	0.014	0.015	0.002	0.160	0.006	0.168	0.004	-	0.004	0.008
<u>Water Pollutants</u>													
BOD	lbs	-	-	-	-	-	0.050	-	0.050	-	-	-	-
Phenol	lbs	-	-	-	-	-	0.014	-	0.014	-	-	-	-
Sulfides	lbs	-	-	-	-	-	0.018	-	0.018	-	-	-	-
Oil and Grease	lbs	-	-	-	-	-	0.030	-	0.030	-	0.110	-	0.110
Oil	lbs	-	-	-	-	-	0.160	-	0.160	-	-	-	-
Suspended Solids	lbs	-	-	-	-	-	0.090	-	0.090	-	-	-	-
Dissolved Solids	lbs	0.050	-	-	0.050	0.056	-	0.063	0.119	0.103	6.050	0.043	6.196
Other	lbs	0.010	-	-	0.010	0.001	-	0.002	0.003	0.010	-	-	0.010
<u>Solid Wastes</u>	<u>lbs</u>	<u>0.587</u>	<u>-</u>	<u>0.022</u>	<u>0.609</u>	<u>1.016</u>	<u>-</u>	<u>0.028</u>	<u>1.044</u>	<u>1.568</u>	<u>0.600</u>	<u>0.013</u>	<u>2.181</u>

Source: Franklin Associates, Ltd.

Table D-18a

**DETAILED AIR AND WATER POLLUTANTS RESULTING FROM
THE PRODUCTION OF HIGHWAY ROAD CONSTRUCTION MATERIALS**
(All tables are based on 1,000 pounds of material)

		<u>Asphalt Concrete Batching</u>				<u>Portland Cement</u>				<u>Asphalt Aggregate</u>			
		<u>Process</u>				<u>Process</u>				<u>Process</u>			
		<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>	<u>Fuels</u>	<u>Process</u>	<u>Transportation</u>	<u>Total</u>
<u>Air Pollutants</u>													
Particulates	lbs	0.013	0.050	0.010	0.073	2.431	12.50	0.011	14.942	0.010	4.372	0.005	4.387
Nitrogen Oxides	lbs	0.280	-	0.177	0.457	2.081	1.30	0.213	3.594	0.053	-	0.118	0.171
Hydrocarbons	lbs	0.115	-	0.026	0.141	1.386	-	0.051	1.437	0.011	-	0.017	0.028
Sulfur Oxides	lbs	0.046	-	0.026	0.072	5.755	4.50	0.062	10.317	0.048	-	0.016	0.064
Carbon Monoxide	lbs	0.122	-	0.072	0.194	0.683	-	0.229	0.912	0.027	-	0.048	0.075
Other	lbs	0.005	-	0.003	0.008	0.016	-	0.013	0.029	0.002	-	0.015	0.017
<u>Water Pollutants</u>													
BOD	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Sulfides	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Oil and Grease	lbs	-	-	-	-	-	-	-	-	-	-	-	-
COD	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Suspended Solids	lbs	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Solids	lbs	0.060	-	0.051	0.111	0.466	-	0.054	0.520	0.010	-	0.022	0.032
Other	lbs	0.003	-	0.001	0.004	0.506	-	0.001	0.507	0.003	-	0.001	0.004
<u>Solid Waste</u>	lbs	0.166	-	0.014	0.180	46.550	111.111	0.024	157.658	0.487	-	0.010	0.497

Source: Franklin Associates, Ltd.

PRODUCT MIXTURES

In this section, the combinations of the individual components making up the road construction materials, are presented. There are five separate application categories consisting of the alternate mixture products compared in this report. The list below summarizes the categories and mixture products.

SPECIFIC APPLICATIONS OF PRODUCTS FOR HIGHWAY AND ROAD CONSTRUCTION

	<u>Table</u>
A. Stabilized Base Course	D-22
1. Lime-fly ash-aggregate	D-22a
2. Aggregate bituminous	D-22a
3. Crushed stone	D-22b
4. Aggregate cement	D-22b
5. Lime-fly ash-bottom ash	D-22c
6. Lime-fly ash-boiler slag-aggregate	D-22d
7. Lime kiln dust/cement kiln dust- fly ash-aggregate	D-22c
8. Lime kiln dust-incinerator residue	D-22d
B. Asphalt Base Course	D-23
1. Asphalt-incinerator residue	D-23a
2. Asphalt-boiler slag-aggregate	D-23a
3. Asphalt-bottom ash	D-23b
4. Asphalt concrete	D-23b
C. Asphalt Seal Coat (SAM)	D-24
1. Asphalt emulsion	D-24a
2. Asphalt cement	D-24a
3. Asphalt rubber	D-24b
D. Stress Absorbing Membrane Interlayer (SAMI)	D-25
1. Asphalt rubber	D-25a
2. Asphalt cement	D-25b
E. Structural Fill and Embankment	
1. Fly ash with earth cover	
2. Earth fill	

Included within each category section is a:

- Energy and environmental profiles summary
- Material requirements flow chart
- Detailed breakdown of "Energy and Environmental Profiles" for each mixture product

The detailed energy and environmental profiles tables were calculated from the amount of material required, times the energy required and associated pollutants, which are found in the first section of this report, the Individual Components. For example, refer to Table 22a; Lime-Fly Ash-Aggregate category, Limestone Mining and Table 15a Limestone Mining. In Table D-22a, 1,215 tons of LFA require the mining of 72.8 tons of limestone to produce the necessary 36.4 tons of lime. The process and transportation energy requirements for 72.8 tons of limestone were calculated from the fuels consumed to produce 1,000 pounds of limestone, contained in Table D-3. The associated air and water pollutants were calculated from Table D-18a.

BATCHING, SPREADING, AND COMPACTING

The energy requirements for batching, spreading, and compacting the different pozzolanic mixtures are generally similar since the same basic process is used in each case. The processes include conveying the materials into a pugmill, operating the pugmill, then spreading and compacting the mixture. The energy requirements for batching the pozzolanic mixtures were calculated from information contained in Reference 21.

The handling, spreading, and compacting energy requirements were calculated from Reference 13. Table D-19 presents the data used for the pozzolanic mixtures in this section.

Table D-19

DATA FOR BATCHING, SPREADING, AND COMPACTING 1,000 POUNDS OF POZZOLANIC MIXTURES

		<u>Source</u>
Energy	1 kwh	(21)
Handling, Spreading, and Compacting		
Gasoline	0.018 gallon	(13)
Diesel	0.06 gallon	(13)
Transportation		
Truck	15 ton-miles	(22)

Table D-20 contains the energy and environmental factors for batching, spreading, and compacting 1,000 pounds of asphalt concrete.

Table D-20

DATA FOR BATCHING 1,000 POUNDS ASPHALT CONCRETE

		<u>Source</u>
Energy <u>1/</u>		(12, 13)
Diesel Fuel	0.60 gallon	
Gasoline	0.02 gallon	
Natural Gas	75.4 cubic feet	
Electricity	0.6 kwh	
Air Pollutants		(11, 16)
Particulates	0.073 pound	
Nitrogen Oxides	0.457 pound	
Hydrocarbons	0.141 pound	
Sulfur Oxides	0.072 pound	
Carbon Monoxide	0.194 pound	
Other	0.008 pound	
Water Pollutants		(16)
Dissolved Solids	0.111 pound	
Other	0.004 pound	
Solid Waste	0.180 pound	(16)
Transportation		(13)
Truck	15 ton-miles	

1/ Includes fuel for spreading and compacting.

Table D-21 summarizes the data for batching 1,000 pounds of asphalt rubber.

Table D-21

DATA FOR BATCHING 1,000 POUNDS ASPHALT RUBBER

		<u>Source</u>
Energy <u>1/</u>		(28, 13)
Diesel Oil	2.86 gallons	
Air Pollutants <u>2/</u>		(16)
Particulates	0.049 pound	
Nitrogen Oxides	1.238 pounds	
Hydrocarbons	0.181 pound	
Sulfur Oxides	0.168 pound	
Carbon Monoxide	0.506 pound	
Other	0.021 pound	
Water Pollutants		(16)
Dissolved Solids	0.231 pound	
Other	0.009 pound	
Solid Waste	0.103 pound	(16)

1/ Includes mixing and applying asphalt rubber and spreading and compacting aggregate.

2/ Pollutants are the result of burning process fuel only.

STABILIZED BASE COURSE

Eight stabilized base course product mixtures were chosen for comparison in this report. Equivalent thicknesses, based on average state base course thickness design coefficients, were calculated by Valley Forge Laboratories. Then from the known densities of these mixtures, the total tonnage of mixture required for 24,000 square feet of base course was calculated. A standard mix design for each of the products was determined by Valley Forge Laboratories, based on current, accepted practices.

Table D-22 summarizes the eight product mix designs, and total energy requirements for constructing 24,000 square feet of stabilized base course, which is 1,000 feet of two-lane highway.

Table D-22

ENERGY AND ENVIRONMENTAL PROFILES SUMMARY

	<u>Aggregate Bituminous</u> (6.7 Inches Aggregate 96%, Asphalt Cement 4%)	<u>Aggregate Cement</u> (9.0 Inches Aggregate 95%, Portland Cement 5%)	<u>Lime-Fly Ash-Aggregate</u> (9.0 Inches Lime 3%, Fly Ash 12%, Aggregate 85%)	<u>Lime-Fly Ash-Bottom Ash</u> (9.0 Inches Lime 3%, Fly Ash 12%, Bottom Ash 85%)
Materials Required - tons	905.0	1,215.0	1,215.0	960.0
Energy Consumed - 10 ⁶ Btu				
Process	1,777.527 ^{1/}	597.336	365.978	255.623
Transportation	212.703	202.623	385.623	468.151
Total	1,990.230	799.959	751.601	723.774
Air Pollutants - pounds				
Particulates	7,788.0	18,630.5	20,368.8-27,367.8	5,285.9-10,863.9
Nitrogen Oxides	1,188.9	1,102.4	1,329.1	1,444.0
Hydrocarbons	1,226.7	335.3	331.3	283.7
Sulfur Oxides	525.3	1,469.0	578.4	462.5
Carbon Monoxide	505.8	422.6	612.5	652.7
Other	56.8	41.0	56.2	35.0
Water Pollutants - pounds				
BOD	3.6	-	-	-
Phenol	1.0	-	-	-
Sulfides	1.3	-	-	-
Oil and Grease	2.2	-	-	-
COB	11.6	-	-	-
Suspended Solids	6.5	-	-	-
Dissolved Solids	727.3	199.5	230.4	249.4
Other	22.5	85.3	54.1	33.3
Solid Waste - pounds	1,427.7	20,360.0	17,428.0	13,338.7

^{1/} Includes 1,321.3 x 10⁶ Btu for fuel content of asphalt cement.

Source: Franklin Associates, Ltd.

Table D-22 (continued)

ENERGY AND ENVIRONMENTAL PROFILES SUMMARY

	<u>Lime-Fly Ash- Boiler Slag-Aggregate Lime 3%, Boiler Slag 40%, Fly Ash 12%, Aggregate 45%</u>	<u>LKD-Incinerator Residue (10.5 Inches, LKD 8%, IR 92%)</u>	<u>LKD/CKD-Fly Ash-Aggregate (9.0 Inches, Kilo Dust 8%, Aggregate 80%, Fly Ash 12%)</u>	<u>Crushed Stone (12.9 Inches)</u>
Materials Required - tons	968.0	1,000.0	1,215.0	1,548.0
Energy Consumed - 10 ⁶ Btu				
Process	274.657	71.102	129.022	108.360
Transportation	382.961	478.059	390.749	235.466
Total	657.618	549.161	519.771	343.826
Air Pollutants - pounds				
Particulates	11,078.5-16,656.5	911.5-4,751.5	17,343.3-29,000.3	20,811.3
Nitrogen Oxides	1,240.1	1,390.4	1,234.6	767.8
Hydrocarbons	273.2	203.2	223.5	191.9
Sulfur Oxides	462.4	240.6	292.6	263.1
Carbon Monoxide	565.5	617.3	555.5	340.5
Other	40.3	33.8	52.6	46.4
Water Pollutants - pounds				
Dissolved Solids	214.5	233.7	206.1	154.8
Other	38.5	11.9	26.0	30.9
Solid Waste - pounds	13,627.9	1,039.9	1,912.6	1,885.4

Source: Franklin Associates, Ltd.

Table D-22a

ENERGY AND ENVIRONMENTAL PROFILES FOR 24,000 SQUARE FEET OF STABILIZED BASE COURSE MATERIALS 1/

	Lime-Fly Ash-Aggregate (1,215 tons)						Aggregate Bituminous (905 tons)					
	Limestone Mining	Lime Manufacture	Fly Ash Processing	Aggregate Mining & Crushing	Batching, Spread, & Compact	Total	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Fuel Content	Aggregate Mining, & Crushing	Batching, Spread, & Compact	Total
Materials Required - tons	72.8	36.4	145.8	1,032.8	1,215.0		37.3	36.2	36.2	868.8	905.0	
Energy Consumed - 10 ⁶ Btu												
Process	3.887	229.320	3.997	72.296	56.478	365.978	34.558	21.720	1,321.3	61.831	338.075	1,777.527
Transportation	10.265	9.155	50.692	157.099	158.412	385.623	10.163	9.030	-	75.516	117.994	212.703
Total	14.152	238.475	54.689	229.395	214.890	751.601	44.721	30.750	1,321.3	137.347	456.069	1,990.230
Air Pollutants - pounds												
Particulates 2/	953.4	1,448.7	291-7,290	13,884.9	3,790.8	20,368.8-27,367.8	3.7	29.4	-	7,622.8	132.1	7,788.0
Nitrogen Oxides	21.8	134.2	140.8	512.3	520.0	1,329.1	26.5	38.1	-	297.1	827.2	1,188.9
Hydrocarbons	6.3	107.3	21.6	128.1	68.0	331.3	675.7	247.2	-	48.6	255.2	1,226.7
Sulfur Oxides	8.4	281.5	25.1	173.5	89.9	578.4	21.2	262.6	-	111.2	130.3	525.3
Carbon Monoxide	23.4	57.7	61.2	227.2	243.0	612.5	11.3	13.1	-	130.3	351.1	505.8
Other	1.3	2.0	2.6	30.9	19.4	56.2	0.6	12.2	-	29.5	14.5	56.8
Water Pollutants - pounds												
BOD	-	-	-	-	-	-	-	3.6	-	-	-	3.6
Phenol	-	-	-	-	-	-	-	1.0	-	-	-	1.0
Sulfides	-	-	-	-	-	-	-	1.3	-	-	-	1.3
Oil and Grease	-	-	-	-	-	-	-	2.2	-	-	-	2.2
COD	-	-	-	-	-	-	-	11.6	-	-	-	11.6
Suspended Solids	-	-	-	-	-	-	-	6.5	-	-	-	6.5
Dissolved Solids	6.7	28.6	26.2	103.3	65.6	230.4	462.2	8.6	-	55.6	200.9	727.3
Other	0.3	27.2	1.2	20.6	4.8	54.1	8.2	0.2	-	6.9	7.2	22.5
Solid Waste - pounds	22.8	15,426.2	84.5	1,257.9	636.6	17,428.0	162.7	75.6	-	863.6	325.8	1,427.7

1/ All materials are assumed transported to a permanent mixing plant for batching.

2/ Whenever a range is indicated, the lower figure is used in the total. Thus the total represents the minimum particulate pollutant figure.

Source: Franklin Associates, Ltd.

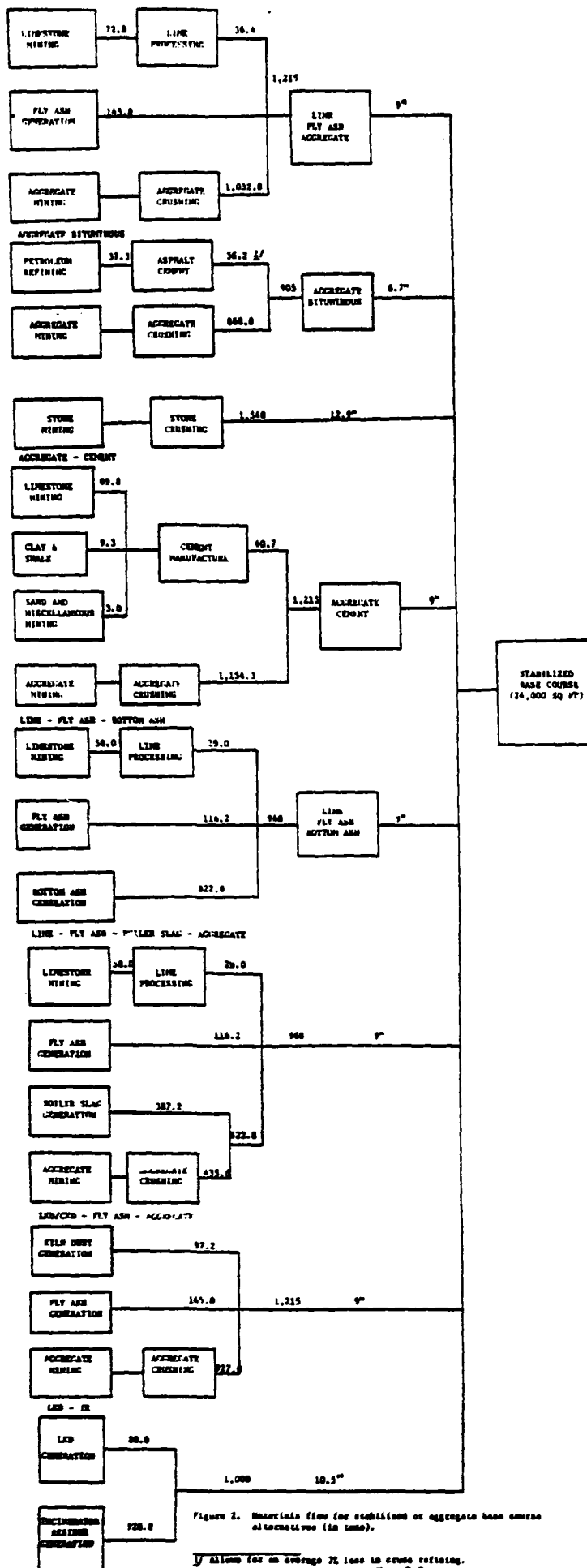


Figure 2. Materials flow for stabilized or aggregate base course alternatives (in tons).

U allows for an average 7% loss in crude refining.

Table D-22b

ENERGY AND ENVIRONMENTAL PROFILES FOR 24,000 SQUARE FEET OF STABILIZED BASE COURSE MATERIALS

	<u>Crushed Stone 1/ (1,548 tons)</u>	<u>Limestone Mining</u>	<u>Clay & Shale Mining 2/</u>	<u>Aggregate Cement (1,215 tons)</u>				<u>Total</u>
	<u>Mining & Crushing</u>			<u>Sand & Misc. Mining</u>	<u>Cement Mfg.</u>	<u>Aggregate 1/ Mining</u>	<u>Batching, Sprading, Compact</u>	
Materials Required - tons	1,548.0	89.8	9.3	3.0	60.7	1,154.3	1,215.0	
Energy Consumed - 10 ⁶ Btu								
Process	108.360	4.795	0.497	0.130	488.028	80.801	23.085	597.336
Transportation	235.466	12.662	1.311	0.261	12.809	175.580	-	202.623
Total	<u>343.826</u>	<u>17.457</u>	<u>1.808</u>	<u>0.391</u>	<u>500.837</u>	<u>256.381</u>	<u>23.085</u>	<u>799.959</u>
Air Pollutants - pounds								
Particulates	20,811.3	1,176.0	121.8	0.4	1,813.9	15,518.4	3/	18,630.5
Nitrogen Oxides	767.8	26.9	2.8	0.8	436.3	572.5	63.1	1,102.4
Hydrocarbons	191.9	7.7	0.8	0.1	174.4	143.1	9.2	335.3
Sulfur Oxides	263.1	10.4	1.1	0.3	1,252.5	196.2	8.5	1,469.0
Carbon Monoxide	340.5	28.9	3.0	0.3	110.7	253.9	25.8	422.6
Other	46.4	1.6	0.2	<0.1	3.5	34.6	1.1	41.0
Water Pollutants - pounds								
Dissolved Solids	154.8	8.2	0.8	0.2	63.1	115.4	11.8	199.5
Other	30.9	0.3	<0.1	<0.1	61.5	23.1	0.4	85.3
Solid Waste - pounds	1,885.4	28.2	2.9	1.9	19,155.7	1,405.9	5.3	20,560.0

1/ Figures include data for mining, crushing, transportation, spreading, and compacting.

2/ Same energy and pollution factors as limestone.

3/ Included in aggregate mining.

Source: Franklin Associates, Ltd.

Table D-22c

ENERGY AND ENVIRONMENTAL PROFILES FOR 24,000 SQUARE FEET OF STABILIZED BASE COURSE MATERIALS 1/

	<u>LKD/CKD-Fly Ash-Aggregate (1,215 tons)</u>					<u>Lime-Fly Ash-Bottom Ash (960 tons)</u>					<u>Total</u>
	<u>Kiln Dust</u>	<u>Fly Ash</u>	<u>Aggregate Mining & Crushing</u>	<u>Batch, Spread, & Compact</u>	<u>Total</u>	<u>Limestone Mining</u>	<u>Lime Processing</u>	<u>Fly Ash</u>	<u>Bottom Ash</u>	<u>Batch, Spread, & Compact</u>	
Materials Required - tons	97.2	145.8	972.0	1,215.0		58.0	29.0	116.2	822.8	968.0	
Energy Consumed - 10 ⁶ Btu											
Process	0.507	3.997	68.040	56.478	129.022	3.097	182.700	3.186	21.644	44.996	255.623
Transportation	33.794	50.692	147.851	158.412	390.749	8.178	7.294	40.400	286.071	126.208	468.151
Total	34.301	54.689	215.891	214.890	519.771	11.275	189.994	43.586	307.715	171.204	723.774
Air Pollutants - pounds											
Particulates	194-4,860	291-7,290	13,067.5	3,790.8	17,343-29,008	759.5	1,154.2	232-5,810	120.1	3,020.1	5,286-10,864
Nitrogen Oxides	91.7	140.8	482.1	520.0	1,234.6	17.4	106.9	112.2	793.2	414.3	1,444.0
Hydrocarbons	13.4	21.6	120.5	68.0	223.5	5.0	85.5	17.2	121.8	54.2	283.7
Sulfur Oxides	12.4	25.1	165.2	89.9	292.6	6.7	224.3	20.0	139.9	71.6	462.5
Carbon Monoxide	37.5	61.2	213.8	243.0	555.5	18.7	46.0	48.8	345.6	193.6	652.7
Other	1.5	2.6	29.1	19.4	52.6	1.0	1.6	2.1	14.8	15.5	35.0
Water Pollutants - pounds											
Dissolved Solids	17.1	26.2	97.2	65.6	206.1	5.3	22.8	20.9	148.1	52.3	249.4
Other	0.6	1.2	19.4	4.8	26.0	0.2	21.7	0.9	6.6	3.9	33.3
Solid Waste - pounds	7.6	84.5	1,183.9	636.6	1,912.6	18.2	12,290.1	67.4	455.8	507.2	13,338.7

1/ All materials are assumed transported to a permanent mixing plant for batching.

Source: Franklin Associates, Ltd.

Table D-22d

ENERGY AND ENVIRONMENTAL PROFILES FOR 24,000 SQUARE FEET OF STABILIZED BASE COURSE MATERIALS 1/

	<u>Lime-Fly Ash-Boiler Slag-Aggregate (968 tons)</u>							<u>LKD-Incinerator Residue (1,000 tons)</u>			
	<u>Limestone Mining</u>	<u>Lime Processing</u>	<u>Fly Ash</u>	<u>Boiler Slag</u>	<u>Aggregate Mining, & Crushing</u>	<u>Batch, Spread, & Compact</u>	<u>Total</u>	<u>Kiln Dust</u>	<u>Incinerator Residue</u>	<u>Batch, Spread, & Compact</u>	<u>Total</u>
Materials Required - tons	58.0	29.0	116.2	387.2	435.6	968.0		80.0	920.0	1,000.0	
Energy Consumed - 10 ⁶ Btu											
Process	3.097	182.700	3.186	10.186	30.492	44.996	274.657	0.417	24.201	46.484	71.102
Transportation	8.178	7.294	40.400	134.622	66.259	126.208	382.961	27.814	319.865	130.380	478.059
Total	11.275	189.994	43.586	144.808	96.751	171.204	657.618	28.231	344.066	176.864	549.161
Air Pollutants - pounds											
Particulates	759.5	1,154.2	232-5,810	56.5	5,856.2	3,020.1	11,078.5-16,656.5	160-4,000	51.5	700.0	911.5-4,751.5
Nitrogen Oxides	17.4	106.9	112.2	373.3	216.0	414.3	1,240.1	75.5	886.9	428.0	1,390.4
Hydrocarbons	5.0	85.5	17.2	57.3	54.0	54.2	273.2	11.0	136.2	56.0	203.2
Sulfur Oxides	6.7	224.3	20.0	65.8	74.0	71.6	462.4	10.2	156.4	74.0	240.6
Carbon Monoxide	18.7	46.0	48.8	162.6	95.8	193.6	565.5	30.9	386.4	200.0	617.3
Other	1.0	1.6	2.1	7.0	13.1	15.5	40.3	1.3	16.5	16.0	33.8
Water Pollutants - pounds											
Dissolved Solids	5.3	22.8	20.9	69.7	43.5	52.3	214.5	14.1	165.6	54.0	233.7
Other	0.2	21.7	0.9	3.1	8.7	3.9	38.5	0.5	7.4	4.0	11.9
Solid Waste - pounds	18.2	12,290.1	67.4	214.5	530.5	507.2	13,627.9	6.2	509.7	524.0	1,039.9

1/ All materials are assumed transported to a permanent mixing plant for batching.

Source: Franklin Associates, Ltd.

ASPHALT BASE COURSE

Four asphalt base course products were chosen for comparison in this category. Equivalent thicknesses based on average state base course thickness design coefficients were calculated by Valley Forge Laboratories. Then from the known densities of these mixtures, the total tonnage of mixture required for 24,000 square feet of base course was calculated. A standard mix design for each of the products was determined by Valley Forge Laboratories, based on current, accepted practices. In all these products compared to asphalt concrete, the recovered materials serve only as substitutes for aggregate.

Table D-23 summarizes the four product mix designs and total energy requirements for constructing 24,000 square feet of asphalt base course.

Table D-23

ENERGY AND ENVIRONMENTAL PROFILES SUMMARY

	<u>Asphalt-Boiler Slag-Aggregate</u> (6.0 Inches Asphalt Cement 8%, Boiler Slag 46%, Aggregate 46%)	<u>Asphalt-Dry</u> <u>Bottom Ash</u> (6.0 Inches Asphalt Cement 8%, Dry 92%)	<u>Asphalt-Incin-</u> <u>erator Residue</u> (6.0 Inches Incinerator Residue 46%, Aggregate 46%, Asphalt Cement 8%)	<u>Asphalt Concrete</u> (4.0 Inches Asphalt Cement 4.5%, Aggregate 95.5%)
Materials Required - tons	780.0	780.0	645.0	560.0
Energy Consumed - 10 ⁶ Btu				
Process	2,700.874 <u>1/</u>	2,684.778 <u>2/</u>	2,233.426 <u>3/</u>	1,206.173 <u>4/</u>
Transportation	290.686	384.248	240.378	132.841
Total	2,991.560	3,069.026	2,473.804	1,339.014
Air Pollutants - pounds				
Particulates	3,340.9	257.4	2,759.0	4,797.8
Nitrogen Oxides	1,292.7	923.6	1,069.4	739.6
Hydrocarbons	1,889.4	1,913.9	1,562.5	832.9
Sulfur Oxides	712.3	658.6	589.0	348.1
Carbon Monoxide	549.1	1,046.3	454.1	314.5
Other	53.0	99.4	47.1	37.6
Water Pollutants - pounds				
BOD	6.2	6.2	5.1	2.5
Phenol	1.7	1.7	1.4	0.7
Sulfides	2.2	2.2	1.9	0.9
Oil and Grease	17.8	17.8	14.8	7.2
COD	19.9	19.9	16.5	8.1
Suspended Solids	11.2	11.2	9.3	4.5
Dissolved Solids	1,070.9	1,017.8	885.9	485.4
Other	12.3	9.5	10.2	8.9
Solid Wastes - pounds	1,242.5	1,050.2	1,027.5	900.0

Asphalt cement energy content for each product is as follows:

1/ 2,277.6 x 10⁶ Btu.

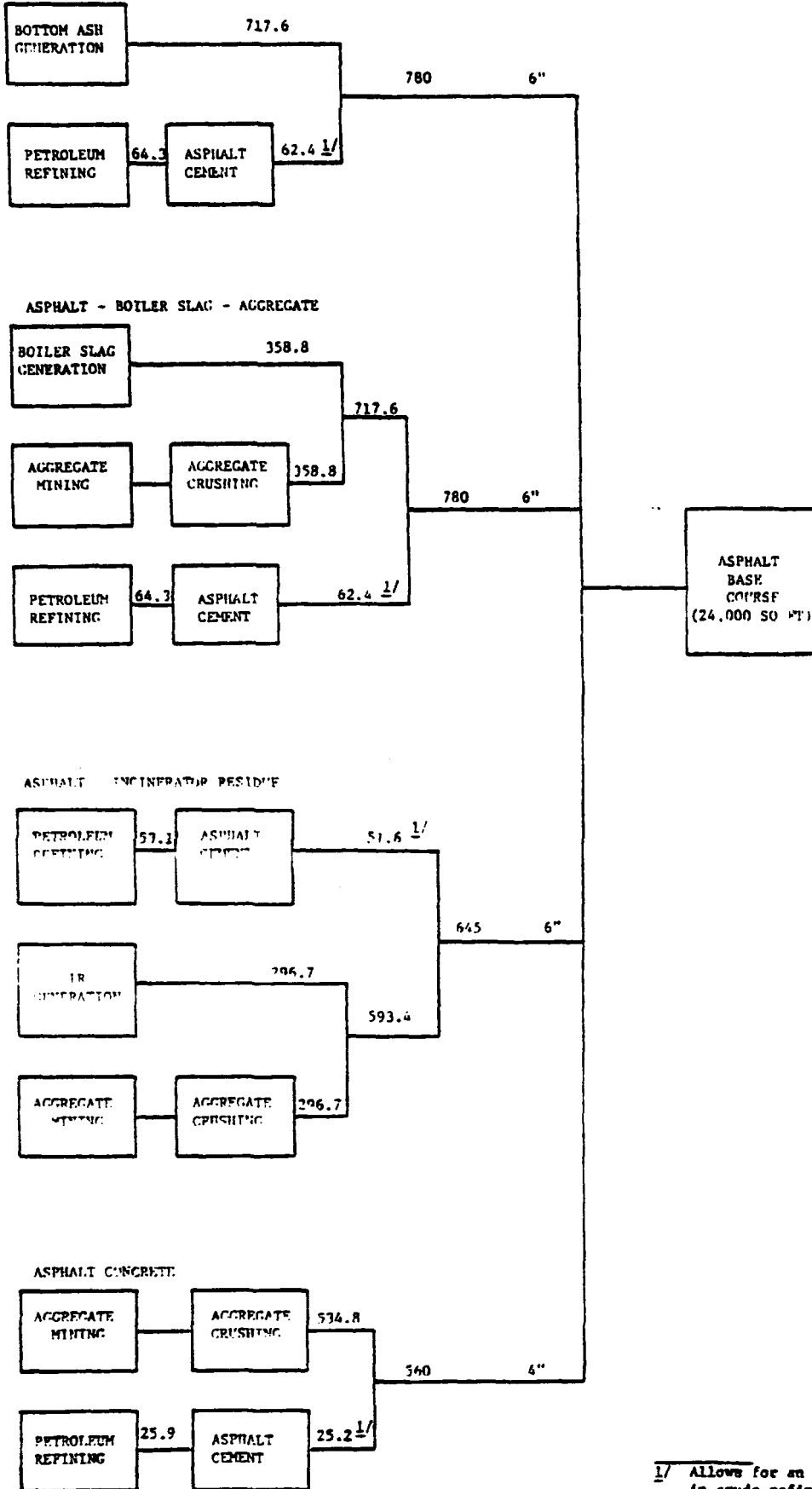
2/ 2,277.6 x 10⁶ Btu.

3/ 1,883.4 x 10⁶ Btu.

4/ 918.8 x 10⁶ Btu.

Source: Franklin Associates, Ltd.

ASPHALT - DRY BOTTOM ASH



^{1/2} Allows for an average 3% loss in crude refining.

* Numbers represent tons required.

Figure D-3. Materials flow for asphalt base alternatives (in tons).

Table D-23a

**ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF ASPHALT BASE COURSE MATERIALS**

	Asphalt-Boiler Slag-Aggregate (780 tons)							Asphalt-Incinerator Residue (645 tons)						
	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Energy Content	Boiler Slag	Aggregate Mining, & Crushing	Batch, Spread, & Compact	Total	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Energy Content	Incinerator Residue	Aggregate Mining, & Crushing	Batching, Spread, & Compact	Total
Materials Required - tons	64.2	62.4	62.4	358.8	358.8	780.0		53.1	51.6	51.6	296.7	296.7	645.0	
Energy Consumed - 10 ⁶ Btu														
Process	59.481	37.440	2,277.6	9.438	25.535	291.380	2,700.874	49.197	30.960	1,883.4	7.805	21.115	240.949	2,233.426
Transportation	17.492	15.565	-	124.747	31.186	101.696	290.686	14.467	12.871	-	103.156	25.789	84.095	240.378
Total	76.973	53.005	2,277.6	134.185	56.721	393.076	2,991.560	63.664	43.831	1,883.4	110.961	46.904	325.044	2,473.804
Air Pollutants - pounds														
Particulates	6.4	52.4	-	20.1	3,148.1	113.9	3,340.9	5.3	43.3	-	13.0	2,603.2	94.2	2,759.0
Nitrogen Oxides	45.6	65.6	-	345.9	122.7	712.9	1,292.7	37.7	54.3	-	286.0	101.5	589.9	1,069.4
Hydrocarbons	1,163.0	435.5	-	30.9	20.1	219.9	1,889.4	961.9	360.1	-	42.1	16.6	181.8	1,562.5
Sulfur Oxides	36.4	456.8	-	60.9	45.9	112.3	712.3	30.1	377.7	-	50.4	37.9	92.9	589.0
Carbon Monoxide	19.5	22.5	-	150.7	53.8	302.6	549.1	16.1	18.7	-	124.6	44.5	250.2	434.1
Other	1.0	20.9	-	6.4	12.2	12.5	53.0	0.8	20.6	-	5.3	10.1	10.3	47.1
Water Pollutants - pounds														
BOD	-	6.2	-	-	-	-	6.2	-	5.1	-	-	-	-	5.1
Phenol	-	1.75	-	-	-	-	1.75	-	1.44	-	-	-	-	1.4
Sulfides	-	2.24	-	-	-	-	2.24	-	1.86	-	-	-	-	1.8
Oil & Grease	14.1	3.74	-	-	-	-	17.84	11.7	3.09	-	-	-	-	14.8
COD	-	19.97	-	-	-	-	19.97	-	16.51	-	-	-	-	16.5
Suspended Solids	-	11.23	-	-	-	-	11.23	-	9.29	-	-	-	-	9.3
Dissolved Solids	795.5	14.8	-	64.6	22.9	173.1	1,070.9	658.0	12.3	-	53.4	19.0	143.2	885.9
Other	-	0.4	-	2.9	2.8	6.2	12.3	-	0.3	-	2.4	2.4	5.1	10.2
Solid Wastes - pounds	280.0	133.53	-	191.6	356.6	280.8	1,242.5	231.6	110.4	-	158.4	294.9	232.2	1,027.5

V Transportation figures for recovered materials are based on 40 mile transport distance.

Source: Franklin Associates, Ltd.

Table D-23b

ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF ASPHALT BASE COURSE MATERIALS

	Asphalt Concrete (560 tons)						Asphalt-Dry Bottom Ash (780 tons)					
	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Energy Content	Aggregate Mining, & Crushing	Asphalt Concrete Batch & Spread	Total	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Energy Content	Dry Bottom Ash 1/ Batching, Spread & Compact	Total	
Materials Required - tons	25.9	25.2	25.2	534.8	560.0		64.2	62.4	62.4	717.6	780.0	
Energy Consumed - 10 ⁶ Btu												
Process	23.996	15.120	919.8	38.061	209.196	1,206.173	59.481	37.440	2,277.6	18.877	291.380	2,684.778
Transportation	7.057	6.286	-	46.485	73.013	132.842	17.492	15.565	-	249.495	101.696	384.248
Total	31.053	21.406	919.8	84.546	282.209	1,339.014	76.973	53.005	2,277.6	268.372	393.076	3,069.026
Air Pollutants - pounds												
D-47 Particulates	2.6	21.2	-	4,692.3	81.7	4,797.8	6.4	52.4	-	84.7	113.9	257.4
Nitrogen Oxides	18.4	26.5	-	182.9	511.8	739.6	45.6	65.6	-	183.7	628.7	923.6
Hydrocarbons	469.2	175.9	-	29.9	157.9	832.9	1,163.0	435.5	-	31.5	283.9	1,913.9
Sulfur Oxides	14.7	184.4	-	68.4	80.6	348.1	36.4	456.8	-	53.1	112.3	658.6
Carbon Monoxide	7.9	9.1	-	80.2	217.3	314.5	19.5	22.5	-	93.3	911.0	1,046.3
Other	0.4	10.1	-	18.2	8.9	37.6	1.0	20.9	-	22.9	54.6	99.4
Water Pollutants - pounds												
BOD	-	2.5	-	-	-	2.5	-	6.2	-	-	-	6.2
Phenol	-	0.7	-	-	-	0.7	-	1.75	-	-	-	1.75
Sulfides	-	0.9	-	-	-	0.9	-	2.24	-	-	-	2.24
Oil & Grease	5.7	1.5	-	-	-	7.2	14.1	3.74	-	-	-	17.84
COD	-	8.1	-	-	-	8.1	-	19.97	-	-	-	19.97
Suspended Solids	-	4.5	-	-	-	4.5	-	11.23	-	-	-	11.23
Dissolved Solids	320.9	6.0	-	34.2	124.3	485.4	795.5	14.8	-	34.4	173.1	1,017.8
Other	-	0.1	-	4.3	4.5	8.9	-	0.4	-	2.9	6.2	9.5
Solid Wastes - pounds	112.9	53.9	-	531.6	201.6	900.0	280.0	133.53	-	355.9	280.8	1,050.2

1/ Transportation figures for recovered materials are based on 40 mile transport distance.

Source: Franklin Associates, Ltd.

ASPHALT SEAL COATS

Three asphalt seal coat products were chosen for comparison in this category. Mix designs and material requirements were determined by Valley Forge Laboratories, based on past and present practice.

Table D-24 summarizes the three product mix designs and total energy requirements for laying 24,000 square feet of seal coat.

Table D-24

ENERGY AND ENVIRONMENTAL PROFILES SUMMARY

	<u>Asphalt Concrete</u> (2.0 Inches Asphalt Cement 6%, Aggregate 94%)	<u>Asphalt Rubber</u> (Asphalt Rubber 10%, Aggregate 90%)	<u>Asphalt Emulsion</u> (Asphalt Emulsion 8%, Aggregate 92%)
Materials Required - tons	290.0	59.5	36.4
Energy Consumed - 10^6 Btu			
Process	789.857 <u>1/</u>	235.608 <u>2/</u>	87.226 <u>3/</u>
Transportation	70.721	14.247	8.939
Total	860.578	249.855	96.165
Air Pollutants - pounds			
Particulates	2,450.0	479.6	299.2
Nitrogen Oxides	389.2	192.2	48.7
Hydrocarbons	540.1	145.8	59.7
Sulfur Oxides	213.0	70.9	24.0
Carbon Monoxide	165.1	92.6	20.7
Other	19.9	7.1	2.3
Water Pollutants - pounds			
BOD	1.7	0.5	0.2
Phenol	0.5	0.1	<0.1
Sulfides	0.6	0.2	0.1
Oil & Grease	4.9	1.3	0.5
COD	5.5	1.5	0.6
Suspended Solids	3.1	0.8	0.3
Dissolved Solids	307.4	94.6	34.5
Other	4.6	2.0	0.7
Solid Waste - pounds	490.6	158.8	64.7

Asphalt cement energy content for each product is as follows:

- 1/ 635.1×10^6 Btu.
2/ 167.9×10^6 Btu.
3/ 68.2×10^6 Btu.

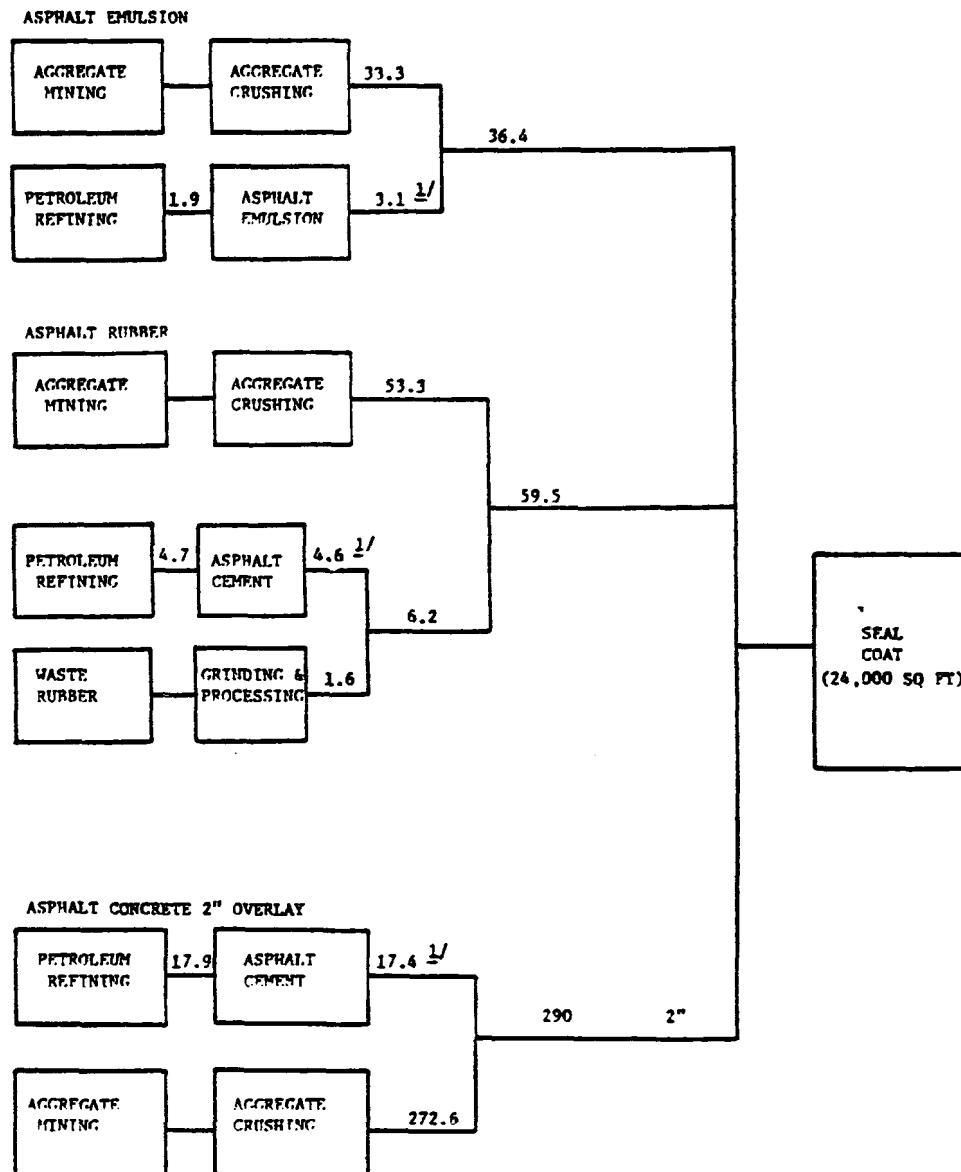


Figure D-4. Materials flow for seal coat alternatives (in tons).

^{1/} Allows for an average 1% loss in crude refining.
 * Numbers represent tons required.

Table D-24a
ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF SEAL COAT MATERIALS

	Asphalt Emulsion (36.4 tons)						Asphalt Concrete (290 tons)					
	Crude Oil Production	Asphalt Emulsion Production	Asphalt Cement Energy Content	Aggregate Mining & Crushing	Batch, Spread & Compact	Total	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Energy Content	Aggregate Mining, & Crushing	Batch, Spread, & Compact	Total
Materials Required - tons	1.93	3.1	1.87	33.3	36.4		17.9	17.4	17.4	272.6	290.0	
Energy Consumed - 10 ⁶ Btu												
Process	1.788	1.215	68.255	2.370	13.598	87.226	16.584	10.440	635.1	19.400	108.333	789.857
Transportation	0.526	0.773	-	2.894	4.746	8.939	4.877	4.340	-	23.694	37.810	70.721
Total	2.314	1.988	68.255	5.264	18.354	96.165	21.461	14.780	635.1	43.094	146.143	860.578
Air Pollutants - pounds												
Particulates	0.2	1.5	-	292.2	5.3	299.2	1.8	14.1	-	2,391.8	42.3	2,450.0
Nitrogen Oxides	1.4	2.7	-	11.4	33.2	48.7	12.7	18.3	-	93.2	265.0	389.2
Hydrocarbons	34.9	12.8	-	1.8	10.2	59.7	324.3	118.8	-	15.2	81.8	540.1
Sulfur Oxides	1.1	13.5	-	4.2	5.2	24.0	10.2	126.2	-	34.9	41.7	213.0
Carbon Monoxide	0.6	1.0	-	5.0	14.1	20.7	5.4	6.3	-	40.9	112.5	165.1
Other	<0.1	0.6	-	1.1	0.6	2.3	0.3	5.8	-	9.2	4.6	19.9
Water Pollutants - pounds												
BOD	-	0.2	-	-	-	0.2	-	1.7	-	-	-	1.7
Phenol	-	0.05	-	-	-	0.05	-	0.5	-	-	-	0.5
Sulfides	-	0.07	-	-	-	0.07	-	0.6	-	-	-	0.6
Oil & Grease	0.4	0.1	-	-	-	0.5	3.9	1.0	-	-	-	4.9
COB	-	0.6	-	-	-	0.6	-	5.5	-	-	-	5.5
Suspended Solids	-	0.3	-	-	-	0.3	-	3.1	-	-	-	3.1
Dissolved Solids	23.9	0.4	-	2.1	8.1	34.5	221.8	3.8	-	17.4	64.4	307.4
Other	-	0.01	-	0.3	0.3	0.7	-	0.1	-	2.2	2.3	4.6
Solid Waste - pounds	8.4	10.1	-	33.1	13.1	64.7	78.1	37.2	-	270.9	104.4	490.6

Source: Franklin Associates, Ltd.

Table D-24b

ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF SEAL COAT MATERIALS

	Asphalt Rubber (59.5 tons)						
	<u>Crude Oil</u> <u>Production</u>	<u>Asphalt</u> <u>Cement</u> <u>Refining</u>	<u>Asphalt</u> <u>Cement</u> <u>Energy Content</u>	<u>Rubber</u> <u>Processing</u>	<u>Aggregate</u> <u>Mining,</u> <u>& Crushing</u>	<u>Batch,</u> <u>Spread, &</u> <u>Compact</u>	<u>Total</u>
Materials Required - tons	4.7	4.6	4.6	1.6	53.3	59.5	
Energy Consumed - 10 ⁶ Btu							
Process	4.354	2.760	167.9	2.721	3.793	54.080	235.608
Transportation	1.280	1.147	-	7.187	4.633	1/	14.247
Total	5.634	3.907	167.9	9.908	8.426	54.080	249.855
Air Pollutants - pounds							
Particulates	0.5	3.7	-	2.0	467.6	5.8	479.6
Nitrogen Oxides	3.3	4.8	-	18.6	18.2	147.3	192.2
Hydrocarbons	85.1	31.4	-	4.8	3.0	21.5	145.8
Sulfur Oxides	2.7	33.4	-	8.0	6.8	20.0	70.9
Carbon Monoxide	1.4	1.6	-	21.4	8.0	60.2	92.6
Other	0.1	1.5	-	1.2	1.8	2.5	7.1
Water Pollutants - pounds							
BOD	-	0.5	-	-	-	-	0.5
Phenol	-	0.1	-	-	-	-	0.1
Sulfides	-	0.2	-	-	-	-	0.2
Oil & Grease	1.0	0.3	-	-	-	-	1.3
COD	-	1.5	-	-	-	-	1.5
Suspended Solids	-	0.8	-	-	-	-	0.8
Dissolved Solids	58.2	1.0	-	4.5	3.4	27.5	94.6
Other	-	<0.1	-	0.5	0.4	1.1	2.0
Solid Wastes - pounds	20.5	9.8	-	63.3	53.0	12.2	158.8

1/ Transportation factors included in asphalt cement refining column.

Source: Franklin Associates, Ltd.

STRESS ABSORBING MEMBRANE/INTERLAYER

In this category two products were selected for comparison, a four-inch layer of asphalt concrete versus a layer of asphalt rubber and aggregate with a two-inch overlay of conventional asphalt concrete. The asphalt rubber mix design and energy requirements are based on data supplied by Arizona Refinery Company, gathered from their experience with Arm-R-Shield, the trade name of their asphalt rubber. Table D-25 summarizes the mix design and energy data.

Table D-25

ENERGY AND ENVIRONMENTAL PROFILES SUMMARY

	<u>Asphalt Concrete</u> (4.0 Inches Asphalt Cement 6%, Aggregate 94%)	<u>Asphalt Rubber with 2-Inch Asphalt</u> <u>Concrete Overlay</u> (Asphalt Rubber 0.6 gal/yd ² Aggregate 40 lb/yd ² , Asphalt Concrete 290 tons)
Materials Required - tons	580.0	
Energy Consumed - 10 ⁶ Btu		
Process	1,579.717 <u>1/</u>	1,025.295 <u>2/</u>
Transportation	<u>141.443</u>	<u>84.519</u>
Total	1,721.160	1,109.814
Air Pollutants - pounds		
Particulates	4,900.1	2,929.5
Nitrogen Oxides	778.5	580.3
Hydrocarbons	1,080.1	685.6
Sulfur Oxides	426.1	283.3
Carbon Monoxide	330.3	256.3
Other	40.1	26.9
Water Pollutants - pounds		
BOD	3.5	2.2
Phenol	1.0	0.6
Sulfides	1.2	0.7
Oil & Grease	9.9	6.2
COD	11.1	7.0
Suspended Solids	6.2	3.9
Dissolved Solids	614.9	401.7
Other	9.1	6.4
Solid Wastes - pounds	981.3	645.4

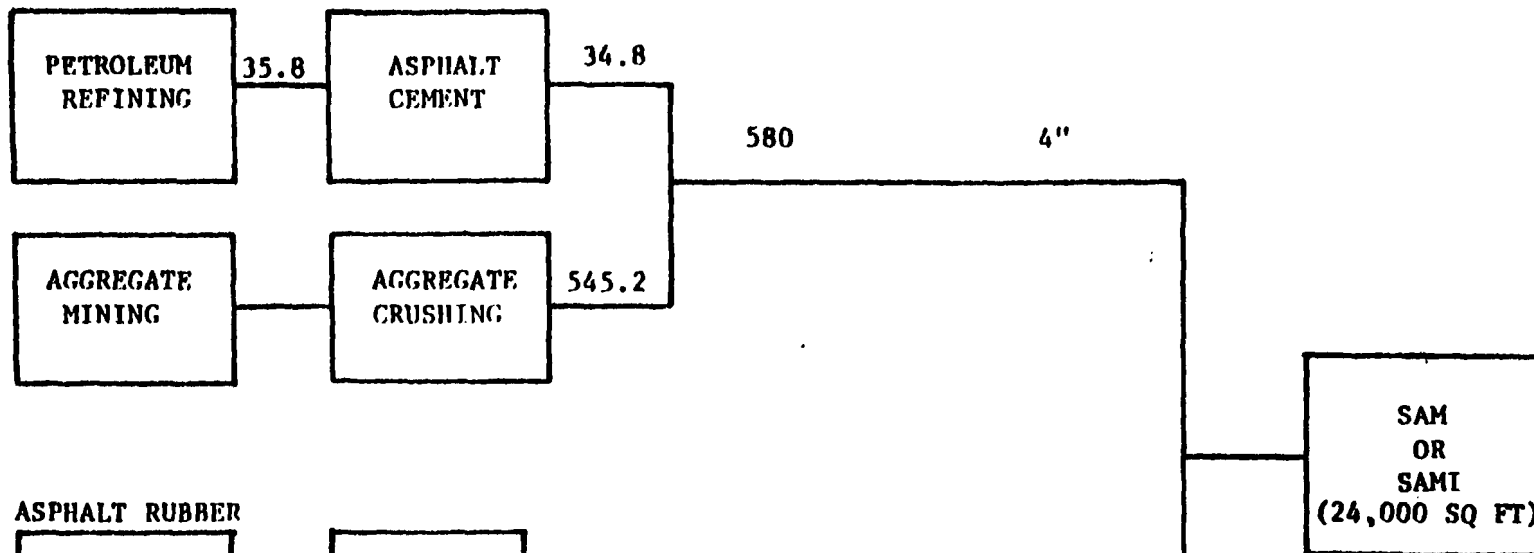
Asphalt cement energy content for each product is as follows:

1/ 1,270.2 x 10⁶ Btu.

2/ 803.0 x 10⁶ Btu.

Source: Franklin Associates, Ltd.

ASPHALT CONCRETE



ASPHALT RUBBER

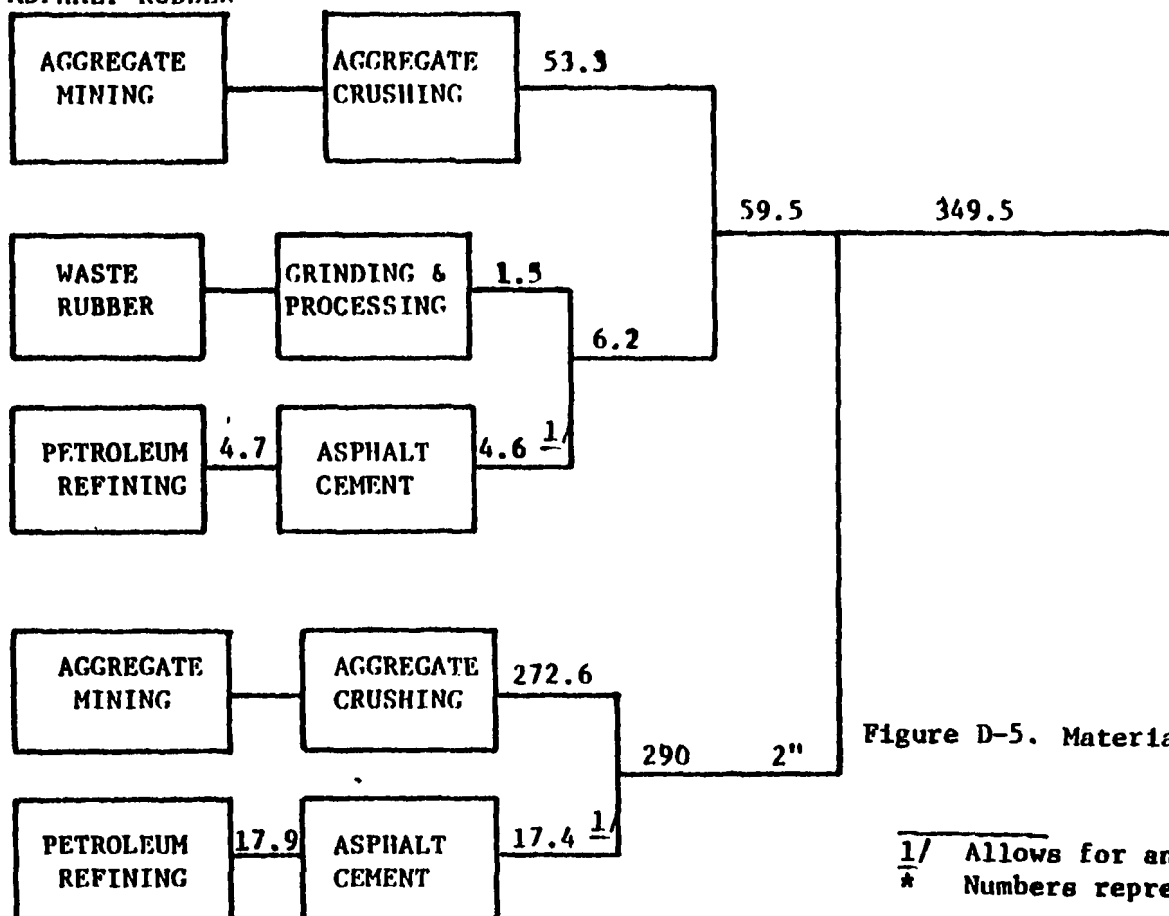


Figure D-5. Materials flow for SAM or SAMI (in tons).

^{1/} Allows for an average 3% loss in crude refining.
 * Numbers represent tons required.

Table D-25a

**ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF STRESS ABSORBING MEMBRANE MATERIALS**

	Asphalt Rubber with 2" Asphalt Concrete Overlay											
	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Fuel Content	Waste Rubber Processing	Aggregate Mining, & Crushing	Batch, Spread, & Compact	Crude Oil Production	Asphalt Cement Refining	Asphalt Cement Fuel Content	Aggregate Mining, & Crushing	Batch, Spread, & Compact	Total
Materials Required - tons	4.7	4.6	4.6	1.5	53.3	59.5	17.9	17.4	17.4	272.6	290.0	
Energy Consumed - 10 ⁶ Btu												
Process	4.354	2.760	167.9	2.551	3.793	54.080	16.584	10.440	635.1	19.400	108.333	1,025.295
Transportation	1.280	1.147	-	6.738	4.633	1/	4.877	4.340	-	23.694	37.810	84.519
Total	5.634	3.907	167.9	9.289	8.426	54.080	21.461	14.780	635.1	43.094	146.143	1,109.814
Air Pollutants - pounds												
Particulates	0.5	3.7	-	1.9	467.6	5.8	1.8	14.1	-	2,391.8	42.3	2,929.5
Nitrogen Oxides	3.3	4.8	-	17.4	18.2	147.3	12.7	18.3	-	93.2	265.1	580.3
Hydrocarbons	85.1	31.4	-	4.5	3.0	21.5	324.3	118.8	-	15.2	81.8	685.6
Sulfur Oxides	2.7	33.4	-	7.5	6.8	20.0	10.1	126.2	-	34.9	41.7	283.3
Carbon Monoxide	1.4	1.6	-	20.0	8.0	60.2	5.4	6.3	-	40.9	112.5	256.3
Other	0.1	1.5	-	1.1	1.8	2.5	0.3	5.8	-	9.2	4.6	26.9
Water Pollutants - pounds												
BOD	-	0.5	-	-	-	-	-	1.7	-	-	-	2.2
Phenol	-	0.1	-	-	-	-	-	0.5	-	-	-	0.6
Sulfides	-	0.1	-	-	-	-	-	0.6	-	-	-	0.7
Oil & Grease	1.0	0.3	-	-	-	-	3.9	1.0	-	-	-	6.2
COD	-	1.5	-	-	-	-	-	5.5	-	-	-	7.0
Suspended Solids	-	0.8	-	-	-	-	-	3.1	-	-	-	3.9
Dissolved Solids	58.2	1.0	-	4.2	3.4	27.5	221.8	3.8	-	17.4	64.4	401.7
Other	-	40.1	-	0.5	0.4	1.1	-	0.1	-	2.2	2.3	6.4
Solid Waste - pounds	20.5	9.8	-	59.4	52.9	12.2	78.1	37.2	-	270.9	104.4	645.4

1/ Transportation factors included in asphalt cement refining column.

Source: Franklin Associates, Ltd.

Table D-25b

ENERGY AND ENVIRONMENTAL PROFILES FOR
24,000 SQUARE FEET OF STRESS ABSORBING MEMBRANE MATERIALS

	Asphalt Cement (580 tons)					
	<u>Crude Oil</u> <u>Production</u>	<u>Asphalt</u> <u>Cement</u> <u>Refining</u>	<u>Asphalt</u> <u>Cement</u> <u>Fuel Content</u>	<u>Aggregate</u> <u>Mining,</u> <u>& Crushing</u>	<u>Batch,</u> <u>Spread,</u> <u>& Compact</u>	<u>Total</u>
Materials Required - tons	35.8	34.8	34.8	545.2	580.0	
Energy Consumed - 10 ⁶ Btu						
Process	33.169	20.880	1,270.2	38.801	216.667	1,579.717
Transportation	9.754	8.680	-	47.389	75.620	141.443
Total	<u>42.923</u>	<u>29.560</u>	<u>1,270.2</u>	<u>86.190</u>	<u>292.287</u>	<u>1,721.160</u>
Air Pollutants - pounds						
Particulates	3.6	28.2	-	4,783.6	84.7	4,900.1
Nitrogen Oxides	25.4	36.6	-	186.4	530.1	778.5
Hydrocarbons	648.5	237.6	-	30.5	163.5	1,080.1
Sulfur Oxides	20.3	252.5	-	69.8	83.5	426.1
Carbon Monoxide	10.9	12.6	-	81.8	225.0	330.3
Other	0.6	11.7	-	18.5	9.3	40.1
Water Pollutants - pounds						
BOD	-	3.5	-	-	-	3.5
Phenol	-	1.0	-	-	-	1.0
Sulfides	-	1.2	-	-	-	1.2
Oil & Grease	7.9	2.0	-	-	-	9.9
COD	-	11.1	-	-	-	11.1
Suspended Solids	-	6.2	-	-	-	6.2
Dissolved Solids	443.6	7.6	-	34.9	128.8	614.9
Other	-	0.2	-	4.3	4.6	9.1
Solid Wastes - pounds	156.1	74.5	-	541.9	208.8	981.3

Source: Franklin Associates, Ltd.

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- (2) "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4 and 5 Energy Data and Flowsheets)," Battelle Columbus Laboratories.
- (3) Reding, J. T., "Energy Consumption: Paper/Stone/Clay/Glass/Concrete and Food Industries," Dow Chemical Company.
- (4) "Impact of Proposed Energy Deregulation/Tax Program on Six Energy Intensive Industries," prepared by Industrial Programs, Energy Conservation and Environment, Federal Energy Administration.
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- (6) "Energy and Environmental Impacts Associated With a Federal Trade Commission Decision," prepared by Franklin Associates, Ltd. for The Pepsi-Cola Bottling Company.
- (7) "Regulations for the Control of Sulfur Oxide Emissions," APCA Critical Reviews, January 1974.
- (8) Gutt, W. and Nixon, P. J., "Use of Waste Materials in the Construction Industry," Analysis of the RILEM Symposium by correspondence.
- (9) "Industrial Energy Study of the Petroleum Refining Industry," Sobotka and Company, 1974.
- (10) "Particulate Pollutant System Study," Volume III Handbook of Emission Properties, Midwest Research Institute.
- (11) "Compilation of Air Pollutant Emission Factors," Second Edition, Part B, Environmental Protection Agency.
- (12) "Bituminous Construction Handbook," published by the Barber Green Company.

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- (16) Pollutants were calculated by Franklin Associates, Ltd.
- (17) Assumed to require the same energy as that for crushing rock in cement plants.
- (18) U.S. Census of Transportation, 1972.
- (19) Hunt, R. G., et al, "Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives," Volume II, Midwest Research Institute for U.S. Environmental Protection Agency, Report SW-91c, 1974.
- (20) Myers, J. G., et al, "Energy Consumption in Manufacturing," the Conference Board for the Energy Policy Project of the Ford Foundation, Ballinger Publishing Co., Cambridge, Massachusetts, 1974.
- (21) "Material and Energy Conservation with Pozzolanic Aggregate Mixture (PAM)," Dick Merkel, P.E., Executive Secretary, American Pozzolanic Concrete Association, presented at the IPCA Pozzolanic Aggregate Mixture Workshop Seminar, Chicago, Illinois, April 1-2, 1980.

Mr. Merkel's figure of 7,000 Btu/ton for mixing PAM was converted to 2 kwh/ton on the basis of approximately 3,500 Btu/kwh.
- (22) Adjusted to be the same as asphalt concrete.
- (23) Sell, Nancy J., and Fischbach, Fritz, "The Economic and Energy Costs of Dust Handling in the Cement Industry," Resource Recovery and Conservation 3(1979) 331-342.
- (24) Forty miles was considered a maximum economical hauling distance for truck transport.
- (25) Nelson, W. L., "Guide to Refining Operating Costs," Petroleum Publishing Co., Tulsa, Oklahoma, 1970.

- (26) Rubber grinding energy number provided by Genstar Conservation Systems, Inc., Phoenix, Arizona.
- (27) U.S. Department of Energy, Monthly Energy Review, July 1980
DOE/EIA 0035/80(07).
 6.636×10^6 Btu/bbl = 36.5×10^6 Btu/ton.
- (28) Arizona Refining Company publication, "Arm-R-Shield, Cuts Re-surfacing Costs in Half."
- (29) Federal Highway Administration tables appearing in Reference 13.
- (30) Estimated due to wide variations in handling practices.

Appendix E

LEACHATE EXTRACTION AND EVALUATION

As a part of this research project, a limited number of samples were obtained from existing roads and embankments in which recovered materials had been utilized. These samples were subjected to leachate extraction procedures, with the leachate being subsequently evaluated by standard laboratory procedures to determine if it is potentially hazardous. The procedures used were in accordance with EPA recommendations.

Included in this Appendix is a description of the method used in the leaching tests, the Federal Register notice describing the "EP Toxicity Test," and a summary of the results.

Method for Leaching of Highway Construction Products Containing Recovered Materials

1. Scope

1.1 This method covers procedures for sampling and testing highway construction products, which contain recovered materials, to obtain an aqueous solution to be used to determine the materials leached under the specified testing conditions.

1.2 The method outlines the types of sampling methods that may be used, and provides for the leaching of a known weight of waste with an appropriate extraction fluid and the separation of the aqueous phase for analysis.

2. Summary of Method

2.1 The method is organized by the following sections:

- Section 1 - Scope
- Section 2 - Summary of Practice
- Section 3 - Applicable Documents
- Section 4 - Significance and Use
- Section 5 - Definitions
- Section 6 - Apparatus
- Section 7 - Reagents
- Section 8 - Sampling Methodology - Field Samples
- Section 9 - Preparation of Solidified Samples
- Section 10 - Leaching Methodology
- Section 11 - Analysis of Leachate

3. Applicable Documents

3.1 Sampling --

3.1.1 ASTM Methods

- D420 - Practice for Investigating and Sampling Soil and Rock for Engineering Purposes
- D1452 - Method for Soil Investigation and Sampling by Auger Borings
- D2013 - Method for Preparing Coal Samples for Analysis

D2113 - Method for Diamond Core Drilling for Site Investigation

D2234 - Method for Collection of a Gross Sample of Coal

3.2 Leaching

3.2.1 Federal Register Vol. 43, No. 243 (December 18, 1978)

3.2.2 Federal Register Vol. 45, No. 98 (May 19, 1980)

3.2.3 ASTM Methods

D1193 - Specification for Reagent Water

3.3 Analysis

3.3.1 "Methods for Analysis of Water and Wastes," EPA 600/4-79-020, March 1979.

3.3.2 ASTM Methods

"Water", Part 31 of Book of Standards

4. Significance and Use

4.1 The method is intended to provide a laboratory method for determining the relative level of pollutants which can be extracted under controlled conditions from construction products using recovered materials. The information thus obtained can be used to categorize the relative environmental hazard associated with a particular construction product.

4.2 It is intended that leaching of the product be done in an aqueous solution which simulates the most severe exposure that is anticipated in use.

4.3 In practice, environmental impact depends on many site specific factors, such as climate and hydrogeologic conditions, quantity of waste used, etc. Since these factors cannot be con-

sidered as a part of the method, the method is not intended to provide a site-specific estimate of environmental impact.

4.4 The method is intended for use with products which have structural stability; that is, are not liquid or semi-solid materials.

4.5 Within the constraints which are created by the type of sample utilized, it is intended that all sample surfaces shall be continuously brought into contact with well mixed extraction fluid during the leaching test.

5. Definitions

5.1 Highway Construction products -- materials which are intended for use in highway construction, including roadbase mixtures, asphalt paving mixtures, structural fill or related applications.

5.2 Recovered materials -- postconsumer waste and other secondary materials or by-products which have been collected from solid waste that has been disposed of or is destined for disposal.

6. Apparatus

6.1 Field Sampling Apparatus

6.1.1 The apparatus used depends on the sampling methodology selected, as discussed in Section 8, but typically may include coring or excavation procedures for physically stabilized materials and sampling tube, split-barrel samplers or excavation procedures for granular materials.

6.2 Apparatus for Leaching Method

6.2.1 EPA Extractor -- A stirring type agitator, as described in Federal Register, Vol. 43, No. 243, December 18, 1978, pages 58956-58957 and illustrated on p. 58961.

- 6.2.2 NBS Extractor -- A rotary tumbling agitator, as described in "Test Methods for Evaluation of Solid Waste, Physical/Chemical Methods." Report No. SW846 U.S. Environmental Protection Agency.
- 6.2.3 Reciprocating Platform Shaker -- A shake table, capable of operating continuously at 110 to 130 one-inch cycles per minute without incorporation of air or heat in the sample being tested. A cycle consists of one forward and one equal return movement.

7. Reagents

- 7.1 Reagent water -- Type IV (Specification D1193), at 18 to 27C
- 7.2 Acetic acid -- 0.5N acetic acid.

8. Sampling Methodology - Field Samples

8.1 Cementitious Compositions

- 8.1.1 Diamond core drilling procedures are recommended, but excavation techniques may also be used.
- 8.1.2 If diamond core drilling is used, a four or six-inch diameter core can be used to obtain a large enough sample to be representative.

8.2 Non-Cementitious Compositions

- 8.2.1 Auger sampling is recommended, but excavation techniques may be used.
- 8.2.2 If auger sampling is used, a six-inch diameter geological soil auger pinned to the bottom of a continuous flight auger can be used to sample the non-cementitious material. The material received should be quartered down to a sample size of 100 gm.

9. Preparation of Solidified Samples

9.1 When tests are to be performed on solid samples, the samples are to be prepared as follows.

- 9.1.1 Samples will be crushed to pass a 0.375 inch sieve as specified in the Federal Register, Vol. 45, No. 98, May 19, 1980, page 33127, section 3. The sample will then be quartered down to 100 gms.

10. Leaching Methodology - The leaching procedure shall be in accordance with the method described in Federal Register Vol. 45, No. 98 (May 19, 1980), pp. 33127-33128.

10.1 The agitation procedures shall be as follows:

10.1.1 Cementitious Materials - The NBS extractor shall be the preferred agitation device, but a reciprocating shaker may also be used.

10.1.2 Granular Materials - The NBS extractor shall be the preferred agitation device, but an EPA extractor may also be used.

11. Analysis of Leachate

11.1 The leachates that are obtained from a minimum of three samples shall be analyzed for concentration of arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.

11.2 The preferred analytical techniques are specified in the Federal Register Vol. 45, No. 98, pages 33130-33131 (see especially Table 2). Appropriate substitutions from the ASTM Book of Standards, Part 31, may be made.

11.3 If the individual results on the leachates do not agree within 20% of the average results, in all cases, the number of leach tests performed shall be increased in order to improve the estimate of the leaching potential.

Hazardous Waste No.	Substance ¹
U223	Toluene diisocyanate
U224	Toxaphene
	2,4,5-TP see U233
U225	Trichloromethane
U226	1,1,1-Trichloroethane
U227	1,1,2-Trichloroethane
U228	Trichloroethane
	Trichloroethylene see U228
U229	Trichlorofluoromethane
U230	2,4,5-Trichlorophenol
U231	2,4,6-Trichlorophenol
U232	2,4,5-Trichlorophenoxyacetic acid
U233	2,4,5-Trichlorophenoxypropionic acid alpha, alpha, alpha-Trichlorotoluene see U023
	TRI-CLENE see U228
U234	Tribromobenzene (R, T)
U235	Tris(2,3-dibromopropyl) phosphate
U236	Trypan blue
U237	Uracil mustard
U238	Urethane-
	Vinyl chloride see U043
	Vinylidene chloride see U078
U239	Xylene

¹ The Agency included those trade names of which it was aware; an omission of a trade name does not imply that it is not hazardous. The material is hazardous if it is listed under its generic name.

Appendix I—Representative Sampling Methods

The methods and equipment used for sampling waste materials will vary with the form and consistency of the waste materials to be sampled. Samples collected using the sampling protocols listed below, for sampling waste with properties similar to the indicated materials, will be considered by the Agency to be representative of the waste.

Extremely viscous liquid—ASTM Standard

D140-70 Crushed or powdered material—

ASTM Standard D348-75 Soil or rock-like

material—ASTM Standard D420-69 Soil-

like material—ASTM Standard D1452-65

Fly Ash-like material—ASTM Standard

D2234-76 [ASTM Standards are available from ASTM, 1910 Race St., Philadelphia, PA 19103]

Containerized liquid wastes—"COLIWASA"

described in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. 20460. [Copies may be obtained from Solid Waste Information, U.S. Environmental Protection Agency, 26 W. St. Clair St., Cincinnati, Ohio 45268]

Liquid waste in pits, ponds, lagoons, and similar reservoirs—"Pond Sampler" described in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods,"¹

This manual also contains additional information on application of these protocols.

¹ These methods are also described in "Samplers and Sampling Procedures for Hazardous Waste Streams," EPA 600/3-80-01a, January 1980.

Appendix II—EP Toxicity Test Procedure

A. Extraction Procedure (EP)

1. A representative sample of the waste to be tested (minimum size 100 grams) should be obtained using the methods specified in Appendix I or any other methods capable of yielding a representative sample within the meaning of Part 260. [For detailed guidance on conducting the various aspects of the EP see "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," SW-846, U.S. Environmental Protection Agency Office of Solid Waste, Washington, D.C. 20460.]

2. The sample should be separated into its component liquid and solid phases using the method described in "Separation Procedure" below. If the solid residue² obtained using this method totals less than 0.5% of the original weight of the waste, the residue can be discarded and the operator should treat the liquid phase as the extract and proceed immediately to Step 8.

3. The solid material obtained from the Separation Procedure should be evaluated for its particle size. If the solid material has a surface area per gram of material equal to, or greater than, 3.1 cm² or passes through a 9.5 mm (0.375 inch) standard sieve, the operator should proceed to Step 4. If the surface area is smaller or the particle size larger than specified above, the solid material should be prepared for extraction by crushing, cutting or grinding the material so that it passes through a 9.5 mm (0.375 inch) sieve or, if the material is in a single piece, by subjecting the material to the "Structural Integrity Procedure" described below.

4. The solid material obtained in Step 3 should be weighed and placed in an extractor with 16 times its weight of deionized water. Do not allow the material to dry prior to weighing. For purposes of this test, an acceptable extractor is one which will impart sufficient agitation to the mixture to not only prevent stratification of the sample and extraction fluid but also insure that all sample surfaces are continuously

¹ Copies may be obtained from Solid Waste Information, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.

² The percent solids is determined by drying the filter pad at 80° C until it reaches constant weight and then calculating the percent solids using the following equation:

$$\frac{(\text{weight of pad} + \text{solid}) - (\text{tare weight of pad})}{\text{initial weight of sample}} \times 100 = \% \text{ solids}$$

brought into contact with well mixed extraction fluid.

5. After the solid material and deionized water are placed in the extractor, the operator should begin agitation and measure the pH of the solution in the extractor. If the pH is greater than 5.0, the pH of the solution should be decreased to 5.0 ± 0.2 by adding 0.5 N acetic acid. If the pH is equal to or less than 5.0, no acetic acid should be added. The pH of the solution should be monitored, as described below, during the course of the extraction and if the pH rises above 5.2, 0.5N acetic acid should be added to bring the pH down to 5.0 ± 0.2 . However, in no event shall the aggregate amount of acid added to the solution exceed 4 ml of acid per gram of solid. The mixture should be agitated for 24 hours and maintained at 20°–40° C (68°–104° F) during this time. It is recommended that the operator monitor and adjust the pH during the course of the extraction with a device such as the Type 45-A pH Controller manufactured by Chemtrix, Inc., Hillsboro, Oregon 97123 or its equivalent, in conjunction with a metering pump and reservoir of 0.5N acetic acid. If such a system is not available, the following manual procedure shall be employed:

(a) A pH meter should be calibrated in accordance with the manufacturer's specifications.

(b) The pH of the solution should be checked and, if necessary, 0.5N acetic acid should be manually added to the extractor until the pH reaches 5.0 ± 0.2 . The pH of the solution should be adjusted at 15, 30 and 60 minute intervals, moving to the next longer interval if the pH does not have to be adjusted more than 0.5N pH units.

(c) The adjustment procedure should be continued for at least 6 hours.

(d) If at the end of the 24-hour extraction period, the pH of the solution is not below 5.2 and the maximum amount of acid (4 ml per gram of solids) has not been added, the pH should be adjusted to 5.0 ± 0.2 and the extraction continued for an additional four hours, during which the pH should be adjusted at one hour intervals.

6. At the end of the 24 hour extraction period, deionized water should be added to the extractor in an amount determined by the following equation:

$$V = (20)(W) - 16(W) - A$$

V = ml deionized water to be added
W = weight in grams of solid charged to extractor
A = ml of 0.5N acetic acid added during extraction

7. The material in the extractor should be separated into its component liquid and solid phases as described under "Separation Procedure."

8. The liquids resulting from Steps 2 and 7 should be combined. This

combined liquid (or the waste itself if it has less than 1/2 percent solids, as noted in Step 2) is the extract and should be analyzed for the presence of any of the contaminants specified in Table I of § 261.24 using the Analytical Procedures designated below.

Separation Procedure

Equipment: A filter holder, designed for filtration media having a nominal pore size of 0.45 micrometers and capable of applying a 5.3 kg/cm² (75 psi) hydrostatic pressure to the solution being filtered shall be used. For mixtures containing nonabsorptive solids, where separation can be affected without imposing a 5.3 kg/cm² pressure differential, vacuum filters employing a 0.45 micrometers filter media can be used. (For further guidance on filtration equipment or procedures see "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods.")

Procedure:^{*}

(i) Following manufacturer's directions, the filter unit should be assembled with a filter bed consisting of a 0.45 micrometer filter membrane. For difficult or slow to filter mixtures a prefilter bed consisting of the following prefilters in increasing pore size (0.65 micrometer membrane, fine glass fiber prefilter, and coarse glass fiber prefilter) can be used.

(ii) The waste should be poured into the filtration unit.

(iii) The reservoir should be slowly pressurized until liquid begins to flow from the filtrate outlet at which point the pressure in the filter should be immediately lowered to 10-15 psig. Filtration should be continued until liquid flow ceases.

(iv) The pressure should be increased stepwise in 10 psi increments to 75 psig and filtration continued until flow ceases or the pressurizing gas begins to exit from the filtrate outlet.

(v) The filter unit should be depressurized, the solid material removed and weighed and then transferred to the extraction apparatus, or, in the case of final filtration prior to analysis, discarded. Do not allow the

^{*}This procedure is intended to result in separation of the "free" liquid portion of the waste from any solid matter having a particle size >0.45µm. If the sample will not filter, various other separation techniques can be used to aid in the filtration. As described above, pressure filtration is employed to speed up the filtration process. This does not alter the nature of the separation. If liquid does not separate during filtration, the waste can be centrifuged. If separation occurs during centrifugation the liquid portion (centrifugate) is filtered through the 0.45µm filter prior to becoming mixed with the liquid portion of the waste obtained from the initial filtration. Any material that will not pass through the filter after centrifugation is considered a solid and is extracted.

material retained on the filter pad to dry prior to weighing.

(vi) The liquid phase should be stored at 4°C for subsequent use in Step 8.

B. Structural Integrity Procedure

Equipment: A Structural Integrity Tester having a 3.18 cm (1.25 in.) diameter hammer weighing 0.33 kg (0.73 lbs.) and having a free fall of 15.24 cm (6 in.) shall be used. This device is available from Associated Design and Manufacturing Company, Alexandria, VA., 22314, as Part No. 125, or it may be fabricated to meet the specifications shown in Figure 1.

Procedure:

1. The sample holder should be filled with the material to be tested. If the sample of waste is a large monolithic block, a portion should be cut from the block having the dimensions of a 3.3 cm (1.3 in.) diameter x 7.1 cm (2.8 in.) cylinder. For a fixated waste, samples may be cast in the form of a 3.3 cm (1.3 in.) diameter x 7.1 cm (2.8 in.) cylinder for purposes of conducting this test. In such cases, the waste may be allowed to cure for 30 days prior to further testing.

2. The sample holder should be placed into the Structural Integrity Tester, then the hammer should be raised to its maximum height and dropped. This should be repeated fifteen times.

3. The material should be removed from the sample holder, weighed, and transferred to the extraction apparatus for extraction.

Analytical Procedures for Analyzing Extract Contaminants

The test methods for analyzing the extract are as follows:

(1) For arsenic, barium, cadmium, chromium, lead, mercury, selenium or silver: "Methods for Analysis of Water and Wastes," Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268 (EPA-800/4-79-020, March 1979).

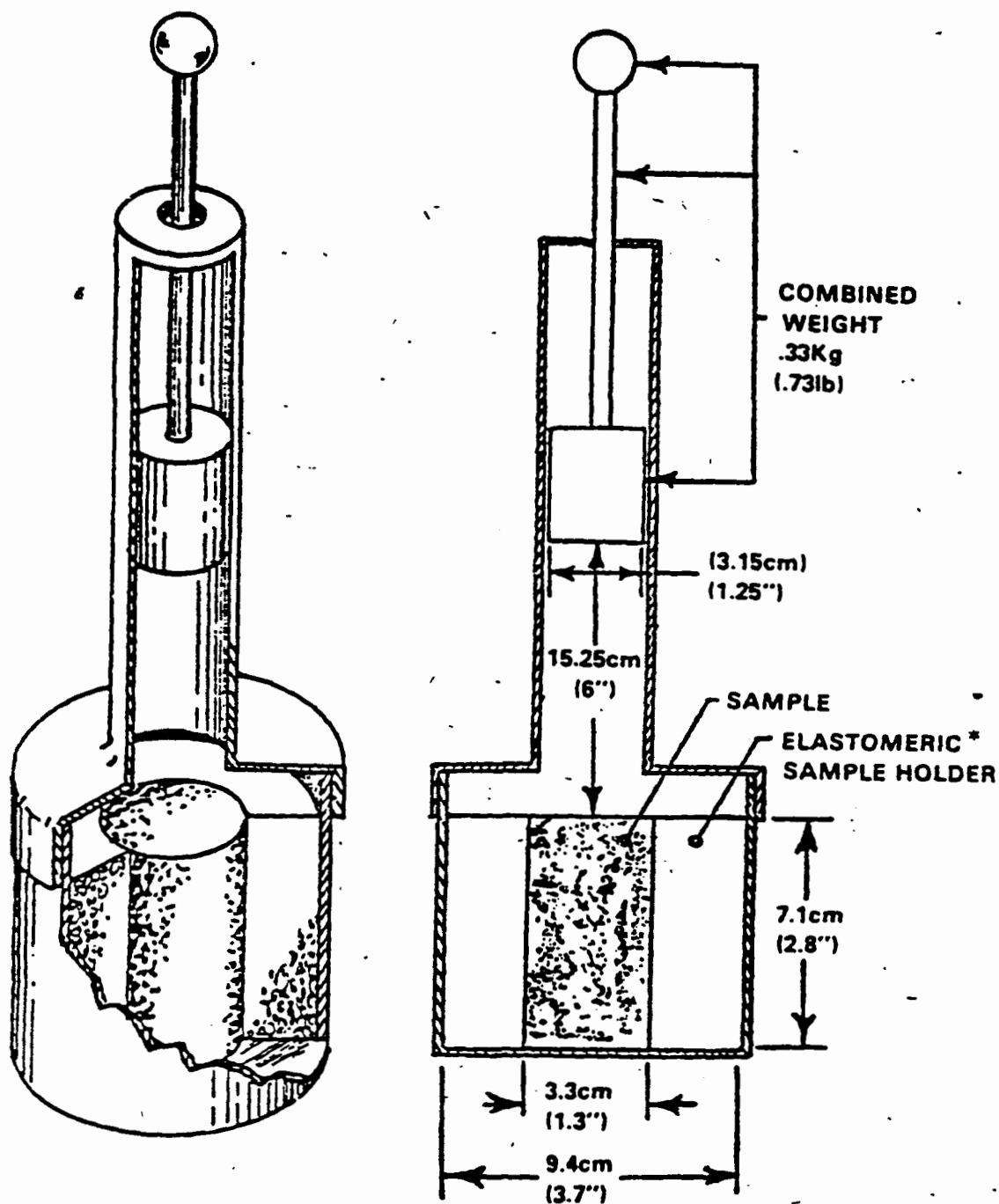
(2) For Endrin; Lindane; Methoxychlor; Toxaphene; 2,4-D; 2,4,5-TP Silver: in "Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," September 1978, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 42568.

as standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods."

For all analyses, the method of standard addition shall be used for the quantification of species concentration.

This method is described in "Test Methods for the Evaluation of Solid Waste." (It is also described in "Methods for Analysis of Water and Wastes.")

BILLING CODE 6560-01-M



*ELASTOMERIC SAMPLE HOLDER FABRICATED OF MATERIAL FIRM ENOUGH TO SUPPORT THE SAMPLE

Figure 1
COMPACTION TESTER

BILLING CODE 5490-01-C

Appendix III—Chemical Analysis Test Methods

Tables 1, 2 and 3 specify the appropriate analytical procedures, described in "Test Methods for Evaluating Solid Waste" (SW-846), which should be used in determining whether the waste in question contains a given toxic constituent. Table 1 identifies the analytical class and the approved measurement techniques for each organic chemical listed in Appendix VII. Table 2 identifies the corresponding methods for the inorganic

species. Table 3 identifies the specific sample preparation and measurement instrument introduction techniques which may be suitable for both the organic and inorganic species as well as the matrices of concern.

Prior to final selection of the analytical method the operator should consult the specific method descriptions in SW-846 for additional guidance on which of the approved methods should be employed for a specific waste analysis situation.

Table 1.—Analytical Characteristics of Organic Chemicals

Compound	Sample handling class/traction	Non-GC methods	Measurement techniques		
			GC/MS	Conventional GC	Detector
Acetonitrile	Volatile		8.24	8.03	NSD
Acrolein	Volatile		8.24	8.03	NSD
Acrylamide	Volatile		8.24	8.01	FID
Acrylonitrile	Volatile		8.24	8.03	NSD
Benzene	Volatile		8.24	8.02	PID
Benzo(a)anthracene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID
Benzo(a)pyrene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID
Benzotrichloride	Extractable/BN		8.25	8.12	ECD
Benzyl chloride	Volatile or Extractable/BN		8.24	8.01	HSD
			8.25	8.12	ECD
Benz(b)fluoranthene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID
Bis(2-chloroethoxymethane)	Volatile		8.24	8.01	HSD
Bis(2-chloroethyl)ether	Volatile		8.24	8.01	HSD
Bis(2-chloroisopropyl)ether	Volatile		8.24	8.01	HSD
Carbon disulfide	Volatile		8.24	8.01	HSD
Carbon tetrachloride	Volatile		8.24	8.01	HSD
Chlordane	Extractable/BN		8.25	8.08	HSD
Chlorinated dibenzodioxins	Extractable/BN		8.25	8.08	ECD
Chlorinated biphenyls	Extractable/BN		8.25	8.08	HSD
Chloroacetaldehyde	Volatile		8.24	8.01	HSD
Chlorobenzene	Volatile		8.24	8.01	HSD
				8.02	PID
Chloroform	Volatile		8.24	8.01	HSD
Chloromethane	Volatile		8.24	8.01	HSD
2-Chlorophenol	Extractable/BN		8.25	8.04	FID, ECD
Chrysene	Extractable/BN	8.10 (HPLC)	8.25	8.10	FID
Cresol	Extractable/BN		8.25	8.10	ECD
Cresol(s)	Extractable/A		8.25	8.04	FID, ECD
Cresylic acid(s)	Extractable/A		8.25	8.04	FID, ECD
Dichlorobenzene(s)	Extractable/BN		8.25	8.01	HSD
				8.02	PID
				8.12	ECD
Dichloroethane(s)	Volatile		8.24	8.01	HSD
Dichloromethane	Volatile		8.24	8.01	HSD
Dichlorophenoxy-acetic acid	Extractable/A		8.25	8.40	HSD
Dichloropropanol	Extractable/BN		8.25	8.12	ECD
2,4-Dimethylphenol	Extractable/A		8.25	8.04	FID, ECD
Dinitrobenzene	Extractable/BN		8.25	8.09	FID, ECD
4,6-Dinitro-o-cresol	Extractable/A		8.25	8.04	FID, ECD
2,4-Dinitrotoluene	Extractable/BN		8.25	8.09	FID, ECD
Endrin	Extractable/BN		8.25	8.08	HSD
Ethyl ether	Volatile		8.24	8.01	FID
				8.02	PID
Formaldehyde	Volatile		8.24	8.01	FID
Formic acid	Extractable/BN		8.25	8.08	FID
Heptachlor	Extractable/P		8.25	8.06	HSD
Hexachlorobenzene	Extractable/BN		8.25	8.12	ECD
Hexachlorobutadiene	Extractable/BN		8.25	8.12	ECD
Hexachloroethane	Extractable/BN		8.25	8.12	ECD
Hexachlorocyclopentadiene	Extractable/BN		8.25	8.12	ECD
Lindane	Extractable/P		8.25	8.08	HSD
Maleic anhydride	Extractable/BN		8.25	8.08	ECD, FID
Methanol	Volatile		8.24	8.01	FID
Methomyl	Extractable/BN	8.32 (HPLC)			
Methyl ethyl ketone	Volatile		8.25	8.01	FID
				8.02	FID
				8.01	FID
				8.02	FID
Methyl isobutyl ketone	Volatile		8.25	8.01	FID
				8.02	FID
Naphthalene	Extractable/BN		8.25	8.10	FID
Naphthoquinone	Extractable/BN		8.25	8.08	ECD, FID
				8.09	FID
Nitrobenzene	Extractable/BN		8.25	8.09	ECD, FID
4-Nitrophenol	Extractable/A		8.24	8.04	ECD, FID
Paraldehyde (trimer of acetaldehyde)	Volatile		8.24	8.01	FID

Appendix VII—Basis for Listing Hazardous Wastes

EPA hazardous waste No.	Hazardous constituents for which listed
P001	tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorinated fluorocarbons, carbon tetrachloride
P002	tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-tetrafluoroethane, o-dichlorobenzene, trichlorofluoromethane
P003	N.A.
P004	cresols and o-cresol acid, nitrobenzene
P005	methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine
P006	cadmium, chromium, nickel, cyanide (complexed)
P007	cyanide (salts)
P008	cyanide (salts)
P009	cyanide (salts)
P010	cyanide (salts)
P011	cyanide (salts)
P012	cyanide (complexed)
P013	cyanide (complexed)
P014	cyanide (complexed)
P015	cyanide (salts)
P016	cyanide (complexed)
K001	benzene, benz(a)anthracene, benzo(a)pyrene, chrysene, 4-nitrophenol, toluene, naphthalene, phenol, 2-chlorophenol, 2,4-dimethyl phenol, 2,4,6-trichlorophenol, pentachlorophenol, 4,8-dinitro-o-cresol, trichlorophenol
K002	chromium, lead
K003	chromium, lead
K004	chromium
K005	chromium, lead
K006	chromium
K007	cyanide (complexed), chromium
K008	chromium
K009	chloroform, formaldehyde, methylene chloride, methyl chloride, paraaldehyde, formic acid
K010	chloroform, formaldehyde, methylene chloride, methyl chloride, paraaldehyde, formic acid, chloroacetaldehyde
K011	acrylonitrile, acetonitrile, hydrocyanic acid
K012	acrylonitrile, acetonitrile, acrolein, acrylamide
K013	hydrocyanic acid, acrylonitrile, acetonitrile
K014	acetonitrile, acrylamide
K015	benzyl chloride, chlorobenzene, toluene, benzene
K016	hexachlorobenzene, hexachlorobutadiene, carbon tetrachloride, hexachloroethane, perchloroethylene
K017	epichlorohydrin, chloroethers [bis(chloroethoxy) ether and bis (2-chloroethoxy) ethers], isochloropropane, dichloropropane
K018	1,2-dichloroethane, trichloroethylene, hexachlorobutadiene, hexachlorobenzene
K019	ethylene dichloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethanes (1,1,2,2-tetrachloroethanes and 1,1,1,2-tetrachloroethanes), trichloroethylene, tetrachloroethylene, carbon tetrachloride, chloroform, vinyl chloride, vinylidene chloride

ECG = Electron capture detector; FID = Flame ionization detector; FPD = Flame photometric detector; MSD = Mass selective detector; HPLC = High pressure liquid chromatography; NSD = Nitrogen-specific detector; PID = Photoionization detector.

Species	Sample handling class	Measurement technique	Method number
Antimony	Digestion	Atomic absorption-Arsenic/Thiome	1.50
Arsenic	Hydrolysis	Atomic absorption-Thiome	1.51
Bismuth	Digestion	Atomic absorption-Arsenic/Thiome	1.52
Cadmium	Digestion	Atomic absorption-Arsenic/Thiome	1.53
Chromium	Digestion	Atomic absorption-Arsenic/Thiome	1.54
Cobalt	Hydrolysis	Atomic absorption-spectroscopy	1.55
Copper	Digestion	Atomic absorption-Arsenic/Thiome	1.56
Mercury	Cold vapor	Atomic absorption	1.57
Nickel	Digestion	Atomic absorption-Arsenic/Thiome	1.58
Selenium	Hydrolysis Digestion	Atomic absorption-Arsenic/Thiome	1.59
Silver	Digestion	Atomic absorption-Arsenic/Thiome	1.60

Procedure and Method Number(s)

Digestion—See appropriate procedure for element of interest.

Direct injection—3.50

Headspace—3.52

Hydride—See appropriate procedure for element of interest.

Purge & Trap—3.53

Shake out—3.54

Sonication—3.55

Soxhlet—3.55

E-11

Valley Forge Laboratories, Inc.

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February 23, 1981
Project No. 15170

Mr. William J. Kline
U.S. Environmental Protection Agency
Office of Solid Waste Management
401 M Street, S.W.
Washington, D.C. 20460

Re: EPA Contract No. 68-01-6014
"Development of Guidelines for Procure-
ment of Highway Construction Products
Containing Recovered Materials"

Dear Bill:

Leachate extraction tests have been performed on a total of ten samples of highway construction products containing one or more of the following recovered materials: power plant ash, cement or lime kiln dust, or incinerator residue. The tests have been performed in accordance with the EPA extraction procedure and as discussed in my letter to you dated November 5, 1980. The purpose of these tests was to determine the concentrations of various inorganic chemicals present in leachates from each of the samples tested and what, if any, degree of potential hazard would be associated with their use in a highway.

The enclosed table summarizes the test results and clearly indicates that none of the samples tested appear to be hazardous, insofar as leachate concentrations from all samples tested were well within the established limits of 100 times the drinking water standards. No test was performed on an asphalt-rubber test specimen because the test results for the incinerator residue black base test sample were definitely not hazardous and the asphalt-rubber was an interlayer between two layers of blacktop. The asphalt-rubber would have to have been scraped and divided into particles all of which would have to be less than 3/8 inch size prior to leachate testing. Since the sample containing 70 percent incinerator residue bituminous base was not found

Mr. William J. Kline
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to be hazardous, then it seems highly unlikely that a sample in which only 25 percent of the mix is granulated rubber tires would be in any way hazardous.

It should be noted that four tests were performed on fly ash embankment samples taken at various depths from a project in Waukegan, Illinois. In no case was the fly ash leachate concentration near the hazardous level.

Although the number of tests performed is not of sufficient magnitude to extrapolate the results to all highway construction products containing recovered materials, it does indicate that there does not appear to be any environmental hazard associated with such use. As far as I know, there are no known leachate extraction test results from field highway construction samples that do indicate any degree of hazardousness associated with this kind of use.

If there are any questions concerning these test results or the methods employed in deriving the test results, please feel free to contact me.

Sincerely,



Robert J. Collins, P.E.
Executive Vice-President

RJC:lcw
Enclosures
cc: ~~Robert J. Collins~~
William C. Webster

RESULTS OF LEACHATE EXTRACTION TESTS PERFORMED ON SAMPLES
OF HIGHWAY CONSTRUCTION PRODUCTS CONTAINING RECOVERED MATERIALS

OF HIGHWAY CONSTRUCTION PRODUCTS CONTAINING RECOVERED MATERIALS										
Sample Description		Sample Location	Leachate Analysis Concentration (ppm)							
			As	Ba	Cd	Cr	Pb	Hg	Se	Ag
1.	Fly Ash Embankment (Sample 1 - 2 to 6 ft.)	Waukegan, Illinois	.05	<1.0	.06	.20	<.20	<.001	<.01	<.05
2.	Fly Ash Embankment (Sample 2 - 6 to 9 ft.)	Waukegan, Illinois	<.05	<1.0	.04	.13	<.20	<.001	<.01	<.05
3.	Fly Ash Embankment (Sample 3 - 12 to 16.5 ft.)	Waukegan, Illinois	<.05	<1.0	.09	.13	<.20	<.001	<.01	<.05
4.	Fly Ash Embankment (Sample 4 - 20 to 24 ft.)	Waukegan, Illinois	<.05	11.0	.06	.10	.20	<.001	.01	<.05
5.	Lime-Fly Ash-Aggregate (Wyo. Coal Fly Ash)	Chicago, Illinois	.05	17.0	<.05	.05	<.20	<.001	<.01	<.05
6.	Lime-Fly Ash-Aggregate (Ill. Coal Fly Ash)	Chicago, Illinois	.05	9.0	.06	.10	<.20	<.001	.01	<.05
7.	Kiln Dust-Fly Ash-Aggregate	Chicago, Illinois	<.01	<1.0	<.05	.05	.20	<.001	<.01	<.05
8.	Lime-Fly Ash-Boiler Slag	Coffeen, Illinois	<.01	<1.0	.26	.10	.40	<.001	<.01	<.05
9.	Cement-Stabilized Bottom Ash	Charleston, W. Va.	<.05	26.0	<.05	.05	.40	<.001	<.01	<.05
10.	Incinerator Residue Black Base Wash., D.C.		<.05	1.0	<.05	<.05	<.20	<.001	<.01	<.05
			Drinking Water Standards (ppm)							
			.05	1.0	.01	.05	.05	.002	.01	.05
			100X Drinking Water Standards (ppm)							
			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0

Appendix F

SUMMARY OF QUESTIONNAIRE RESPONSES

In the course of this study, the American Association of State Highway and Transportation Officials (AASHTO) surveyed their membership with regard to some of the issues considered in this report. This Appendix is a summary and analysis of the responses received.

ASSESSMENT OF RECOVERED MATERIALS USE BY STATE

This section will assess on a state-by-state basis the use of the individual recovered material products, tests or experiments with regard to use, attitudes of states towards use of the products, barriers to implementation of procurement guidelines or material use, and recommendations to EPA on the most favorable policy or alternatives to pursue with each state.

The method of assessment is through analysis of a questionnaire distributed to highway and transportation officials in each of the 50 states by the AASHTO Subcommittee on Materials and the AASHTO Subcommittee on Construction. These were sent to the materials and construction engineers of the U.S. member departments from each state during April 1980.

Following is a complete summary of the Materials and Construction Subcommittee's replies to the questionnaire. Generally, the results from the questionnaires show about 70 percent of the states having used fly ash and granulated rubber tires, over 40 percent of the states having used bottom ash or boiler slag, about 30 percent having used cement or lime kiln dust, and only about 10 percent having used incinerator residue. The most frequently used applications of the recovered materials in descending order are: granulated rubber tires as an asphalt-rubber seal coat (~26 states) and as a stress-absorbing membrane or stress-absorbing membrane interlayer (~22 states), bottom ash or boiler slag as an aggregate in asphalt paving (~18 states), and fly ash as a mineral filler in asphalt paving (~18 states) or in lime-fly ash-aggregate base, sub-base, or shoulders (~16 states).

SUMMARY OF RECOVERED MATERIALS QUESTIONNAIRE

The Subcommittee on Materials circulated a questionnaire to the materials engineers of the U.S. member departments in April 1980 concerning their experience and attitude toward the use of various recovered materials. Following is a tabulation of the replies. Forty-six member departments responded to the questionnaire. The large majority of those responding favor increased use of recovered materials but do not favor any mandatory guidelines to stimulate such use.

1. Which of the following recovered materials have been used in highway construction products in your state?

34 Fly Ash AL, AZ, AR, CA, CO, CT, DC, FL, GA, IL, IA, LA, MD, MA, MI, MN, MS, MO, MT, NE, NJ, NM, NY, NC, ND, OH, OR, PA, SC, TX, VA, WV, WI, WY

22 Bottom Ash or Boiler Slag AL, AZ, AR, CT, FL, GA, IL, IA, KS, MI, MN, MO, NE, NY, NC, OH, OK, OR, TX, WA, WV, WI

18 Cement of Lime Kiln Dust AZ, AR, CA, CO, CT, DC, IL, IA, KS, LA, MT, NE, NJ, NY, OR, TX, VA, WY

38 Granulated Rubber Tires AL, AK, AZ, AR, CA, CO, CT, DE, DC, FL, GA, HI, ID, IL, IA, KS, LA, MI, MN, MS, MT, NE, NV, NH, NM, NY, NC, ND, OK, OR, PA, RI, SD, TX, UT, VT, WA, WY

6 Incinerator Residue AL, CT, DC, MA, OH, PA

1 None of these (If so, omit questions 2 through 5). CT

The remaining questions pertain to specific applications for recovered materials. (Please refer to the appropriate letter code when answering these questions.) For example, fly ash use as structural fill will be referred to by the letter "A."

2. In what applications have these recovered materials been used in your state?

FLY ASH

A. 9 Structural Fill AZ, IL, IA, MN, NY, OH, WV, WI, WY

B. 16 Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders AZ, CO, GA, IL, MD, MI, MS, MO, NJ, NY, NC, ND, OH, PA, TX, WV

C. 18 Mineral Filler in Asphalt Paving AL, AR, CO, GA, IL, IA, LA, MD, MI, MT, NE, NY, NC, OH, SC, TX, WV, WY

BOTTOM ASH OR BOILER SLAG

- D. 7 Aggregate in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders
IL, NC, OH, OR, TX, WA, WV
- E. 17 Aggregate in Asphalt Paving AL, AZ, AR, CT, FL, GA, IL, IA, KS,
MI, MN, NE, NY, OH, OK, TX, WV

CEMENT OR LIME KILN DUST

- F. 8 Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders CO, IL,
IA, KS, MT, OR, VA, WY

GRANULATED RUBBER TIRES

- G. 24 Stress-Absorbing Membrane of Stress-Absorbing Membrane Interlayer
AL, AZ, AR, CA, CO, FL, HI, ID, IL, KS, MI, MN, NH, NM, NC, ND, OK, OR,
PA, TX, UT, VT, WA, WY
- H. 26 Asphalt-Rubber Seal Coat AZ, CA, CO, CT, DE, FL, GA, ID, IA, KS, LA,
MI, MN, MS, MT, NV, NM, NY, OK, OR, PA, RI, SD, TX, UT, WY

2. INCINERATOR RESIDUE

- I. 4 Aggregate Supplement in Asphalt Paving AL, DC, MI, PA
- J. 3 Lime Stabilized Base, Subbase, or Shoulders MI, NY, OH

2. K&L Other Applications

Fly Ash in PC Concrete - Wisc., CA, MD, Oreg. Iowa, Fla., Ohio, Nebr., Va.,
Minn., W.VA

Fly Ash in PC Concrete Pavement - New Mexico

Fly Ash in PC Concrete base - Ohio

Recycled Bituminous Concrete Pavement - Conn., Vermont

Blast Furnace Slag Aggregate in Bituminous Concrete - Wisc., MD.

Blast Furnace Slag for concrete & bituminous aggregate - Mich.

Kiln Dust is used as a mineral filler in bituminous concrete - N.J., Nebr., Ark., Louisiana,
CA

Steel Slag from Open Hearth Furnace used in Asphalt Paving - Missouri

Steel furnace slag for bituminous aggregate and base course - Michigan

Steel slag-aggregate in asphalt paving - Minn.

Steel Slag for structural fill, base, asphalt paving - Ohio

Granulated Rubber Tires-subgrade waterproofing membrane - N.M.

Fly Ash and wet bottom boiler slag in Type IP Cement (produced by intergrinding
Portland Cement and pozzolan) An experimental project to let in the near future - Missouri

Glass in AC Pavement Demonstration - Iowa

Boiler slag - ice control - Iowa

Granulated rubber - AC crack sealing - Iowa

Use of CASO_4 (recovered from production of H_2SO_4 by Allied Chemical) as base
material - Delaware

Glass Waste for structural fill - Ohio

Winter Ice and Snow Control on New Concrete Pavement - Nebraska

Chalk Sealing on Concrete and Asphalt Highways - Nebraska

Ground rubber tires in hot asphalt pavement (SKEGA) - Alaska

Fly ash in concrete paving (research) - Texas

Fly ash in concrete box culverts (research) - Texas

Fly ash in sub-sealing concrete pavement - Texas

Sawmill waste (hog fuel) - lightweight fill - Washington

Magnetherm Slag (decrepitated)-soil stabilization - Washington

Sulfur extended asphalt - Illinois

Granulated rubber tires in joint and crack sealer - Illinois

Cold Milled Asphaltic Concrete - Illinois

2. K&L Other Applications -(continued)

Bottom ash for winter anti-skid material - PA

Asphalt-Rubber in Hot Dense Graded Wearing Course - PA

Fly ash and Kiln Dust used to fill abandoned underground structures - D.C.

Asphalt-Granulated Rubber in bituminous mixtures - D.C.

Waste lime from Acetylene production used for soil modification - Oklahoma

Fly ash (class F) as an admixture - Florida

Recycled PCC - Conn.

Rubber in joint seal and asphalt concrete mixes - N.Y.

Fly ash in cement-fly ash grout - N.Y.

Fly ash-aggregate base, subbase, or shoulders - Louisiana

Asphalt-Rubber Crack Sealant - N.D.

Granulated Rubber Tires in Guardrail blocks - Oregon

Taconite Tailings-Aggregate in Asphalt Paving - Minn.

Slag Base & Surfacing - Slag waste from Phosphate Fertilizer Plant - Idaho

3. EXTENT OF USE (MATERIALS)

APPLICATIONS	LABORATORY INVESTIGATION	FIELD EXPERIMENTATION	LIMITED FIELD USE	ROUTINE FIELD USE
<u>FLY ASH</u>				
A. STRUCTURAL FILL	(5) AZ, IA, MN, WI, WY	(4) AZ, MN, WV, WI	(4) MN, NY, WI, WY	(2) IL, OH
B. LIME-FLY ASH-AGGREGATE BASE SUBBASE OR SHOULDER	(9) AZ, CO, GA, MS, MO, NY, NC, ND, TX	(6) AZ, CO, MO, NT, ND, TX	(7) CO, MD, MI, NJ, TX, WV, ND	(3) IL, OH, PA
C. MINERAL FILLER IN ASPHALT PAVING	(3) CO, GA, WY	(1) WY	(6) AR, CO, GA, MT, OH, SC	(9) AL, IL, LA, MO, MI, NE, NY, NC, WV
<u>BOTTOM ASH OR BOILER SLAG</u>				
D. AGGREGATE IN LIME-FLY ASH-AGG. BASE SUBBASE OR SHOULDERS	(2) NC, WY	(0)	(3) OR, WA, WY	(2) IL, OH
E. AGGREGATE IN ASPHALT PAVING	(6) AZ, CT, FL, GA, KS, MN	(9) AZ, AR, CT, FL, KS, MI, MN, NY, WV	(7) FL, MN, NE, KS, OK, WV, OH	(3) AL, IL, MO
<u>CEMENT OR LIME KILN DUST</u>				
F. KILN DUST-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDERS	(4) CO, IA, KS, VA	(2) KS, OR	(3) CO, KS, MT	(1) IL
<u>GRANULATED RUBBER TIRES</u>				
G. STRESS-ABSORBING MEMBRANE OR STRESS-ABSORBING MEMBRANE INTERLAYER	(7) CO, ID, KS, MN, OR, PA, UT	(20) AL, AZ, CA, CO, FL, HI, ID, IL, KS, MI, MN, NH, NM, NC, ND, OK, PA, TX, UT, VT	(10) AZ, AR, CO, FL, ID, KS, MN, OR, PA, UT	(2) NM, WA
H. ASPHALT-RUBBER SEAL COAT	(11) CO, CT, GA, ID, KS, LA, MN, MS, OR, PA, UT	(18) AZ, CA, CO, CT, FL, GA, ID, KS, MI, MN, MS, MT, NV, NM, NY, OK, PA, UT	(15) AZ, CA, CO, CT, DE, FL, ID, MN, NM, OR, PA, RI, SD, TX, UT	(1) ID
<u>INCINERATOR RESIDUE</u>				
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING	(1) PA	(2) DC, PA	(0)	(1) AL
J. LIME STABILIZED BASE, SUBBASE, OR SHOULDERS	(1) NY	(0)	(1) OH	(0)
		P-7		

3 EXTENT OF USE (con't.)

OTHERS - K&L

LABORATORY INVESTIGATION

Fly ash in PC Concrete - (7) FL, MD, NM, OH, OR, TX, WI
Recycled Bituminous Concrete Pavement - (1) CT
Sulfur Extended Asphalt - (1) IL
Fly ash-aggregate base, subbase, or shoulders - (1) LA
Magnetherm Slag (decrepitated) - soil stabilization - (1) WA
Recycled PCC - (1) CT
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Fly ash in sub-sealing concrete pavement - (1) TX
Slag Base & Surfacing - Slag waste from Phosphate Fertilizer Plant - (1) ID

FIELD EXPERIMENTATION

Glass Waste for Structural Fill - (1) OH
Steel Slag from Open Hearth Furnace Used in Asphalt Paving - (1) MO
Use of Ca SO₄ (recovered from production of H₂SO₄ by Allied Chemical)
as base material - (1) DE
Sulfur Extended Asphalt - (1) IL
Fly Ash and Kiln Dust used to fill abandoned underground structures - (1) DC
Recycled Bituminous Concrete Pavement - (2) CT, VT
Fly Ash in PCC - (4) FL, NM, TX, WI
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Granulated Rubber Tires - Subgrade waterproofing membrane - (1) NM
Recycled PCC - (1) CT
Asphalt-Granulated Rubber in bituminous mixtures - (2) AK, DC
Boiler Slag - ice control - (1) IA
Fly ash in concrete box culverts (research) - (1) TX
Cold Milled Asphaltic Concrete - (1) IL
Granulated Rubber - A.C. crack sealing - (1) IA
Slag Base & Surfacing - Slag waste from Phosphate Fertilizer Plant - (1) ID

LIMITED FIELD USE

Waste Lime from Acetylene production used for soil modification - (1) OK
Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO
Sawmill Waste (hog fuel) - lightweight fill - (1) WA
Fly Ash in PCC - (7) FL, IA, NY, NM, OR, VA, WI
Fly Ash and Kiln Dust used to fill abandoned underground structures - (1) DC
Cement Kiln Dust - Mineral Filler in Asphalt Paving - (2) AR, NE
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Granulated Rubber Tires in Joint and Crack Sealer - (2) IL, ND
Fly Ash and Wet Bottom Boiler Slag in Type IP Cement EMO - (1) MO
Fly Ash in Sub-sealing Concrete Pavement - (1) TX
Bottom Ash or Boiler Slag in Ice and Snow Control - (1) NE

ROUTINE FIELD USE

Kiln Dust is used as a mineral filler in bituminous concrete - (2) LA, NJ
Rubber in joint seal and asphalt concrete mixes - (1) NY
Fly Ash in PCC - (2) CA, FL
Taconite Tailings - Aggregate in Asphalt Paving - (1) MN

3 EXTENT OF USE (con't.)

OTHERS - K&L

ROUTINE FIELD USE (con't.)

Steel Slag-Aggregate in Asphalt Paving - (1) MN
Steel Slag for Structural Fill, Base, Asphalt Paving - (1) OH
Cement Dust as AS Supplemental Fine Aggregate - (1) CA
Blast Furnace Slag as Aggregate - (1) MD
Granulated Rubber Tires - subgrade waterproofing membrane - (1) NM
Fly Ash in PCC Base - (1) OH
Slag Base & Surfacing - slag waste from phosphate fertilizer plant - (1) ID
Granulated Rubber Tires - check sealing on highways - (1) NE

4. PERFORMANCE

(MATERIALS)

APPLICATIONS	EXCELLENT	GOOD	ACCEPTABLE	MARGINAL	POOR
<u>FLY ASH</u>					
A. STRUCTURAL FILL	WI (1)	IL (3) NY, WV	MN (2) OH	(0)	(0)
B. LIME-FLY ASH-AGGREGATE BASE SUBBASE OR SHOULDER	(4) MS, OH, TX, WA	(4) AZ, CO, GA, IL	(4) MD, NJ, ND, PA, NC	(1)	MI (1)
C. MINERAL FILLER IN ASPHALT PAVING	(3) CO, NE, WV	(5) AL, IL, MI, NY, NC	(7) AR, GA, LA, MD, MT, OH, SC	(0)	(0)
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH-AGGREGATE BASE SUBBASE OR SHOULDER	(0)	(3) IL, OH, WA	(1) OR	(1) NC	(0)
E. AGGREGATE IN ASPHALT PAVING	(0)	(7) AL, GA, IL, KS, MI, MO, WV	(5) AR, FL, MN, NE, NY	(4) AZ, CT, OH, OK	(0)
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE BASE SUBBASE OR SHOULDER	(0)	(1) IL	(5) CO, KS, MT, OR, VA, WY	(1)	(0)
<u>GRANULATED RUBBER TIRES</u>					
G. STRESS-ABSORBING-MEMBRANE OR STRESS-ABSORBING MEMBRANE INTERLAYER	AL (1)	(7) CA, IL, KS, NC, ND, WA, WY	(7) AR, CA, MI, NM, OR, TX, UT	(7) AZ, CA, HI, ID, OK, PA, VT	(2) CO, NH
H. ASPHALT-RUBBER SEAL COAT	GA (1)	(6) CA, ID, LA, MS, SD, UT	(3) CA, KS, MI, NV, NM, OR, RI, TX	(6) AZ, CO, CT, MT, NY, OK	(5) CA, DE, PA, UT, WY
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING	(0)	(2) AL, DC	(1) PA	(0)	(0)
J. LIME STABILIZED BASE, SUBBASE, OR SHOULDERS	(0)	(1) OH	(0)	(0)	(0)

4 PERFORMANCE (con't.)
OTHER APPLICATIONS K&L

Excellent

Glass Waste for Structural Fill - (1) OH
Taconite Tailings-Aggregate in Asphalt Paving - (1) MN
Sawmill Waste (hog fuel) - lightweight fill - (1) WA
Fly Ash in Concrete - (4) FL, MN, TX
Magnetherm Slag (decrepitated) - soil stabilization - (1) WA
Steel Slag-Aggregate in Asphalt Paving - (1) MN
Fly Ash in PCC Base - (1) OH
Slag Base & Surfacing - Slag waste from Phosphate Fertilizer Plant - (1) ID
Granulated Rubber Tires - Crack sealing on concrete & asphalt highways - (1) NE

Good

Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO
Use of Cs SO₄ (recovered from production of H₂SO₄ by Allied Chemical) as base material - (1) DE
Fly Ash in Concrete - (5) IA, CA, OR, WI, NE
Asphalt-Rubber Crack Sealant - (2) IL, ND
Sulfur Extended Asphalt - (1) IL
Recycled Bituminous Concrete Pavement - (1) VT
Ground Rubber Tires in Hot Asphalt Pavement (SKEGA) - (1) AK
Fly Ash and Kiln Dust used to Fill Abandoned Underground Structures - (1) DC
Steel Slag for Structural Fill, Base, Asphalt Paving - (1) OH
Granulated Rubber Tires - subgrade, waterproofing membrane - (1) NM
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Fly Ash in Cement-Fly Ash Grout - (1) NY
Fly Ash Aggregate Base, Subbase, or Shoulders - (1) LA
Cement Dust as AS Supplemental Fine Aggregate - (1) CA
Fly Ash or Boiler Slag - ice & snow control - (1) NE

Acceptable

Fly Ash in Concrete - (6) FL, MD, NM, OH, TX, VA
Cement Kiln Dust for Mineral Filler in Asphalt Concrete - (1) AR
Rubber in Joint Seal and Asphalt Concrete Mixes - (1) NY
Kiln Dust is Used as a Mineral Filler in Bituminous Concrete - (1) NJ
Cement Kiln Dust - mineral filler in asphalt paving - (1) LA
Glass Waste for Structural Fill - (1) OH
Blast Furnace Slag as Aggregate - (1) MD
Fly Ash and Wet Bottom Boiler Slag in Type IP Cement (produced by inter-grinding PCC and pozzolan) - (1) MO
Fly Ash in Sub-sealing Concrete Pavement -
Waste Lime from Acetylene Production used for Soil Modification - (1) OK

Marginal

Fly Ash Used in Hydraulic Cement Concrete - (1) VT
Asphalt-Granulated Rubber in Bituminous Mixtures - (1) DC

Poor

Kiln-Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders -
Boiler Slag - ice control - (1) IA
Granulated Rubber - AC crack sealing - (1) IA
Cement or Lime Kiln Dust - mineral filler in asphalt paving - (1) NE

5. Applications that have performed either excellently or poorly and the reasons given for such performance

Excellent Performance:

- a. Granulated rubber tires in Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - No reflective cracking noted after 3 years. (AL)
- b. Granulated rubber tires in asphalt-rubber seal coat - Effective as retarder for reflective cracking. (GA)
- c. Fly ash as a mineral filler in asphalt paving - There was a severe need for additional fines and fly ash solved the problem. (CO)
Excellent pavement performance, low prices and lower asphalt demand than other mineral filler. (NE)
- d. Fly ash as a portland cement replacement - The substitution ratio of 1.0 is nearly adequate at high cement content used in lab tests, while the ration should exceed 1.0 for cement content of 5-1/2 bags per cubic yard used in field. (FL) Improves concrete workability, reduces cost but increases time of set. (MN) Quality fly ash, knowledgeable ready mixed concrete plant, good contractor, excellent inspectors. (TX)
- e. Fly ash as an admixture in concrete - Lab tests with high cement content have demonstrated that fly ash will (1) increase corrosion protect properties (2) increase sulfate resistance, (3) reduce heat of hydration (hot weather concreting). (FL)
- f. Taconite tailings used as an aggregate in asphalt paving - Good skid resistance, high stability, low abrasion loss, somewhat higher in cost in southern part of state. (MN)
- g. Steel slag used as aggregate in asphalt paving - Good skid resistance, high stability, low abrasion loss, limited availability. (MN)
- h. Fly ash-lime-aggregate base, subbase, or shoulder - Gains strength with age. (OH) Accomplishing the needed laboratory study in the design phase along with mixing and compaction on the project. (TX) Pozzolanic activity of fly ash when mixed with calcium (cement). (WV)
- i. Fly ash in portland cement concrete base - Greater concrete workability with less water and excellent strengths. (OH)
- j. Fly ash used in structural fill - Compacted easily, stable, low cost, no volume change. (WI)
- k. Magnetherm slag (decrepitated) for soil stabilization - similarity of this material to commercial lime. (WV)
- l. Granulated rubber tires as crack sealing on concrete and asphalt highways - Cracks remain sealed and higher initial cost have good benefit/cost ratio since we expect longer service life. (NE)

5. Applications that have performed either excellently or poorly and the reasons given for such performance (continued)

Poor Performance:

- a. Granulated rubber tires in asphalt rubber seal coat - Due to inadequate binder properties, we did not obtain the reflection crack retardation and/or the chip retention expected or desired (CA). Did not control reflective cracking (CO). After 1 year of service most of the cover aggregate is gone (DE). Construction conditions: (1) distribution of asphalt rubber, (2) cover aggregate application (PA). Workmanship in mixing rubber and asphalt; also application onto roadway and subsequent coverage with chips (UT). Wet chips, loss of chips and did not impede cracking (WY). Critical temperature and aggregate conditions that seriously affect performance (KS).
- b. Granulated rubber tires in stress-absorbing membrane or stress-absorbing membrane interlayer. - While SAM and SAMI seem to be beneficial we were anticipating a prolonged period of non-cracking, both showed extensive cracking within 6 months (ID). - May have used incorrect formulation (NH).
- c. Boiler slag for ice control. - Crushed too easily under traffic (IA).
- d. Granulated rubber in an asphalt cement crack sealer. - Did not significant— reduce crack reflection (IA).
- e. Fly ash in lime-fly ash-aggregate base, subbase or shoulders. - Too temperature and moisture sensitive for cure, frost susceptibility, poor drain ability, and more expensive than conventional aggregate mixtures (MI).
- f. Kiln dust as a mineral filler in asphalt - Good results obtained several years ago but recent pollution equipment added at cement plant has produced cement dust that is very fine and has such a high asphalt demand that mixes tend to become unstable (NE).
- g. Kiln dust-fly ash-aggregate base subbase, or shoulders. - Lime kiln dust to non-uniform, contains variable amounts of lime (VA).
- h. Fly ash used in portland cement concrete - Performance of concrete was poor with much scaling noted in first winter (VA).
- i. Sawmill waste used in a light-weight fill. - Limited application to specific sites (WA).
- j. Fly ash as mineral filler in asphalt pavings - Periodic poor behavior noted - Believed due to gradation and source differences of fly ash (LA).

(MATERIALS)

6. ATTITUDE TOWARD FUTURE USE OF RECOVERED MATERIALS

APPLICATIONS	FAVOR INCREASED USE	MORE FIELD STUDY NEEDED	MORE LAB-ORATORY STUDY NEEDED	DO NOT FAVOR FURTHER USE	UNCERTAIN
<u>FLY ASH</u>					
A. STRUCTURAL FILL.	(6) IL NY OH WV WI WY	(3) MN SC WY	(1) IA		(2) AZ RI
B. LIME-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(9) AZ CO GA IL MS ND OH TX WV	(2) MO NJ	(2) MO NC	(1) MI	(3) NY PA RI
C. MINERAL FILLER IN ASPHALT PAVING.	(7) AL CO IL MI NE NY NC	(5) AR MT PA SC WY	(5) AR GA LA MT WY		(1) LA
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(3) IL OH WA	(1) WY			(2) NC OR
E. AGGREGATE IN ASPHALT PAVING.	(6) AL GA IL KS MO OH	(6) AR FL MI MN AR NE NY	(1) IA		(2) AZ OK
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(1) IL	(2) KS VA	(2) IA KS		(3) CO MT OR
<u>GRANULATED RUBBER TIRES</u>					
G. STRESS-ABSORBING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(7) AL IL MN NM OR UT WA	(14) AZ AR CA FL HI MI MN NM NC OH RI TX UT VT	(2) OH UT	(1) CO	(4) ID NH NO OK
H. ASPHALT RUBBER SEAL COAT.	(8) GA IL MN MS NM OR SD UT	(16) AZ CA CO DE FL KS MI MN MT NM NY OH PA RI TX UT	(4) KS MT OH UT		(4) ID LA NV OK
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(3) AL DC IL			(1) PA	
J. LIME STABILIZED BASE, SUBBASE OR SHOULDERS.	(2) IL OH	(1) OH	(1) OH	(1) SC	(1) NY

6. Attitude toward future use of recovered materials OTHER APPLICATIONS - K&L

Favor Increased Use

Taconite Tailings - Aggregate in Asphalt Paving - (1) MN
Fly ash in concrete - (9) FL, IA, MN, NE, MN, OR, TX, WV, WI
Sawmill waste (hog fuel) - lightweight fill - (1) WA
Glass waste for structural fill - (1) OH
Slag base and surfacing - slag waste from phosphate fertilizer plant - (1) ID
Recycled bituminous concrete pavement - (1) VT
Sulfur extended asphalt - (1) IL
Cement kiln dust for mineral filler in asphalt concrete - (1) LA
Asphalt-rubber crack sealant - (1) ND
Fly ash and kiln dust used to fill abandoned underground structures - (1) DC
Waste lime from acetylene production used for soil modification - (1) OK
Fly ash in cement-fly ash grout - (1) NY
Granulated rubber tires in joint and crack sealer - (1) IL
Steel slag- aggregate in asphalt paving - (1) MN
Fly ash in sub-sealing concrete pavement - (1) TX
Fly ash in PCC base - (1) OH
Cold milled asphaltic concrete - (1) IL
Granulated rubber tires - crack sealing on concrete and asphalt highways - (1)

More Field Study Needed

Kiln dust is used as a mineral filler in bituminous concrete - (1) NJ
Ground rubber tires in hot asphalt pavement (SKEGA) - (1) AK
Steel slag from open hearth furnace used in asphalt paving - (1) MO
Recycled bituminous concrete pavement - (1) CT
Fly ash used in concrete - (1) VA
Boiler slag - ice control - (2) IA, NE
Magnetherm slag (decrepitated) soil stabilization - (1) WA
Recycled PCC - (1) CT
Blast furnace slag aggregate in bituminous concrete - (1) WI
Fly ash aggregate base, subbase, or shoulders - (1) LA

More Laboratory Study Needed

Kiln dust as a mineral filler in bituminous concrete - (1) NJ
Steel slag from open hearth furnace used in asphalt paving - (1) MO
Recycled bituminous concrete pavement - (1) CT
Fly ash used in concrete - (1) VA
Fly ash-aggregate base, subbase, or shoulders - (1) LA
Recycled PCC - (1) CT

Do Not Favor Further Use

Cement kiln dust-mineral filler in asphalt paving - (2) AR, NE
Asphalt-granulated rubber in bituminous mixtures - (1) DC
Granulated rubber - AC crack sealing - (1) IA
CaSO₄ (from H₂SO₄ - Allied Chemical) as base materials - (1) DE

Uncertain

Glass waste for structural fill - (1) OH
Rubber in joint seal and asphalt concrete mixes - (1) NY
Boiler slag - ice control - (1) IA
Fly ash and wet bottom boiler slag in Type IP cement (produced by inter-grinding PCC and pozzolan)

7. Reasons for not wanting to use a recovered material

The recovered material did not perform acceptably

Fly Ash

Lime-fly ash-aggregate base, subbase or shoulders - (1) MI

Granulated Rubber Tires

Stress-absorbing membrane or stress-absorbing membrane interlayer - (1) CO
Cement or lime kiln dust - mineral filler in asphalt paving - (1) NE

The recovered material is not available in sufficient quantities

Granulated Rubber Tires

Stress-absorbing membrane or stress-absorbing membrane interlayer - (1) KS
Asphalt-rubber seal coat - (1) KS

Incinerator Residue

Aggregate supplement in asphalt paving - (1) PA

Other recovered materials or other applications of listed materials

Cement kiln dust - mineral filler in asphalt paving - (1) AR
Use of Ca SO₄ (recovered from production of H₂SO₄ by Allied Chemical) as
base material - (1) DE

The cost of using the recovered is too high in this application

Fly Ash

Lime-fly ash-aggregate base, subbase, or shoulders - (1) MI

Bottom Ash

Aggregate in lime-fly ash-aggregate base, subbase, or shoulders - (1) WY

Granulated Rubber Tires

Stress-absorbing membrane or stress-absorbing membrane interlayer - (3) CO, ID, KS
Asphalt-rubber seal coat - (3) ID, KS, NE

Incinerator Residue

Aggregate supplement in asphalt paving - (1) PA
Lime stabilized base, subbase or shoulders - (1) SC

Other Recovered Materials or Other Applications of Listed Materials

Aggregate in lime-fly ash-aggregate base, subbase, or shoulders - "Economics
of Haul Restricts Use to Close Vicinity of Source" (1) OR

7. Reasons for not wanting to use a recovered material (continued)

Kiln dust-fly ash aggregate base, subbase, or shoulders - "Economics of Haul Restricts Use to Close Vicinity of Source" (1) OR

Asphalt-granulated rubber in bituminous mixtures - "Use of material did not significantly improve long term pavement performance" (1) DC

Granulated rubber - AC crack sealing - "Did not justify additional expenses; there was no improved performance" (1) IA

Performance was not acceptable in reducing amount of cracking. We may find reduction in magnitude of the reflected cracks (1) ID

The actual materials costs are not too high, however, the special equipment and handling or application costs are too high for benefits received (1) KS

8. Assuming sufficient research funds are available, what is your attitude toward possible future use in applications which you have not as yet investigated?

Would not be interested in investigating any other recovered materials - (5)
CO, CT, ID, NH, OK

May possibly be interested in investigating other recovered materials - (33)
AZ, AR, DE, FL, GA, IL, IA, KS, LA, MI, MN, MS, MO, MT, NE, NV, NJ, NM, NY, ND, OH, OR, PA, RI, SC, SD, TX, VT, VA, WA, WI, WY

Fly Ash

Structural fill - (7) AR, MO, OH, OR, SD, TX, WY
Lime-fly ash-aggregate base, subbase, or shoulders - (15) AR, DE, DC, IA, KS, LA, MT, NM, OH, OR, RI, SC, WY, VA, SD
Mineral filler in asphalt paving - (8) AZ, KS, MO, NV, OR, PA, VA, WA

Bottom Ash

Aggregate in lime-fly ash-aggregate base, subbase, or shoulders - (7) AR, IA, KS, MS, MO, ND, OH
Aggregate in asphalt paving - (9) KS, NJ, NC, ND, RI, SC, WA, WI, WY

Kiln Dust

Kiln dust-fly ash-aggregate base, subbase, or shoulders - (4) AZ, DC, GA, TX

Granulated Rubber Tires

Stress-absorbing membrane or stress-absorbing membrane interlayer - (6) LA, MO, NE, NV, OH, SC
Asphalt-rubber seal coat - (8) AR, MO, NE, ND, OH, SC, VA, WI

Incinerator Residue

Aggregate supplement in asphalt paving - (8) GA, IL, MI, MN, NJ, NM, NY, OH
Lime stabilized base, subbase, or shoulders - (6) GA, IL, MT, NY, SC, WA

Would definitely be interested in investigating the following applications for recovered materials.

Fly Ash

Structural fill - (3) KS, LA, VT
Lime-fly ash-aggregate base, subbase, or shoulders - (2) HI, KS
Mineral filler in asphalt paving - (3) HI, NJ, TX

Bottom Ash

Aggregate in lime-fly ash-aggregate base, subbase, or shoulders - (2) GA, LA

Aggregate in asphalt paving - (3) MI, PA, TX

Kiln Dust

Kiln dust-fly ash-aggregate base, subbase, or shoulders - (5) AL, GA, MS, MO, TX

Granulated Rubber Tires

Stress-absorbing membrane or stress-absorbing membrane interlayer - (5) DE, GA, MI, NY, RI

Asphalt-rubber seal coat - (4) IL, MI, RI, WY

Incinerator Residue

Aggregate supplement in asphalt paving - (3) CA, GA, HI

Lime stabilized base, subbase, or shoulders - (2) CA, GA

9. ATTITUDE TOWARD PROCUREMENT GUIDELINES (MATERIALS)

APPLICATIONS	FAVOR OPTIONAL GUIDELINES	FAVOR MANDATORY GUIDELINES	OPPOSED TO MANDATORY GUIDELINES	OPPOSED TO ANY GUIDELINES	UNCERTAIN
<u>FLY ASH</u>					
A. STRUCTURAL FILL.	(9) AZ DE IL IA MI OK SC WV WY		(8) DE IA MI MN OK WV WI WY	(1) NY	RI (1)
B. LIME-FLY ASH- AGGREGATE BASE, SUBBASE, OR SHOULDER.	(12) AZ DE IL MI MS MO NT NC OK UT WV WY		(11) CO DE GA MI MS MO OK TX UT WV WY	(3) NY ND PA	RI (1)
C. MINERAL FILLER IN ASPHALT PAVING.	(9) DE IL LA MI NC OK SC WV WY		(12) AL AR CO DE GA LA MI MT NE OK WV WY	(1) NY	
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH- AGGREGATE BASE, SUBBASE, OR SHOULDER.	(10) DE IL MI NC OK OR UT WA WV WY		(8) DE MI OK OR UT WA WV WY	(1) NY	
E. AGGREGATE IN ASPHALT PAVING.	(7) DE IL MI MO OK UT WY	(1) AL	(10) AR DE GA KS MI MN MO OK UT WY	(2) NE NY	AZ (1)
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(9) DE IL IA MI OK OR UT VA WV		(10) CO DE IA KS MI MT OK OR UT WY	(1) NY	
<u>GRANULATED RUBBER TIRE S</u>					
G. STRESS-ABSORB- ING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(16) AL DE FL HI IL IA MI MN NA NC OK OR SC VT WA WV	(1) RI	(13) AZ AR CO DE GA IA KS MI OK OR TX WA WY	(5) CA ID NY ND PA	(1) NM
H. ASPHALT RUBBER SEAL COAT.	(15) DE FL IL IA LA MI MN MS NM OK OR RI SC SD WV		(15) AZ CO DE GA IA KS LA MI MS AT NV OK OR TX WV	(3) CA ID NY	
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(7) AL DE DC IL MI OK WV		(5) DE DC MI OK WV	(2) NY PA	
J. LIME STABIL- IZED BASE, SUBBASE OR SHOULDERS.	(5) DE IL MI OK WV		(4) DE MI OK WV NY	(1) NY	

9. Attitude toward procurement guidelines - Other Applications K&L

Favor Optional Guidelines

Recycled bituminous concrete pavement - (2) CT, VT
Fly ash (Class F) as a PC replacement - (2) FL, WV
Waste lime from acetylene production used for soil modification - (1) OK
Fly ash used in hydraulic cement concrete - (1) VA
Sulfur extended asphalt - (1) IL
Kiln dust is used as a mineral filler in bituminous concrete - (1) NJ
Steel slag from open hearth furnace used in asphalt paving - (1) MO
Fly ash - PCC pavement - (1) NM
Cement kiln dust for mineral filler in asphalt concrete - (1) LA
Blast furnace slag for concrete and bituminous aggregate - (1) MI
Use of Ca SO₄ (recovered from production of H₂SO₄ by Allied Chemical)
as base material - (1) DE
Fly ash as additive in PCC - (1) OR
Steel furnace slag for bituminous aggregate and base course -
Fly ash-aggregate base, subbase, or shoulders - (1) LA
Granulated rubber tires - subgrade waterproofing membrane - (1) NM
Fly ash and wet bottom boiler slag in Type IP cement - (1) MO
Granulated rubber tires in joint and crack sealer - (1) IL, IA
Fly ash (Class F) as an admixture - (1) FL
Recycled PCC -
Cold milled asphaltic concrete - (1) IL
Fly ash - cement replacement - (1) IA

Opposed to Mandatory Guidelines

Glass waste for structural fill -
Steel slag for structural fill, base, asphalt paving -
Fly ash in PCC base -
Fly ash in concrete - (8) IA, MN, MO, NE, OR, TX, WV, WI
Blast furnace slag for concrete and bituminous aggregate - (1) MI
Use of Ca SO₄ (recovered from production of H₂SO₄ by Allied Chemical)
as base material - (1) DE
Cement kiln dust - mineral filler in asphalt paving - (3) LA, NE, AR
Steel slag from open hearth furnace used in asphalt paving - (2) MN, MO
Taconite tailings - aggregate in asphalt paving - (1) MN
Waste lime from acetylene production used for soil modification - (1) OK
Recycled bituminous concrete pavement - (1) CT
Recycled PCC -
Blast furnace slag aggregate in bituminous concrete -
Fly ash-aggregate base, subbase, or shoulders - (1) LA
Granulated rubber - AC crack sealing - (1) IA

Opposed to Any Guidelines

Asphalt-rubber crack sealant - (1) ND
Slag base and surfacing - slag waste from phosphate fertilizer plant - (1) ID
Rubber in joint seal and asphalt concrete mixes - (1) NY
Fly ash in cement-fly ash grout - (1) NY
Sawmill waste (hot fuel) - lightweight fill - (1) WA
Fly ash in concrete - (1) CA
Ground rubber tires in hot asphalt pavement (SKEGA) - (1) AK
Cement dust as AS supplemental fine aggregate - (1) CA
Bottom ash or boiler slag - winter ice & snow control on new concrete
pavement - (1) NE
Cement or lime kiln dust - mineral filler in asphalt paving - (1) NE

COMMENTS

1. Essentially no recovered materials available for use within the state. (AK)
2. Would be opposed in general to any mandatory guidelines. Believe the "State of the Art" of these recovered materials is not to development point that anything beyond advisory comments is justified. (AZ)
3. It is hard to express an opinion on guidelines without knowing something about what they will contain. (AR)
4. Recycling of existing asphalt plant mix is becoming absolutely necessary because of high cost of asphalt. Other recovered materials listed in this report may prove beneficial but a limited budget will not allow us to participate. (ID)
5. The general goal to utilize recovered or postconsumer "waste" material is certainly laudible, however at the current time very few of these products have any kind of quality control or quality assurance systems. In the current state it would seem entirely inappropriate to insist or mandate that states must provide a market to dispose of these materials. The producers of the "waste" products should provide controls to assist in development of proper markets. I seriously doubt that all "waste" materials have potential for road building materials. (KS)
6. Fly ash as lime-fly ash-aggregate base, subbase, or shoulders and as portland cement substitute - use limited due to economic considerations. (MD)
7. Just starting to investigate use of fly ash as structural fill and lime-fly ash stabilization. Also one experimental project using incinerator residue. (MA)
8. High quality, long lasting construction must be a prime concern in the use of waste materials for constructing and maintaining transportation facilities. (MN)
9. We would not favor guidelines, either optional or mandatory, since we are now using these products) exception incinerator residue as none is available) and see no purpose for imposing guidelines on states that are already using waste/recovered products. (NE)
10. We favor the use of recovered materials when use is cost-effective as determined by our department. (NY)
11. NC is fortunate in having ample good quality natural aggregate. It is doubtful that bottom ash will be competitive in the immediate future due to the fact that haul distances would seldom be less than a good aggregate source. Attached letter. (NC)

COMMENTS (continued)

12. We have found that while a product may work satisfactorily in one area it may not in a different area of the country where the climate is different. It should be up to the user to determine if a product is beneficial or not. (ND)
13. In general I am opposed to mandatory guidelines. The use of a material must be determined by satisfactory performance, availability, and economics. All of these are related. (OH)
14. Availability, hauling costs, and limited uses to which these materials have been found acceptable necessitate opposition to mandatory guidelines. (OR)
15. In the above you will see that I checked "Favor Optional Guidelines." I am reluctant to do this, however, because optional guidelines often become mandatory and I am definitely opposed to mandatory guidelines. (SC)
16. Any application would favor optional guidelines. (SD)
17. Approximately \$500,000 obligated to fly ash research; 30 test sections being evaluated; approximately a dozen projects with some dating back to 1959. (TX)
18. Opposed to EPA establishing guidelines for materials to be used in construction. Recommended that they make suggestions only and guidelines to be established by states or AASHTO. (UT)
19. Would be interested in using recovered materials which are available within a reasonable distance. (VT)
20. We would favor guidelines encouraging use of these materials where conditions would allow for their use. Any mandatory guidelines are opposed. (WV)
21. We favor use of more alternative materials, including waste products, if we could be reasonably assured of producing a durable and serviceable product, but we must proceed carefully in attempts to lump all waste products into our work. Directives and mandatory guidelines, we don't want. (WI)

Summary of Recovered Materials Questionnaire

The Subcommittee on Construction circulated a questionnaire to the construction engineers of the U.S. member departments in April 1980 concerning their experience and attitude toward the use of various recovered materials. Following is a tabulation of the replies. Forty-eight member departments responded to the questionnaire. The large majority of those responding favor increased use of recovered materials but do not favor any mandatory guidelines to stimulate such use.

1. Which of the following recovered materials have been used in highway construction products in your state?

Fly Ash - (34) AL, AZ, CA, CO, DC, FL, GA, IL, IN, IA, KY, LA, MI, MN, MS, MO, MT, PA, NE, NJ, NM, NY, NC, ND, OH, OK, OR, TN, TX, UT, VA, WV, WI, WY

Bottom Ash or Boiler Slag - (22) AL, FL, GA, ID, IL, IN, IA, KS, KY, MI, MN, MO, NE, NJ, NY, OH, OR, TX, WA, WV, WI, PA

Cement or Lime Kiln Dust - (13) CA, CO, DC, IL, IA, KS, LA, NE, NJ, NY, OR, WY, PA

Granulated Rubber Tires - (32) AL, AK, AZ, CA, CO, DE, DC, FL, GA, HI, KS, LA, ME, MI, MN, MS, NE, NJ, NM, NY, NC, ND, OK, OR, SD, TN, TX, UT, VT, WA, WY, PA

Incinerator Residue - (4) AL, DC, TX, PA

None of these (if so, omit questions 2 through 5). (4) CT, MD, NV, SC

The remaining questions pertain to specific applications for recovered materials. (Please refer to the appropriate letter code when answering these questions). For example, fly ash use as structural fill will be referred to by the letter "A."

2. In what applications have these recovered materials been used in your state?

FLY ASH

A. Structural Fill - (8) WV, WI, WY, AZ, IL, IA, MN, NY

B. Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (15) AZ, CO, GA, IL, MA, MI, WV, TX, OK, OH, ND, NC, NY, NJ, MO

C. Mineral Filler in Asphalt Paving - (17) AL, CO, FL, GA, IL, KY, LA, MI, MT, NE, NY, NC, ND, TN, WV, WY, PA

BOTTOM ASH OR BOILER SLAG

D. Aggregate in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (6) ID, IL, OH, OR, WA, WV

E. Aggregate in Asphalt Paving - (18) AL, AZ, FL, GA, ID, IL, IN, KS, KY, MI, MN, MO, NE, NJ, NY, TX, WV, PA

CEMENT OR LIME KILN DUST

- F. Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders - (4) CO, IA, KS, OR

GRANULATED RUBBER TIRES

- G. Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (21) AL, AZ, CA, CO, FL, HI, ID, KS, ME, MI, MN, MS, NM, NC, ND, OK, OR, VT, WA, WY, PA
- H. Asphalt-Rubber Seal Coat - (26) AK, AZ, CA, CO, DE, FL, GA, KS, LA, ME, MA, MI, MN, MS, NM, NY, ND, OK, OR, SD, TN, TX, UT, WA, WY, PA

INCINERATOR RESIDUE

- I. Aggregate Supplement in Asphalt Paving - (6) AL, DC, MA, MI, TX, PA
- J. Lime Stabilized Base, Subbase, or Shoulders - (3) MA, MI, NY

OTHERS

- K. and L.

Fly Ash in PC Concrete - (15) AZ, CA, IN, IA, MN, NM, OR, UT, WV, WI, WY, MS, MO, NY, NE

CaSO₄ (from H₂SO₄ - Allied Chemical) as base material - (1) DE

Fly Ash & Kiln Dust Used to Fill Abandoned Underground Structures - (1) DC

Sulfur Extended Asphalt (hot mix base & pavement) - (2) IL, MS

Boiler Slag as Deicing Agent - (4) KS, IN, IA, NE

Waste from Coal Processing - Shoulder Material - (1) KY

Cement Kiln Dust as Mineral Filler in Asphalt Concrete - (5) LA, NJ, AZ, NE, CA

Rubberized Bituminous Pavement - (1) ME

Rubber-Asphalt As a Crack Filler - (2) MA, NE

Blast Furnace Slag for Concrete & Bituminous Aggregate - (2) MI, WI

Taconite Tailings - Aggregate in Asphalt Paving - (1) MN

Steel Slag from Open Hearth Furnace in Asphalt Paving - (1) MO

Phosphate or Iron Ore Slag - Aggregate in Asphalt Paving - (1) TN

Vulcanized Rubber Shreds and Fine Aggregate in Emulsion Slurry as a Strain Relieving Interlayer - (1) VT

Saw Mill Waste (hog fuel) - lightweight fill - (1) WA

OTHERS (continued)

Fly Ash in Cement Treated Base and Slabjacking - (1) WY

Rubber in Joint Seal - (2) NY, NJ

Asphalt Granulated Rubber in Bituminous Mix - (2) DC, NY

Cold Milled Asphaltic Concrete - (2) IL, VT

Fly Ash - Aggregate Base, Subbase or Shoulder - (1) LA

Steel Furnace Slag - Bituminous Aggregate and Base Course - (2) MI, MN

Wet Bottom Boiler Slag in Cement - (1) MO

Ground Rubber Tires - Subgrade Waterproof Membrane - (1) NM

Fly Ash Grout - (1) NY

Ground Rubber Tires in Guard Rail Blocks - (1) OR

Magnetherm Slag (decrepitated) soil stabilization - (1) WA

Cement Kiln Dust-Subgrade Stabilization - (1) WY

Slag-Coarse Aggregate in PCC Pavement - (1) TX

3. EXTENT OF USE (CONSTRUCTION)

APPLICATIONS	LABORATORY INVESTIGATION	FIELD EXPERIMENTATION	LIMITED FIELD USE	ROUTINE FIELD USE
<u>FLY ASH</u>				
A. STRUCTURAL FILL.	(4) AZ, IA, MN, WI	(4) MN, NY, WV, WI	(4) IL, MN, WI, WY	(1) NY
B. LIME-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.	(7) AZ, CO, GA, MO, NY, NC, OK	(6) AZ, CO, MA, MO, OK, WV	(5) CO, MI, ND, OH, TX	(2) AZ, NJ
C. MINERAL FILLER IN ASPHALT PAVING.	(4) CO, GA, KY, WY	(2) KY, TN	(7) CO, FL, GA, KY, MT, ND, WY	(8) AL, LA, MI, NE, NY, NC, WV, PA
<u>BOTTOM ASH OR BOILER SLAG</u>				
D. AGGREGATE IN LIME-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.		(1) MS	(5) ID, OH, OR, WA, WV	
E. AGGREGATE IN ASPHALT PAVING.	(3) CO, KY, MN	(5) MI, MN, NY, WV, PA	(10) AZ, CO, FL, ID, IN, KS, MN, NE, NJ, TX	(4) AL, GA, KY, MO
<u>CEMENT OR LIME KILN DUST</u>				
F. KILN DUST-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.	(2) IA, KS	(1) OR	(1) KS	
<u>GRANULATED RUBBER TIRE S</u>				
G. STRESS-ABSORBING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(6) AZ, CO, MN, OK, OR, PA	(14) AL, AZ, CA, CO, HI, KS, ME, MI, MN, NM, NC, OK, WY, PA	(9) FL, ID, MN, ND, OK, OR, VT, WA, WY	(4) AZ, CO, NM, WA
H. ASPHALT RUBBER SEAL COAT.	(9) AK, AZ, CO, GA, LA, MN, OK, OR, PA	(16) AK, AZ, CA, CO, FL, GA, KS, ME, MI, MN, NM, NY, OK, UT, WY, PA	(15) AK, CA, CO, DE, IA, MN, MS, NM, OK, OR, SD, TN, TX, WA, WY	(3) AZ, ND, WA
<u>INCINERATOR RESIDUE</u>				
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(1) TX	(3) DC, MA, PA		(1) AL
J. LIME STABILIZED BASE, SUBBASE OR SHOULDERS.	(1) NY	(1) MA F-27		

3. Extent of Use OTHERS

LABORATORY INVESTIGATION

Fly Ash in PC Concrete - (3) NM, OR, WI
Fly Ash-Aggregate Base, Subbase, or Shoulders - (1) LA
Magnettherm Slag (decrepitated) - soil stabilization - (1) WA
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Rubberized Bituminous Pavement - (1) ME
Steel Slag - Aggregate in Asphalt Paving - (1) MN

FIELD EXPERIMENTATION

Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO
Use of Ca SO₄ (recovered from production of H₂SO₄ by Allied Chemical) as base material - (1) DE
Sulfur Extended Asphalt - (2) IL, MS
Fly Ash and Kiln Dust used to fill abandoned underground structures - (1) DC
Fly Ash in PCC - (2) NM, WI
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Asphalt-Granulated Rubber in bituminous mixtures - (1) DC
Boiler slag - ice control - (1) IA
Cold Milled Asphaltic Concrete - (1) IL
Rubberized Bituminous Pavement - (1) ME
Granulated Rubber - Joint Sealer - (1) NJ

3. Extent of Use (Continued)

Others

LIMITED FIELD USE

Cold Recycling of Bituminous Concrete Pavement - (1) VT
Steel Slag from Open Hearth Furnace Used in Asphalt Paving - (1) MO
Sawmill Waste (hog fuel) - lightweight fill - (1) WA
Asphalt-Rubber Crack Sealant - (1) NE
Fly Ash in PCC - (6) IL, IA, NM, OR, UT, WI
Fly Ash and Kiln Dust used to fill abandoned underground structures - (1) DC
Cement Kiln Dust - Mineral Filler in Asphalt Paving - (1) NE
Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI
Fly Ash in Cement-Fly Ash Grout - (1) NY
Waste from Coal Processing - Shoulder Material - (1) KY
Bottom Ash or Boiler Slag - Ice and Snow Control - (1) NE
Vulcanized Rubber Shreds and Fine Aggregate in Emulsion Slurry - (1) VT

ROUTINE FIELD USE

Rubber in Joint Seal and Asphalt Concrete Mixes - (1) NY
Cement Kiln Dust for Mineral Filler in Asphalt Concrete - (3) CA, LA, NJ
Fly Ash in PCC (5) CA, MN, MS, NE, WV
Taconite Tailings - Aggregate in Asphalt Paving - (1) MN
Steel Slag-Aggregate in Asphalt Paving - (1) MN
Sulfur Extended Asphalt Hot Mix Base and Pavement - (1) MS
Phosphate or Iron Ore Slag - Aggregate in Asphalt Paving - (1) TN

4. PERFORMANCE (CONSTRUCTION)

APPLICATIONS	EXCELLENT	GOOD	ACCEPTABLE	MARGINAL	POOR
<u>FLY ASH</u>					
A. STRUCTURAL FILL.	(1) WI	(4) IL, NY, WV, WY	(2) AZ, MN		
B. LIME-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(1) AZ	(8) CO, GA, IL, NJ, ND, OH, TX, WV	(1) OK		(2) MI, NC
C. MINERAL FILLER IN ASPHALT PAVING.	(2) CO, NE	(11) AL, FL, IL, KY, MI, NY, NC, ND, WV, WY, PA	(4) GA, LA, MT, TN		
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.		(5) ID, IL, OH, WA, WV	(1) OR		
E. AGGREGATE IN ASPHALT PAVING.	(2) AZ, KY	(8) AL, GA, ID, IL, KS, MI, MO, TX	(6) FL, IN, MN, NE, NY, PA	(1) WV	(1) NJ
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.		(1) KS	(2) CO, OR		
<u>GRANULATED RUBBER TIRES</u>					
G. STRESS-ABSORBING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(2) AL, AZ	(5) FL, ND, WA, CA, PA	(7) MI, NM, OK, OR, WY, CA, PA	(6) HI, ID, KS, ME, VT, CA	(2) AZ, CO
H. ASPHALT RUBBER SEAL COAT.	(2) GA, ND	(12) AK, FL, LA, ME, OK, SD, TN, TX, UT, WA, CA, PA	(6) MA, MI, NM, OR, CA, PA	(4) MS, NY, WY, CO	(3) DE, KS, CA
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(1) PA	(3) AL, DC, TX			
J. LIME STABILIZED BASE, SUBBASE OR SHOULDERS.					

4. Performance

Other Recovered Materials or other Applications of listed Recovered Materials

Excellent

Taconite Tailings-Aggregate in Asphalt Paving - (1) MN
Sawmill Waste (hog fuel) - lightweight fill - (1) WA
Fly ash in concrete - (3) MN, MS, WV
Magnetherm Slag (decrepitated) - soil stabilization - (1) WA
Steel Slag-Aggregate in Asphalt Paving - (1) MN
Cold Recycling of Bituminous Concrete Pavement - (1) VT

Good

Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO
Use of Ca SO_4 (recovered from production of H_2SO_4 by Allied Chemical) as base material - (1) DE
Fly ash in concrete - (5) CA, IA, NE, OR, WI
Cement dust as mineral filler in asphalt concrete - (2) CA, NE
Asphalt - Rubber Crack Sealant - (1) NE
Sulfur Extended Asphalt - (2) IL, MS
Recycled Bituminous Concrete Pavement - (1) IL
Fly ash and kiln dust used to fill abandoned underground structures - (1) DC
Granulated Rubber Tires - subgrade waterproofing membrane - (1) NM
Blast furnace slag aggregate in bituminous concrete - (1) WI
Fly ash in cement-fly ash grout - (1) NY
Boiler Slag as Deicing Agent - (2) IN, NE
Phosphate or Iron Ore Slag - Aggregate in Asphalt Paving - (1) TN

4. Performance (continued)

Other Recovered Materials or other Applications of listed Recovered Materials

Acceptable

Fly ash in concrete - (2) IN, NM

Rubber in joint seal and asphalt concrete mixes - (1) NY

Cement kiln dust - Mineral filler in asphalt paving - (1) NJ

Fly ash and wet bottom boiler slag in Type IP cement (produced by intergrinding PCC and pozzolan) - (1) MO

Marginal

Asphalt-Granulated Rubber in bituminous mixtures - (1) DC

Waste from coal processing - shoulder material - (1) KY

Rubberized Bituminous Pavement - (1) ME

Poor

Boiler slag - ice control - (1) IA

Rubber tires - joint sealer - (1) NJ

Vulcanized Rubber Shreds and fine aggregate in emulsion slurry for strain relieving interlayer - (1) VT

5. Applications that have performed either excellently or poorly and the reasons given for such performance.

Excellent performance

- a. Granulated rubber tires in Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - no reflective cracking noted after 3 years. (AL)
- b. Bottom Ash or Boiler Slag as Aggregate in Asphalt Paving - heavy, stable, sharp faces (do not use in seal coat chip application - Sp. Gr. too heavy - breaks windshields). (AZ)
- c. Fly Ash as mineral filler in Asphalt Paving - There was a severe need for additional fines and fly ash solved this problem. (CO)
- d. Granulated Rubber Tires in Asphalt-Rubber Seal Coat - retarder for cracking. (GA)
- e. Boiler Slag as ice control material - salt wasn't used - the angularity and color (black) of slag eliminated the ice rather rapidly. (KS)
- f. Bottom Ash or Boiler Slag as Aggregate in Asphalt Paving - bituminous surface, crushed, sharp edges provide good skid resistance. (KY)
- g. Fly Ash in Concrete - improves concrete workability, reduces cost but increases time of set. (MN)
- h. Taconite Tailings as Aggregate in Asphalt Paving - good skid resistance, high stability, low abrasion loss, somewhat higher in cost in southern part of state. (MN)
- i. Steel Slag - Aggregate in Asphalt Paving - Good skid resistance, high stability, low abrasion loss, limited availability. (MN)
- j. Fly Ash used in Structural Concrete - Provides a more dense concrete for the pipe or small drainage structure, therefore, more resistant to sulfate reaction. (MS)
- k. Fly Ash as Mineral Filler in Asphalt Paving - lower price and lower asphalt demand than other mineral fillers. (NE)
- l. Granulated Rubber Tires in Asphalt-Rubber Seal Coat - excellent chip retention and resistance to bleeding. (ND)
- m. Cold recycling of bituminous concrete pavement - process of cold recycling is relatively simple. (VT)
- n. Saw mill waste (hog fuel) - lightweight fill - limited application to specific sites. (WA)
- o. Magnetherm Slag (decrepitated) soil stabilization - similarity of this material to commercial lime. (WA)
- p. Fly Ash in Portland Cement Concrete for pavements - provides equal strength and durability and improved workability. (WV)

5. Applications (continued)

Excellent performance

- q. Fly Ash in Structural Fill - compacted easily - stable - low cost - no volume change. (WI)
- r. Incinerator Residue as Aggregate Supplement in Asphalt Paving - good quality aggregate-type material, but too costly. (PA)

Poor Performance

- a. Granulated Rubber Tires in Asphalt-Rubber Seal Coat - inadequate binder properties, chips not retained, cracks reflected through. (CA)
- b. Granulated Rubber Tires - problems in application. (AZ)
- c. Granulated Rubber Tires in Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - did not control reflective cracking. (CO)
- d. Granulated Rubber Tires in Asphalt Rubber Seal Coat - chips not retained. (DE)
- e. Boiler Slag - ice control to minimize slipping - crushed too easily under traffic. (IA)
- f. Granulated Rubber Tires in Asphalt-Rubber Seal Coat - Air temperature requirements appear to be above 70°F for proper sealing. Aggregates must be dry - otherwise failure. (KS)
- g. Waste from coal processing - shoulder material - material weathered and produced excessive fines. (KY)
- h. Fly Ash as Mineral Filler in Asphalt Paving - periodic poor behavior noted, believed due to gradation, differences of fly ash. (LA)
- i. Granulated Rubber Tires as Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - did not stop reflective cracking. (ME)
- j. Granulated Rubber Tires in Asphalt-Rubber Seal Coat - has more cracks than adjacent conventional pavement. (ME)
- k. Fly Ash as Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - Too temperature and moisture sensitive for cure, frost susceptible, poor drain ability, and more expensive than conventional aggregate mixtures. (MI)
- l. Cement or lime kiln dust as mineral filler in Asphalt Paving- good results obtained several years ago but recent pollution equipment added at cement plant has produced cement dust that is very fine and has such a high asphalt demand that mixes tend to become unstable. (NE)
- m. Bottom Ash or Boiler Slag as Aggregate in Asphalt Paving - poor skid resistance. (NJ)

5. Applications (continued)

Poor performance

- n. Granulated Rubber Tires as joint sealer - Rubber difficult to get into solution, clogged hand pouring pots, need double wall kettle, uses more energy, remained too soft and tracked. (NJ)
- o. Fly Ash in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - Strength of Lime-Fly Ash- stabilization of aggregate base at 7 days was about 12% of aggregate base with 3% cement & 3 times as expensive. (NC)
- p. Vulcanized Rubber Shreds & Fine Aggregate in emulsion slurry for stress relieving interlayer - pavement overlay shoved, ravelled, and stripped severely; rubberized interlayer acted as a moisture barrier which caused surface moisture to be retained in the overlays. (VT)

(CONSTRUCTION)

6. ATTITUDE TOWARD FUTURE USE OF RECOVERED MATERIALS

APPLICATIONS	FAVOR INCREASED USE	MORE FIELD STUDY NEEDED	MORE LAB-ORATORY STUDY NEEDED	DO NOT FAVOR FURTHER USE	UNCERTAIN
<u>FLY ASH</u>					
A. STRUCTURAL FILL.	(5) AZ, IL, NY, WI, WY	(3) AZ, MN, WV	(2) AZ, IA		
B. LIME-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.	(8) AZ, CO, GA, IL, NJ, OK, TX, WV	(6) AZ, MA, MO, NJ, ND, OH	(3) AZ, MO, TX	(2) MI, NC	(1) NY
C. MINERAL FILLER IN ASPHALT PAVING.	(12) AL, CO, FL, IL, KY, MI, NE, NY, NC, ND, WY, PA	(2) MT, TN	(5) GA, LA, MT, NV, WY		(1) LA
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.	(3) ID, IL, WA	(2) OH, WV			(1) OR
E. AGGREGATE IN ASPHALT PAVING.	(9) AL, AZ, FL, GA, ID, IL, KS, KY, MO	(6) IN, MI, MN, NE, NY, WV	(3) NT, TX, PA	(1) NT	
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE, BASE, SUBBASE, OR SHOULDER.	(1) KS		(2) IA, NV		(2) CO, OR
<u>GRANULATED RUBBER TIRES</u>					
G. STRESS-ABSORBING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(7) AL, FL, MN, NM, OK, OR, WA	(13) AZ, CA, CO, HI, ID, MI, MN, MS, NM, NC, ND, VT, PA	(1) AZ	(3) CO, KS, ME	(1) WY
H. ASPHALT RUBBER SEAL COAT.	(10) CA, GA, MN, NM, ND, OK, OR, SD, TX, WA	(16) AK, AZ, CA, CO, DE, ME, MA, MI, NM, MS, MN, NY, TN, TX, UT, PA	(2) AZ, TX	(3) CO, KS, UT	(5) FL, LA, ME, UT, WY
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(2) AL, DC	(1) MA		(1) PA	(1) TX
J. LIME STABILIZED BASE, SUBBASE OR SHOULDERS.		(1) MA			(1) NY

6. Attitude toward future use of recovered materials

Other Recovered Materials or Other Applications of listed materials

Favor Increased Use

Taconite Tailings - Aggregate in Asphalt Paving - (1) MN

Fly Ash in concrete - (10) AZ, CA, IA, MN, MS, NE, NM, OR, WV, WI,

Sawmill waste (hog fuel) - lightweight fill - (1) WA

Sulfur Extended Asphalt - (1) IL

Cement kiln dust for mineral filler in asphalt concrete - (2) CA, LA

Fly ash and kiln dust used to fill abandoned underground structures - (1) DC

Fly ash in cement - fly ash grout - (1) NY

Steel Slag - aggregate in Asphalt Paving - (1) MN

Cold Milled Asphaltic concrete - (2) IL, VT

Granulated Rubber - (1) IN

Phosphate or Iron Ore Slag - Aggregate in Asphalt Paving - (1) TN

More Field Study Needed

Kiln Dust is used as a mineral in bituminous concrete - (1) NJ

Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO

Fly Ash used in Concrete - (2) IN, UT

Boiler Slag - ice control - (2) IA, NE

Magnetherm Slag (decrepitated) soil stabilization - (1) WA

Blast Furnace Slag Aggregate in Bituminous Concrete - (1) WI

Fly-ash aggregate base, subbase, or shoulders - (1) LA

Sulfur extended Asphalt hot mix base and pavement - (1) MS

Ground Rubber Tires - joint sealer - (1) NJ

6. Attitude (continued)

Other Recovered Materials or other Applications of listed materials

More Laboratory Study Needed

Kiln Dust as a mineral filler in bituminous concrete - (1) NJ
Steel Slag from Open Hearth Furnace used in Asphalt Paving - (1) MO
Fly ash used in Concrete - (1) AZ
Fly ash-aggregate base, subbase, or shoulders - (1) LA
Ground Rubber Tires - joint sealer - (1) NJ

Do Not Favor Further Use

Asphalt-Granulated Rubber in bituminous mixtures - (1) DC
 CaSO_4 (from H_2SO_4 - Allied Chemical) as base material - (1) DE
Waste from coal processing - shoulder material - (1) KY
Vulcanized Rubber shreds and fine aggregate in emulsion slurry for strain relieving interlayer - (1) VT
Fly Ash used in concrete - (1) UT

Uncertain

Rubber in joint seal and asphalt concrete mixes - (1) NY
Boiler Slag - ice control - (2) IN, IA
Fly ash and wet bottom boiler slag in Type IP Cement (produced by inter-grinding PCC and pozzolan) - (1) MO
Rubberized Bituminous Pavement - (1) ME

7. Reasons for not wanting to use a recovered material

The recovered material did not perform acceptably

Fly Ash

Lime-Fly Ash Aggregate Base, Subbase or Shoulders - (2) MI, NC

Bottom Ash or Boiler Slag

Aggregate in Asphalt Paving - (1) NJ

Cement or Lime Kiln Dust

Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders - (1) NE

Granulated Rubber Tires

Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (3) CO, ME, NE

Other Recovered Materials or other applications of listed materials

Waste from coal processing - shoulder material - (1) KY

Rubberized bituminous pavement - (1) ME

Vulcanized rubber shreds and fine aggregate in emulsion slurry - (1) VT

The recovered material is not available in sufficient quantities

Bottom Ash or Boiler Slag

Aggregate in Asphalt Paving - (0)

Incinerator Residue

Aggregate Supplement in Asphalt Paving - (1) NV

Other Recovered Materials or other applications of listed materials

CaSO₄ (from H₂SO₄ - Allied Chemical) as base material - (1) DE

The cost of using the recovered material is too high in this application

Fly Ash

Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders (2) MI, NC

Bottom Ash

Aggregate in Asphalt Paving - (1) AZ

7. Reasons (continued)

The cost of using the recovered material is too high in this application

Granulated Rubber Tires

Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (2) CO, KS

Asphalt-Rubber Seal Coat - (1) UT

Incinerator Residue

Aggregate Supplement in Asphalt Paving - (1) PA

Other Reasons

Ambient Temperature and Moisture Requirement too critical and results not worth the cost

Granulated Rubber Tires

Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (1) KS

Asphalt-Rubber Seal Coat - (1) KS

Economics, or Haul restricts use to close vicinity or source

Bottom Ash or Boiler Slag

Aggregate in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (1) OR

Cement or Lime Kiln Dust

Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders - (1) OR

Did not improve performance

Asphalt granulated rubber in bituminous mixtures - (1) DC

Not certain to the effect on concrete durability

Fly Ash- PC Concrete (1) UT

8. Assuming sufficient research funds are available, what is your attitude toward possible future use in applications which you have not as yet investigated

Would not be interested in investigating any other recovered materials - (4)

May possibly be interested in investigating other recovered materials (31)

Fly Ash

Structural Fill - (6) MA, MO, OR, TX, WY, PA

Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (13) AK, DE, DC, FL, HI, IA, LA, NM, OR, SD, TN, WY, PA

Mineral Filler in Asphalt Paving - (7) HI, ID, MO, NV, OR, WA, PA

Bottom Ash

Aggregate in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (5) IA, MO, ND, WY, PA

Aggregate in Asphalt Paving - (4) WA, WI, WY, PA

Kiln Dust

Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders - (7) DC, GA, NV, OH, TX, WY, PA

Granulated Rubber Tires

Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (10) AZ, KY, LA, NO, NE, NV, OH, TN, TX, PA

Asphalt-Rubber Seal Coat - (8) AZ, KY, NO, NE, NC, OH, WI, PA

Incinerator Residue

Aggregate Supplement in Asphalt Paving - (10) FL, GA, HI, IL, MI, MN, NM, NY, OH, PA

Lime Stabilized Base, Subbase, or Shoulders - (7) AK, FL, GA, NY, OH, WA, PA

Others

Fly Ash in concrete - (1) AZ

Ground rubber tires in guard rail blocks - (1) OR

Would definitely be interested in investigating the following applications for recovered materials (14)

Fly Ash

8. Future use (continued)

Would definitely be interested in investigating the following applications for recovered materials

Structual Fill - (4) KS, LA, OK, WY

Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (2) KS, MS

Mineral Filler in Asphalt Paving - (3) KS, OK, WY

Bottom Ash

Aggregate in Lime-Fly Ash-Aggregate Base, Subbase, or Shoulders - (3) GA, LA, MS

Aggregate in Asphalt Paving - (2) MS, OK

Kiln Dust

Kiln Dust-Fly Ash-Aggregate Base, Subbase, or Shoulders - (6) AL, GA, MS, MO, NJ, OK

Granulated Rubber Tires

Stress-Absorbing Membrane or Stress-Absorbing Membrane Interlayer - (4) DE, GA, MI, NY

Asphalt-Rubber Seal Coat - (2) MI, NJ

Incinerator Residue

Aggregate Supplement in Asphalt Paving - (2) CA, GA

Lime Stabilized Base, Subbase, or Shoulders - (2) CA, GA

Fly Ash in cement treated base and slabjacking - (1) WY

9. ATTITUDE TOWARD PROCUREMENT GUIDELINES (CONSTRUCTION)

APPLICATIONS	FAVOR OPTIONAL GUIDELINES	FAVOR MANDATORY GUIDELINES	OPPOSED TO MANDATORY GUIDELINES	OPPOSED TO ANY GUIDELINES	UNCERTAIN
<u>FLY ASH</u>					
A. STRUCTURAL FILL.	(7) AZ, DE, IL, IA, KS, MI, WY		(10) AK, DE, IL, IA, KS, MI, MN, WI, WY, PA	(3) AK, NY, SC	
B. LIME-FLY ASH- AGGREGATE BASE, SUBBASE, OR SHOULDER.	(12) AZ, DE, IL, KS, MA, MI, MO, ND, OH, OK, WV, WY		(14) MA, AK, CO, DE, OH, GA, IL, KS, OK, MI, WY, NC, WY, PA	(4) AK, NC, SC, TX	
C. MINERAL FILLER IN ASPHALT PAVING.	(10) DE, FL, IL, KS, KY, LA, MI, ND, TN, WY		(14) AL, AK, CO, DE, FL, GA, IL, KS, LA, MI, NE, NC, WY, PA	(5) AK, MT, NV, NC, SC	
<u>BOTTOM ASH OR BOILER SLAG</u>					
D. AGGREGATE IN LIME-FLY ASH- AGGREGATE BASE, SUBBASE, OR SHOULDER.	(8) DE, IL, KS, MI, OH, OR, WA, WY		(10) AK, OH, DE, IL, KS, MI, OR, WY, PA, WA	(2) AK, SC	(1) ID
E. AGGREGATE IN ASPHALT PAVING.	(8) DE, IL, IN, KS, KY, MI, MO, WY	(1) AL	(11) AK, DE, FL, GA, IL, KS, MI, MN, MO, WY, PA,	(5) AK, AZ, NE, SC, TX	(1) ID
<u>CEMENT OR LIME KILN DUST</u>					
F. KILN DUST-FLY ASH-AGGREGATE BASE, SUBBASE, OR SHOULDER.	(7) DE, IA, KS, MI, NJ, OR, WY		(9) AK, CO, DE, IA, KS, MI, OR, WY, PA	(2) AK, SC	
<u>GRANULATED RUBBER TIRES</u>					
G. STRESS-ABSORB- ING MEMBRANE OR STRESS ABSORBING MEMBRANE INTERLAYER.	(12) AL, DE, FL, HI, ID, MI, MN, NM, OK, OR, WA, WY		(13) AK, CO, DE, FL, MI, MS, NC, OK, OR, VT, WA, WY, PA	(6) AK, AZ, CA, NC, ND, SC	
H. ASPHALT RUBBER SEAL COAT.	(15) DE, FL, LA, MA, MI, MN, NJ, NM, OK, OR, SD, TN, UT, WA, WY		(13) AK, CO, DE, FL, GA, LA, MI, MS, OK, OR, WA, WY, PA	(6) AK, AZ, CA, ND, SC, TX	
<u>INCINERATOR RESIDUE</u>					
I. AGGREGATE SUPPLEMENT IN ASPHALT PAVING.	(6) AL, DE, DC, MA, MI, WY		(6) AC, DC, DE, MI, WY, PA	(2) AK, SC	
J. LIME STABIL- IZED BASE, SUBBASE OR SHOULDERS.	(4) DE, MA, MI, WY		(5) AK, DE, MI, WY, PA	(2) AK, SC	

9. Attitude toward procurement guidelines

Other Recovered Materials or other applications of listed materials

Favor Optional Guidelines

Fly Ash in concrete - (7) AZ, IN, IA, NM, OR, UT, WV
Sulfur extended asphalt - (1) IL
Cold milled asphaltic concrete - (1) IL
Boiler Slag as deicing agent - (1) IN
Cement Kiln Dust as mineral filler in asphalt concrete - (1) LA
Fly Ash & Wet bottom boiler slag in cement - (1) MO
Steel Slag from open hearth furnace in Asphalt Paving - (1) MD
Fly Ash - Aggregate base, subbase or shoulder - (1) LA
Ground rubber tires - subgrade waterproof membrane - (1) NM
Phosphate or iron ore slag - aggregate in asphalt paving - (1) TN

Opposed to Mandatory Guidelines

Sulfur extended asphalt - (2) IL, MS
Cold milled asphaltic concrete - (2) IL, VT
Fly Ash in concrete - (7) IA, MN, MS, NE, OR, WV, WI
Cement Kiln Dust as mineral filler in asphalt concrete - (1) LA
Fly Ash - Aggregate base, subbase, or shoulder - (1) LA
Taconite tailings - aggregate in asphalt paving - (1) MN
Steel Slag - aggregate in asphalt paving - (1) MN
Steel slag from open hearth furnace in asphalt paving - (1) MO
Fly Ash and Wet bottom boiler slag in cement - (1) MO
Saw mill waste (hog fuel) - lightweight fill - (1) WA
Blast furnace slag for concrete & bituminous aggregate - (1) WI

Opposed to Any Guidelines

Fly Ash in PC Concrete - (1) CA
Cement Kiln Dust as mineral filler in asphalt concrete - (2) CA, NE
Waste from coal processing - shoulder material - (1) KY
Rubber-asphalt as crack filler - (1) NE
Boiler Slag as deicing agent - (1) NE
Rubber in joint seal - (1) NY
Slag - coarse aggregate in PCC pavement - (1) TX

Comments

1. Guidelines promulgated by any federal agency for procurement of any material can only result in red tape, paper work, increased cost of the product and possible use of materials unsuitable for highway construction use at any cost. AL (letter included)
2. ...waste products should be utilized wherever possible and welcomes the circulation of information on the subject. ...oppose the imposition of federal guidelines... CA (letter included)
3. High quality, long lasting construction must be a prime concern in the use of waste materials for construction and maintaining transportation facilities. MN
4. ...utilizes certain waste materials where economically feasible to do so. trap rock in seal coat or asphaltic concrete mixtures, by-product of lead and zinc mining in asphaltic concrete mixtures and ice control, etc. MO (letter included)
5. We would not favor guidelines, either optional or mandatory, since we are now using these products (except incinerator residue as none is available) and see no purpose for imposing guidelines on states that are already using waste/recovered products. NE
6. We favor the use of recovered materials when use is cost-effective as determined by our department. NY
7. Availability, hauling costs and limited uses to which these materials have been found acceptable necessitate opposition to mandatory guidelines. OR
8. We are interested in use of these materials because they are recoverable, should not be wasted and are fairly cost competitive at this time. Guidelines, particularly mandatory ones, would tend to remove the "cost competitiveness" by reason of requiring their use. TX
9. We are opposed to mandatory EPA or FHWA guidelines for any use of any recovered materials. VT
10. We favor use of more alternative materials, including waste products, if we could be reasonable assured of producing a durable and serviceable product, but we must proceed carefully in attempts to dump all waste products into our work. Directives and mandatory guidelines, we don't want. WI (letter included)

Other recovered materials or other applications of the listed materials are shown in the summaries. A few of the more common "other" applications are fly ash in portland cement concrete, boiler slag as a de-icing agent, cement kiln dust as a mineral filler in asphalt concrete, and recycling of bituminous concrete pavement.

The extent of use for each of the recovered materials and their applications is shown in the summary in Table 3. This gives an indication of the low level of development of recovered material use with only a limited number of applications in routine field use. Granulated rubber tires and fly ash have the highest extent of use in most categories.

The performance rating from the construction group (Table 4) shows a high response of "good" performance replies for most of the recovered materials with a varied response for granulated rubber tires. The materials group results were more evenly spread over "marginal," "acceptable," and "good" replies. There were some "excellent" and some "poor" performance ratings for many of the recovered materials. The reasons for either excellent or poor performance are shown in the summary in Section 5 along with "Attitude Toward Future Use of Recovered Materials" - Table 6, and "Reasons for Not Wanting to Use a Recovered Material" - Section 7.

A considerable number of states from both the materials and construction groups favor increased use and remark that more field study is needed. There were considerably less states stating that more laboratory study is needed and only a few states did not favor further use of a few of the recovered materials.

Many of the states showed possible and definite interest in investigating applications for the recovered materials.

There was a strong response from states who are "opposed to mandatory guidelines" and also who "favor optional guidelines" with a notable number of states "opposed to any guidelines." These responses were consistent across all recovered materials and applications of recovered materials.

Following are general comments from the questionnaire concerning guidelines for the use of recovered materials in highway construction: "We favor use of more alternative materials, including waste products." "Guidelines can only result in red tape, paper work, increased cost of the product and possible use of materials unsuitable for highway construction..." "We favor the use of recovered materials when use is cost effective..." "Guidelines, particularly mandatory ones, would tend to remove the cost competitiveness by reason of requiring their use." "Availability, hauling costs, and limited uses...necessitate opposition to mandatory guidelines." "...Very few of these products have any kind of quality control or quality assurance systems. ...inappropriate to insist or mandate that states must provide a market to dispose of these materials. The producers of the 'waste' products should provide controls to assist in development of proper markets." "High quality, long lasting construction must be a prime concern in the use of waste materials for constructing and maintaining transportation facilities." "Recommended that they (EPA) make suggestions only and guidelines be established by states or AASHTO." "Directives and mandatory guidelines, we don't want."

By taking the questionnaire summaries and comparing the states which produce the various recovered materials with the states which have used the recovered material as a highway material, the following observations have been made:

- o Power plant ash (fly ash and bottom ash) is available in approximately 37 states. Fly ash has been used to varying extents as a highway material in 36 states. There are 10 states with fly ash available who do not use it; and there are 7 states who use fly ash although it is not produced in that state. Bottom ash has been used as a highway material in 22 states. There are 14 states where bottom ash is produced but not used and 3 states where bottom ash is used although not produced in that state.
- o Cement or lime kiln dust is produced in approximately 43 states and it has been used in highway construction in about 15 states. There are approximately 27 states where cement or lime kiln dust is available and not used; and only one state which has used cement or lime kiln dust and does not produce it.
- o Since all states have automobiles, it is assumed that granulated rubber tires are available in all states. There are about 35 states which have used granulated rubber tires in highway construction.
- o Incinerator residue is produced in 23 states. Incinerator residue has been used in highway construction in only about 5 states. There are about 19 states which have incinerator residue available but do not use it in highway construction, and only one state in which incinerator residue is not available and has been used.