United States
Environmental Protection
Agency

Municipal Environmental
Research Laboratory
Cincinnati OH 45268

EPA-600/2-78-035
March 1978

Research and Development

EPA

Optimization and Testing of Highway Materials to Mitigate Ice Adhesion

Interim Report

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EPA-600/2-78-035
March 1978

OPTIMIZATION AND TESTING OF HIGHWAY MATERIALS TO MITIGATE ICE ADHESION

Interim Report

by

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Grant No. R-804660

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FOREWORD

The Enviromental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment for public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

The study described here was undertaken to optimize the ice-release and wear-resistance properties of hydrophobic materials as developed in earlier Environmental Protection Agency research. These materials will be used in environmentally sensitive areas as an alternative for conventional deicing materials.

Francis T. Mayo
Director
Municipal Environmental Research
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ABSTRACT

This project optimized and evaluated hydrophobic materials developed by EPA research in 1974. Laboratory optimizing of materials was accomplished by Ball Brothers Research Corporation (BBRC) under contract with Washington State University (WSU).

Field tests at the WSU Pavement Test Facility augment BBRC laboratory tests with comparative results. Factors of concern included pavement type, tire type, environment and toxicity, wear, ice/snow adhesion and asphalt overlays which included the substances as a component of the mix.

Although the winter conditions were mild, the limited amount of tests and data did allow a ranking based on skid resistance change, water beading, and snow/ice removal properties of the different formulations. The most effective formulations were combinations of modified traffic paints and room-temperature-curing silicone rubber.

Of the formulations tested, only one was deemed toxic. Other formulations showed little or no toxicity.

The applied costs of the hydrophobic coatings in this study were about $.046/ft^2 ($.50/m^2) compared to $.037/ft^2 ($.40/m^2) for salt when taking into account salt's costs from environmental damage (excluding adverse health effects). It should be emphasized that the hydrophobic material costs are on the high side since actual program purchase costs for small quantities were used in the calculations. The amount by which these material costs could be reduced by volume purchasing is somewhere between 20 and 40 percent.

Although definitive results were obtained in the study, unusually mild winter conditions in eastern Washington in 1976-1977 restricted completion of the desired operational parameters. In order to obtain research fulfillment, a repeat of the test program is planned during the winter of 1977-1978. Iteration will also increase the statistical validity of the results discussed in this project.

This interim report was submitted in partial fulfillment of Grant No. R-804660 by Washington State University, under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period of October 1976 to April 1977.

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ACKNOWLEDGEMENTS

Many individuals took part directly or indirectly in this project. Their efforts are greatly appreciated. Sincere thanks go to the following:

U.S. Environmental Protection Agency, Storm & Combined Sewer Section:
Hugh E. Masters, Project Officer; J. Howard McCormick, Research Aquatic Chemist.

Ball Brothers Research Laboratories, Materials & Processes - Aerospace Division:
H. C. Poehlmann, Jr., Staff Scientist; G. A. Ahlborn, Senior Member Technical Staff; Bill Deshler, Technician.

Washington State University, College of Engineering:

Department of Civil & Environmental Engineering:
Environmental Analyses:
Dr. Surinder Bhagat, Professor and Head, Environmental Engineering Section; Ervin Hindin, Professor; Gary C. Bailey, Junior Environmental Scientist; Jim Skrinde, Civil Engineering Graduate Student.
Work at the Test Track:
Randy Elliott, Joe Floyd, Keith Metcalf, Rich Riedesel.

Engineering Photographic Laboratory:
Herbert D. Howard, Photographic Supervisor; Glen F. Sprouse, photographer.

Mechanical Engineering Shops:
Norman H. Shoup, Research Engineer; Tom Hellesto, Technical Services Supervisor; Marion Johnson, Leadman; Robert J. Skipper, Instrument Maker; Bill N. Yockey, Maintenance Mechanic.

Electrical Engineering Research Laboratory:
Robert A. Bureau, Electrical Technician; John D. Hunter, Electrical Technician.

INTRODUCTION

Objectives of the Project

The purpose of the project is to continue the development of a highway coating material, which, when placed on existing highway surfaces, will significantly reduce the adhesion of ice to the pavement surfaces, and will also be cost-effective as compared to conventional methods. This research effort involved Ball Brothers Research Corporation (BBRC), Aerospace Division, Boulder, Colorado, and the Transportation Systems Section, Department of Civil and Environmental Engineering, Washington State University, Pullman, Washington. The sponsor was the Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Project Tasks

Task No. 1: Contracts, Coordination and Test Timing. This portion of the overall task required the establishment of many arrangements necessary for the timely completion and effective performance of this research. This included the exact time-phasing for all consulting work, logistics with respect to other research, financial workings, timing, definition of various laboratory and Test Track results, and the coordination of requests and purchases.

Task No. 2: Coating Optimization. Formulations of paint/DC 732, DriSil 73/DC 732, Petroset AT, and Viscospin B were selected based on tests concerning (a) the magnitude and stability of their contact angles, (b) their ice release abilities on both asphalt and concrete, (c) their skid resistance levels on asphalt only, (d) their durability/wear properties on both asphalt and concrete, and (e) their environmental contamination potentials. Tests for contact angles for the latter two materials are inapplicable. Based on recommendations made on the test results on the Petroset AT and the Viscospin B, two concentration levels in 1.6 in (4.25 cm) asphalt overlays were determined for use at the WSU test track. Wear, skid resistance, environmental contamination potential, and ice release ability were tested using laboratory techniques.

Task No. 3: Washington State University Test Track Coating Verification. The results from the above tasks showed which coating/substrate combinations would have the best possibility for success. These combinations were used on the WSU Test Track. Various combinations of tire types were used to study their effects. The data obtained from the WSU Test Track includes air and surface temperatures, visual observation of water beading and ice release, photographs of coatings and substrate conditions, and coating skid values.

Task No. 4: Reporting. Progress reports were submitted. This interim report includes details and results of all work completed.

Task Division

The Transportation Systems Section, Department of Civil and Environmental Engineering, Washington State University, had prime contract responsibility and direct control of the Test Track operational phase of the program described in Task No. 3.

Ball Brothers Research Corporation, Aerospace Division, Boulder, Colorado, worked directly with WSU and had direct responsibility for Tasks 1 and 2.

Background

Winter driving has increased significantly in recent years. The motorists expect the roadways to be safe and clear. Hence cities, counties, and states are expected to keep the streets, roads and highways clear of snow and ice to facilitate these motorist needs. This is done to lessen the probability of accidents, accident injuries, and fatalities.

Also, to answer this need, tire manufacturers have developed winter tread tires, different rubber compounds, and traction devices. However, these devices have limited use.[1] Winter tires do add to winter driving safety as they are more effective than regular tires. However, this use is limited to light snow and ice conditions. Rubber compounds have been tried with some success and sometimes dubious claims. Traction devices have proved to be useful for use under winter conditions but they too have their drawbacks.

Chains have been used successfully for years, but their use is limited to short distance driving because of limited durability of the chain links and pavement damage causability. Studded tires have been more successful in that they can be used under most conditions, but they do cause pavement damage.[2] This damage has resulted in the refusal of many American and Canadian highway engineers to endorse or permit their use. In fact, the Federal Highway Administration, U.S. Department of Transportation, has recommended that their use be banned.[3] Studded tires are allowed in Europe but with the requirement that they be used on all four wheels.[4] In the United States, several tire stud manufacturers have ceased operations.

[1]Numbers refer to references listed in separate section.

The city, county and state highway departments have responded to help the motorist drive in the winter by plowing the roads, improving traction by sand and cinder applications, and facilitating the melting of snow and ice by the use of chemical compounds, principally salt and salt compounds. Plowing the roads does create some damage to the curbs, the pavement surfaces and the striping, but it is the only way to clear the roads of deep snow and drifts. Sand and cinder applications have aided traction and lowered minor accidents, but there is the problem of appearance, cleanup and pollution. The use of salt and salt mixtures are successful in melting the snow and ice but at the cost of environmental damage[5], pavement damage[6], accelerated bridge deck deterioration and bridge corrosion[7], and corrosion decay of automobiles and trucks. The fact remains that the costs incurred by snow and ice removal by salt use may outweigh the benefits.[8]

D. M. Murray[8] states "The costs of actual damage to water supplies and health, vegetation, vehicles, bridge and utilities are immense. The annual damage costs at a very lower bound, approach $3 billion. This "hidden" cost is almost 15 times the annual national budget for the purchase and application of road salt, and about 6 times the entire national budget for snow and ice removal," p. 21; and "As much as 5% of the population consuming water contaminated by road salt may be adversely affected", p. 22.

Hence there is a need to develop a compound or compounds which can be used as an alternate for salt in environmentally sensitive areas. The compounds should be economical, easy to apply, long-lasting, and without the harmful side effects previously mentioned. The development of such a compound or compounds is the long-range purpose of this research.

CONCLUSIONS

Although the winter conditions were mild, the limited amount of tests and data did allow a ranking based on skid resistance change, water beading, and snow/ice removal properties of the different formulations. The four most effective formulations were F, G, C and B (see page 22). These results, except for formulation B, compared favorably with laboratory results.

Of the overlays, the three rubberized asphalt sections and the two Petroset asphalt sections were most effective. The best rubberized asphalt section also showed reduced abrasion resistance which would negate its other performance. The superiority of the rubberized sections was due to their flexibility which, under cold temperatures of 10°F (-12.2°C) or less, may not be so effective. The Viscospin sections did not perform very well. The open-graded asphalt sections may not be effective in heavy snowfalls since the pores become clogged and frozen.

On the basis of toxicity tests, only the Petroset was deemed toxic. Other formulations showed little or no toxicity. The Petroset also showed high hydrocarbon levels from run-off.

Ice and snow removal from the highway is dependent upon many factors. One of these factors is the type of tire. Of the various types used at the Test Track, the driving wheel, a garnet impregnated truck tire, "cleared" the wheel path the most rapidly. The F-32 passenger car tire "cleared" the wheel path the slowest. Because this aspect of removal is based on interdependent factors, the data is presented more for information than conclusion.

These conclusions are based on the rather narrow range of winter conditions encountered at the Test Track in 1976-77. A wider base is anticipated as further operations occur.

RECOMMENDATIONS

More testing is required to conclusively confirm the inference of these results. It is important to know if lower temperatures will change the results. Comparison with existing methods of snow/ice control should be accomplished. Results from additional traffic wear should be obtained.

The formulations to be tested should be reduced to the four best and these then should be replicated on both portland cement concrete and asphalt concrete pavements. The underlying assumption of limiting testing to the four best formulations is that low temperatures would not significantly improve the relative performance of the other formulations.

It is recommended that no more testing be continued on the Petroset AT treatments and on the Viscospin asphalt overlays, the former because of their toxicity and the latter because of its poor performance in these tests. The Petroset asphalt overlay should continue to be tested on the basis of its performance.

The rubberized asphalt overlays should continue to be tested to see if low temperatures will change the results. The amount of rubber additive should be optimized based on pavement durability, and a wide range of rubber amounts should be tried. If possible, other overlays, for example, sulfur-asphalt combinations, should also be tested for snow/ice removal properties.

G. A. RIEDESEL PAVEMENT TESTING FACILITY

Description

The G. A. Riedesel Pavement Testing Facility consists of an apparatus with three loading arms supporting a water tank. These arms revolve in a circle on three sets of dual tires. A 60 hp direct current electric motor on each arm provides the motive power. An eccentric mechanism enables the apparatus to move so that a specified width of the pavement can be covered by the test wheels.

The apparatus was extensively modified in 1972 for studded tire research. The present facility has two sets of passenger tires inside the dual truck tires running in Wheel Paths #1 and #2, while the dual truck tires run in Wheel Paths #3 and #4. Two passenger tires are attached to each of the two arms so as to travel in four separate wheel paths, #5, #6, #7 and #8. A total of 16 tires are mounted on the apparatus. Each passenger car tire carries a 1,000 pound load, applied via individual load cells, and each set of the dual truck tires carries 6,600 pounds, except on Arm #3 where the duals carry 8,600 pounds load.

An overall view of the G. A. Riedesel Pavement Testing Facility is shown in Figure 1. The observation tower houses the apparatus controls and recorders (built in 1972).

Tires

A total of 16 tires were used; 6 truck tires, all unstudded, and 10 passenger winter snow tires, of which 3 were studded. The truck tires used on the truck track were size 11 X 22.5, inflated to 80 psi air pressure; the inside tire is the driving tire while the outside tire is free-wheeling. The truck tires are garnet dust impregnated retreads.

The passenger tires were all size 15 with different widths and snow tread designs, and consisted of 3 unstudded garnet retread tires size G78-15 in Wheel Path #1; 3 with 112 controlled protrusion studs, tire size G78-15 in Wheel Path #2; 1 steel radial tire size GR78-15 in Wheel Path #5; 1 radial tire size HR70-15 in Wheel Path #6; one regular winter tread tire H78-15 in Wheel Path #7; and a radial tire with special soft rubber F-32, size GR78-15, in Wheel Path #8. Each tire was inflated to 32 psi and carried a 1,000 pound load. All the passenger tires were free-wheeling. Information about all the tires is given in Table 1. The different tires are shown in Figures 2 and 3.

Figure 1. A view of the present G. A. Riedesel Pavement Testing Facility.

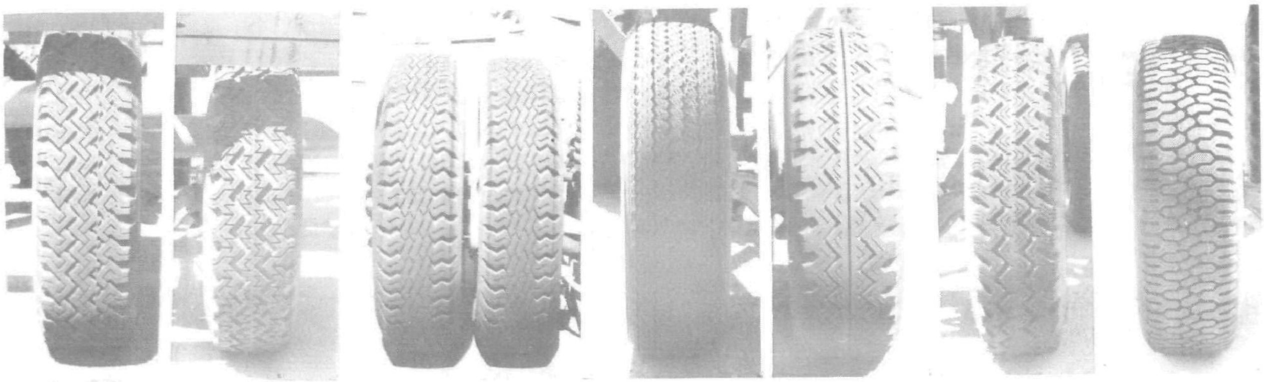
TABLE 1. TYPES OF TIRES USED AT THE WSU TEST TRACK

WHEEL PATH [1] (1)	NUMBER OF TIRES (2)	TYPE OF TIRE (3)	TREAD (4)	SPECIAL FEATURES (5)	TIRE SIZE (6)	NUMBER OF PLYS (7)	BRAND NAME (8)	TIRE PRESSURE PSI (9)	WEIGHT ON TIRE POUNDS (10)
1	3	Passenger	Winter	Garnet Dust Impregnated Treads	G78-15	4	Martin Retread	32	1,000
2	3	Passenger	Winter	Studded[2]	G78-15	4	Goodyear Polyglass	32	1,000
3	3[3]	Truck	Regular	Garnet Dust Impregnated Treads	11 x 22.5	12	Oliver Garnetread	70-80	3,300
4	3[3]	Truck	Regular	Garnet Dust Impregnated Treads	11 x 22.5	12	Oliver Garnetread	70-80	3,300
5	1	Passenger	Winter	Steel Radial	GR78-15	4	Goodyear Custom Steelgard Radial	32	1,000
6	1	Passenger	Winter	Radial	HR70-15	6	Goodyear Custom Wide Tread Radial	32	1,000
7	1	Passenger	Winter	None	H78-15	4	Atlas Weathergard	32	1,000
8	1	Passenger	Winter	Radial F-32	GR78-H5	4	Goodyear All Winter Radial F-32	32	1,000

[1]The wheel paths are numbered consecutively from the inside edge to the outside edge of the track.

[2]112 studs in each tire - controlled protrusion type.

[3]On arm #3, the weight on each of the truck tires was 4,300 pounds.



WP 1 WP 2 WP 3, 4 WP 5 WP 6 WP 7 WP 8

Figure 2. Wheel paths (WP) are numbered from inside to outside of track. See Table 1 for tire types.

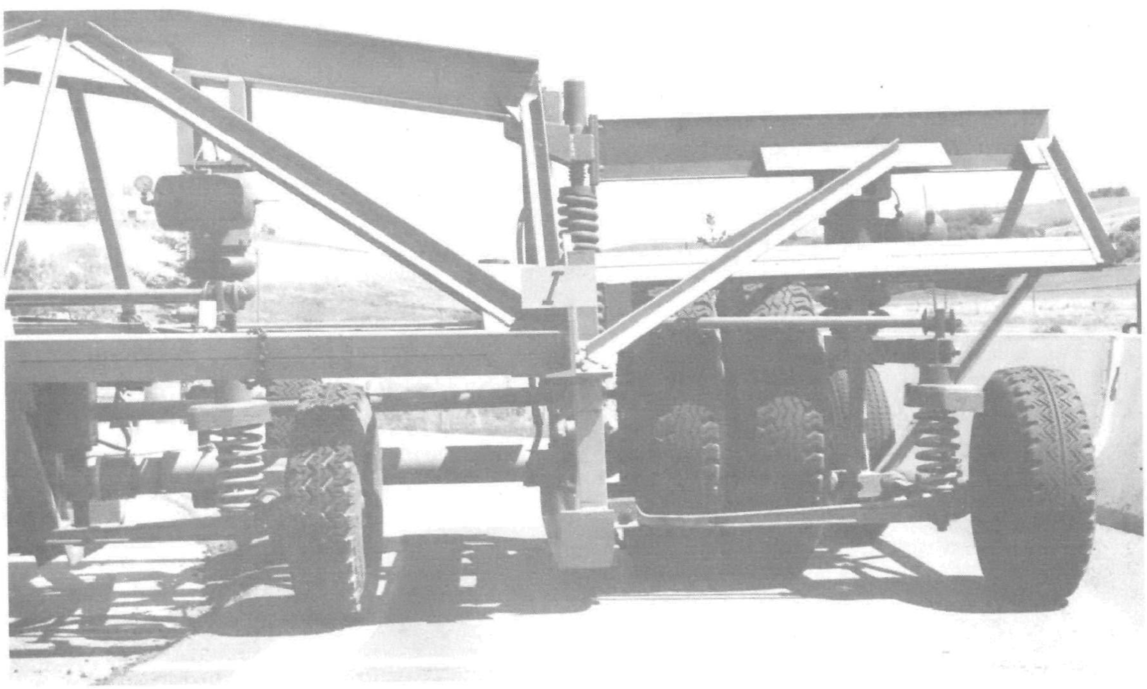


Figure 3. The arrangement of tires on the apparatus. This photograph shows Wheel Paths #1 to #6.

Instrumentation

Instrumentation of the Test Track was kept to a minimum due to lack of funds. A Belfort thermograph recorded air and soil temperatures continuously. Surface pavement temperatures were measured using surface thermometers. Measurement of the revolutions and speeds were recorded continuously in the observation tower. Skid resistance measurements were made by a BBRC technician using a British Portable Skid Tester. Photographs of the project were taken by the WSU Engineering Photograph Service.

CONSTRUCTION

Overall Concept

The project consists of 30 test sections; each section has an average length of 8 feet (2.4 m) at the track diameter and an 11-foot (3.3 m) track width. Four portland cement concrete dividers were placed between sections from Sections 26 to 30. Two 4-foot (1.2 m) long transitions zones were established between Sections 1 and 30, and between Sections 10 and 11, using the existing portland cement concrete. The overall view showing the location of the sections is shown in Figure 4.

Existing Track Surface

Approximately two-thirds of the existing Test Track pavement (Sections 11-30), consisting of both asphalt concrete and portland cement concrete, was removed to depths of 1.5-1.75 inches (3.81-4.45 cm). The remaining pavement surface was portland cement concrete (Sections 1-10), which was in place and utilized in this project.

General Preparation Procedure

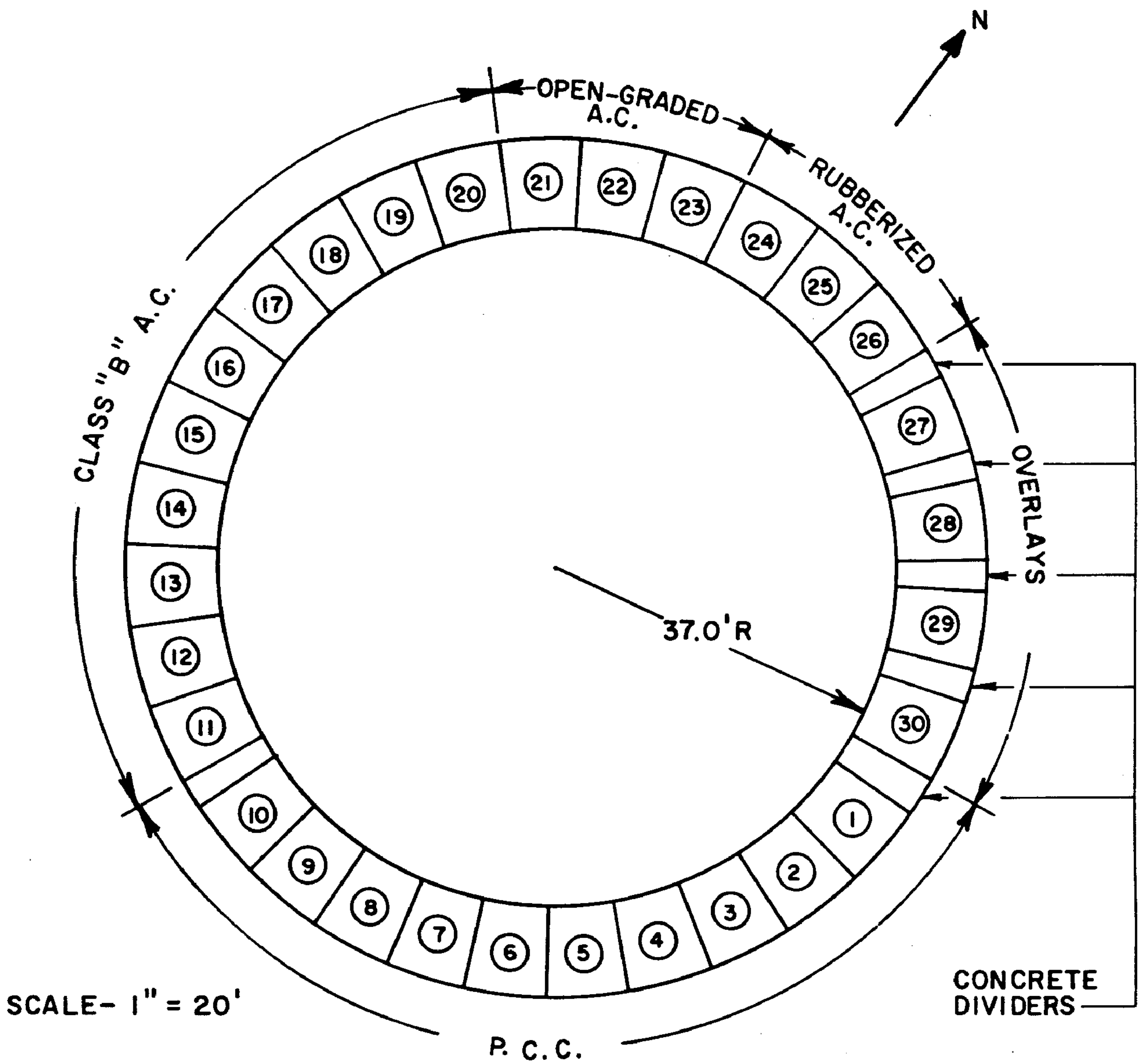
The exposed subsurface areas were uneven in depth which made it necessary to level these areas to a prescribed depth. The appearance of these subsurface areas is shown in Figures 5 and 6. The exposed surface was primed with asphalt emulsion (SS-1) and leveled to 0.75 inch (1.91 cm) depth with Class "B" asphalt concrete mix.

Between Sections 26 to 30, four portland cement concrete dividers, average center length of 3 feet (0.9 m) and 11 feet (3.3 m) wide, were placed to minimize contamination between the special asphalt concrete overlays. Figure 7 shows two of the four dividers in place between Sections 30 and 29, and Sections 29 and 28, respectively.

There was no need for any kind of preparation for the existing portland cement concrete Sections 2 to 10. Figure 8 shows the surface appearance of portland cement concrete Sections 8 to 10.

General Description of Pavements

All of the asphalt sections were placed in the latter part of October 1976 within a two-week period. The Test Track section identification is shown in Table 2. The mix designs are shown in Table 3.



G. A. RIEDESEL PAVEMENT TESTING FACILITY
WASHINGTON STATE UNIVERSITY

Figure 4. Section location at Test Track.

Figure 5. Appearance of subsurface, Section 16. 10/19/76

Figure 6. Appearance of subsurface, Section 23. 10/19/76

Figure 7. Appearance of subsurface, Sections 29 and 30, with dividers in place. 10/19/76

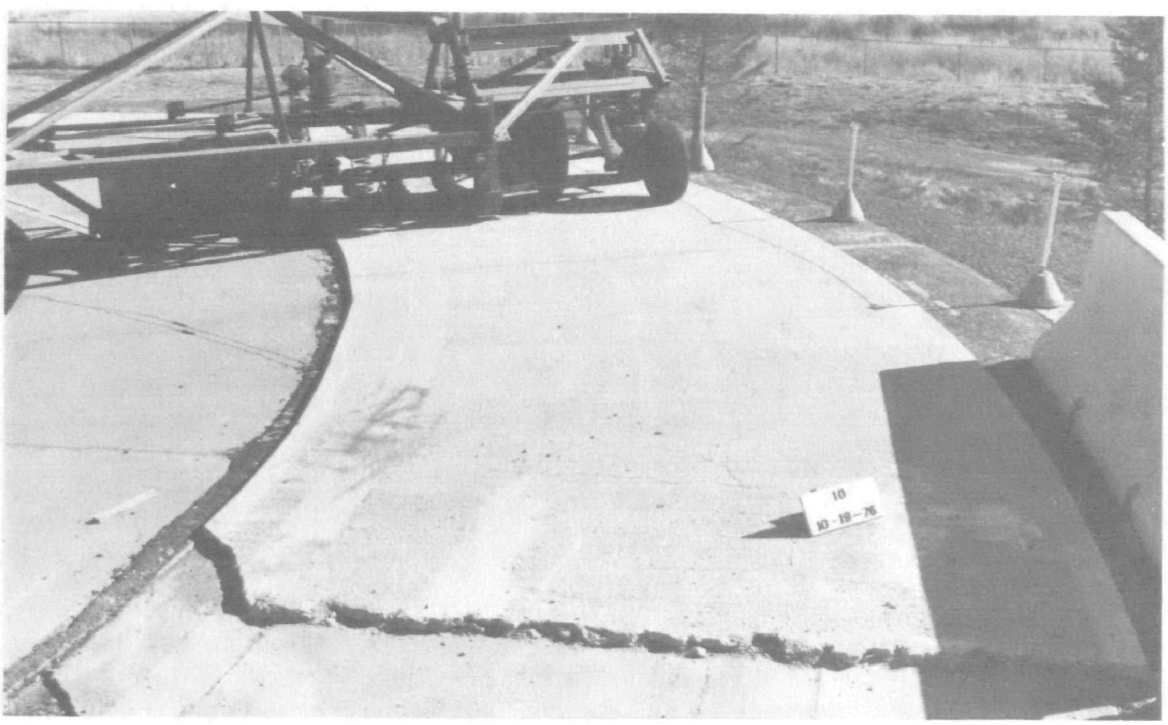


Figure 8. Appearance of in-place portland cement concrete pavement, Sections 7-10. 10/19/76

TABLE 2. TEST TRACK SECTION IDENTIFICATION

SECTION[1] (1)	DATE PLACED (1976) (2)	TYPE OF MATERIAL[2] (3)	COMMENTS (4)
1-10	INTACT	Portland Cement Concrete	No additional surface preparation
11-16	10-27	Class "B" Asphalt Concrete Mix[3]	1/2" Aggregates, 6.0% AR 4000 W[4]
17-20	10-29	Class "B" Asphalt Concrete Mix	Second placing of Class "B" A-C
21-23	10-27	Open Graded Asphalt Concrete Mix	FHWA friction course demonstration project[5]
24-26	10-18	Rubberized Asphalt Concrete Mix	Reclaimed rubber from tires[6]
29-30	10-27	Viscospin Asphalt Concrete Overlays	4%, 8% Viscospin B, respectively[7]
27	10-27	Petroset AT Asphalt Concrete Overlays	8.33% Petroset AT
28	10-29	Petroset AT Asphalt Concrete Overlays	25.0% Petroset AT

Footnotes:

[1]If more than one section, designation is inclusive.

[2]All asphalt concrete mixes were hot-mixes.

[3]Class "B" asphalt concrete mix is the Washington Department of Highways designation, and is deemed to be typical of northern tier of states.

[4-7]See mix designs in Table 2.

TABLE 3. TEST TRACK ASPHALT MIX DESIGNS[1]

MIX PARAMETERS	TYPE OF ASPHALT MIX								
	CLASS "B" A.C.	OPEN-GRADED A.C.	RUBBERIZED ASPHALT CONCRETE[3]			PETROSET A.C.		VISCOSPIN A.C.	
			5%	10%	5%	8.33%	25.0%	4.0%	8.0%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SECTIONS	11-20	21-23	24	25	26	27	28	29	30
Aggregate Size (pounds)	1/2" - 350 3/8" - 1350 Sand - 1070 Fines- 50	1/2" - 56 3/8" - 1503 #8 - 1049 Fines- 227	5/8" - 137 3/8" - 524 Sand - 421 Fines- 18	5/8" - 129 3/8" - 448 Sand - 376 Fines- 17	5/8" - 513 3/8" - 0 Sand - 572 Fines- 20	Same as Class "B" A.C.	Same as Class "B" A.C.	Same as Class "B" A.C.	Same as Class "B" A.C.
Lbs Asphalt[2]	180	165	130	130	130	180	180	180	180
% Asphalt	6.0	5.5	10.0	10.0	10.0	6.0	6.0	6.0	6.0
% Additive	---	---	5.0	10.0	5.0	8.33	25.0	4.0	8.0

Footnotes:

[1]All asphalt mixes were hot-mixed.

[2]Asphalt used in all mixes was AR 4000 W.

[3]Gradation of rubber used in Sections 24-26 is:

Screen	% Passing
5/8"	100
1/4"	99
#6	94
#10	76
#40	2
#80	1
#200	0.5

The paving contractor, United Paving, Inc., placed all of the asphalt mixes using standard highway paving procedures as much as possible. Due to the small amount of mix and the paving areas for some sections, some hand leveling, tamping and compaction was necessary but was kept to a minimum. The mixes for the rubberized asphalt concrete sections were prepared at the United Paving plant but were placed by Yakima County personnel.

Some placing problems occured with the Viscospin asphalt concrete mixes in Sections 29 and 30. Both mixes had a disagreeable odor and both mixes were hard to work. Their appearance was dull and lifeless, similar to cold-asphalt mixes, with similar handling properties. The 4% Viscospin asphalt mix was easier to compact.

The Petroset asphalt concrete mix in Section 27 with the lower Petroset content was very easy to place and compact. In contrast, the 25% Petroset AT asphalt mix placed in Section 28 had the appearance of a cold mix and was difficult to place.

Figures 9 to 14 show the placing and the appearance of some asphalt sections. The placing of asphalt mix in Sections 21-23 using the Blaw-Knox paver is shown in Figure 9. Figure 10 shows the reclaimed rubber used in Sections 24-26, and Figure 11 shows the final appearance of Sections 24, 25 and 26 after rolling. Close-up views of Sections 27 and 28 with 8.33% and 25% Petroset AT additive in the Class "B" asphalt mix, are shown in Figures 12 and 13, respectively. Figure 14 shows the appearance of the 8% Viscospin asphalt mix placed in Section 30.

Figure 9. Placement of asphalt, Sections 21-23. 10/27/76

Figure 10. Reclaimed rubber in bag used in Sections 24, 25, 26. 10/18/76

Figure 11. Appearance of rubberized asphalt concrete Sections 26-24 after rolling. 10/19/76

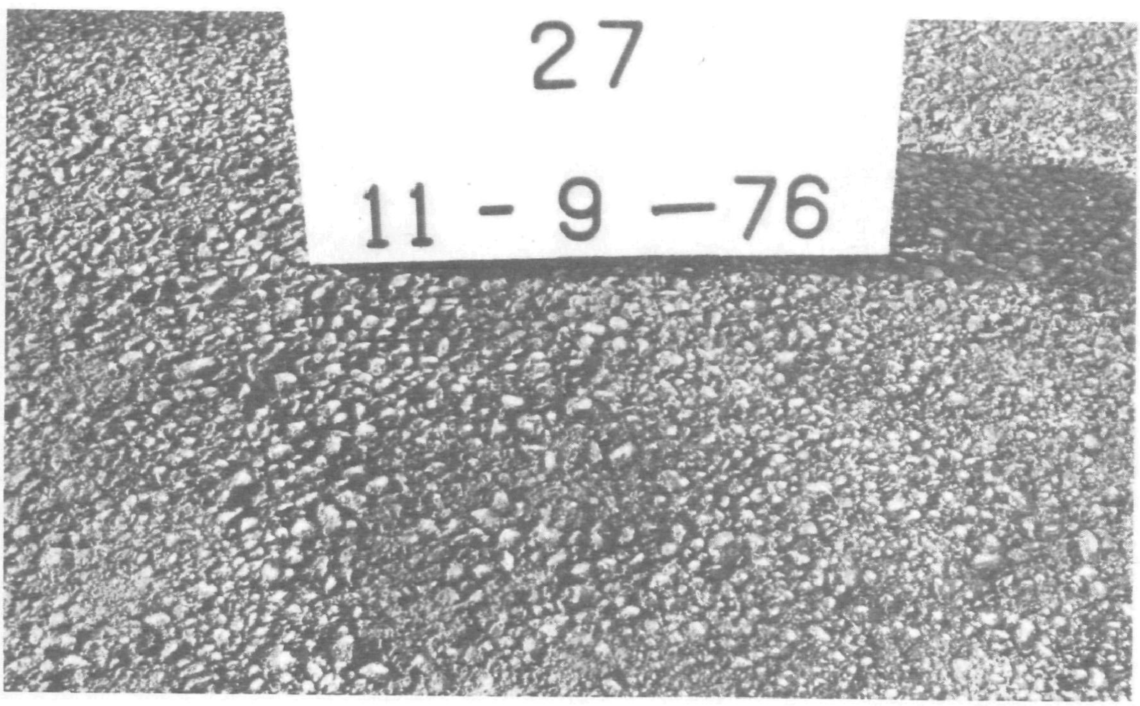


Figure 12. Close-up view of Section 27 with 8.33% Petroset AT, placed 10/27/76.

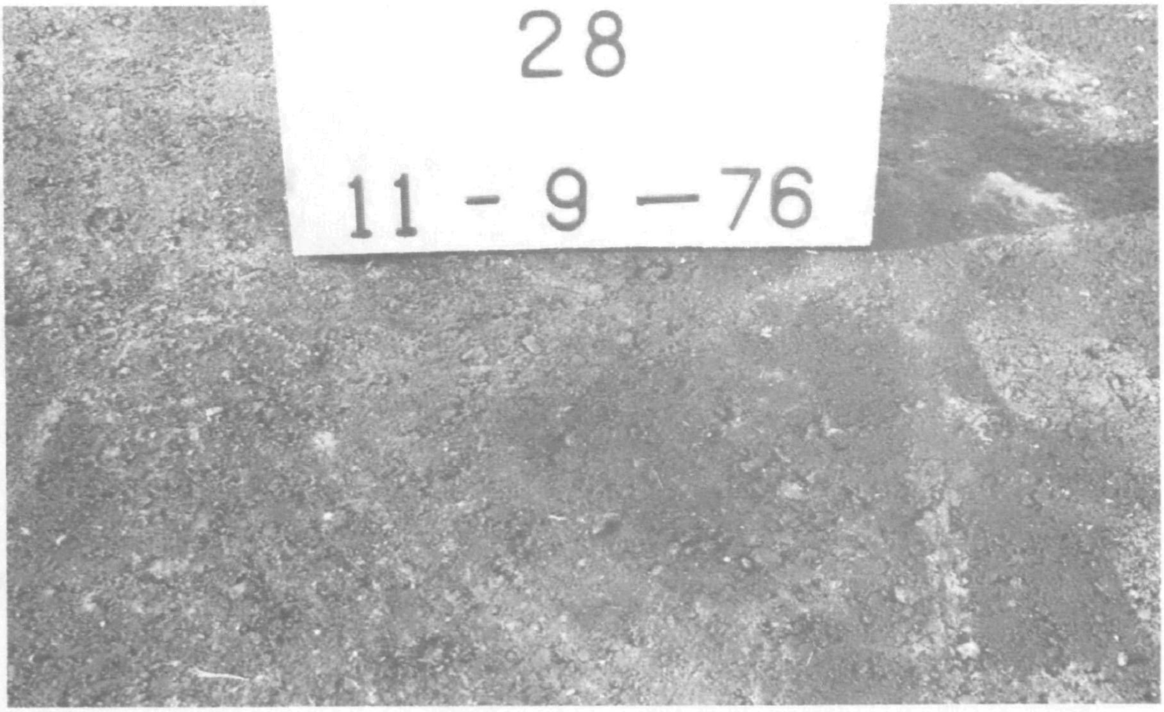


Figure 13. Close-up view of Section 28 with 25% Petroset AT, placed 10/29/76.

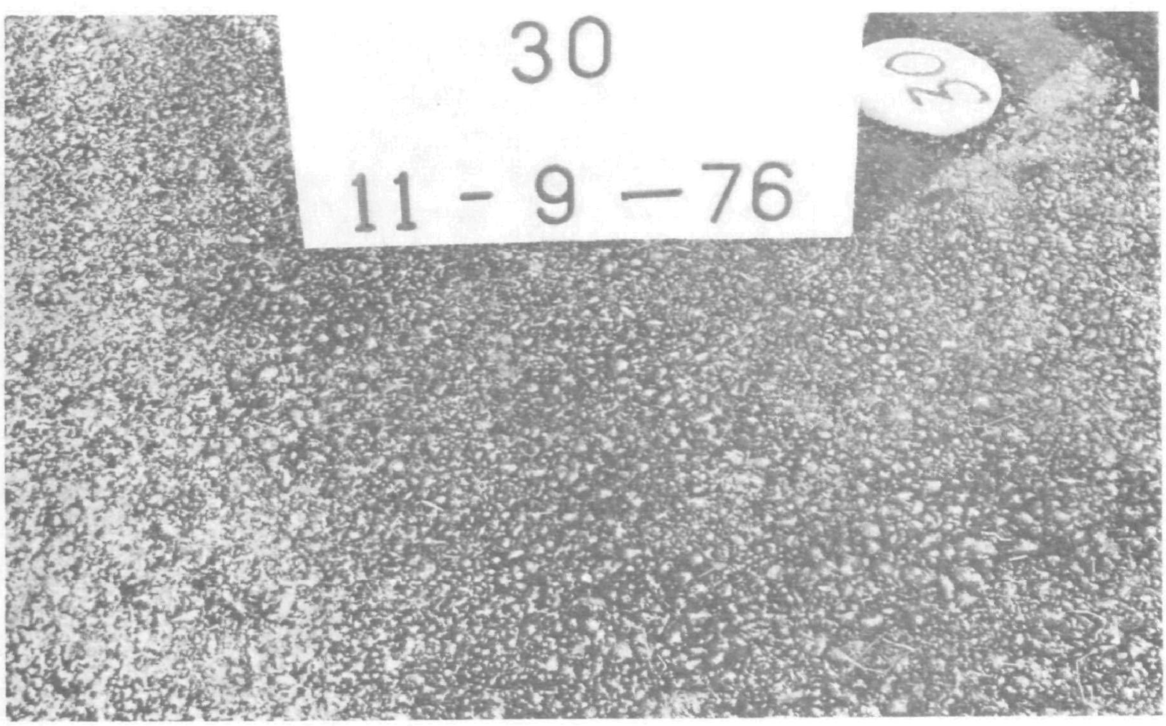


Figure 14. Close-up view of Section 30 with 8% Viscospin, placed 10/27/76.

Optimization Tests on Formulations

These tests were conducted by Ball Brothers Research Corporation. The results have been summarized in Tables 4 to 8. These tests were concerned with (1) applied coating formulations - Table 4, (2) disc contact angles - Table 5, (3) disc scratch tests - Table 5, (4) environmental test data - Table 6, (5) plate ice adhesion data - Table 7, and (6) skid test numerical data and water beading observations for coatings on BBRC asphalt and concrete - Table 8. The latter table includes skid test data on the WSU Test Track. Full descriptions of the tests are given in Reference #9.

From the results obtained from these tests, eight formulations plus Petroset AT were tested on different pavement surfaces at the WSU Test Track. Table 9 shows the formulations, quantities used, and in what section they were applied.

Formulation Application

The Test Track apparatus was used to "break in" the pavement. A total of 3,798 revolutions was applied equivalent to 11,394 wheel loads in Wheel Paths 1-4, and 3,798 wheel loads in Wheel Paths 5-8.

Based on previous Ball Brothers Research Corporation tests, the formulations showing the most promise of success were to be used at the Test Track. These formulations and their Test Track location is shown in Table 10. The formulations were mixed and sprayed on between the 14th and 20th of January by a BBRC technician. The pavement surface was swept clean and dried by using a butane weed burner. The paint formations were then hand-sprayed on a 4-foot by 12-foot area using an electric hand sprayer. Some problems were encountered with strong winds which caused some over-spraying. Air temperatures ranged between 34° and 42°F. during the period. After skid resistance readings were measured, the pavements were ready for testing.

Sections 2, 4 and 10 were the control sections on the portland cement concrete, while Sections 12, 14 and 20 were the control sections on the Class "B" asphalt concrete.

TABLE 4. FORMULATIONS AND COVERAGE RATES

FORMULATION CODE (1)	PRINCIPAL INGREDIENT NAME (2)	PRINCIPAL INGREDIENT AMOUNT cm^3 (3)	OTHER INGREDIENTS & AMOUNTS: DC732 gms (4)	VMP NAPTHA cm^3 (5)	ISOPROPANOL cm^3 (6)	OTHER: NAME (7)	OTHER: AMOUNT - cm^3 (8)	OTHER INFORMATION (9)	APPLICATION RATE $\frac{1}{m^2}$ OR AS NOTED (10)
A	LR 8198[1]	225	22.5	169	6.0				0.235
B		205	35.8	182	7.7				0.232
C		170	59.0	216	14.8				0.234
D		160	72.0	244	18.0				0.237
E	LR 8652[2]	515	19.3	257	6.4				0.461
F		480	30.0	276	9.0				0.453
G		415	51.8	312	15.5				0.433
H		365	68.4	319	18.2				0.406
I	DRISIL 73	305	18.3	198	6.0				0.302
J		275	35.7	219	8.2				0.295
K		250	50.0	237	12.5				0.290
L		230	59.8	253	13.8				0.289
M	PETROSET AT	415	--	--	--	DISTILLED H_2O	138		0.328
N	GOODYEAR 533C	100	--	50	--			(LR 8652 + 1% CLAY)	POURED ON META SUBSTRATE
O	GOODYEAR 533B	150	--	50	--			(LR 8652)	0.510
P	DOW XR-5013	100	--	--	--	DISTILLED H_2O	100	SILICONE	0.520
Q	GOODYEAR VTL	20	--	95	--	XYLENE	5	(PAINT BASE)	SPRAYED ON
R	VISCOSPIN B	50	--	50	--				SPRAYED ON
W	VISCOSPIN B	8%						% OF BINDER IN AC	OVERLAY
X	VISCOSPIN B	4%						% OF BINDER IN AC	
Y	PETROSET AT	25%						% OF BINDER IN AC	
Z	PETROSET AT	8.33%						% OF BINDER IN AC	

Source: Ball Brothers Research Corporation, 1976.

[1]LR 8198 is Akron Paint Mod. TT-P-115 D (without TiO_2).

[2]LR 8652 is Akron's Resin-Only Version.

TABLE 5. DISC CONTACT ANGLES[1] AND TOUGHNESS OBSERVATIONS

COATING		WATER CONTACT[3]	OIL CONTACT	TOUGHNESS[4] COMMENTS
CODE (1)	APPEARANCE[2] (2)	ANGLE-DEGREES (3)	ANGLE-DEGREES (4)	(5)
CONTROL	(no coating)	58, 57, 60	22	
A	Even but rough	122, 110, 108	88, 88 (W)[5]	Medium
C	Even but rough	106, 106, 105	66, 50	Soft
D	Even but rough	106, 103, 90	67, 68 (W)	
E	Even but rough	98, 88, 91	67, 71 (W)	Medium
F	Uneven & "lumps"	87, 85, 93	63, 65	Hard
H	Crazed	105, 95, 98	62, 62 (W)	Soft
I	Uneven	98, 93, 92	68, 59, 63	Medium } May not be fully cured
K	Uneven	94, 91, 91	37, 63, 59	Very soft } May not be fully cured
L	Uneven	94, 94, 94	51, 54	Very soft } May not be fully cured
N	Some orange peel	40, 40, 35(W)	44, 42	Medium
O	Even	85, 92, 90	25, 30	Medium
P	Crazed in center	85, 88, 86	60	Hard
Q	Very even	91, 83, 91	22	Medium
B	(Ref. 9)	119, 115, 116		
J	(Ref. 9)	104, 103, 103		

Source: Ball Brothers Research Corporation, 1976.

Note the drastic effect of a small amount of clay (compare N and O).
All coatings considered usefully hydrophobic except N.

[1]All coated discs (non-corrosion resistant steel) subjected to 70% R.H. at 45°C. for 24 hours before testing. None indicated water vapor penetration of coating (no rust).

[2]Appearance must be related to non-porous nature of (steel) substrate.

[3]No particular trends noted between similar formulations (except A–D).

[4]Qualitatively judged with steel probe.

[5]W = coating wetted by fluid.

TABLE 6. ENVIRONMENTAL TEST DATA (HOUSER REPT. 76-498)

COATING CODE (1)	H_2O CONTACT ANGLE-DEGREES (2)	PH (3)	TOTAL DISSOLVED SOLIDS gms (4)	TOTAL DISSOLVED SOLIDS WT. % OF FILM (5)	BIOLOGICAL OXYGEN DEMAND (BOD) (6)	CHEMICAL OXYGEN DEMAND (COD) (7)
BLANK H_2O SAMPLE		5.86	0.0027		3	11
UNCOATED SHEET	64, 68, 74	6.66	0.0074		6	16
A	122, 119, 120	7.05	0.0051	1.0	11	25
C	108, 93, 105	7.16	0.0103	1.4	9	25
D	101, 107, 103	7.09	0.0115	2.1	10	25
E	100, 100, 98	6.02	0.0033	2.1	4	11
F	103, 99, 104	5.89	0.0015	0.8	4	11
H	104, 106, 106	5.97	0.0026	0.8	4	14
I	110, 91, 100	5.82	0.0068	0.7	6	18
L	93, 102, 102	5.88	0.0073	4.3	4	13
R[1]	0	7.65	0.3420	88.0	252	791
B (Ref. 9)	102, 106, 109	6.98	0.0140	0.7	5	15
M (Ref. 9)	0	6.10	0.0183	1.3	22	84
DC 732[2] (Ref. 9)	107, 108, 109	5.90	0.0023	4.6	3	16

Source: Ball Brothers Research Corporation, 1976.

[1]As expected, Viscospin B (Coating R) was poor in these tests.

[2]Trends appear to be related to DC 732 content.

TABLE 7. ICE ADHESION DATA (METAL SUBSTRATE) (HOUSER RPT. 76-475)

COATING (1)	WATER CONTACT ANGLE, DEGREE (2)	AVERAGE ICE ADHESION: FORCE - kg/cm^2 (3)	RANGE OF DATA kg/cm^2 (4)	FILM APPEARANCE (5)	COMMENTS (6)
CONTROL PLATE	71, 76, 71	9.2	5.5		
A	93, 112, 106	8.3	5.0	Fairly smooth	85% of coating removed in one spot
B	96, 103, 111	4.1	4.1	Uneven, rough	70% coating removed
C	82, 88, 98	1.9	0.6	Smooth	60% coating removed - 3rd release
D	104, 80, 105	2.1	0.8	Smooth	Large portion of coating removed
E	105, 99, 95	1.2	0.8	Smooth	
F	98, 103, 99	1.2	1.6	Smooth	
G	104, 90, 107	0.9	0.8	Uneven but smooth	30% coating removed - 3rd release
H	96, 98, 102	0.7	0.4	Smooth	
I	90, 96, 98	2.4	0.7	Uneven but smooth	
J	100, 90, 92	3.0	2.3	Smooth	
K	107, 101, 90	2.5	3.4	Smooth	
L	101, 101, 98	1.7	1.1	Smooth	
O	97, 94, 94	7.4	6.4	Fairly smooth	
P	83, 83, 89	3.4	6.7	Fairly smooth	
Q	100, 96, 98	4.8	3.5	Smooth but uneven	
B (Ref. 9)	119, 117, 110	2.1	3.3	Fairly smooth	Lowest value found for a formulated coating in prior contract
CONTROL PLATE (Ref. 9)	56, 65, 63	7.6	4.6		
J(ON A.C., (Ref. 9)		5.2	4.0		

Source: Ball Brothers Research Corporation, 1976.

Comments: 1. Coating removal from metal plates is not indicative of pavement performance (where solvent "binding" occurs on asphalt and mechanical pore locking occurs on concrete).

2. Some trends are evident. C appears about optimum for LR 8198/DC 732. H appears optimum for LR 8652/DC 732 but coating smoothness variations may dominate. The DRI-SIL 73/DC 732 foundations show an inverted curve and core results are needed to reach any decision.

TABLE 8. ASPHALT AND CONCRETE SKID VALUES AND WATER BEADING[1]

COATING CODE	ASPHALT VALUES AT BBRC AT 27°C	CONCRETE VALUES AT BBRC AT 24°C	BEADING AT BBRC DURING SNOW AT 5°C		WSU TRACK	
			ASPHALT	CONCRETE	SKID VALUES AT 14°C	BEADING DURING SKID TESTS
(1)	(2)	(3)	(4)	(5)	(6)	(7)
CONTROL, UNCOATED	70, 72, 72	78, 78, 79	None	None		
A	68, 69, 68	66, 66, 66	Good	Some		
B	68, 68, 67	70, 69, 68	Very good	Some		
C	68, 68, 70	70, 70, 69	Very good	Good		
D	63, 62, 63	65, 65, 65	Very Good	Good		
E[2]	44, 43, 44	48, 48, 48	Excellent	Excellent		
F[2]	49, 50, 49	54, 53, 55	Excellent	Excellent		
G[2]	58, 60, 58	58, 56, 58	Excellent	Excellent		
H[2]	62, 60, 60	56, 55, 57	Excellent	Excellent		
I	73, 73, 73	74, 74, 75	Excellent	Some		
J	65, 65, 64	74, 75, 75	Excellent	Some		
K	71, 72, 72	74, 75, 75	Excellent	Good		
L	67, 67, 68	78, 78, 78	Excellent	Good		
M[3]	47, 46, 46	62, 62, 62	None	None		
O	30, 30, 30	40, 38, 38	None	Good		
P	53, 52, 53	56, 58, 57	Very good	Excellent		
W					80, 83, 83	None
X					88, 88, 87	None
Y					78, 78, 78	Some
Z					83, 83, 84	None
RUBBERIZED A.C.					72, 73, 74	Some
OPEN-GRADED A.C.					83, 84, 83	None
THREE A.C. SECTIONS					87, 87, 89	
					77, 74, 73	
					82, 82, 80	
THREE P.C.C. SECTIONS					76, 76, 78	
					89, 90, 90	
					88, 88, 87	
B (Ref. 9)	60, 61, 60, 61 (15°C)	76, 77, 76, 77 (30°C)	Excellent	Excellent		
J (Ref. 9)	68, 68, 68, 69 (30°C)	67, 67, 68, 68 (32°C)	Fair	Excellent		
M (Ref. 9)	65, 65, 67, 67 (40°C)	63, 63, 63, 63 (30°C)	Good	Fair		

Source: Ball Brothers Research Corporation, 1976.

[1]Beading: tendency for water to form droplets on surface with high contact angles.

[2]Unexpected trends (such as E, F, G, H) exist but may be explained by core ice adhesion results.

[3]"Petroset AT" applied at 3 times the application rate as in ref. 9 research.

TABLE 9. FORMULATIONS AND QUANTITIES SPRAYED ON DIFFERENT TRACK SECTIONS

TRACK SECTION	FORMULA	PRINCIPAL INGREDIENT		OTHER INGREDIENTS - AMOUNTS				QUANTITY PREPARED	
		NAME	AMOUNT (cm^3)	DC 732 (gm)	NAPHTHA BINDER/DC 732 (CM^3)	ISOPROPANOL (cm^3)	DISTILLED H_2O (cm^3)	TOTAL VOLUME[2] (LITERS)	VOLUME SPRAYED[3] (LITERS)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
19	B	LR 8198	721	126	362/278	27		2.17	1.15
9			655	114	329/253	25		2.17	1.04
18	C		598	207	299/461	52		2.19	1.16
8			544	188	272/419	47		2.19	1.05
17	F	LR 8652	1690	105	634/338	32		4.23	2.24
7			1536	95	576/307	29		4.23	2.04
16	G		1460	182	549/549	54		4.05	2.14
6			1327	165	499/499	49		4.05	1.95
15	I	DRISIL 73	1074	64	535/162	21		1.485	1.485
5	J		880	114	438/262	26		1.323	1.323
3	K		800	160	400/358	40		1.296	1.305
13	L		810	210	404/485	49		1.413	1.413
22			810	210	404/485	49		1.413	1.413
11		PETROSET AT	780				1170	3.108	1.624
1			708				1080		1.476

Source: Ball Brothers Research Corporation, January 1977.

[1]Sections 1-10 are portland cement concrete; sections 11-20 are Class "B" asphalt concrete; and Section 22 is open-graded asphalt concrete.

[2]Excess quantities were needed for samples for use in environmental tests.

[3]Area sprayed in section was 4' x 12' or $4.5 m^2$.

TABLE 10

TEST TRACK SPRAY COATING SUMMARY

FORMULATION	QTY. APPLIED LITERS	TRACK SECTION #	DATE APPLIED	TIME (a) APPLIED	AIR TEMP. °C (b)	TRACK SURFACE TEMP. °C
B	1.04	9	1/17/77	1230-1530	6 to 5	8 to 6
	1.15	19	1/18/77	1730-1930	2 to -1	4 to 2
C	1.05	8	1/17/77	1230-1530	6 to 5	8 to 6
	1.16	18	1/18/77	1730-1930	2 to -1	4 to 2
F	2.04	7	1/17/77	1230-1530	6 to 5	8 to 6
	2.24	17	1/18/77	1730-1930	2 to -1	4 to 2
G	1.95	6	1/17/77	1230-1530	6 to 5	8 to 6
	2.14	16	1/18/77	1730-1930	2 to -1	4 to 2
I	1.48	15	1/18/77	1100	8	16
J	1.32	5	1/17/77	1230-1530	6 to 5	8 to 6
K	1.30	3	1/17/77	1230-1530	6 to 5	8 to 6
L	1.41	13	1/18/77	1100	8	16
	1.41	22(c)	1/19/77	1000	6	8
Petroset AT	1.62	11	1/18/77	1730-1930	2 to -1	4 to 2
	1.48	1(d)	1/18/77	1730	2	2

Notes:

(a) At 0800, 1/18/77, track was damp and was flame dried. At 1100, 1/18/77, high winds stopped operations until 1730.

(b) Measured relative humidity was between 80% and 100% during all spraying operations.

(c) Formulation L was selected for the open graded asphalt on section 22 as having the best chance on this very porous surface.

(d) Petroset AT appeared to penetrate poorly on section 1.

TESTING PROCEDURE

Test Track Apparatus Application

The use of the apparatus started in January 1977, before the paint formulations were put on. The purpose of these wheel applications was to try to simulate a road pavement which had some traffic. This would allow the application of the ice mitigation formulations on pavement surfaces with some traffic applications as in the real world. Table 11 summarizes the WSU Test Track operations.

Before spraying, 3,793 revolutions were accumulated by the apparatus. This is equivalent to 11,379 and 3,793 wheel traffic applications on Wheel Paths #1-4 and #5-8, respectively. After spraying, 14,408 revolutions were accumulated on the apparatus. This is equivalent to 43,224 and 14,408 wheel traffic applications on Wheel Paths #1-4 and #5-8, respectively.

The amount of time the apparatus was in operation was limited by the weather. It was planned to operate during and after snow storms. Snow did not materialize in any significant amounts. It was decided to spray the track with water so that ice would form on the pavements. This met with various success as the freezing temperatures needed for ice formation had to be below 30°F and had to last at least two or more hours. Unfortunately, the weather and air temperatures had started to warm rather prematurely and ice formation on the pavements proved to be a difficult task showing minimal success. This limited the operations of the Test Track apparatus. It was then decided to use the apparatus for determination of traffic durability for the various paint formulations. Test Track operations ended on April 19, 1977.

Weather Analysis

The most charitable thing that can be said of the weather is that the local population and area enjoyed a most mild and dry winter. The temperatures and the precipitation were below normal levels. This area was in a midst of drought unknown in any records. The climatological data is summarized for the months of December 1976 to April 1977 in Tables 12 to 16, showing maximum and minimum daily air and soil temperatures as measured locally. It can be seen that by the time the paint formulations were applied, most of the cold periods had passed. The freezing time had also been reduced.

Skid Resistance Measurements

Skid resistance measurements, using the British Portable Skid Resistance Tester, were taken before testing started on November 9, 1976, before and after spraying of the formulations on January 17 and 19, 1977 respectively; and on April 26-27, 1977 after all testing was completed. Due to variations in pavement surface temperatures during measurements, all skid values were corrected to 20°C according to accepted procedures.[10]

TABLE 11. SUMMARY OF WSU TEST TRACK OPERATIONS - JANUARY THROUGH APRIL 1977

TIME			TOTAL TIME APPARATUS IN OPERATION				AVERAGE SPEED MPH	NUMBER OF REVOLUTIONS		WHEEL APPLICATIONS WHEEL PATHS			
MONTH	DATES	TOTAL DAYS	MONTH		ACCUMULATED			MONTHLY	TOTAL	1 - 4		5 - 8	
			HOURS	MINUTES	HOURS	MINUTES				MONTHLY	TOTAL	MONTHLY	TOTAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
01	12-14[1]	3	13	17	13	17	12	3,793	3,793	11,379	11,379	3,793	3,793
	19-31	4	6	23	19	40	10	1,243	5,036	3,729	15,108	1,243	5,036
02	01-26	8	11	57	31	37	10	2,523	7,559	7,569	22,677	2,523	7,559
03	01-30	23	40	45	72	22	13	10,250	17,809	30,750	53,427	10,250	17,809
04	14-19	3	1	25	73	47	14	392	18,201	1,176	54,603	392	18,201
BEFORE SPRAYING:					13	17			3,793		11,379		3,793
AFTER SPRAYING:					60	30			14,408		43,224		14,408
TOTAL					73	47	12		18,201		54,603		18,201

[1]During January 17-19, the formulations on all sections had been sprayed.

TABLE 12. CLIMATOLOGICAL DATA - DECEMBER 1976 (2400 TO 2400)

DATE	AIR TEMPERATURE (°F)					SOIL TEMPERATURE WSU TEST TRACK[3] (°F)		PRECIPITATION (INCHES)
	PALOUSE CONSERVATION FIELD STATION[1]		WSU TEST TRACK		FREEZING[2] TIME-HRS			
	MAX	MIN	MAX	MIN		MAX	MIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	46	18	45	17	17	32	15	
2	41	16	42	17	17	25	15	
3	38	16	41	16	18	25	9	
4	25	20	25	23	24	20	18	
5	22	20	28	24	24	21	18	
6	36	27	37	27	--	22	21	0.03 R
7	43	27	43	28	18	28	21	0.22 R
8	41	33	42	35	0	37	22	0.19 R
9	37	31	40	28	3	28	21	
10	39	28	40	25	7	25	20	
11	45	28	46	30	3	32	21	
12	42	31	44	30	8	31	21	
13	43	31	45	26	8	37	21	
14	37	29	39	26	15	27	20	
15	41	27	[4]	[4]	[4]	[4]	[4]	
16	51	30						
17	41	32						
18	43	25						
19	39	25						
20	39	23	39	22	18	33	21	
21	40	23	40	22	18	28	18	
22	41	23	43	26	9	37	21	
23	33	22	33	24	20	25	22	0.14 Snow
24	30	23	33	23	22	22	20	
25	32	23	35	26	10	22	21	0.40
26	44	38	42	35	0	28	22	Trace
27	44	34	45	29	21	42	24	
28	38	31	40	32	0	34	20	
29	32	25	31	24	20	24	20	Trace
30	26	18	23	21	24	20	18	
31	26	22	25	21	24	20	19	
SUM					348			0.98
AVE	37.9	25.8	39.4	26.3	13.9	29	20.4	2.74[5]
DIFF								-1.76

[1]Pullman 2NW - the station is about 9 miles NW of WSU Test Track.

[2]Freezing time = No. of hours below 32°F.

[3]Temperature probe is buried 1.5 feet below the surface.

[4]Data missing.

[5]Normal average precipitation for this area.

TABLE 13. CLIMATOLOGICAL DATA - JANUARY 1977 (2400 TO 2400)

DATE	AIR TEMPERATURE (°F)					SOIL TEMPERATURE WSU TEST TRACK[3] (°F)		PRECIPITATION (INCHES)
	PALOUSE CONSERVATION FIELD STATION[1]		WSU TEST TRACK					
	MAX	MIN	MAX	MIN	FREEZING[2] TIME-HRS	MAX	MIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	25	10	25	10	24	23	10	
2	26	10	24	14	24	20	14	0.05
3	20	16	21	18	24	20	15	0.04
4	20	0	19	0	24	18	9	
5	19	4	19	5	24	18	5	
6	24	10	25	10	24	20	8	
7	24	4	25	4	24	20	8	
8	15	4	16	4	24	14	5	
9	23	1	26	1	24	20	5	
10	19	8	22	5	24	15	3	
11	25	17	32	20	23	19	18	
12	31	20	28	18	24	17	15	0.09
13	32	27	31	23	24	21	17	0.01
14	34	27	33	27	22	21	19	0.07
15	37	27	37	25	11	22	19	
16	39	33	40	32	0	26	21	0.07
17	44	37	43.5	34	0	29	22	
18	50	38	50	26	3	34	21	0.05
19	40	30	40	24	14	30	20	
20	43	26	43	27	15	34	21	
21	30	28	29	24.5	24	22	20	
22	30	27	29	27	24	21	20	
23	28	22	27	25	24	21	21	
24	29	22	30	20	24	20	19	
25	26	16	26	19	24	20	18	
26	32	21	32.5	16	18	25	14	
27	26	15	27	19	24	21	16	
28	30	15	32	18	22	27	15	
29	24	17	24	22	24	20	19	
30	36	17	36	16	22	29	14	
31	31	20	31	22	24	21	20	0.02
SUM					630			0.40
AVE	29.4	18.4	29.8	17.9	20.3	22.2	15.2	2.67[4]
DIFF								-2.27

[1]Pullman 2NW - the station is about 9 miles NW of the WSU Test Track.

[2]Freezing Time = No. of hours below 32°F.

[3]Temperature probe is buried 1.5 feet below the surface.

[4]Normal average precipitation for this area.

TABLE 14. CLIMATOLOGICAL DATA - FEBRUARY 1977 (2400 TO 2400)

DATE	AIR TEMPERATURE (°F)					SOIL TEMPERATURE WSU TEST TRACK[3] (°F)		PRECIPITATION (INCHES)
	PALOUSE CONSERVATION FIELD STATION[1]		WSU TEST TRACK		FREEZING[2]			
	MAX	MIN	MAX	MIN	TIME-HRS	MAX	MIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	27	24	28	25	24	20	20	
2	32	26	32	27	24	21	20	
3	41	28	41	29	18	30	21	
4	31	26	32	27	23	26	21	
5	34	24	37	25	22	28	20	
6	31	26	31	27	24	22	21	
7	45	24	47	25	15	37	21	
8	44	23	46	26	5	31	20	0.01
9	46	28	47	28.5	12	43	21	
10	54	28	56	36	0	40	24	
11	51	32	54	30	1	45	23	
12	58	32	59	43.5	0	44	31	
13	49	33	51	28	8	50	28	
14	49	25	52	23	10	46	21	
15	55	36	59	31	1	49	24	
16	56	34	58	32	0	49	27	
17	50	32	52	31	2	38	25	
18	56	32	58	31	4	52	25	
19	59	38	62	30	2	51	26	
20	61	32	63	37	0	45	27	
21	43	34	42	32	0	30	25	0.11
22	43	32	45	33	0	39	26	
23	44	34	44	25	14	41	21	
24	44	19	43	17	14	36	17	
25	37	22	38	31	5	27	21	0.12
26	41	26	42	29	7	33	21	0.01
27	46	30	41	32.5	0	30	23	0.02
28	42	31	42	34	0	30	25	0.18
SUM					235			0.45
AVE	45.3	29.0	46.5	29.5	8.4	36.9	23.0	2.10[4]
DIFF								-1.65

[1]Pullman 2NW - the station is about 9 miles NW of WSU Test Track.

[2]Freezing Time - No. of hours below 32°F.

[3]Temperature probe is buried 1.5 feet below the surface.

[4]Normal average precipitation for this area.

TABLE 15. CLIMATOLOGICAL DATA - MARCH 1977 (2400 TO 2400)

DATE	AIR TEMPERATURE (°F)					SOIL TEMPERATURE WSU TEST TRACK[3] (°F)		PRECIPITATION (INCHES)
	PALOUSE CONSERVATION FIELD STATION[1]		WSU TEST TRACK					
	MAX	MIN	MAX	MIN	FREEZING[2] TIME-HRS	MAX	MIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	36	28	36	30	4	29	23	0.18
2	40	28	41	30	4	39	22	
3	40	28	40	32	0	32	24	0.03
4	43	30	45	28	7	42	21	
5	48	34	50	26	7	43	22	
6	54	37	55	38	0	42	28	
7	47	37	47	38	0	32	29	0.30
8	45	31	45	33	0	34	24	0.32
9	42	33	43	33	0	37	24	0.18
10	44	29	45	28	4	44	22	
11	45	28	46	28	7	40	21	
12	43	30	43	33	0	32	24	
13	35	26	37	23	20	26	21	0.10
14	35	20	34.5	21	16	25	20	0.01
15	42	24	45	28	15	37	20	
16	42	28	48	32	2	38	23	0.04
17	40	26	40	28	10	36	22	0.02
18	42	27	42	28	8	36	21	
19	45	31	45	28	4	38	24	0.04
20	43	28	43	28	6	37	22	
21	48	32	50	34	0	36	25	
22	61	31	64	29	5	55	22	
23	45	38	49	35	0	36	27	0.07
24	58	32	48	28	3	47	24	
25	49	23	50	22	8	49	21	
26	48	31	49	36	0	37	26	
27	40	23	46	32.5	0	32	23	0.08
28	41	26	42	29	6	37	22	
29	45	25	46	25	9	38	22	
30	52	27	54	24	7	53	21	
31	43	33	46	30	2	38	26	
SUM					154			1.35
AVE	44.6	29.2	45.6	29.6	5.0	38.0	23.1	2.12[4]
DIFF								-0.77

[1]Pullman 2NW - the station is about 9 miles NW of WSU Test Track.

[2]Freezing Time = No. of hours below 32°F.

[3]Temperature probe is buried 1.5 feet below the surface.

[4]Normal average precipitation for this area.

TABLE 16. CLIMATOLOGICAL DATA - APRIL 1977 (2400 TO 2400)

DATE	AIR TEMPERATURE (°F)					SOIL TEMPERATURE WSU TEST TRACK[3] (°F)		PRECIPITATION (INCHES)
	PALOUSE CONSERVATION FIELD STATION[1]		WSU TEST TRACK		FREEZING[2]			
	MAX	MIN	MAX	MIN	TIME-HRS	MAX	MIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	45	28	46.5	26	3	40	23	0.03
2	49	21	50	22	8	46	20	
3	60	29	60	29	4	54	25	
4	65	36	66	32	3	64	27	
5	65	37	71	36	0	69	30	
6	74	37	76	36	0	74	31	
7	77	44	80	44	0	75	38	
8	72	48	72	45	0	60	42	
9	51	32	58	33	0	57	30	
10	55	24	61	28	4	59	27	
11	55	35	60	35	0	59	33	
12	63	27	68	27	4	67	27	
13	52	41	54	37	0	50	33	0.19
14	50	27	61	31	1	60	26	0.01
15	58	32	61	36	0	50	31	T
16	52	39	52	32	0	49	30	0.09
17	49	26	60	27	6	58	24	
18	48	21	48	24	7	45	22	
19	48	27	57	24	6	56	22	
20	56	36	64	33	0	61	30	
21	60	36	62	39	0	55	36	
22	78	41	82	44	0	79	36	
23	85	55	90	60	0	89	48	
24	87	58	94	56	0	93	49	
25	82	46	90	60	0	89	58	
26	61	34	80	50	0	66	37	
27	67	30	80	52	0	79	41	
28	74	35	85	40	0	74	32	
29	70	45	81	50	0	69	42	
30	71	38	79	43	0	73	34	
SUM					46			0.32
AVE	62.6	35.5	68.3	38.0	1.5	64.0	32.8	1.49[4]
DIFF								-1.17

[1]Pullman 2NW - the station is about 9 miles NW of WSU Test Track.

[2]Freezing Time = No. of hours below 32°F.

[3]Temperature probe is buried 1.5 feet below the surface.

[4]Normal average precipitation for this area.

EXPERIMENTAL RESULTS

Skid Resistance Results

The results from the British Portable Skid Tester, taken before testing, before spraying, after spraying and at completion of testing are summarized in Tables 17 to 23.

The summarized results from skid resistance data in BPN taken on untravelled pavement, and before and after spraying of the formulations are shown in Table 17. This data is uncorrected for pavement surface temperature variations. The difference in skid resistance readings taken before and after spraying indicates the effect of the formulations on pavement skid performance. This is shown in Table 18.

It is apparent that the immediate effect of these formulations on both portland cement concrete and asphalt concrete pavement is to reduce the skid resistance. These reductions can vary from a high of 35 to a low of 2. The exception is Petroset AT application which increased skid resistance of both types of pavements. On the PCC Pavements, formulations C and next J reduced skid resistance the least. On the basis of increasing reduction of skid resistance, the ranking of formulations is C, J, K, G, B and F. On the Class "B" asphalt concrete pavements, formulations C, I and L in that order caused the least reduction in skid resistance. The ranking based on increasing reduction of skid resistance is C, I, L, B, G and F respectively. The L formulations on the open-graded asphalt concrete overlay reduced its skid resistance by only 6 which was superior to any of the Class "B" asphalt concrete overlays. This is due in part to the open-graded nature of the pavement.

It is difficult to measure wear of a coating. In this project one criteria was the use of the change in skid resistance. A Skid Resistance Change Rate (SRCR) was developed as a measure of skid reisitance change and wear of coating. Under most circumstances, all pavements suffer a loss in skid resistance with traffic and time. In this project, an increase in skid resistance as denoted by a positive SRCR indicates more wear than a negative SRCR. The reason for this use of skid resistance in such a manner is that the coatings reduce skid resistance and when they are worn off, the skid resistance will increase.

Using SRCR as a measure of change in skid resistance, Tables 19-23 were developed to show the comparisons of skid resistance changes for the different sections and formulations. The changes in skid resistance for the portland cement concrete sections are shown in Table 19. The BPN and SRCR show the following ordering on the basis of decreasing wear: formulations F, B, J, K, G, C, Petroset AT, and the nontreated section. Formulation F had the least resistance to traffic wear while C had the most.

Wear is also a function of the type of tire. The testing apparatus had seven different types of tires. The effect of these tires on portland cement concrete pavements is also shown in Table 19. The garnet tread truck tires caused the most wear as would be expected, the inside driving tire more than the free-wheeling tire. Of the two inside passenger tires, the studded tire caused more wear and a polishing action on the pavement as compared to the garnet tread tire. The tires in Wheel Paths #5-8 had different treads and tire construction. In order of the highest SRCR, the tires in Wheel Paths #7, #5, #6 and #8 are ranked accordingly. The tire with the special compound F-32 in Wheel Path #8 appears to cause the least wear of any of the outside passenger tires.

Table 20 shows the skid resistance results for the Class "B" asphalt concrete sections. The BPN and SRCR show the following ordering on the basis of decreasing wear: formulations G, F, B, L, I, C, Petroset AT and the nontreated sections. The studded passenger wheel tires (Wheel Path #2) increased the skid resistance more than the passenger wheel garnet tread tires (Wheel Path #1) thus indicating more wear of the formulations. In order of the highest SRCR, the ranking according to Wheel Paths is #5, #6, #7, and #8. The tire with F-32 rubber in Wheel Path #8 again caused the least wear.

The skid resistance results for the open-graded asphalt sections are summarized in Table 21. Section 22 with formulation L had less reduction in skid resistance but the initial skid readings were lower. In the group of asphalt overlays, the tires in Wheel Paths #6, #5, #7, and #8 caused the most reduction in SRCR, respectively. The garnet tire lowered the SRCR more than the studded tire in these asphalt pavement types. The reason is that the garnet dust acted as an abrasive polishing the aggregates.

Table 23 shows the skid values for the four asphalt overlays. On the basis of skid resistance reduction, Section 27 with 8.33% Petroset was inferior to Section 28 with 25%, but the final BPN was still higher for Section 27 than for Section 28. The 25% Petroset Section 28 had initial lower BPN's. Comparing the two Viscospin asphalt overlays, Section 29 with 4% Viscospin had higher initial BPN's and also lower final BPN's than Section 30 with 8% Viscospin. In other words for both types of overlays, the overlays with the most additive had a lower reduction in SRCR. This may indicate that additives help in lowering the reduction in skid resistance.

Table 23 also shows that the garnet tread passenger tires in Wheel Path #1 caused the greatest loss in BPN, again indicating the abrasive action of the garnet dust on the aggregates. Of the other passenger tires, the tire in Wheel Path #8 caused the least loss in BPN, followed by the tire in Wheel Paths #5, #7 and #6 in that order. It appears that the F-32 rubber passenger tire has the least effect on pavement skid resistance in general.

TABLE 17. TRACK SKID DATA SUMMARY-SKID NUMBERS

SECTION	COMPOSITION	INITIAL DATA	SKID VALUES JUST PRIOR TO SPRAYING								COATING	SPRAYED VALUES	
			WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8		WP3	WP4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	PCC		95	84	81	89	85	89	95	99	PETROSET		
2	"										NONE		
3	"		91	81	95	93	93	98	98	98	K	71	72
5	"	89	98	80	81	97	94	85	97	85	J	69	75
6	"		95	82	90	95	88	85	94	96	G	65	68
7	"		93	84	87	89	88	92	93	92	F	58	56
8	"	76	88	70	86	79	93	88	94	96	C	77	73
9	"		92	73	96	87	93	94	91	92	B	66	66
12	ASPHALT	81	85	90	76	75	74	76	81	87	NONE		
13	"										L	71	68
15	"	74									I	73	70
16	"										G	64	55
17	"										F	61	64
18	"		83	90	80	90	90	90	88	88	C	78	75
19	"	88									B	65	66
22	OPEN-GRADED										L	47	
23	"	83									NONE	76	75
24	RUBBERIZED ASPHALT										NONE	72	73
25	"	73									NONE	80	73
26	"										NONE	74	75
27	PETROSET OVERLAY	83									OVERLAY	79	80
28	"	78									"	78	80
29	VISCOSPIN OVERLAY	88									"	78	73
30	"	82									"	81	77

Notes: WP = wheel path numbered from inside diameter of track.

Initial data temps: Air = 12°C, asphalt = 14°C and concrete = 15°C

Prior spraying temps: Air = 8°C, asphalt = 7°C and concrete = 7°C

Sprayed temps: Air = 6-1/2°C, asphalt = 7°C and concrete = 10"C

The Petroset on Section 1 was not dry enough for testing.

TABLE 18. THE EFFECT OF SPRAYING OF FORMULATIONS ON SKID RESISTANCE NUMBERS (BPN)[1]

TYPE OF PAVEMENT MATERIAL	SECTION[2]	FORMULATION	REDUCTION (-) OR INCREASE (+) IN SKID RESISTANCE NUMBERS (BPN)							
			WHEEL PATHS							
			#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PCC	1	PETROSET AT	+ 8	+17	+20	+12	+16	+12	+ 6	+ 2
	3	K	-19	- 9	-23	-20	-20	-20	-20	-25
	5	J	-28	-10	-11	-21	-18	- 9	-21	- 9
	6	G	-29	-16	-24	-26	-19	-16	-25	-27
	7	F	-35	-26	-28	-32	-24	-24	-35	-34
	8	C	-15	+ 6	- 8	- 5	-15	-12	-18	-19
	9	B	-25	- 6	-29	-20	-26	-27	-23	-25
CL "B" AC	11	PETROSET AT	- 2	- 7	+ 7	+ 8	+ 9	+ 7	+ 2	- 4
	13	L	-14	-20	- 7	-14	-12	-13	-15	-17
	15	I	+13	-19	- 5	-12	-10	-11	-13	-15
	16	G	-24	-30	-14	-17	-22	-23	-25	-27
	17	F	-21	-28	-19	-26	-28	-28	-26	-26
	18	C	- 7	-14	- 2	-15	-14	-14	-12	-12
	19	B	-18	-25	- 5	-24	-24	-24	-22	-22
O.G. AC	22	L	- 6	- 6	- 6	- 6	- 6	- 6	- 6	- 6

[1]All BPN corrected to 20°C.

[2]The non-treated sections have been excluded.

TABLE 19. COMPARISON OF SKID RESISTANCE VALUES FOR THE PORTLAND CEMENT CONCRETE SECTIONS 1-10, IN BPN AND CORRECTED TO 20°C

SECTION	FORMULATIONS	PARAMETERS FOR SKID RESISTANCE VALUES	SKID RESISTANCE VALUES IN BPN AT 20°C								
			WHEEL PATHS								
			UT[5]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	PETROSET AT	AFTER SPRAYING[1]	97	97	97	97	97	97	97	97	97
		AFTER TESTING[2]	97	90	79	74	74	87	81	81	89
		CHANGE	--	-7	-18	-23	-23	-10	-16	-16	-8
		SRCR[3]	--	-162	-416	-532	-532	-694	-1,111	-1,111	-555
2	NT[4]	AFTER SPRAYING	96	96	96	96	96	96	96	96	96
		AFTER TESTING	96	88	67	72	72	80	82	79	87
		CHANGE	--	-8	-9	-24	-24	-16	-14	-17	-9
		SRCR	--	-185	-208	-555	-555	-1,111	-972	-1,180	-625
3	K	AFTER SPRAYING	86	69	69	69	70	69	69	69	69
		AFTER TESTING	86	83	67	75	75	75	73	75	69
		CHANGE	--	+14	-2	+6	+5	+6	+4	+6	--
		SRCR	--	+324	-46	+139	+116	+416	+278	+416	--
4	NT	AFTER SPRAYING	90	90	90	90	90	90	90	90	90
		AFTER TESTING	90	83	69	76	76	78	83	90	94
		CHANGE	--	-7	-21	-14	-14	-12	-7	--	+4
		SRCR	--	-162	-486	-324	-324	-833	-486	--	+278
5	J	AFTER SPRAYING	81	70	70	67	73	70	70	70	70
		AFTER TESTING	81	72	62	81	81	76	73	74	76
		CHANGE	--	+2	-8	+14	+8	+6	+3	+4	+6
		SRCR	--	+46	-185	+324	+185	+416	+208	+278	+416
6	G	AFTER SPRAYING	66	65	65	63	66	65	65	65	65
		AFTER TESTING	66	70	60	63	63	71	77	69	60
		CHANGE	--	+5	-5	--	-2	+6	+8	+4	+5
		SRCR	--	+116	-116	--	-46	+416	+555	+278	+347

CONTINUED

TABLE 19 (CONTINUED)

SECTION (1)	FORMULATIONS (2)	PARAMETERS FOR SKID RESISTANCE VALUES (3)	SKID RESISTANCE VALUES IN BPN AT 20°C								
				WHEEL PATHS							
			UT[3] (4)	#1 (5)	#2 (6)	#3 (7)	#4 (8)	#5 (9)	#6 (10)	#7 (11)	#8 (12)
7	F	AFTER SPRAYING	54	55	55	56	54	55	55	55	55
		AFTER TESTING	54	75	62	69	69	76	66	72	57
		CHANGE	--	+20	+7	+13	+15	+11	+11	+17	+2
		SRCR	--	+463	+162	+301	+347	+763	+763	+1,180	+136
8	C	AFTER SPRAYING	78	74	74	76	71	74	74	74	74
		AFTER TESTING	78	73	64	68	68	78	77	79	67
		CHANGE	--	-1	-10	-8	-3	+4	+3	+5	-7
		SRCR	--	-23	-231	-185	-69	+278	+208	+347	-486
9	B	AFTER SPRAYING	81	64	64	64	64	64	64	64	64
		AFTER TESTING	81	71	63	74	74	74	73	79	76
		CHANGE	--	+7	-1	+10	+10	+10	+9	+15	+12
		SRCR	--	+162	-23	+231	+231	+694	+625	+1,041	+833
10	NT	AFTER SPRAYING	88	88	88	88	88	88	88	88	88
		AFTER TESTING	88	69	61	60	60	75	76	79	84
		CHANGE	--	-19	-27	-28	-28	-13	-12	-9	-4
		SRCR	--	-440	-625	-648	-648	-902	-833	-625	-278

[1]The formulations were sprayed on after 3,793 wheel applications, which is taken as zero wheel applications.

[2]There were 43,224 and 14,408 wheel applications put on Wheel Paths 1-4 and 5-8, respectively, after spraying.

[3]Skid resistance change ratio (SRCR) = $(\Delta BPN/WL) \times 10^{-6}$

[4]NT = not treated

[5]UT = untravelled

TABLE 20. COMPARISON OF SKID RESISTANCE VALUES FOR THE CLASS "B" ASPHALT CONCRETE SECTIONS 11-20, IN BPN AND CORRECTED TO 20°C

SECTION	FORMULATIONS	PARAMATERS FOR SKID RESISTANCE VALUES	SKID RESISTANCE VALUES IN BPN AT 20°C								
				WHEEL PATHS							
			UT[5]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
11	PETROSET AT	AFTER SPRAYING[1]	81	81	81	81	81	81	81	81	81
		AFTER TESTING[2]	81	65	71	68	68	62	62	78	77
		CHANGE	--	-16	-10	-13	-13	-19	-19	-3	-4
		SRCR[3]	--	-370	-231	-301	-310	-1,319	-1,319	-208	-278
12	NT[4]	AFTER SPRAYING	81	81	81	81	81	81	81	81	81
		AFTER TESTING	81	69	81	57	57	66	65	76	78
		CHANGE	--	-12	--	-24	-24	-15	-14	-5	-3
		SRCR	--	-278	--	-555	-555	-1,041	-972	-348	-208
13	L	AFTER SPRAYING	79	66	66	67	64	66	66	66	66
		AFTER TESTING	79	67	76	68	68	67	64	76	79
		CHANGE	--	+1	+10	+1	+4	+2	-2	+10	+12
		SRCR	--	+23	+231	+23	+93	+139	-139	+694	+833
14	NT	AFTER SPRAYING	83	83	83	83	83	83	83	83	83
		AFTER TESTING	83	68	79	62	62	64	68	72	74
		CHANGE	--	-15	-4	-21	-21	-19	-15	-11	-9
		SRCR	--	-347	-93	-486	-486	-1,319	-1,041	-763	-625
15	I	AFTER SPRAYING	87	67	67	69	66	67	67	67	67
		AFTER TESTING	87	66	75	68	68	65	67	74	74
		CHANGE	--	-1	+8	-1	+2	-2	--	+7	+7
		SRCR	--	-23	+185	-23	+46	-139	--	+486	+486
16	G	AFTER SPRAYING	70	56	56	60	51	56	56	56	56
		AFTER TESTING	70	67	74	58	58	65	63	71	76
		CHANGE	--	+11	+8	-2	+7	+9	+7	+15	+20
		SRCR	--	+254	+185	-46	+162	+625	+486	+1,041	+1,388

CONTINUED

TABLE 20 (CONTINUED)

SECTION (1)	FORMULATIONS (2)	PARAMETERS FOR SKID RESISTANCE VALUES (3)	SKID RESISTANCE VALUES IN BPN AT 20°C								
			WHEEL PATHS								
			UT[5] (4)	#1 (5)	#2 (6)	#3 (7)	#4 (8)	#5 (9)	#6 (10)	#7 (11)	#8 (12)
17	F	AFTER SPRAYING	74	58	58	57	60	58	58	58	58
		AFTER TESTING	74	63	76	67	67	72	66	69	69
		CHANGE	--	+5	+18	+10	+7	+14	+8	+11	+11
		SRCR	--	+116	+416	+231	+162	+972	+555	+763	+763
18	C	AFTER SPRAYING	70	72	72	74	71	72	72	72	72
		AFTER TESTING	70	67	79	65	65	77	72	77	78
		CHANGE	--	-5	+7	-9	-6	+5	--	+5	-6
		SRCR	--	-116	+162	-208	-139	+348	--	+348	-416
19	B	AFTER SPRAYING	71	61	61	61	62	61	61	61	61
		AFTER TESTING	71	67	77	65	65	71	75	73	76
		CHANGE	--	+6	+16	+4	+3	+10	+14	+12	+15
		SRCR	--	+139	+370	-93	+69	+694	+972	+833	+1,041
20	NT	AFTER SPRAYING	83	83	83	83	83	83	83	83	83
		AFTER TESTING	83	66	85	70	70	72	74	75	79
		CHANGE	--	-17	+2	-13	-13	-11	-9	-8	-4
		SRCR	--	-393	+46	-301	-301	-763	-625	-555	-278

[1] The formulations were sprayed on after 3,793 wheel applications, which is taken as zero wheel applications.

[2] There were 43,224 and 14,408 wheel applications put on Wheel Paths 1-4 and 5-8, respectively after spraying.

[3] Skid resistance change ratio (SRCR) = $(\Delta BPN/WL) \times 10^{-6}$

[4] NT = not treated

[5] UT = untravelled

TABLE 21. COMPARISON OF SKID RESISTANCE VALUES FOR THE THREE OPEN-GRADED ASPHALT CONCRETE OVERLAYS, SECTIONS 21-23, IN BPN AND CORRECTED TO 20°C

WHEEL PATHS	OPEN-GRADED ASPHALT CONCRETE OVERLAYS											
	REGULAR				FORMULATION L				REGULAR			
	SECTION 21				SECTION 22				SECTION 23			
	SKID RESISTANCE VALUES				SKID RESISTANCE VALUES				SKID RESISTANCE VALUES			
	BPN			SRCR[3]	BPN			SRCR	BPN			SRCR
	BEFORE[1]	AFTER[2]	CHANGE		BEFORE[4]	AFTER[5]	CHANGE		BEFORE[1]	AFTER[2]	CHANGE	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	81	66	-15	-275	75	67	-8	-185	81	67	-14	- 256
2	81	79	- 2	- 87	75	82	+7	+162	81	83	+ 2	+ 37
3	81	64	-17	-311	75	69	-6	-139	81	61	-20	- 366
4	81	64	-17	-311	75	69	-6	-139	81	61	-20	- 366
5	81	66	-15	-824	75	71	-4	-278	81	64	-17	- 934
6	81	67	-14	-769	75	67	-8	-555	81	60	-21	-1.154
7	81	72	- 9	-494	75	73	-2	-139	81	65	-16	- 879
8	81	73	- 8	-440	75	74	-1	- 69	81	74	- 7	- 385
UNTRAVELLED	81	84	+ 4	+ 73	75	75	0	--	81	84	+ 3	+ 55

[1]Zero wheel applications.

[2]After 18,201 wheel applications, 54,603 wheel applications on Wheel Paths 1-4, and 18,201 wheel applications on Wheel Paths 5-8.

[3]Skid resistance change ratio (SRCR) = $\Delta BPN/WL \times 10^{-6}$

[4]The formulation was sprayed on after 3,793 wheel applications, which is taken as zero wheel applications.

[5]There were 43,224 and 14,408 wheel applications put on Wheel Paths 1-4 and 5-8, respectively, after spraying.

TABLE 22. COMPARISON OF SKID RESISTANCE VALUES FOR THE THREE RUBBERIZED ASPHALT CONCRETE OVERLAYS, SECTIONS 24-26, IN BPN AND CORRECTED TO 20°C

WHEEL PATHS	RUBBERIZED ASPHALT CONCRETE OVERLAYS											
	5% RUBBER				10% RUBBER				5% RUBBER			
	SECTION 24				SECTION 25				SECTION 26			
	SKID RESISTANCE VALUES				SKID RESISTANCE VALUES				SKID RESISTANCE VALUES			
	BPN			SRCR[3]	BPN			SRCR[3]	BPN			SRCR[3]
	BEFORE[1]	AFTER[2]	CHANGE		BEFORE[1]	AFTER[2]	CHANGE		BEFORE[1]	AFTER[2]	CHANGE	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	81	71	-10	-183	79	72	- 7	-128	83	68	-15	-275
2	81	78	- 3	- 55	79	81	+ 2	+37	83	74	- 9	-165
3	81	66	-15	-275	79	73	- 6	-110	83	58	-25	-458
4	81	66	-15	-275	79	73	- 6	-110	83	58	-25	-458
5	81	72	- 9	-494	79	69	-10	-549	83	79	- 4	-220
6	81	72	- 9	-494	79	73	- 6	-330	83	71	-12	-659
7	81	72	- 9	-494	79	73	- 6	-330	83	73	-10	-549
8	81	75	- 6	-330	79	81	+ 2	+110	83	81	- 2	-110
UNTRAVELLED[4]	81	81	0	--	79	79	0	--	83	83	0	--

[1]Zero wheel applications.

[2]After 18,201 wheel applications; 54,603 wheel applications on Wheel Paths 1-4, and 18,201 wheel applications on Wheel Paths 5-8.

[3]Skid resistance change ratio (SRCR) = $\Delta BPN/WL \times 10^{-6}$

[4]Only one set of measurements before testing started were taken, and this was in Section 25. The BPN was 71, so the BPN obtained from the untravelled areas were used for comparison purposes.

TABLE 23. COMPARISON OF SKID RESISTANCE VALUES FOR THE FOUR ASPHALT CONCRETE OVERLAYS, SECTIONS 27-30, IN BPN AND CORRECTED TO 20°C

WHEEL PATHS	PETROSET A.C. OVERLAY								VISCOSPIN A.C. OVERLAY							
	8.33%				25.0%				4%				8%			
	SECTION 27				SECTION 28				SECTION 29				SECTION 30			
	SKID RESISTANCE VALUES				SKID RESISTANCE VALUES				SKID RESISTANCE VALUES				SKID RESISTANCE VALUES			
	BPN			SRCR[3]	BPN			SRCR	BPN			SRCR	BPN			SRCR
	BEFORE[1]	AFTER[2]	CHANGE		BEFORE	AFTER	CHANGE		BEFORE	AFTER	CHANGE		BEFORE	AFTER	CHANGE	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1	81	75	- 6	-110	76	68	- 8	-147	86	69	-15	-275	80	70	-10	-183
2	81	85	+ 4	+ 73	76	88	+12	+220	86	76	-10	-183	80	80	0	0
3	81	65	-16	-293	76	66	-10	-183	86	66	-20	-366	80	62	-18	-330
4	81	65	-16	-293	76	66	-10	-183	86	66	-20	-366	80	62	-18	-330
5	81	72	- 9	-494	76	73	- 3	-165	86	73	-13	-714	80	70	-10	-549
6	81	73	- 8	-440	76	70	- 6	-330	86	68	-18	-989	80	69	-11	-604
7	81	74	- 7	-385	76	72	- 4	-220	86	73	-13	-714	80	76	-14	-769
8	81	79	- 2	-110	76	79	+ 3	-165	86	81	- 7	-385	80	74	-16	-879
UNTRAVELLED	81	89	+ 8	+ 15	76	88	+12	+219	86	88	+ 2	+ 37	80	85	+ 5	+ 92

[1]Zero wheel applications.

[2]After 18,201 wheel applications; 54,603 wheel applications on Wheel Paths 1-4, and 18,201 wheel applications on Wheel Paths 5-8.

[3]SRCR = Skid resistance change ratio = $(\Delta BPN \div WL) \times 10^{-6}$.

TABLE 24. WEAR RANKING SCALE BASED ON WATER BEADING CRITERIA (BEAD WEAR RANKING NUMBER)

RANKING SCALE (1)	WATER BEADING CRITERIA (2)
0	No beading
1	Very slight beading
1.5	Slight beading
2	Moderate beading
3	Good beading
4	Excellent beading
5	Superior beading

TABLE 25. WEAR RANKING OF WSU TEST TRACK SECTIONS AT END OF TEST BY WATER BEADING CRITERIA (BWR)[1]

TYPE OF MATERIAL	SECTION	FORMULATION CODE	WEAR RANKINGS								
			WHEEL PATHS								
			UT[2]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PCC	1	PETROSET AT	1	0	0	1	1	1	1	1.5	1.5
	2	NT[3]	0	0	0	0	0	0	0	0	0
	3	K	5	2	1	3	3	4	4	4	4
	4	NT	0	0	0	0	0	0	0	0	0
	5	J	5	2	1	1	1	3	3	3	3
	6	G	5	1.5	1	1	1	2	2	2	2
	7	F	5	2	1	1	1	1	1	2	2
	8	C	5	2	1	2	2	3	4	4	4
	9	B	5	2	0	1	1	1	1	2	3
	10	NT	0	0	0	0	0	0	0	0	0
CLASS "B" A.C.	11	PETROSET AT	4	3	1.5	1	1	1	1	1	1
	12	NT	1	1	0	0	0	1	1	1	1
	13	L	5	2	2	1	1	2	2	3	3
	14	NT	1	0	0	0	0	0	1	1	1
	15	I	5	3	0	0	0	1	1	1	2
	16	G	5	2	1	1	1	2	3	4	4
	17	F	5	3	0	2	2	3	2	3	3
	18	C	5	1	0	2	2	4	4	4	3
	19	B	5	2	0	1	1	3	3	2	3
	20	NT	1	0	0	0	0	0	0	0	0
OPEN-GRADED A.C.	21	NT	0	0	0	0	0	0	0	0	0
	22	L	4	3	3	3	3	3	3	3	3
	23	NT	0	0	0	0	0	0	0	0	0
RUBBERIZED A.C.	24	5%	2	1	2	1	1	1	1	1	1
	25	10%	2	2	2	1	1	1	1	1	1
	26	3%	1	1	1	1	1	1	1	1	1
ASPHALT OVERLAYS	27	PETROSET AT	1	1	1	1	1	1	1	1	1
	28	PETROSET AT	2	1	0	1	1	2	2	2	2
	29	VISCOSPIN	1	1	0	0	0	0	0	0	0
	30	VISCOSPIN	0	0	0	0	0	0	0	0	0

[1]It will be named Beading Wear Ranking Number or BWR.

[2]UT = untravelled

[3]NT = not treated

TABLE 26. COMPARISON OF SKID RESISTANCE CHANGE RATES (SRCR) WITH BEADING WEAR RANKING (BWR) FOR PCC SECTIONS

SECTION	FORMULATIONS	COMPARISON OF WEAR RATIOS	WHEEL PATHS								
			UT[3]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	PETROSET AT	SRCR[1]	0	-162	-416	-532	-532	- 694	-1,111	-1,111	-555
		BWR	1	0	0	1	1	1	1	1.5	1.5
2	NT[2]	SRCR	0	-185	-208	-555	-555	-1,111	- 972	-1,180	-625
		BWR	0	0	0	0	0	0	0	0	0
3	K	SRCR	0	+324	- 46	+139	+116	+ 416	+ 278	+ 416	0
		BWR	5	2	1	3	3	4	4	4	4
4	NT	SRCR	0	-162	-486	-324	- 24	- 833	- 486	0	+278
		BWR	0	0	0	0	0	0	0	0	0
5	J	SRCR	0	+ 46	-185	+324	+185	+ 416	+ 208	+ 278	+416
		BWR	5	2	1	1	1	3	3	3	3
6	G	SRCR	0	+116	-116	0	- 46	+ 416	+ 555	+ 278	+347
		BWR	5	1.5	1	1	1	2	2	2	2
7	F	SRCR	0	+463	+162	+301	+347	+ 763	+ 763	+1,180	+139
		BWR	5	2	1	1	1	1	1	2	2
8	C	SRCR	0	- 23	-231	-185	- 69	+ 278	+ 208	+ 347	-486
		BWR	5	2	1	2	2	3	4	4	4
9	B	SRCR	0	+162	- 23	+231	+231	+ 694	+ 625	+1,041	+833
		BWR	5	2	0	1	1	1	1	2	3
10	NT	SRCR	0	-440	-625	-648	-648	- 902	- 833	- 625	-278
		BWR	0	0	0	0	0	0	0	0	0

[1]SRCR = (Change in BPN at 20°C ÷ Number of Wheel Applications) x 10^{-6}.

[2]NT = not treated

[3]UT - untravelled

TABLE 27. COMPARISON OF SKID RESISTANCE CHANGE RATES (SRCR) WITH BEADING WEAR RANKING (BWR) FOR CLASS "B" A.C. SECTIONS

SECTION	FORMULATIONS	COMPARISON OF WEAR RATIOS	WHEEL PATHS								
			UT[3]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
11	PETROSET AT	SRCR[1]	0	-370	-231	-301	-301	-1,319	-1,319	- 208	- 278
		BWR	4	3	1.5	1	1	1	1	1	1
12	NT[2]	SRCR	0	-278	0	-555	-555	-1,041	- 972	- 348	- 208
		BWR	1	1	0	0	0	1	1	1	1
13	L	SRCR	0	+ 23	+231	+ 23	+ 93	+ 139	- 139	+ 694	+ 833
		BWR	5	2	2	1	1	2	2	3	3
14	NT	SRCR	0	-347	- 93	-486	-486	-1,319	-1,041	- 763	- 625
		BWR	1	0	0	0	0	0	1	1	1
15	I	SRCR	0	- 23	+185	- 23	+ 46	- 139	0	+ 486	+ 486
		BWR	5	3	0	0	0	1	1	1	2
16	G	SRCR	0	+254	+185	- 46	+162	+ 625	+ 486	+1,041	+1,388
		BWR	5	2	1	1	1	2	3	4	4
17	F	SRCR	0	+116	+416	+231	+162	+ 972	+ 555	+ 763	+ 763
		BWR	5	3	0	2	2	3	2	3	3
18	C	SRCR	0	-116	+162	-208	-139	+ 348	0	+ 348	- 416
		BWR	5	1	0	2	2	4	4	4	3
19	B	SRCR	0	+139	+370	- 93	+ 68	+ 694	+ 972	+ 833	+1,041
		BWR	5	2	0	1	1	3	3	2	3
20	NT	SRCR	0	-393	+ 46	-301	-301	- 763	- 625	- 555	- 278
		BWR	1	0	0	0	0	0	0	0	0

[1]SRCR = (Change in BPN at 20°C ÷ Number of Wheel Applications) x 10^{-6}.

[2]NT = not treated

[3]UT = untravelled

TABLE 28. COMPARISON OF SKID RESISTANCE CHANGE RATES (SRCR) WITH BEADING WEAR RANKING (BWR) FOR ASPHALT CONCRETE OVERLAYS

SECTION	SECTION DESCRIPTION		COMPARISON OF WEAR RATIOS	WHEEL PATHS								
	OVERLAY TYPE	% OR F[1]		UT[4]	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
21	OPEN-GRADED ASPHALT CONCRETE	NT[3]	SRCR[2]	+ 73	-275	- 37	-311	-311	-824	-769	-494	-440
			BWR	0	0	0	0	0	0	0	0	0
22		L	SRCR	0	-185	+162	-139	-139	-278	-555	-139	- 69
			BWR	4	3	3	3	3	3	3	3	3
23		NT	SRCR	+ 55	-256	+ 37	-366	-366	-434	-1,154	-879	-385
			BWR	0	0	0	0	0	0	0	0	0
24	RUBBERIZED ASPHALT	5	SRCR	0	-183	- 55	-275	-275	-494	-494	-494	-330
			BWR	2	1	2	1	1	1	1	1	1
25		10	SRCR	0	-128	+ 37	-110	-110	-549	-330	-330	+110
			BWR	2	2	2	1	1	1	1	1	1
26		5	SRCR	0	-275	-165	-458	-458	-220	-659	-549	-110
			BWR	1	1	1	1	1	1	1	1	1
27	PETROSET AT	8.33	SRCR	+ 15	-110	+ 73	-293	-293	-494	-440	-385	-110
			BWR	1	1	1	1	1	1	1	1	1
28		25	SRCR	+219	-147	+220	-183	-183	-165	-330	-220	-165
			BWR	2	1	0	1	1	2	2	2	2
29	VISCOSPIN AC	4	SRCR	+ 37	-275	-183	-366	-366	-714	-989	-714	-385
			BWR	1	1	0	0	0	0	0	0	0
30		8	SRCR	+ 92	-183	0	-330	-330	-549	-604	-769	-879
			BWR	0	0	0	0	0	0	0	0	0

[1]% or F = Percent or Formulation

[2]SRCR = (Change in BPN at 20°C ÷ Number of Wheel Applications) x 10^{-6}.

[3]NT = not treated

[4]UT - untravelled

Beading/Wear Results

The mild winter resulted in the necessity for utilizing another measure for the effectiveness of the formulations and the overlays. This measure was the beading of water.[9] Beading is an evidence of the wetting characteristics of the substrate as the efficacy of the applied formulation changes over time. The Test Track operation did not include application of either salt or sand, therefore reduction in beading occurred as traffic wear progressed. Frequent observations were made on each section, with natural or artificial application of water to the surface. A wear ranking scale based on observations of beading was developed.

This scale is shown in Table 24. Ratings are stated in a Bead Wear Ranking Number (abbreviated BWR). The final results are summarized in Table 25.

Such ranking is entirely subjective. It does, however, provide an indication of the wear resistance of the hydrophobic substances.

For the portland cement concrete pavements, a ranking of traffic wear resistance can be made. In order of most to least wear resistance, the following ranking is obtained: K - Section 3, C - Section 8, J - Section 5, G - Section 6, F - Section 7, B - Section 9, and Petroset AT - Section 1, respectively. Wheel Paths #1-4 showed more wear than Wheel Paths #5-8. This is expected because there is three times the number of passes per revolution.

On the Class "B" asphalt concrete pavements, the traffic wear resistance in the order of most to least wear resistance is: C - Section 18, F - Section 17, G - Section 16, B - Section 19, L - Section 13, I - Section 15, and Petroset AT - Section 11, respectively. Here too, Wheel Paths #1-4 showed the most wear. The studded tire in Wheel Path #2 caused more wear than the truck garnet tires or the passenger garnet tire. The single tires in Wheel Paths #5-8 did not abrade the formulations as rapidly as the inside tires.

On the open-graded asphalt sections, the formulation L appears to be more resistant than when applied on the Class "B" asphalt - Section 13. Some beading was noticed on the rubberized and Petroset asphalt overlays, but almost none on the Viscospin sections. On the basis of BWR, very little can be concluded as this criteria is not applicable.

A comparison of SRCR with BWR for the different overlays and formulations has been tabulated in Tables 25-28.

Snow and Ice Removal Properties

These results are based on subjective evaluation of the effectiveness of the various formulaticns and overlays in accelerating the removal of snow and ice from the pavement surfaces. Observations after traffic simulation operations were made of the snowy-icy conditions of the various pavements after a snowfall or after the formation of ice. The apparatus was operated in each case until there were noticeable differences in snow/ice conditions. The amount of snow/ice removed by traffic was estimated for each section and wheel path. A ranking was developed for each group of pavements - the portland cement concrete, the Class "B" asphalt concrete, and the asphalt overlays. Originally it was planned to use salt and sand-ice combinations to compare their ice mitigation capabilties.

As mentioned previously, the lack of suitable weather minimized the number of observations. Although there were many observations, only six were complete with observations obtained on all sections. There was difficulty in trying to estimate the amount of snow and ice removal. Time was a factor; it was very important to evaluate conditions before the ambient temperature increased.

The rankings of the various tests are shown in Table 29 for the portland cement concrete sections, Table 30 for the Class "B" asphalt concrete sections, and Tables 31 and 32 for the various asphalt overlays.

From Table 29, the ranking of the sections in order of "best" snow/ice removal properties are 7, 6, 8, 9, 1, 10, 3, 2, 5 and 10. The best formulations on portland cement concrete were F, G, C, B, Petroset, K and J respectively.

On the Class "B" asphalt concrete pavements, the rankings as shown in Table 30 showed a slightly different ranking of the formulations than that obtained from portland cement concrete. The section ranking was 16, 17 and 19, 18, 13 and 15, 20, 14, 11 and 12, respectively. The best formulations for snow/ice removal properties were G, F and B about equal, C, L and I about equal, and Petroset least.

The rankings of the asphalt overlays are shown in Tables 31 and 32. The rankings were made between the same materials in Table 31, and between different materials in Table 32. Sections 27-30 were also compared. The overall ranking for all overlays shows that the best overlays with respect to snow/ice removal properties were Sections 25, 26, 27, 24, 22, 28, 21, 30, 23 and 29, respectively. Overall the rubberized asphalt sections performed the best with the Petroset asphalt sections next. The open-graded sections did not perform as well as expected but the formulation did some good. The Viscospin asphalt sections did not perform very well.

One observation noted was that the ice on the sections where formulations were applied appeared to be softer and had less adhesion than the ice on the untreated portions. Another observation was as the ice melted, the untreated sections dried out more quickly than the treated sections. This was an indication of the beading properties of the materials. On the open-graded asphalt concrete sections, fine snow had a tendency to filter into the pores of the mix and took longer to melt. In Section 23, some pumping of the Palouse silt was noted. Since the pavement was not cracked, the pumping of the silt was coming through the concrete base from the silt subgrade. This indicates that this type of overlay should not be used over cracked bases or used to prevent reflective cracking by itself.

The rubberized asphalt concrete sections were quite successful in accelerating the removal of snow and ice. The flexibility apparently caused fatigue cracking in the ice and thus weakened the ice bonds. This is shown in

Figure 35. One problem with the rubberized asphalt concrete is that excessive rubber will permit raveling which occurred in Section 25. Even though it was superior to the other two rubberized pavements with respect to snow/ice removal properties, its surface rapidly showed raveling which would disqualify it for use on roads. This is shown in Figure 28.

Neither of the four asphalt overlays with Petroset AT and Viscospin evidenced superiority. But one thing is evident, more is not necessarily better because the pavements with less additive frequently performed better than the ones with more additive.

Tires do affect snow and ice removal. Table 33 shows the tire ranking according to the most rapid snow/ice removal properties. The tires in Wheel Paths #1-4 should be compared separately as these wheel paths had three times the traffic of Wheel Paths #5-8. In the Wheel Paths #1-4, the ranking using the wheel path numbering system, is as follows: #3, #1, #4 and #2, respectively. The most effective tire was the inside driving truck garnet tread truck tire and the least effective being the studded passenger tire in Wheel Path #2. In Wheel Paths #5-8, the ranking was as follows: #5 and #6 being about the same, then #7, and finally #8. The two types of passenger tires were the most effective while the winter tire with F-32 rubber was the least effective. It should be emphasized that the differences between tires were not large. Further consideration should be given to the fact that the tires (and wheels) were restrained in the transverse motion. The wander or "sweeping" action of tires could affect this rating. It is reported for information only and was not included in the ranking of the formulations.

Figures 15-36 show the appearance of various sections during various time periods. These series of figures show the subtle differences between the various sections, treated and untreated, and between the wheel paths. It can be seen that there are differences.

Overall Comparison of Test Sections

Using the three criteria developed for ranking the different sections, an overall ranking was calculated which is shown in Table 34. The three criteria were Skid Resistance Change Rate (SRCR), Beading Wear criteria (BWR), and Snow/Ice Removal criteria. Each was weighed equally and on that basis an overall ranking was calculated for each pavement type.

On this basis, for portland cement concrete and in order of the most effective formulation, the ranking was as follows: formulation F, G and C about equal, B and K about equal, J, and Petroset last. It can be seen that the non-treated sections ranked low.

On the Class "B" asphalt concrete section, the formulations in order of most effectiveness were ranked as follows: G, F, B, C, L, I and Petroset last. The non-treated sections were ranked lowest.

Of the asphalt overlays, the rubberized asphalt sections and the Petroset sections on overall ranking were superior to the other two types. It can be seen that the untreated open-graded asphalt sections did not rank that well.

The two Viscospin sections were not as effective and were accordingly ranked low.

It can be concluded that the formulations on portland cement and asphalt concrete do have effect on winter pavement conditions and therefore are useful.

Comparison of Test Results with Laboratory Tests

The rankings obtained from the WSU Test Track were compared with laboratory rankings based on ice-adhesion force. These are shown in Table 35. It can be seen that the formulations F and G performed as predicted by laboratory tests while formulation B exceeded the laboratory performances indicated. Formulation C results were as predicted on the asphalt concrete with increased performance on the portland cement concrete. In summary, the test results indicate good conformance with the laboratory results.

Environmental Test Results

Laboratory test results by BBRC indicated that the main concern insofar as environment and toxicity of the substances is the naptha component. This is considered to be a solvable problem. (Discussion is included in Appendix A).

Toxicity tests at the test track were of two types: water leachate from dried material and leachate from newly applied material. With the exception of Petroset, materials are not considered to be significantly toxic in either mode. (Discussion is included in Appendix B).

TABLE 29. RANKING OF PORTLAND CEMENT CONCRETE SECTIONS ACCORDING TO SNOW/ICE REMOVAL PROPERTIES

SECTION	FORMULATION	RANKING ACCORDING TO SNOW/ICE REMOVAL PROPERTIES						
		RANKING FROM TESTS						OVERALL
		#1	#2	#3	#4	#5	#6	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	PETROSET	2	4	7	8	4	1	5
2	NT[1]	4	6	10	6	8	4	8
3	K	8	5	4	7	4	3	7
4	NT	7	5	9	9	7	5	10
5	J	9	5	6	10	4	5	9
6	G	1	2	2	2	2	2	2
7	F	3	1	1	1	1	1	1
8	C	6	3	3	4	3	1	3
9	B	5	5	5	3	5	1	4
10	NT	2	6	8	5	6	4	6

[1]NT = not treated

TABLE 30. RANKING OF CLASS "B" ASPHALT CONCRETE SECTIONS ACCORDING TO SNOW/ICE REMOVAL PROPERTIES

SECTION	FORMULATION	RANKING ACCORDING TO SNOW/ICE REMOVAL PROPERTIES						
		RANKING FROM TESTS						OVERALL
		#1	#2	#3	#4	#5	#6	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11	PETROSET	6	4	2	9	5	2	7
12	NT[1]	3	5	3	8	9	5	8
13	L	3	5	2	7	6	1	4
14	NT	6	6	3	4	7	1	6
15	I	7	6	1	3	6	1	4
16	G	5	2	1	1	1	1	1
17	F	1	5	1	2	3	1	2
18	C	3	1	1	5	8	4	3
19	B	4	3	1	6	2	1	2
20	NT	2	5	1	10	4	3	5

[1]NT = not treated

TABLE 31. RANKING OF ASPHALT OVERLAY SECTIONS ACCORDING TO SNOW/ICE REMOVAL PROPERTIES AND SIMILAR GROUP

PAVEMENT TYPE	SECTION	FORMULATION OR AMOUNTS ADDED	RANKING ACCORDING TO SNOW/ICE REMOVAL PROPERTIES							
			RANKING FROM TESTS							RANKING BETWEEN GROUPS
			#1	#2	#3	#4	#5	#6	SIMILAR GROUP	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
OPEN-GRADED AC	21	NT[1]	1	-	2	2	3	3	2	
	22	L	2	-	1	1	1	1	1	
	23	NT	3	-	2	3	2	2	3	
RUBBERIZED AC	24	5%	2	2	2	3	3	2	3	
	25	10%	1	2	1	1	1	1	1	
	26	5%	3	1	3	2	2	1	2	
PETROSET AC	27	8.33%	1	1	1	1	1	1	1	1
	28	25%	2	2	1	2	2	2	2	2
VISCOSPIN AC	29	4%	1	2	1	2	2	1	2	3
	30	8%	2	1	1	1	1	2	1	4

[1]NT - not treated

TABLE 32. OVERALL GROUP RANKING OF THE ASPHALT OVERLAYS ACCORDING TO SNOW/ICE REMOVAL PROPERTIES

ASPHALT OVERLAY	SECTION	FORMULATION	RANKING FROM TESTS						
			#1	#2	#3	#4	#5	#6	FINAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
OPEN-GRADED AC	21	NT[1]	2	-	3	8	8	5	7
	22	L	3	-	2	5	6	4	5
	23	NT	5	-	3	9	7	4	9
RUBBERIZED AC	24	5%	4	2	2	7	3	2	4
	25	10%	1	2	1	1	1	1	1
	26	5%	4	1	4	2	2	1	2
PETROSET AC	27	8.33%	1	3	4	3	4	1	3
	28	25%	6	4	4	6	5	4	6
VISCOSPIN AC	29	4%	7	6	4	10	10	4	10
	30	8%	8	5	4	4	9	3	8

[1]NT = not treated

TABLE 33. TIRE RANKING ACCORDING TO MOST RAPID SNOW/ICE REMOVAL

TESTS	RANKING IN WHEEL PATHS							
	#1	#2	#3	#4	#5	#6	#7	#8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
#1	2	3	1	1	5	4	6	7
#2	2	1	3	4	6	5	7	8
#3	1	4	2	3	8	7	6	5
#4	3	4	1	2	7	8	5	6
#5	1	1	1	1	2	3	4	5
#6	1	1	1	1	2	3	4	5
FROM ALL TESTS	2	4	1	3	5	5	6	7

Note: Ranking of 1 indicates most rapid snow/ice removal from tire action. Test did not include wandering effect.

TABLE 35. COMPARISON OF TEST RANKINGS WITH LABORATORY RESULTS RANKING

FORMULATION	RANKING[1] BASED ON ICE-ADHESION FORCE	OVERALL RANKING	
		PCC	CLASS "B" AC
(1)	(2)	(3)	(4)
B	8	3	3
C	4	2	4
F	2	1	2
G	1	2	1
I	5	NA[2]	6
J	7	4	NA
K	6	3	NA
L	3	NA	5

[1]See Table **4, Appendix A**

[2]Not applicable

TABLE 34. OVERALL RANKINGS BASED ON THREE CRITERIA WITH RESPECT TO PAVEMENT TYPE

PAVEMENT TYPE (1)	SECTION (2)	FORMULATION (3)	RANKING ACCORDING TO: SKID RESISTANCE CHANGE RATE (4)	BEADING WEAR CRITERIA (5)	SNOW/ICE REMOVAL CRITERIA (6)	OVERALL[3] RANKING (7)
PCC	1	PETROSET	9	7	5	5
	2	NT[1]	10	NA[2]	8	7
	3	K	4	1	7	3
	4	NT	7	NA	10	6
	5	J	3	3	9	4
	6	G	5	4	2	2
	7	F	1	5	1	1
	8	C	6	2	3	2
	9	B	2	6	4	3
	10	NT	8	NA	6	5
CLASS "B" ASPHALT CONCRETE	11	PETROSET	9	7	7	8
	12	NT	8	NA	8	9
	13	L	4	5	4	5
	14	NT	10	NA	6	9
	15	I	5	6	4	6
	16	G	1	3	1	1
	17	F	3	2	2	2
	18	C	6	1	3	4
	19	B	2	4	2	3
	20	NT	7	NA	5	7
OPEN-GRADED ASPHALT CONCRETE	21	NT	7	NA	7	6
	22	L	2	2	5	3
	23	NT	10	NA	9	8
RUBBERIZED ASPHALT CONCRETE	24	5%	5	3	4	5
	25	10%	3	2	1	1
	26	5%	6	1	2	3
PETROSET ASPHALT CONCRETE	27	8.33%	4	1	3	2
	28	25%	1	4	6	4
VISCOSPIN ASPHALT CONCRETE	29	4%	9	NA	10	8
	30	8%	8	NA	8	7

[1]NT = not treated

[2]NA = not applicable

[3]1 = most effective

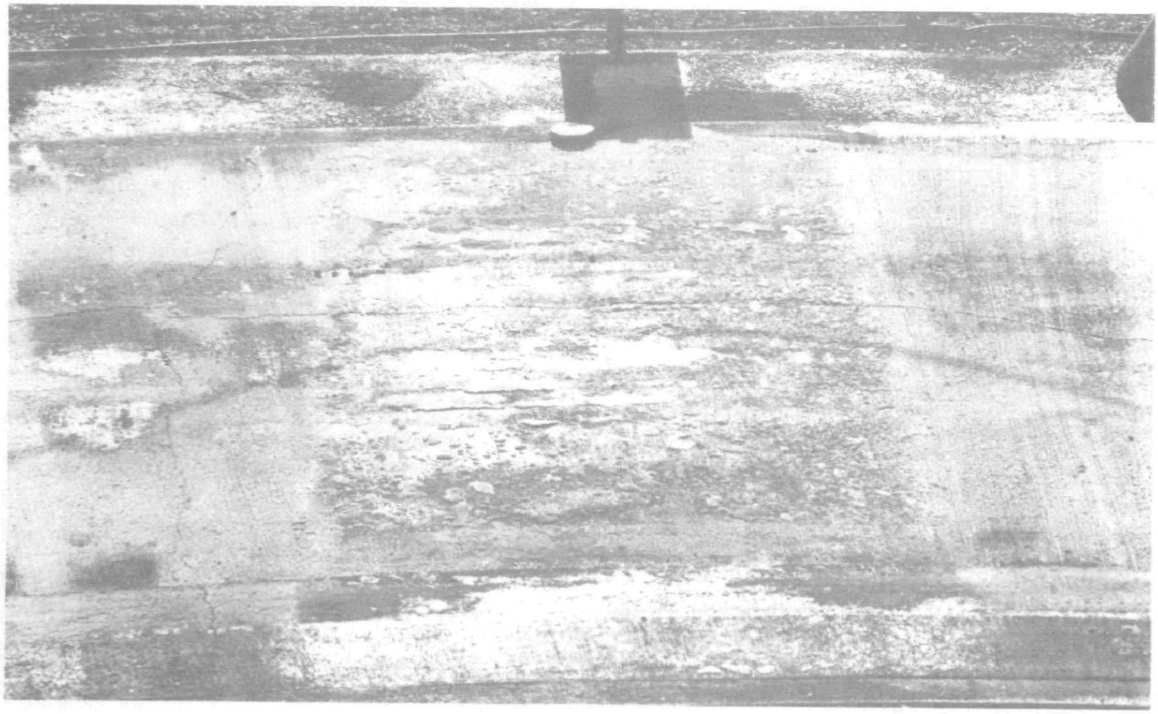


Figure 15. Section 7, 01/20/77. Note the ice formations. plastic plug used in run-off sampling and tests.

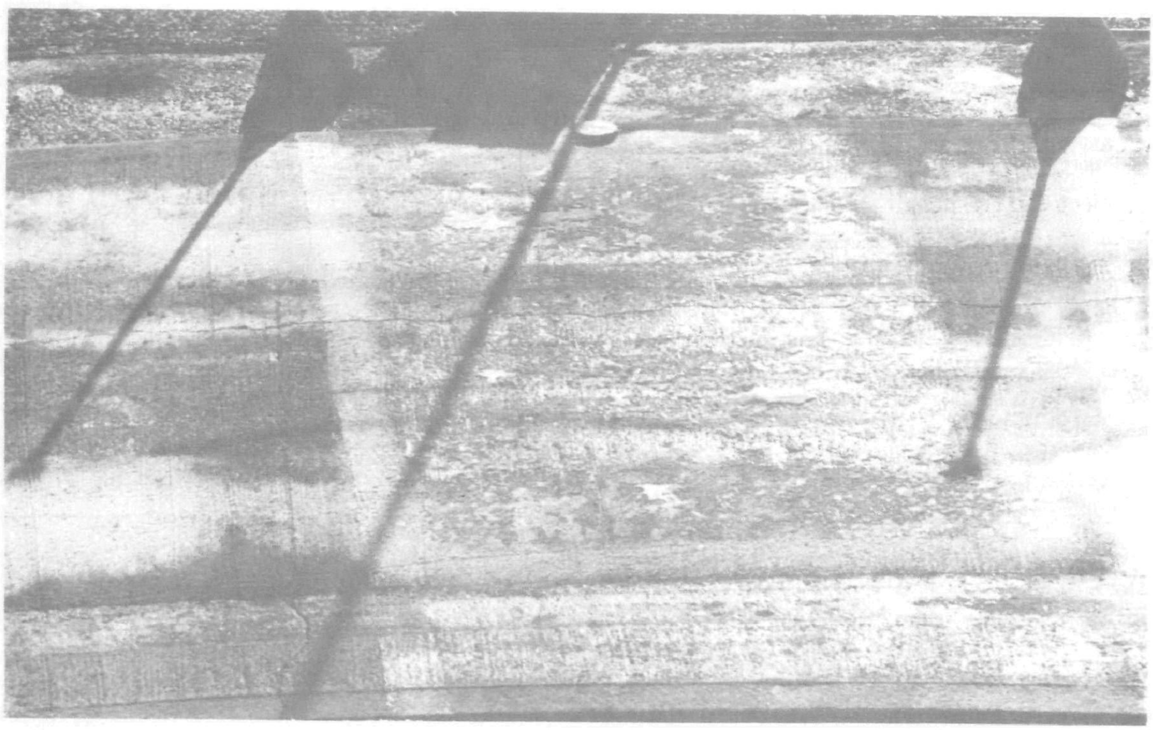


Figure 16. Section 6, 01/20/77. Note the ice formations.

Figure 17. Section 19, 01/20/77. Very little ice is visible. Note color of the treated area.

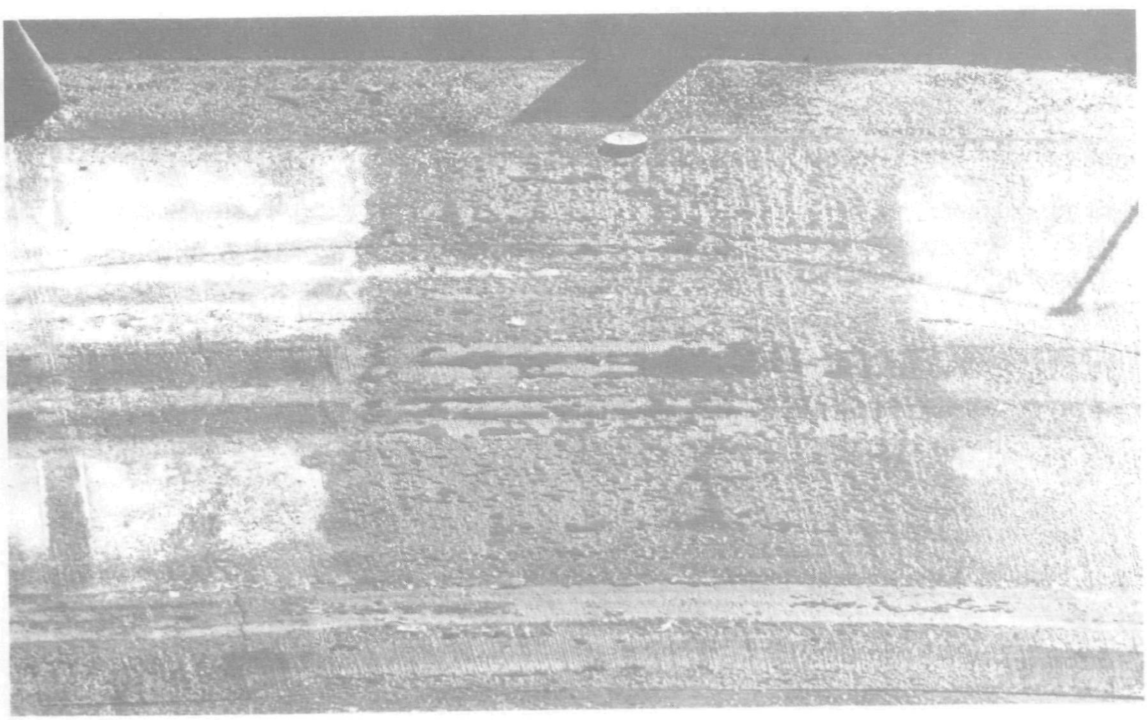


Figure 18. Section 7, 01/26/77. Note formation of ice beads and removal in wheel paths.

Figure 19. Section 13, 01/26/77. Note ice beading on the treated area.

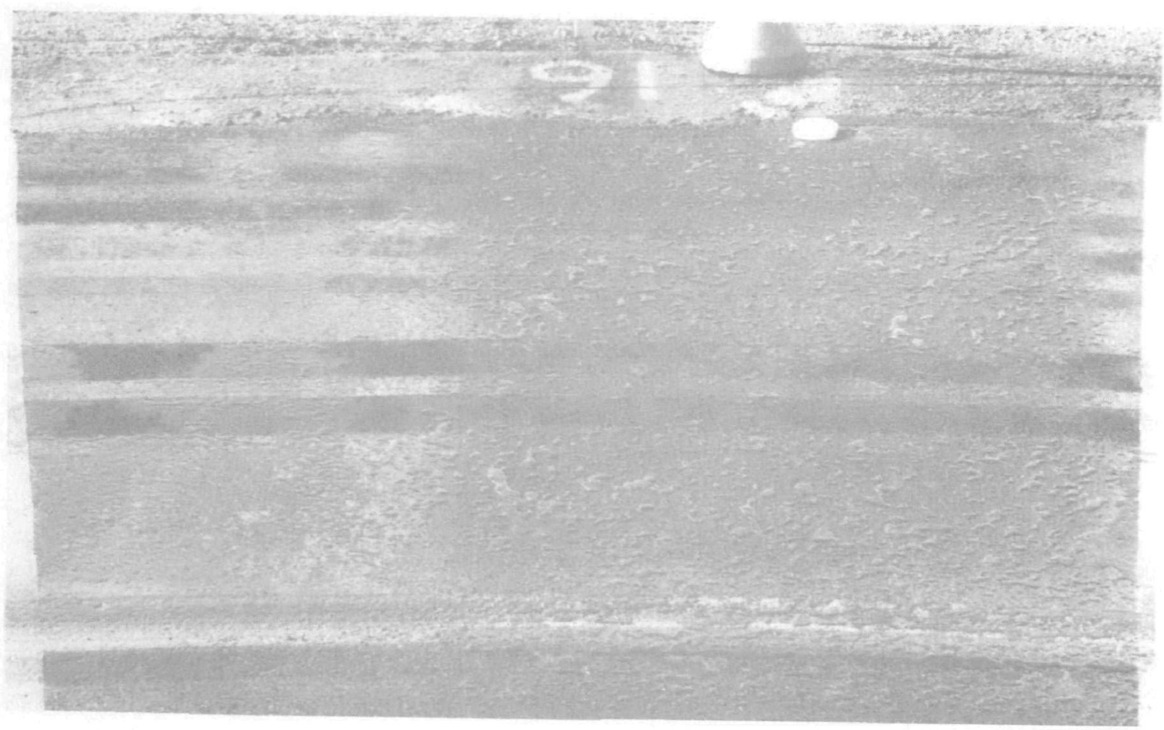


Figure 20. Section 16, 01/26/77. Note ice beading.

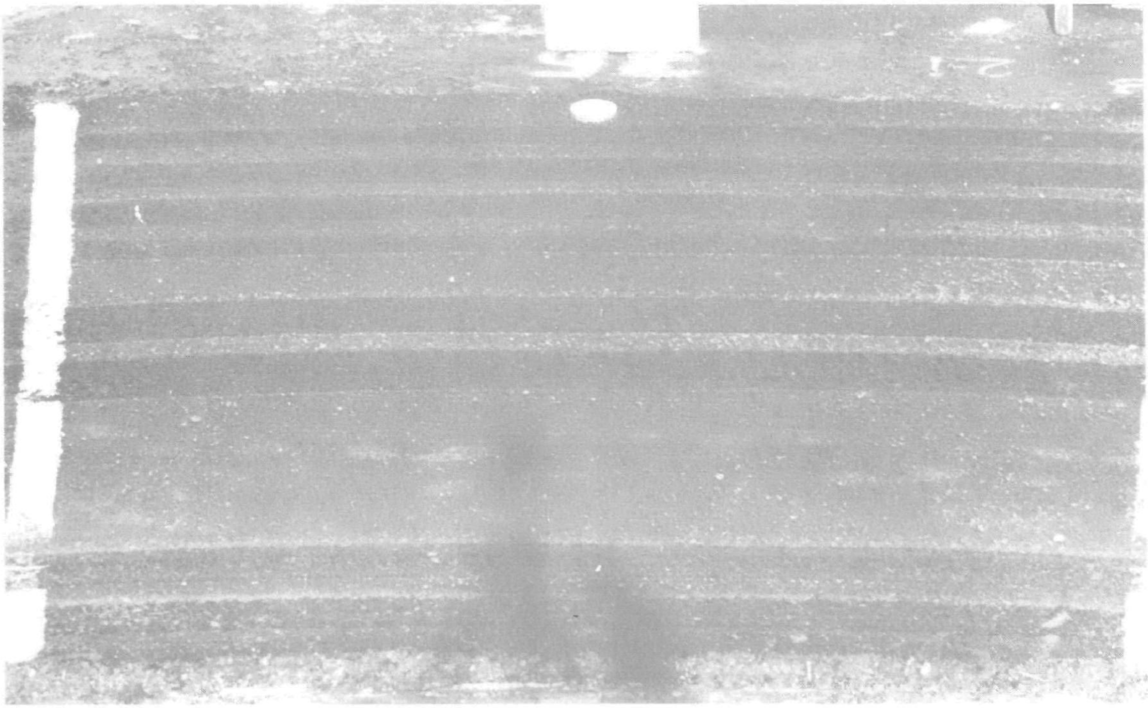


Figure 21. Section 25, 01/26/77. Note slush outside the wheel paths.

Figure 22. Section 6, 01/31/77. Note difference between the treated and untreated areas.

Figure 23. 01/31/77. An overall view of Sections 7, 6, and 5. Note difference between treated and untreated areas and wheel paths.

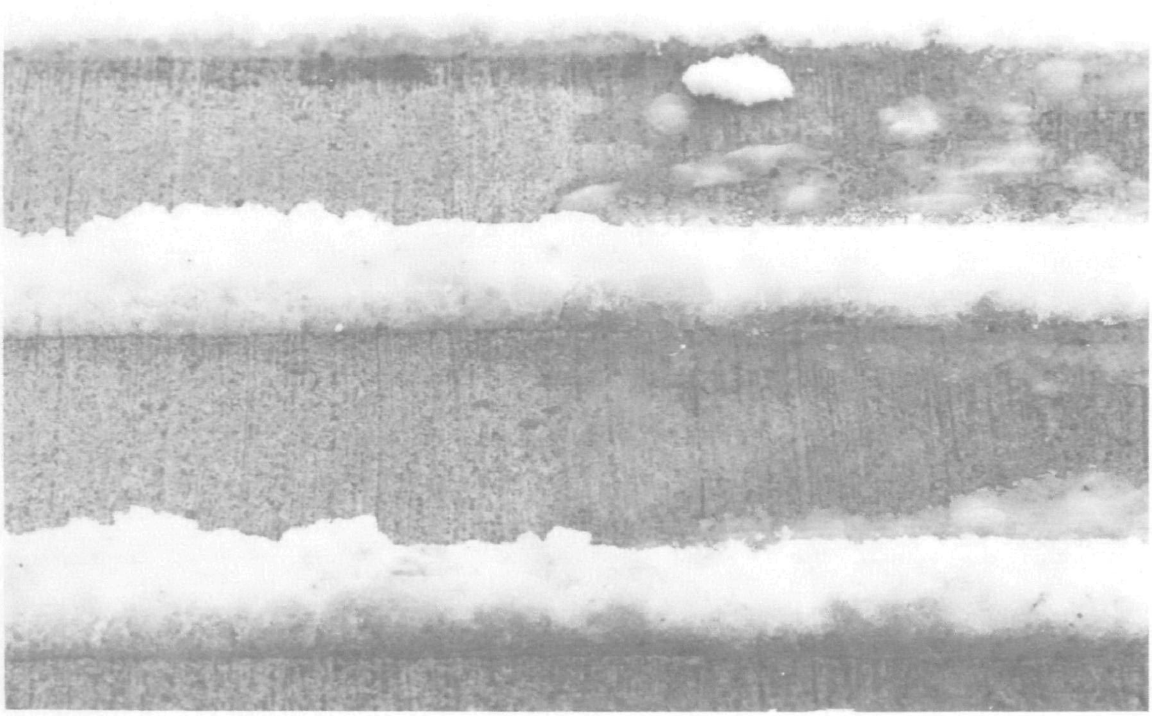


Figure 24. Section 7, 01/31/77. Note difference between the treated and untreated areas in the wheel paths.

Figure 25. 01/31/77. An overall view of Sections 24, 25, 26 and 27. Note the difference between sections in the wheel paths.

Figure 26. 02/01/77. An overall view of Sections 17, 18, 19 and 20. Note the subtle difference in ice formation and wear patterns.

Figure 27. 02/01/77. A view of Sections 6-4 showing wheel paths 3-8 only. Note slush and ice removal by traffic in treated areas.

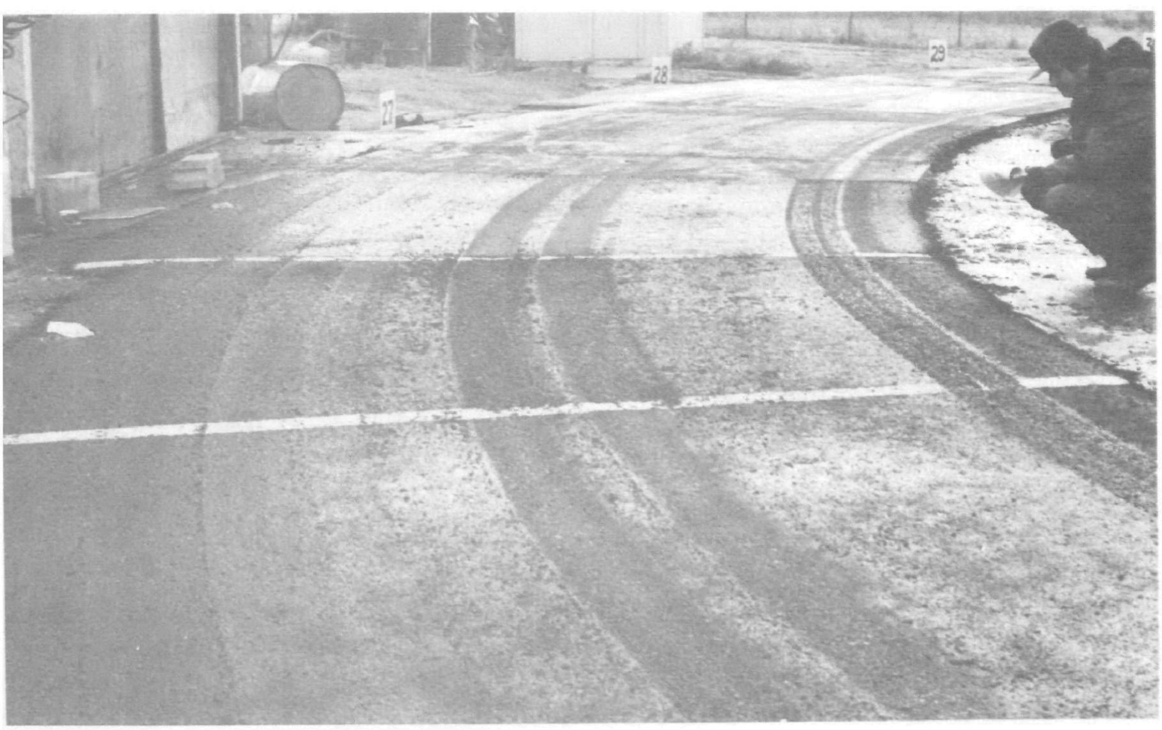


Figure 28. 02/08/77. Sections 24, 25 and 26. Note the raveling of the pavement in Section 25.

Figure 29. 02/08/77. A comparison of ice bead formations between Sections 17 to 14.

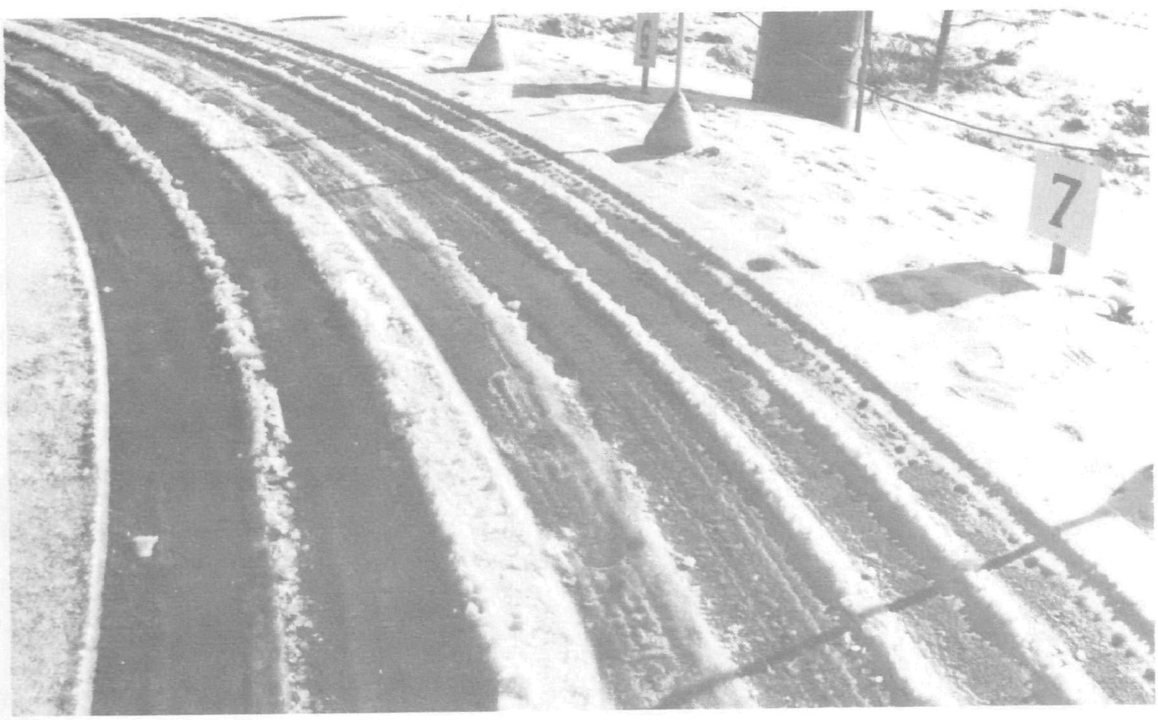


Figure 30. 02/26/77. Overall view of Sections 8 to 5. Note the lack of ice and snow in the wheel paths of the treated areas.

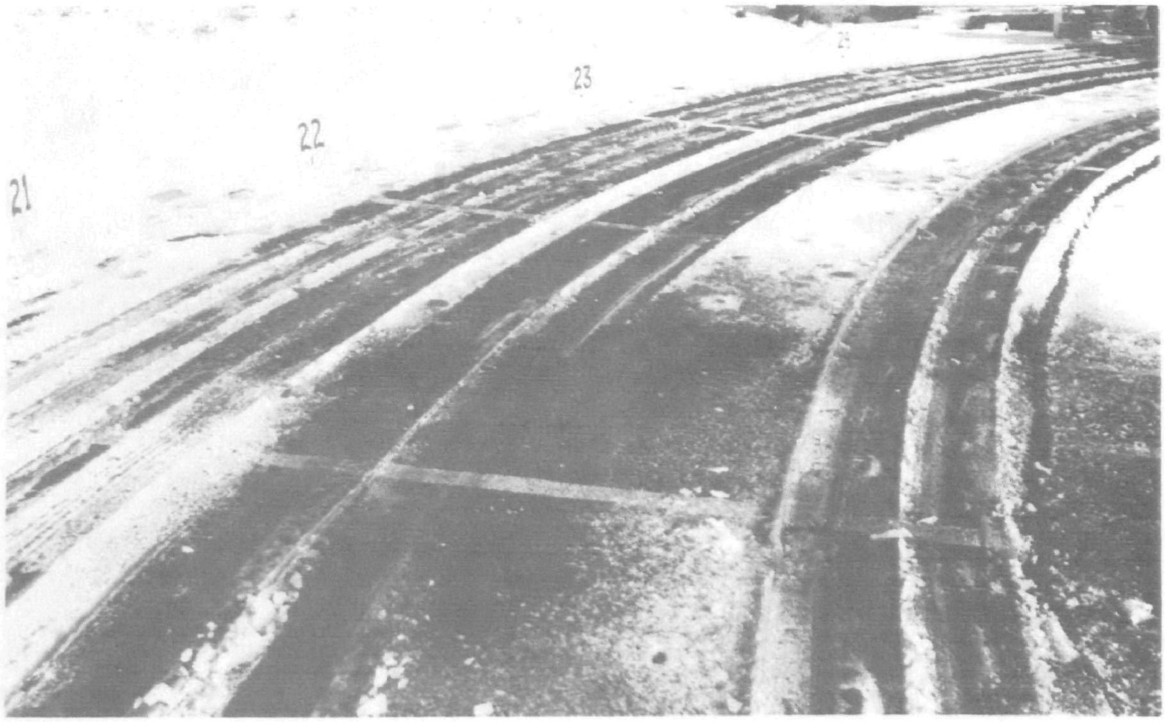


Figure 31. 02/26/77. Overall appearance of the three open-graded asphalt Sections 21-23.

Figure 32. 02/26/77. Appearance of the three rubberized Sections 24-26. Note ice clearance in wheel paths.

Figure 33. 02/26/77. Sections 11 to 15 after a snowfall and testing.

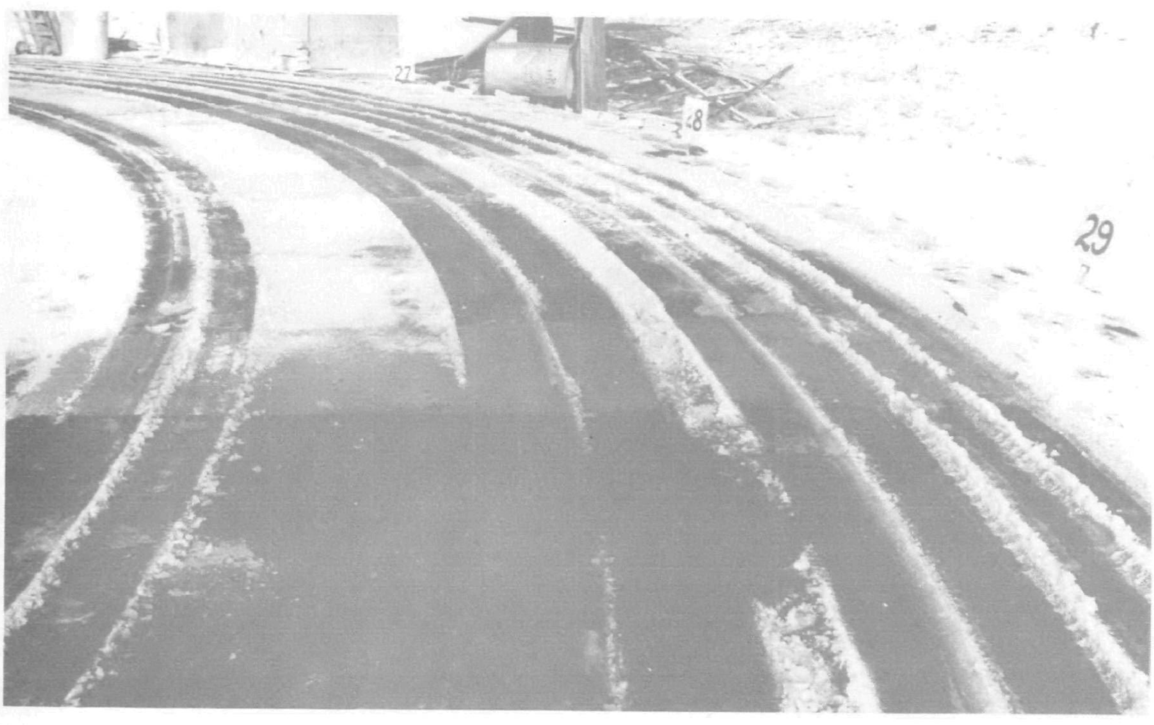


Figure 34. 02/26/77. Sections 30 to 27.

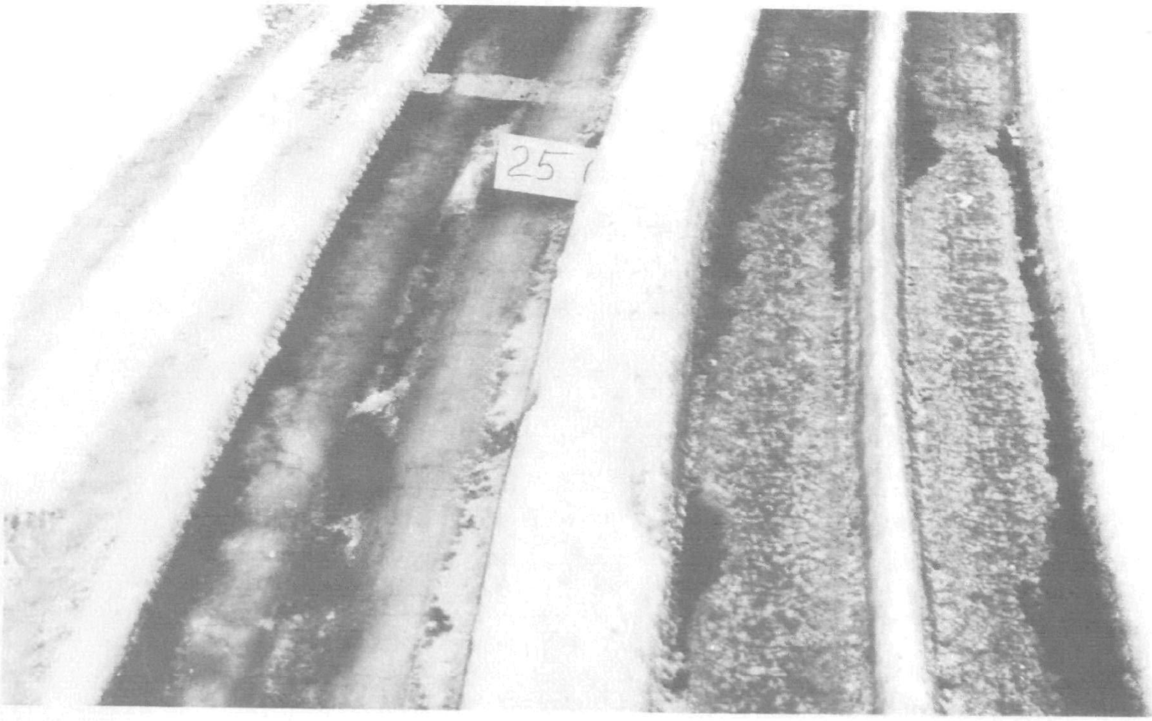


Figure 35. Section 25, 03/13/77. Note the "fatigue cracking" of ice in the wheel paths.

Figure 36. 03/13/77. Appearance of Sections 2, 3, 4, 5, and 6. Note the clear areas in the treated Sections 3, 5 and 6.

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APPENDIX A

OPTIMIZATION AND TESTING OF HIGHWAY MATERIALS TO MITIGATE ICE ADHESION

Ball Brothers Research Corporation Data Summary
in Support of WSU Project 115-3815-1483
on Contract 5884

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INTRODUCTION

The subject investigation is a continuation of the work reported in EPA publication 600/2-76-242, "Development of a Hydrophobic Substance to Mitigate Pavement Ice Adhesion:; G. H. Ahlborn and H. C. Poehlmann, Jr.; EPA Storm and Combined Sewer Section, Wastewater Research Division, Municipal Environmental Research Laboratory (Cincinnati); Edison, N.J. 08817. This report will be frequently referenced in the attached material (as EPA 600) with some data abstracted for clarity in this presentation.

In order of presentation, data and descriptive material are given on the following topics:

1. A summary of the exact formulation of the mixtures as applied including the composition of paint-derived formulas.

2. Mixing procedures and cautionary notes used in preparing the formulations.

3. A discussion of the application procedures and techniques employed and their limitations. Presented are application rate data, material costs, mixing and application costs, desirable application conditions (temperatures, surface precleaning, etc.) and hazards existing during application (such as flammability and toxicity considerations).

4. Laboratory data generated at BBRC including fluid contact angles, coating hardness estimate, coating environmental contamination ratings and coating ice release stresses.

5. Field (real-life substrates) ice-release-coating data based on BBRC and a few WSU test track pavement core samples.

6. Skid (slipperiness) data of the coatings on asphaltic and concrete surfaces. The data are presented as:
   a. BBRC site data, used as screening (ranking) factors and to illustrate aging effects
   b. WSU test track data, used to check
      initial (unworn) coating skid values
      radial and circumferential uniformity of the track surfaces,
      comparative natures of BBRC sites and WSU track pavements
      and to evaluate coating presence/absence after track operation (i.e., coating durability)

7. Suggestions for improvement of the coating mixtures as here formulated.

FORMULATIONS

As stated in the basic contract, we were to optimize the more successful coatings resulting from prior work (EPA 600). We remain of the opinion that optimization of paint-derived (specifically, from Fed. Spec. TT-P-115D TypeII) binders shows great promise. However, scheduling restrictions in the current work did not permit a rigorous optimization study. The Akron Paint formulation LR 8652 was merely a "guess" at an improved version of the prior study's paint binder (same as the LR 8198 used in the present work).

Table 4 (in main report) presents the exact formulation of the mixtures investigated and the application rates employed. Some materials were experimental and were used only to gain further technical data for possible subsequent investigations. The absolute quantities cited for formulations A through M plus formulation P were those used in coating the 1.7m^2 (6' x 3') asphalt and concrete field screening test sections at BBRC.

Table 2 lists the composition of the paint-derived binder formulations employed. Table 3 gives material characteristics necessary to compute application rates (see Table 4) and total applied material costs (see Table 5).

Application Rates and Costs: Sample Calculations for Coatings

The application rates were computed as described in our earlier report (EPA 600, pp. 86-88), with slight modification. As an example, compute the application rate for Formulation G (Table 4, main report).

LR 8652	=	415 cm^3
VMP Naphtha	=	312 cm^3
Isopropanol	=	15.5 cm^3
DC 732	=	51.8 gm

We assume that, in mixing, the isopropanol and DC 732 do not significantly increase the volume of the mixture and that the paint and naphtha volumes are additive. From Table 3 data, we assumed the dried film density of all formulations was ρ = 1.1 except for Petroset AT where ρ = 0.8. The film thickness was assumed to be 0.01 cm except for the Petroset AT where, this time, a film of 0.02 cm thickness was employed.

From EPA 600, for a 0.01 cm film:

$$A = 0.1\rho/P$$

where A = required application rate, l/m^2
ρ = film density, gm/cm^3
P = mixture NVR, kg/l

TABLE 4. FORMULATIONS AND COVERAGE RATES

FORMULATION CODE (1)	PRINCIPAL INGREDIENT NAME (2)	PRINCIPAL INGREDIENT AMOUNT cm^3 (3)	OTHER INGREDIENTS & AMOUNTS: DC732 gms (4)	VMP NAPTHA cm^3 (5)	ISOPROPANOL cm^3 (6)	OTHER: NAME (7)	OTHER: AMOUNT - cm^3 (8)	OTHER INFORMATION (9)	APPLICATION RATE $\frac{l}{m^2}$ OR AS NOTED (10)
A	LR 8196[1]	225	22.5	169	6.0				0.235
B		205	35.8	182	7.7				0.232
C		170	59.0	216	14.8				0.234
D		160	72.0	244	18.0				0.237
E	LR 8652[2]	515	19.3	257	6.4				0.461
F		480	30.0	276	9.0				0.453
G		415	51.8	312	15.5				0.433
H		365	68.4	319	18.2				0.406
I	DRISIL 73	305	18.3	198	6.0				0.302
J		275	35.7	219	8.2				0.295
K		250	50.0	237	12.5				0.290
L		230	59.8	253	13.8				0.289
M	PETROSET AT	415	--	--	--	DISTILLED H_2O	138		0.328
N	GOODYEAR 533C	100	--	50	--			(LR 8652 + 1% CLAY)	POURED ON META SUBSTRATE
O	GOODYEAR 533B	150	--	50	--			(LR 8652)	0.510
P	DOW XR-5013	100	--	--	--	DISTILLED H_2O	100	SILICONE	0.520
Q	GOODYEAR VTL	20	--	95	--	XYLENE	5	(PAINT BASE)	SPRAYED ON
R	VISCOSPIN B	50	--	50	--				SPRAYED ON
W	VISCOSPIN B	8%						% OF BINDER IN AC	OVERLAY
X	VISCOSPIN B	4%						% OF BINDER IN AC	
Y	PETROSET AT	25%						% OF BINDER IN AC	
Z	PETROSET AT	8.33%						% OF BINDER IN AC	

Source: Ball Brothers Research Corporation, 1976.

[1]LR 8196 is Akron Paint Mod. TT-P-115 D (without TiO_2).

[2]LR 8652 is Akron's Resin-Only Version.

Note: Table 1. Same as Table 4 in body of report. Repeated here for convenience.

TABLE 2

PAINT BINDER COMPOSITION SUMMARY

Component	Akron LR 8198	Goodyear BX12J533A	Akron LR 8652	Goodyear BX12J533B	Goodyear BX12J533C
	Quantity in lbs./100 Gallons				
Duramite	220	220			
International X	55	55			
Celite 110	88	88			
Mineralite 3X	60	60			
Bentone 38	5	5			10
Soya Lecithin	8	8			16
Methanol/Water 25/5	2	2			4
Pliolite VTL®	112	112	144	141	211
Polyvel G-110	37	37	48	46	69
Chlorowax 40	37	37	48	46	69
Shell Tolusol 19EC	351	355	460	449	349

®Goodyear trademark for vinyl-toluene/butadiene resins

TABLE 3

DATA REQUIRED FOR APPLICATION RATE AND COST[a] COMPUTATIONS

Material	C Cost ¢/l	P Non-Volatile Content-kg/l	ρ Estimated Film Density-gm/cm³
LR 8198	209	0.72	1.1
LR 8652	209	0.32	1.1
DRI-SIL 73	316	0.54	1.1
DC 732	694	0.98	1.0
VMP naphtha	65	0.00	---
Isopropanol	211	0.00	---
BX12J533B	Experimental	0.29	1.1
BX12J533C	Experimental	0.48	1.1
XR-5013	Experimental(350?)	0.42	1.0
Pliolite VTL	---(b)	Solid = 1.03	1.0
Viscospin B	154	1.00	---(c)
Petroset AT	92	0.65(0.60 vendor)[d]	0.8

Notes:

(a) Prices are 1976 values for relatively small quantities (55 gallon lots or less). Price of LR 8652, especially, would drop for larger quantities.

(b) Pliolite was used for lab testing only and was not priced.

(c) Viscospin B does not dry to a solid film so film density is not meaningful.

(d) The non-volatile phase of Petroset AT consists of 18 pbw rubber to 42 pbw oil (vendor data).

For formulation G, and using Table 3:

$$\rho = 1.1$$

$$P = \frac{0.0518 + 0.415\ (0.32)}{0.413 + 0.312} = 0.254\ kg/l$$

$$A_G = 0.1\ (1.1)/0.254 = 0.433\ l/m^2$$

For cost, we use the formula:

$$Cost/area = A_f/V_T\ \Sigma\ C_i V_i$$

where A_f = application rate, l/m^2
V_T = total volume of formulation, l
C_i = cost of component i, ¢/l
V_i = volume of component i in V_T, l

For the same example:

A_f = 0.433 l/m^2
V_T = 0.415 + 0.312 = 0.727 l

$$Cost/area = \frac{0.433}{0.727}(209 \times 0.415 + 65 \times 0.312 + 211 \times 0.0155 + 694 \times 0.0518)$$

$$= 87¢/m^2$$

In this case, the paint amounts to 60% of the cost. As mentioned, the cost of this "paint" would drop greatly (up to 50% or more) in quantity lots.

Application Rates and Costs: Sample Calculations for Overlays

The last four "formulations" in Table 4 (main report) involve incorporation of the component in the asphaltic overlay prior to application. The computations are quite different.

The rates for Viscospin B and Petroset AT were suggested by the vendors since no theoretical bases for selection existed. Per verbal information from WSU:

Overlay density = 2323 kg/m^3 (145 lbs./ft.^{3})
Overlay thickness = 0.038 lm (1.5 inch)
Weight fraction binder ≈ 0.06

Binder = 2323 (0.0381) (0.06) = 5.31 kg/m^2

Knowing the densities of the as-received materials, namely:

Viscospin B = 0.98 kg/l
Petroset AT = 0.94 kg/l

we can easily compute the material cost. These are:

Overlay W (8% Viscospin B) = 5.31 (0.08) (0.98)$^{-1}$ (154)
= 67¢/m^2

$$\text{Overlay Y (25\% Petroset AT)} = 5.31\ (0.25)\ (0.94)^{-1}\ (92) = 130¢/m^2$$

Conclusion

Detailed formulation descriptions have been presented above. In addition, the application rate computations and material cost estimates are illustrated. It can be seen in Table 4 (main report) that DC 732 concentrations above and below those employed in the EPA 600 preliminary investigation were examined in the current program. Although this does not represent a definitive optimization study, the various concentrations investigated seem to bracket the range within which the optimum concentration of DC 732 would fall.

MIXING AND STORAGE PROCEDURES

Some notes on mixing procedures and cautions applicable to the Table 4 (main report) formulations are presented below.

For the surface coating mixtures, little difficulty has been found in preparation - whether in liter or multiple gallon quantities. As with any paint, the LR components should be thoroughly agitated prior to use. This is also especially true of the Petroset AT (an emulsion). Mixing containers must be clean and dry.

During preparation of the coating mixes, the naphtha, isopropanol and DC 732 are blended together and then combined with the binder (which has been blended with about 1/2 the total quantity of naphtha). The complete mix is then thoroughly stirred and stored in a covered container (at temperatures above 4°C) until it is used. Since VMP naphtha is involved, adequate ventilation must be provided and spark sources must be eliminated.

During preparation of the Petroset AT coating mix, the water used for dilution should be slightly acidic (pH = 5 to 7).

APPLICATION PROCEDURES, TECHNIQUES, LIMITATIONS, QUANTITIES AND COSTS

In this section are summarized the application procedures and techniques as actually used, comments on their limitations, the actual quantities employed in this investigation and the costs involved (material, preparation and application).

Application Procedures

In applying any mixture, agitation just prior to spraying is advisable. As discussed in EPA 600, airless spraying (whether electric or compressor powered) is the preferred method. Any other technique (air suction spraying, painting, etc.) results in excessive evaporation or loss of solvent with consequent poor penetration of either substrate and poor adhesion to asphalt. In this work, Burgess Model

VS-860 electric, airless, spray units were used for all operations including test discs and plates, BBRC field tests and test track coating applications.

For the test track, use of these rather small volumetric capacity units resulted in longer application times, (meaning high costs) and more difficulties with wind-distorted spray patterns than would occur with higher-rate sprays. For the overlays, the required quantities were incorporated during binder/filler dispersion.

Limitations

In this investigation and our EPA 600 work, the following conditions have been found to be optimum during application:

Substrate Temperature: 5C to 15C

Lower temperatures result in poor penetration and slow cure rates while higher temperatures result in poor adhesion (from solvent evaporation) and increased flammability hazards.

Flammability

The VMP naphtha does, of course, create a potential flammability problem.

Toxicity

The toxicity of the materials themselves is rather low. However, as mentioned before, the VMP naphtha remains a minor toxicity (and environmental) problem. The basic consideration on the part of BBRC is that high-solid-content or water-borne equivalents of these formulations are currently available (or are in final development). Thus, these problem areas can be largely eliminated in the near future.

Substrate Condition

In none of the field tests performed 2 years ago was any surface preparation performed (cleaning, drying, etc.). In the current work, the BBRC field tests were performed with no precleaning. At WSU, the test track was swept but was rather damp during some application sequences.

Wind

Above about 15 kpm, poor application has occurred. However, with higher velocity spraying, this limitation can be reduced.

Application Rates

The application rates cited in Table 4 (main report) were used, for the most part, in applying the coatings to the BBRC asphalt and concrete sections ($1.7m^2$) and to the test track sections at WSU ($4.5m^2$) treated. The track asphalt was so rough that the application rate was increased 10% on these sections. The quantities applied are summarized in Table 4.

In using this Table, the specific application locations are cited. This is necessary in order to relate outside vendor test reports (on adhesion of ice to core samples) and our own skid data to formulation codes.

In Figure 1, photographs illustrate:

a. A portion of the BBRC asphalt test area with the coatings applied.
b. A view of the BBRC sidewalk used as our concrete substrate.

Figure 2 illustrates the comparative roughnesses of different asphalt surfaces. The left hand core is typical of the surface of the WSU asphalt, while the right hand core with formulation J (from section N) is typical of BBRC asphaltic surfaces. The differences in surface roughness are evident.

Costs

Material costs are coded to the formulations and rates listed in Table 4 (main report). Sample computations have been given above based on data presented in Table 3. We again emphasize that these costs are, as of 1976, on the high side since actual program purchase costs for small quantities were used in the calculations. The amount by which these material costs could be reduced by volume purchasing is somewhere between 20 and 40 percent.

The mixing and application costs are estimated in two ways:

1. Small quantities as prepared for, and applied to, the test track.
2. Medium quantities such as might be used for treatment of a bridge deck or all approaches of a hazardous intersection.

For the overlays, a flat 5¢/m^2 is assumed for mixing and application. Costs based on the above considerations are presented in Table 5.

In the application and mixing costs given in Table 5, only labor time (@ $10.00/hour) has been considered. It is presumed that the most efficient equipment for a given operation is available. Mixing costs as cited in Table 5 do not drop as rapidly for larger areas as do application costs since - even for "medium" areas - more material must be measured. For application to medium-sized areas we assume that spray application techniques similar to those used in our road tests cited in EPA 600 can be employed.

From the cost figures cited, routine application to medium-sized areas of an optimum mixture would be expected to cost 50¢/m^2 to 100¢/m^2.

TABLE 4

Applied Quantities of Coating Materials

Formulation*	BBRC (1.7m² areas) Asphalt Qty. Applied (liters)	BBRC Asphalt Section	BBRC Concrete Qty. Applied (liters)	BBRC Concrete Section	WSU Test Track (4.5m² areas)** Asphalt Qty. Applied (liters)	WSU Asphalt Section	WSU Concrete Qty. Applied (liters)	WSU Concrete Section
A	0.394	C	0.394	3				
B	0.387	D	0.387	4	1.15	19	1.04	9
C	0.386	E	0.386	5	1.16	18	1.05	8
D	0.404	F	0.404	6				
E	0.772	G	0.772	7				
F	0.756	H	0.756	8	2.24	17	2.04	7
G	0.727	I	0.727	9	2.14	16	1.95	6
H	0.684	J	0.684	10				
I	0.503	M	0.503	13	1.485	15		
J	0.494	N	0.494	14			1.323	5
K	0.487	O	0.487	15			1.305	3
L	0.483	P	0.483	16	1.413 1.413	13 22		
M***	0.553	K	0.553	11	1.624	11	1.476	1
O	0.840	B	0.840	2				
P	0.580	L	0.580	12				
W	Application rates are given in Table 1					30		
X	and discussed in Section 2.2					29		
Y	" "	"	" "	"		28		
Z	" "	"	" "	"		27		

*Per Table 1
**As selected per discussion in Section 7
***For the Petroset AT, as applied to the track sections, the formulation was changed (as discussed in paragraph 6.6.4) to:

- Asphalt section 11: 780 cm³ Petroset/1170cm³ water
- Concrete section 1: 708 cm³ Petroset/1060 cm³ water

1a Asphalt

1b Concrete

FIGURE 1

BBRC Asphalt and Concrete Test Sites

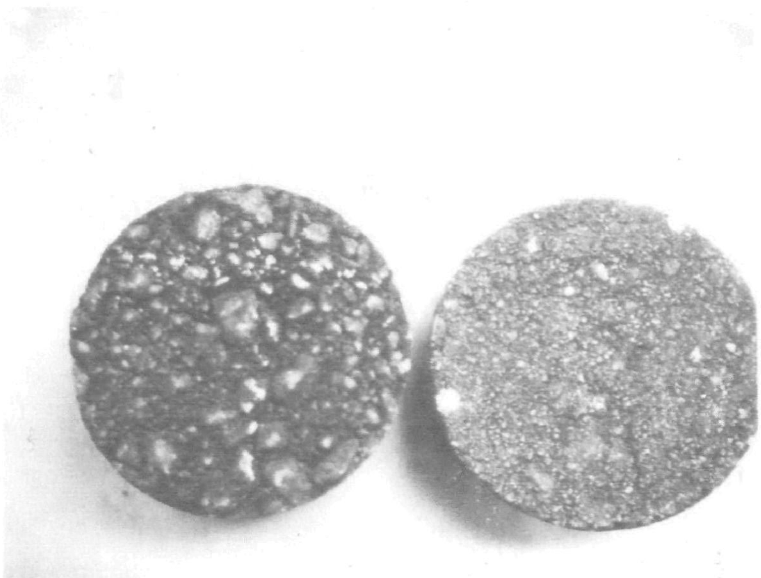

FIGURE 2

Comparative Roughnesses of WSU and BBRC Asphaltic Surfaces

TABLE 5

COATING AND APPLICATION COST SUMMARY

Formulation	Material Cost-¢/m^2	Mixing-¢/m^2 Small Scale[a]	Medium Scale[b]	Application-¢/m^2 Small Scale	Medium Scale
A	45	43	2	87	2
B	49	43	2	87	2
C	57	43	2	87	2
D	60	43	2	87	2
E	83	43	2	87	2
F	84	43	2	87	2
G	87	43	2	87	2
H	88	43	2	87	2
I	74	43	2	87	2
J	76	43	2	87	2
K	78	43	2	87	2
L	80	43	2	87	2
M	23	43	2	87	2
O	88	43	2	87	2
P	91	43	2	87	2
W	67	5	5	5	5
X	33	5	5	5	5
Y	130	5	5	5	5
Z	43	5	5	5	5

[a] ≃ 5m^2 assumed
[b] ≃ 200m^2 assumed

Further refinement of formulations, (e.g., water-borne materials) would cost considerably less and reduce further the toxicity and flammability problems associated with the majority of the formulations used in this work.

BBRC LABORATORY TEST DATA

BBRC laboratory test results, together with a few comments, are summarized in this section.

Coating Contact Angles and Toughness

The coating contact angles were measured as described and illustrated in pp. 37-50 of EPA 600. Basically, the coatings were applied to the surfaces of 52100 steel discs and subjected to high humidity (see Table 6), after which the contact angles of water and oil droplets on the coatings were measured with a Bausch and Lomb stereo microscope using a Unitron goniometer (angle calibration) eyepiece.

The toughness ratings were qualitatively judged with a steel probe. As discussed later, toughness has little to do with wear life on real substrates.

These data are presented in Table 6. As cited in that table, all the coatings except N indicate useful hydrophobicity (high contact angles). Coating P, being a water-borne product, illustrates the remark made earlier that such coatings with satisfactory properties (high contact angle and good mechanical properties) currently exist, even though for this application they are still regarded as experimental. In Table 6, the coatings wetted by the oil are not necessarily to be down-graded since this may indicate good adhesion to asphaltic surfaces.

Environmental Contamination Test Data

Environmental contamination tests were performed exactly as described in pp. 77-79 of EPA 600. The remarks made in that report still are applicable to these new data as presented in Table 6 (in main report). The coatings were applied to aluminum plates, cured and tested per USEPA methods. As pointed out in EPA 600, the test method gives pessimistic values compared to what would be expected in real-life road-coating run-off water (due to the small volume of water employed in the laboratory evaluations). As expected, only the water-borne systems, Sample M (Petroset) and Sample R (Viscospin), indicate any significant degree of environmental hazard.

Laboratory Sample Ice Adhesion Tests

These laboratory evaluations were performed exactly as described for series 1 and 2, pp. 51 and 55 of EPA 600. The coatings were applied to steel plates, cured, and subjected to ice release (in shear) stress measurements.

TABLE 6

Disc Contact Angles[1]

and Toughness Observations

Coating Code and Appearance[2]	Water Contact Angle-Degrees[3]	Oil Contact Angle-Degrees	Toughness Comments[4]	
Control (no coating)	58,57,60	22		
A even but rough	122,110,108	88,88(w)[5]	medium	
C " " "	106,106,105	66,50	soft	
D " " "	106,103,90	67,68 (w)	very soft	
E " " "	98,88,91	67,71 (w)	medium	
F uneven & "lumps"	87,85,93	63,65	hard	
H crazed	105,95,98	62,62 (w)	soft	
I uneven	98,93,92	68,59,63	medium	
K "	94,91,91	57,63,59	very soft	maybe not fully cured
L "	94,94,94	51,54	very soft	
N some orange peel	40,40,35 (w)[6][7]	44,42[6]	medium	
O even	85,92,90[6]	25,30[6]	medium	
P crazed in center	85,88,86	60	hard	
Q very even	91,83,91	22	medium	
B (Rpt. EPA 600)	119,115,116			
J (Rpt. EPA 600)	104,103,103			

Notes: [1]All coated discs (non-corrosion resistant steel) subject to 70% R.H. at 45C for 24 hours before testing. None indicated water vapor penetration of coating (no rust).

[2]Appearance must be related to non-porous nature of (steel) substrate.

[3]No particular trends noted between similar formulations (except A,C,D

[4]Qualitatively judged with steel probe.

[5]w = coating wetted by fluid.

[6]Note the drastic effect of a small amount of clay (compare N and O).

[7]All coatings are considered usefully hydrophobic except N.

TABLE 6. ENVIRONMENTAL TEST DATA (HOUSER REPT. 76-498)

COATING CODE (1)	H_2O CONTACT ANGLE-DEGREES (2)	PH (3)	TOTAL DISSOLVED SOLIDS gms (4)	TOTAL DISSOLVED SOLIDS WT. % OF FILM (5)	BIOLOGICAL OXYGEN DEMAND (BOD) (6)	CONSUMMABLE OXYGEN DEMAND (COD) (7)
BLANK H_2O SAMPLE		5.86	0.0027		3	11
UNCOATED SHEET	64, 68, 74	6.66	0.0074		6	16
A	122, 119, 120	7.05	0.0051	1.0	11	25
C	108, 93, 105	7.16	0.0103	1.4	9	25
D	101, 107, 103	7.09	0.0115	2.1	10	25
E	100, 100, 98	6.02	0.0033	2.1	4	11
F	103, 99, 104	5.89	0.0015	0.8	4	11
H	104, 106, 106	5.97	0.0026	0.8	4	14
I	110, 91, 100	5.82	0.0068	0.7	6	18
L	93, 102, 102	5.88	0.0073	4.3	4	13
R[1]	0	7.65	0.3420	88.0	252	791
B(RPT. F75-18)	102, 106, 109	6.98	0.0140	0.7	5	15
M(RPT. F75-18)	0	6.10	0.0183	1.3	22	84
DC 732[2] (RPT. F75-18)	107, 108, 109	5.90	0.0023	4.6	3	16

Source: Ball Brothers Research Corporation, 1976.

[1]As expected, Viscospin B (Coating R) was poor in these tests.

[2]Trends appear to be related to DC 732 content.

Note: Table 7. Same as Table 6 in body of report. Repeated here for convenience.

These data are presented in Table 7 (in main report). The notes at the bottom of this table present the more important conclusions. In addition, note that:

a. The coatings showing extensive removal (even though, per note 1, that is perhaps not indicative of real life) are the only ones containing clay in the binder (see note 6 at the bottom of Table 6).

b. Per the comment for Sample B, some of the coatings show considerable improvement over the formulations investigated previously (EPA 600) for identical test methods.

c. Graphical analysis at BBRC indicates no correlation of contact angle with ice release force. This is not surprising since tetrafluoroethylene (Teflon) shows a very high water contact angle yet is poor in ice release as is discussed in Section 2 of EPA 600.

Conclusion

Results of laboratory testing, i.e., real-life substrates not being used in the current program have been summarized above. It is emphasized that such testing is intended to:

a. Define the coatings.
b. Indicate possible trends with composition changes.
c. Eliminate obviously inferior materials, such as those showing very low (less than 70^{o}) contact angles.
d. Provide baseline data for new materials such as formulation P not planned for immediate real-life tests.

FIELD ICE-RELEASE EVALUATIONS

This section presents the ice-adhesion data for the coatings applied to asphaltic and concrete surfaces at BBRC and for selected cores (primarily the overlays - formulations W, X, Y, and Z as listed in Table 4 (main text)) from the WSU test track. The 10 cm (4 inch) diameter cores at BBRC were taken about 3 weeks after coating application. The WSU cores were obtained about 3 weeks after application of the overlays and other asphaltic surfaces to the WSU test track. A photo of two typical cores has been given in Figure 2.

The ice-adhesion data were obtained exactly as detailed for test series 3 and 4, pp. 51-55, Report EPA 600, except that more combinations of temperature and strain rate were employed (see following tables). We consider the data obtained at -5C and 0.5 cm sec^{-1} most representative of highway temperatures and loading rates.

LR 8198/DC 732 Data

These data are presented in Tables 9 and 10.

TABLE 7. ICE ADHESION DATA (METAL SUBSTRATE) (HOUSER RPT. 76-475)

COATING (1)	WATER CONTACT ANGLE, DEGREE (2)	AVERAGE ICE ADHESION: FORCE - kg/cm² (3)	RANGE OF DATA kg/cm² (4)	FILM APPEARANCE (5)	COMMENTS (6)
CONTROL PLATE	71, 76, 71	9.2	5.5		
A	93, 112, 106	8.3	5.0	Fairly smooth	85% of coating removed in one spot
B	96, 103, 111	4.1	4.1	Uneven, rough	70% coating removed
C	82, 88, 98	1.9	0.6	Smooth	60% coating removed - 3rd release
D	104, 80, 105	2.1	0.8	Smooth	Large portion of coating removed
E	105, 99, 95	1.2	0.8	Smooth	
F	98, 103, 99	1.2	1.6	Smooth	
G	104, 90, 107	0.9	0.8	Uneven but smooth	30% coating removed - 3rd release
H	96, 98, 102	0.7	0.4	Smooth	
I	90, 96, 98	2.4	0.7	Uneven but smooth	
J	100, 90, 92	3.0	2.3	Smooth	
K	107, 101, 90	2.5	3.4	Smooth	
L	101, 101, 98	1.7	1.1	Smooth	
O	97, 94, 94	7.4	6.4	Fairly smooth	
P	83, 83, 89	3.4	6.7	Fairly smooth	
Q	100, 96, 98	4.8	3.5	Smooth but uneven	
B(RPT. 75-18)	119, 117, 110	2.1	3.3	Fairly smooth	Lowest value found for a formulated coating in prior contract
CONTROL PLATE (RPT. 75-18)	56, 65, 63	7.6	4.6		
J(ON A.C., RPT. 75-18)		5.2	4.0		

Source: Ball Brothers Research Corporation, 1976.

Comments:
1. Coating removal from metal plates is not indicative of pavement performance (where solvent "binding" occurs on asphalt and mechanical pore locking occurs on concrete).
2. Some trends are evident. C appears about optimum for LR 8196/DC 732. H appears optimum for LR 8652/DC 732 but coating smoothness variations may dominate. The DRI-SIL 73/DC 732 foundations show an inverted curve and core results are needed to reach any decision.

Note: Table 8. Same as Table 7 in body of report. Repeated here for convenience.

TABLE 9

CORE ICE ADHESION DATA

HAUSER LAB, REPORT 76-569

All Values in kg cm^{-2}

BASIC SUBSTRATE Asphalt COATING CATEGORY LR 8198/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
A	No coating, control	14.55	6.68	12.67	8.08	14.66	6.26	15.47	5.06
C	A	*12.09	11.47	7.24	3.16	* 5.88	0.72	*10.81	4.85
D	B	*12.60	8.15	13.59	8.08	* 8.43	3.78	12.40	8.23
E	C	*10.92	12.14	* 9.91	1.91	6.14	4.86	* 7.98	3.93
F	D	*11.93	6.33	*11.90	2.74	*10.16	9.56	* 8.55	10.31
REFERENCE DATA									
SOURCE Metal Substrate	Table 8								
	Control			9.2	5.5				
	A			* 8.3	5.0				
	B			* 4.1	4.1				
	C			* 1.9	0.6				
	D			* 2.1	0.8				
REFERENCE DATA									
SOURCE Rpt. EPA 600									
B (metal substrate)				2.1	3.3				
Control (asphalt)		12.35	4.01	13.45	5.09				
B (asphalt core)		7.30	9.28	9.6	3.6				
		(weathered cores from highway)							

X=numeric average of data
R=range (spread, max-min) of data

* = portion of coating removed with ice

TABLE 10

CORE ICE ADHESION DATA

HAUSER LAB, REPORT 76-569

All Values in kg cm^{-2}

BASIC SUBSTRATE Concrete COATING CATEGORY LR 8198/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
1	Control, no coating	13.15	3.94	11.17	6.42	14.78	0.70	15.33	2.81
3	A	*13.37	7.24	6.38	4.46	* 7.59	7.26	*10.74	11.54
4	B	*10.47	9.77	7.58	8.08	* 6.60	1.08	* 9.77	11.86
5	C	8.36	12.68	9.85	7.44	* 6.93	2.14	* 9.58	9.29
6	D	* 7.40	8.21	6.05	8.95	4.56	2.43	* 5.54	5.64
REFERENCE DATA SOURCE Table 8 Metal Substrate									
	Control			9.2	5.5				
	A			* 8.3	5.0				
	B			* 4.1	4.1				
	C			* 1.9	0.6				
	D			* 2.1	0.8				
REFERENCE DATA SOURCE Rpt. EPA 600									
Control (concrete)				12.95	3.48				
B (concrete substrate)				7.6	7.7				

X=numeric average of data

R=range (spread, max-min) of data

* = portion of coating removed with ice

Table 9 presents data on asphalt cores. The spread in the data are rather wide and the adhesion reduction effected by the coatings is not impressive. For this particular paint, partial removal seems to be a fact of life - whether on roadway material or metal substrates. However, the older data, (from Report EPA 600), indicate that either aging or real highway use changes the coating to a more cohesive condition.

Table 10 presents similar data for the formulations applied to concrete. Trends with composition are more obvious and agreement with older data is better than for the asphalt substrate. Removal is still a problem. BBRC has developed an hypothesis on how this removal might be entirely prevented. However, no proof is currently available due to the elimination of the paint optimization phase of the current program.

LR 8652/DC 732 Data

These data are presented in Tables 11 and 12. Trends are much more pronounced and the reduction in adhesion is much more impressive. As in Table 9 and 10, substrate smoothness (cores versus metal) appears to have a drastic effect on shear adhesive strength of ice.

Dri-Sil 73/DC 732 Data

These data are presented in Tables 13 and 14.

In Table 13 an inverted trend is indicated (at -5C and 0.5 cm/sec) with formulation 1 (least DC 732) and formulation L (most DC 732) showing the lowest adhesion. As in the case of most other data, substrate smoothness has a drastic effect and weathering (aging) appears to improve the coating.

For concrete in Table 14, the trend line is somewhat more normal and the adhesive strength reduction is slightly more than for asphalt with this coating.

Petroset AT (Coating) Data

These data are presented in Table 15. Taken as a whole (all four conditions), the current tests indicate that the Petroset has little effect on concrete. Petroset on asphalt does indicate some benefit.

The older data indicate that the 3X application rate used in the current series (compared to that used in 1974) is too high and that about the same benefit (under the -12C, 0.5 cm/sec condition) can be obtained on asphalt and concrete at the lower rate. Statistically, we can make no judgment regarding the -5C, 0.5 cm/sec data.

The overlay data (see Test Track Overlays) corroborate the above. The high concentration overlay is equivalent to 1.33 kg of Petroset/m^2. The track cores appeared to have many closely spaced voids of about 0.5 cm (0.2 inch) diameter each. Thus, the whole top 0.2 inch thick porous layer of the overlay surface can be considered to be exposed.

TABLE 11

CORE ICE ADHESION DATA

HAUSER LAB, REPORT 76-569

All Values in kg cm^{-2}

BASIC SUBSTRATE Asphalt COATING CATEGORY LR 8652/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
A	Control, no coating	14.55	6.68	12.67	8.08	14.66	6.26	15.47	5.06
G	E	5.56	0.59	4.41	4.65	5.21	2.43	6.02	2.65
H	F	3.88	3.11	5.12	2.00	4.20	1.43	4.59	1.22
I	G	3.70	1.43	3.70	0.79	3.27	1.50	3.13	1.69
J	H	5.68	7.25	5.65	4.61	4.21	0.90	4.43	2.40
REFERENCE DATA SOURCE Table 8 Metal Substrate									
	Control			9.2	5.5				
	E			1.2	0.8				
	F			1.2	1.6				
	G			0.9	0.8				
	H			0.7	0.4				
REFERENCE DATA SOURCE									

X=numeric average of data
R=range (spread, max-min) of data

TABLE 12
CORE ICE ADHESION DATA
HAUSER LAB, REPORT 76-569
All Values in kg cm^{-2}

BASIC SUBSTRATE Concrete COATING CATEGORY LR 8652/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
1	Control, no coating	13.15	3.94	11.17	6.42	14.78	0.70	15.33	2.81
7	E	7.72	6.76	6.27	3.47	6.46	2.15	7.89	1.91
8	F	6.71	1.72	4.57	3.73	5.05	2.15	5.25	1.39
9	G	5.24	1.08	3.75	2.86	4.56	1.55	5.77	1.80
10	H	4.86	1.54	4.48	2.90	3.70	0.79	6.17	1.47
REFERENCE DATA SOURCE Table 8 Metal Substrate									
	Control			9.2	5.5				
	E			1.2	0.8				
	F			1.2	1.6				
	G			0.9	0.8				
	H			0.7	0.4				
REFERENCE DATA SOURCE									

X=numeric average of data
R=range (spread, max-min) of data

TABLE 13
CORE ICE ADHESION DATA
HAUSER LAB, REPORT 76-569
All Values in kg cm^{-2}

BASIC SUBSTRATE Asphalt COATING CATEGORY Dri-Sil 73/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
A	Control, no coating	14.55	6.68	12.67	8.08	14.66	6.26	15.47	5.06
M	I	8.95	11.64	8.11	3.47	9.92	7.70	9.35	4.50
N	J	12.65	6.96	9.01	10.91	8.93	9.19	10.33	6.75
O	K	10.56	4.43	11.53	4.92	9.56	1.34	6.53	3.92
P	L	8.46	8.18	8.49	10.83	7.18	2.77	9.39	3.16
REFERENCE DATA Table 8 SOURCE Metal Substrate									
	Control plate			9.2	5.5				
	I			2.4	0.7				
	J			3.0	2.3				
	K			2.5	3.4				
	L			1.7	1.1				
REFERENCE DATA SOURCE Rpt. EPA 600		(weathered cores)							
	Control, no coating	12.35	4.01	13.45	5.09				
	J	4.53	4.99	5.2	4.0				

X=numeric average of data
R=range (spread, max-min) of data

TABLE 14

CORE ICE ADHESION DATA

HAUSER LAB. REPORT 76-569

All Values in kg cm^{-2}

BASIC SUBSTRATE Concrete COATING CATEGORY Dri-Sil 73/DC 732

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
1	Control, no coating	13.15	3.94	11.17	6.42	14.78	0.70	15.33	2.81
13	I	10.67	8.42	11.79	3.02	7.86	4.36	12.16	8.79
14	J	10.56	14.15	13.97	4.36	7.13	1.57	12.74	5.41
15	K	7.72	4.50	5.38	1.65	6.99	4.33	8.87	4.88
16	L	8.98	3.54	6.15	4.39	6.09	1.25	12.27	6.47
REFERENCE DATA SOURCE Table 8 Metal Substrate									
	Control plate			9.2	5.5				
	I			2.4	0.7				
	J			3.0	2.3				
	K			2.5	3.4				
	L			1.7	1.1				
REFERENCE DATA SOURCE Rpt. EPA 600									
	Control, no coating			12.95	3.48				

X=numeric average of data
R=range (spread, max-min) of data

TABLE 15

CORE ICE ADHESION DATA

HAUSER LAB, REPORT 76-569

All Values in kg cm^{-2}

BASIC SUBSTRATE Noted below COATING CATEGORY Petroset AT

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	R	-12C, 0.5cm/sec X	R	-5C, 0.05cm/sec X	R	-12C, 0.05cm/sec X	R
A	Asphalt control	14.55	6.68	12.67	8.08	14.66	6.26	15.47	5.06
K	M(Petroset on asphalt)	11.65	4.78	11.60	6.61	10.14	5.98	13.41	2.67
1	Concrete control	13.15	3.94	11.17	6.42	14.78	0.70	15.33	2.81
11	M(Petroset on concrete)	12.32	4.01	14.18	3.52	14.38	3.94	15.78	4.36
REFERENCE DATA									
SOURCE Rpt. EPA 600									
Asphalt control		12.35	4.01	13.45	5.09				
Petroset on asphalt (1/3 application rate above)		12.00	4.71	10.6	4.5				
Concrete control				12.95	3.48				
Petroset on concrete (1/3 application rate above)				10.1	6.9				
REFERENCE DATA									
SOURCE									

X=numeric average of data

R=range (spread, max-min) of data

For a 1.5 inch thick overlay, this results in a 0.2/1.5 fraction of the total quantity of Petroset being exposed, which is equivalent to 1.33 (0.2/1.5) or 0.18 kg Petroset/m^2. This is quite close to the 0.24 kg Petroset/m^2 used as a coating in the current tests.

Test Track Overlays

These data are given in Table 16. Surprisingly, the lower concentrations of Petroset and Viscospin show the most improvement. For the extremely rough surface of the track overlays, the results for Z and X are impressive - especially when compared to the absolute values shown for some of the other coatings. The values for Z and Y confirm the observations from Table 15 regarding excess Petroset quantities.

No comparative values are available for asphalt surfaces as rough as the test track A.C. substrate (roughness was confirmed by the skid slipperiness values cited in the following section). The track asphalt also appears to be poorly compacted since these were the only cores from which substrate material was removed during ice adhesion tests.

TRACK FORMULATION SELECTION

From the above data and the data presented below, the specific formulations to be evaluated on the test track were selected. The selection procedure and rationale are presented below.

LR 8196/DC 732

Asphalt: Formulations B and C
Concrete: Formulations B and C

From Tables 9 and 10, formulations C and D are indicated from core data. However, from the metal substrate data, D is higher in adhesion than C. Also, from Table 6, D is considerably softer (and presumably less abrasion resistant) than C. Formulations B and C appear to represent the best compromise between minimum ice adhesion, reasonable abrasion resistance, and minimum contamination potential (Table 7).

LR 8652/DC 732

Asphalt: Formulations F and G
Concrete: Formulations F and G

The formulations for use on asphalt are straight-forward selections of the best formulations from the core ice adhesion data. On concrete, H is suggested from core data. However, from Table 6 you can see that H is soft and crazed (cracked) when applied to the contact angle discs. Both F and G are marginal in skid resistance as tested here but would be more satisfactory on the rougher test track.

TABLE 16

CORE ICE ADHESION DATA

HAUSER LAB, REPORT 76-569

All Values in $kg\ cm^{-2}$

BASIC SUBSTRATE Asphalt

COATING CATEGORY Test Track Doped Overlays

Table 4 Section Identification	Table 1 Formulation Code	-5C, 5cm/sec X	-5C, 5cm/sec R	-12C, 0.5cm/sec X	-12C, 0.5cm/sec R	-5C, 0.05cm/sec X	-5C, 0.05cm/sec R	-12C, 0.05cm/sec X	-12C, 0.05cm/sec R
25	Rubberized A.C.	*10.49	6.05	8.89	8.71	8.42	3.92	* 9.21	2.32
27	Z(8-1/3% Petroset)	9.00	3.02	11.16	13.01	12.86	1.90	12.32	4.64
28	Y(2.5% Petroset)	13.74	6.26	14.29	4.99	12.99	7.24	15.84	3.59
29	X(4% Viscospin B)	6.95	8.97	*11.81	3.80	9.20	9.76	14.68	2.46
30	W(8% Viscospin B)	10.30	4.64	10.15	2.67	14.06	5.06	16.24	1.69
REFERENCE DATA SOURCE ____									
REFERENCE DATA SOURCE ____									

X=numeric average of data

R=range (spread, max-min) of data

* = core material removed with ice

Dri-Sil 73/DC 732

Asphalt: Formulations I and L
Concrete: Formulations J and K

The asphalt selection is a straight-forward matter from the core adhesion data. Why the minimum and maximum DC 732 concentrations should appear optimum on asphalt is not clear. Solvent action on the asphalt binder combined with partial separation of the components may be an explanation.

For the concrete, the selection of J in preference to L may not be apparent. However, L is much softer than J and more expensive. L is quite soft (and would be more readily destroyed by the quite abrasive concrete debris) and nearly equal to J in ice release under three of the four test conditions. Finally, J (specifically on concrete) has held up very well in a light traffic location for nearly three years.

Petroset AT

This material was applied to one section each of asphalt and concrete in an amount of Petroset AT per area that was 1/3 that used in Table 1. The dilution rate in the present application was also changed to one part Petroset AT to 1-1/2 parts water. This duplicates the application rate for the reference data of Table 15, where at least a slight improvement in ice release was noted.

Open-Graded Asphalt Coating

It was desired to apply one coating to the open-graded asphalt (track sections 21,22, and 23). Formulation L was selected on the bases of its superior ice release ability (Table 13) and the fact that, for this highly porous substrate, penetration would make its softness (Table 6) relatively unimportant.

Conclusion

"Real life" substrate ice release data have been summarized above. These data were the primary criteria used in selecting the formulations evaluated on the WSU track. Although they are (presented in this report) somewhat out of chronological order, the formulation/track location positions as finally selected per this Section have been included earlier in Table 4 in order to present all applicaiton rate data in one place. Assuming counterclockwise rotation of the tire arms relative to the track, the positioning and spacing of the formulations were such as to minimize tracking of chemicals from one treated section to another. Observed tracking and cure time data from EPA 600 were used to make these judgments.

SKID AND BEADING DATA

Quantitative skid (slipperiness) measurements and qualitative beading (the tendency for water to form high contact angle droplets on surfaces) observations are summarized in this section. The first subsection, Skid Number Discussion, presents our statistical analysis method for the skid data (i.e., do the recorded data represent real differences?). It also presents the real-life significance of the skid numbers. The second subsection, Data from BBRC Test Locations, summarizes the skid/beading data obtained from the BBRC test areas (Figures 1a and 1b) used primarily for screening test decision making. The third subsection presents skid/beading data from the WSU test track surfaces. Judgments on coating wear life (durability) and degree of coating penetration into the pavements (also indicative of effective life) are inferred in some cases from the track data.

Skid values can be employed to infer the presence of the coating. Beading observations serve a similar function.

Skid Number Discussion

Skid numbers are proportional to the frictional loss of energy as a rubber "shoe" quickly slides across the pavement surface. Thus, the higher the numbers the higher the frictional loss and the less slippery (i.e., less danger of automotive skids) the surface. The apparatus is shown in Figure 4-14 of EPA 600. As an approximate guide, values of critical interest are:

Skid value > 65: satisfactory for all driving conditions
Skid value < 45: unsatisfactory for most driving conditions
Skid value of 9 to 17: typical of ice near its melting point.

The value of 45 thus represents a considerable improvement over ice-coated roads. The value of 65, however, is regarded as nearly mandatory by most state highway departments.

In our programs, three duplicate measurements are made for every average quoted in our presentation. We need to know the statistical variation in these measurements (i.e., what is the relationship between the measured average and the true average should, say, 100 measurements be made?). From the literature (Applied Statistics for Engineers; W. Volk; McGraw-Hill, N.Y., 1958.), we can estimate from the range of the three sample measurements the range of values which will include the true average. For the measurements at BBRC, the range of the three numbers is about 2 and for the test track the range is about 3 in most cases. Thus:

BBRC: $2\sigma = 2.4$
Track: $2\sigma = 3.6$

Simply put, if we run an infinite number of groups of three averaged measurements each at one location, each average will be:

BBRC: average = true ± 2.4
Track: average = true ± 3.6

96% of the time. Finally, this means that, in comparing two average skid values, we can say (with 96% confidence) that they are truly different if the absolute value of their difference is:

For BBRC data > 4.8
For track data > 7.2

Data From BBRC Test Locations

Table 17 gives a sampling of data from BBRC obtained during the recent optimization, initial test track values (not reported in subsection 3) and a few values for comparison from EPA 600. From this table, note that:

a. As would be expected from Figure 2, the skid values confirm that the test track pavement surfaces are far rougher than corresponding substrates at BBRC. Compare an average BBRC value of 71 for asphalt with an average of over 81 at WSU. This is approaching twice the difference required for significance given in subsection 1. The difference in concrete values of 78 to 85 also indicates significant difference. This means that we cannot compare BBRC data with WSU data due to differences in pavement roughness.

b. While it is discussed in more detail in subsection 3, note that the track pavement varies significantly from section to section (75 to 88 for asphalt and 77 to nearly 90 for concrete). This means that we cannot assume constancy of roughness around the track for a given pavement type.

c. From the BBRC site data, it is apparent that beading and skid values shown.no correlation. Coating and substrate interact differently to affect each parameter.

d. The effect of DC 732 in the formulations is quite unexpected. This material, by itself, exhibited a value of about 44 on asphalt in our EPA 600 work. No particular trend is apparent with increasing concentration of DC 732 in Dri-Sil 73 (Formulations I, J, K and L). However, in LR 8652, DC 732 appears to increase skid resistance with increasing concentration (E, F, G and H). These observations merely illustrate that formulation component/substrate interactions are extremely complex and not a matter of additive property contributions.

e. The majority of the formulations do not create a severe skid hazard. Formulation O, the Goodyear version of Akron LR 8652, was checked only for information. The Petroset AT (Formulation M) values on asphalt seem to contradict the earlier data. However, the concentration was three times that used in the EPA 600 work. As discussed earlier, too high a concentration of this material is harmful to both ice release and skid resistance and the application rate was cut back for coating track

TABLE 17

Asphalt and Concrete Skid Values and Water Beading[1]

Coating Code	Asphalt Values at BBRC at 27C -11/5/76	Concrete Values at BBRC at 24C -11/5/76	Beading at BBRC During Snow at 5C: Asphalt	Beading at BBRC During Snow at 5C: Concrete	Skid Values at WSU Track[2] at 14C/Beading during Skid Tests -11/9/76
Control, uncoated	70,72,72	78,78,79	none	none	
A	68,69,68	66,66,66	good	some	
B	68,68,67	70,69,68	v.good	some	
C	68,68,70	70,70,69	v.good	good	
D	63,62,63	65,65,65	v.good	good	
E[3]	44,43,44	48,48,48	ex'lent	ex'lent	
F[3]	49,50,49	54,53,55	ex'lent	ex'lent	
G[3]	58,60,58	58,56,58	ex'lent	ex'lent	
H[3]	62,60,60	56,55,57	ex'lent	ex'lent	
I	73,73,73	74,74,75	ex'lent	some	
J	65,65,64	74,75,75	ex'lent	some	
K	71,72,72	74,75,75	ex'lent	good	
L	67,67,68	78,78,78	ex'lent	good	
M[4]	47,46,46	62,62,62	none	none	
O	30,30,30	40,38,38	none	good	
P	53,52,53	56,58,57	v.good	ex'lent	
W					83,83,83/none
X					88,88,87/none
Y					78,78,78/some
Z					83,83,84/none
Rubberized A.C.					72,73,74/some
Open-graded A.C.					83,84,83/none
Three AC sections					87,87,89 77,74,73 82,82,80
Three P.C.C. sections					76,76,78 89,90,90 88,88,87
B(Rpt. EPA 600)	60,61,60,61 (15C)	76,77,76,77 (30C)	ex'lent	ex'lent	
J(Rpt. EPA 600)	68,68,68,69 (30C)	67,67,68,68 (32C)	fair	ex'lent	
M(Rpt. EPA 600)	65,65,67,67 (40C)	63,63,63,63 (30C)	good	fair	

Notes: [1]Beading: tendency for water to form droplets on surface with high contact angles.

[2]Extremely rough surfaces on test track confirmed by high skid values.

[3]Unexpected trends (such as E,F,G,H) exist but are similar to core ice adhesion results (Tables 11 and 12).

[4]"Petroset AT" applied at 3 times the application rate as in prior work.

Sections 1 and 11.

Table 18 illustrates the effect of two months environmental exposure of the coatings on skid resistance and beading (water resistance). Exposure to air and sunlight appear to have no effect on water resistance. This agrees with the EPA 600 observations. The change in skid resistance is more complex. a) The skid resistances of the Dri-Sil 73/DC 732 mixtures (Formulations I, J, K, L) as a group improve with age and the initially slippery Petroset AT improves dramatically. This latter observation indicates that the need for caution in driving on surfaces treated with Petroset AT (high concentration) exists for at most two months. b) The skid resistances of the LR 8652/DC 732 formulations (E, F, G, H) appear nearly unchanged (for the lower DC 732 concentrations) or slightly improved. The greatest improvement is on concrete where the acetic acid liberated by the DC 732 would be immediately neutralized. This neutralization would accelerate cure. c) The LR 8196/DC 732 formulations (A, B, C, D) remain essentially unchanged on concrete but perhaps degrade on asphalt. Long term migration of a component in the LR 8196 to the surface may be responsible.

Application, Skid and Beading Data Summary for WSU Test Track

For the record, Table 10 (in main report) presents the specific weather conditions and the time phasing present during application of the coatints to the 4.5m^2 (4 ft. x 12 ft.) areas of each treated section on the track. The 12 foot dimension of the test sections spanned the entire radial width of the track pavement.

The position of the treated area within each section was adjusted so as to include the holes in which the runoff water contamination samples were collected.

Assumptions and General Observations

Tables 20, 21, and 22 summarize the test track skid and beading data at three points in time for each section:

a. Late April after 18,000 track revolutions
b. Mid-January just after coating application per Table 10 (main report)
c. Mid-January just prior to coating application with 4000 track revolutions on the newly applied asphalt and overlays.

As pointed out previously, the track roughness (for a given type of pavement varies so much in a circumferential direction that general section-to-section comparisons cannot be made. However, it does appear that:

In the same wheel path on the same substrate, the roughness is comparable from section to section judging from the before-coating skid values. A few exceptions to this rule exist (see Table 20, sections 9 and 10, W.P. 2; Table 21, sections 12 and 18, W.P. 5 and 6).

TABLE 18

Effect of Aging on Skid Values and Beading at BBRC

COATING CODE	Asphalt 10/22/76 20C		Asphalt 12/29/76 18C		Concrete 10/22/76 15C		Concrete 12/29/76 15C	
	Skid Values	Beading	Skid Values	Beading	Skid Values	Beading	Skid Values	Beading
Uncoated Control	72	(0)	77	(0)	83	(0)	90	(0)
A	69	(3)	63	(3)	68	(2)	68	(2)
B	70	(4)	68	(4)	68	(2)	65	(2)
C	69	(4)	63	(4)	68	(3)	68	(3)
D	69	(4)	63	(4)	65	(3)	68	(3)
E	45	(5)	40	(5)	48	(5)	48	(5)
F	48	(5)	47	(5)	52	(5)	58	(5)
G	46	(5)	53	(5)	46	(5)	58	(5)
H	53	(5)	60	(5)	55	(5)	62	(5)
I	74	(5)	73	(5)	80	(2)	83	(2)
J	65	(5)	73	(5)	79	(2)	82	(2)
K	66	(5)	74	(5)	77	(3)	78	(3)
L	64	(5)	70	(5)	74	(3)	79	(3)
M	44	(0)	63	(0)	56	(0)	68	(0)
O	30	(0)	31	(0)	40	(3)	39	(3)
P	48	(4)	56	(4)	56	(5)	59	(5)

a) value are averages of three readings with a maximum range of 2 units.

b) beading code: 0 = none
1 = very little
2 = some
3 = good
4 = very good
5 - excellent

TABLE 10

TEST TRACK SPRAY COATING SUMMARY

FORMULATION	QTY. APPLIED LITERS	TRACK SECTION #	DATE APPLIED	TIME (a) APPLIED	AIR TEMP. °C (b)	TRACK SURFACE TEMP. °C
B	1.04	9	1/17/77	1230-1530	6 to 5	8 to 6
	1.15	19	1/18/77	1730-1930	2 to -1	4 to 2
C	1.05	8	1/17/77	1230-1530	6 to 5	8 to 6
	1.16	18	1/18/77	1730-1930	2 to -1	4 to 2
F	2.04	7	1/17/77	1230-1530	6 to 5	8 to 6
	2.24	17	1/18/77	1730-1930	2 to -1	4 to 2
G	1.95	6	1/17/77	1230-1530	6 to 5	8 to 6
	2.14	16	1/18/77	1730-1930	2 to -1	4 to 2
I	1.48	15	1/18/77	1100	8	16
J	1.32	5	1/17/77	1230-1530	6 to 5	8 to 6
K	1.30	3	1/17/77	1230-1530	6 to 5	8 to 6
L	1.41	13	1/18/77	1100	8	16
	1.41	22(c)	1/19/77	1000	6	8
Petroset AT	1.62	11	1/18/77	1730-1930	2 to -1	4 to 2
	1.48	1(d)	1/18/77	1730	2	2

Notes:

(a) At 0800, 1/18/77, track was damp and was flame dried. At 1100, 1/18/77, high winds stopped operations until 1730.

(b) Measured relative humidity was between 80% and 100% during all spraying operations.

(c) Formulation L was selected for the open graded asphalt on section 22 as having the best chance on this very porous surface.

(d) Petroset AT appeared to penetrate poorly on section 1.

Note: Table 19. Same as Table 10 in body of report. Repeated here for convenience.

TABLE 20

FINAL TRACK SKID DATA AND BEADING OBSERVATIONS[a] COMPARED TO REFERENCE DATA[b]

TRACK SECTION	TYPE/TREAT.	W.P.1[c] GARNET SNOW	W.P.2 STUDDED SNOW	NO TRAVEL	W.P.3&4 GARNET TRUCK	W.P.5 "SOFT",CAR,WINTER	W.P.6 "SOFT",CAR,WINTER	W.P.7 STD.,WINTER CAR	W.P.8 STD.,WINTER CAR	SURFACE TEMPS COMMENTS
1	PCC/Petroset[d]	91(0)	80(0)	98(1)	75(1)	88(1)	82(1)	82(1.5)	91(1.5)	
		95	84		81 to 89	85	89	95	99	
2	PCC/None	89(0)	68(0)	97(0)	73(0)	81(0)	83(0)	80(0)	88(0)	
3	PCC/K	84(2)	68(1)	87(5)	76(3)	76(4)	74(4)	76(4)	70(4)	
					71 to 72					
		91	81		95 to 93	93	98	98	98	
4	PCC/None	84(0)	69(0)	91(0)	77(0)	80(0)	84(0)	91(0)	95(0)	16C
5	PCC/J	73(2)	63(1)	82(5)	82(1)	77(3)	74(3)	75(3)	77(3)	
					69 to 75					
		98	80	89	81 to 97	94	85	97	85	
6	PCC/G	72(1.5)	61(1)	67(5)	64(1)	72(2)	78(2)	70(2)	61(2)	
					65 to 68					
		95	82		90 to 95	88	85	94	96	
7	PCC/F	76(2)	63(1)	55(5)	70(1)	77(1)	67(1)	73(2)	58(2)	
					58 to 56					
		93	84		87 to 89	88	92	93	92	
8	PCC/C	74(2)	64(1)	78(5)	69(2)	79(3)	78(4)	80(4)	68(4)	18C
					77 to 73					
		88	70	76	86 to 79	93	88	94	96	
9	PCC/B	72(2)	64(0)	82(5)	74(1)	75(1)	74(1)	80(2)	77(3)	
					66 & 66					
		92	73		96 to 81	93	94	91	92	
10	PCC/None	69(0)	61(0)	89(0)	60(0)	75(0)	76(0)	79(0)	84(0)	

(a) Numbers in ( ) indicate beading code: 0 = zero beading, 1 = very slight beading, 2 = fair beading, 3 = good beading, 4 = good to excellent beading, 5 = excellent beading

(b) Top line in each section: 4/26-4/27/77 data (temperature indicated at right)
2nd line " " " : 1/19/77 data just after coating application (concrete 10C, asphalt = 7C)
3rd line " " " : 1/17/77 data just prior to coating (surface = 7C)

(c) W.P. = wheel **path** numbered from inside of track

(d) PCC = Portland Cement Concrete

TABLE 21

FINAL TRACK SKID DATA AND BEADING OBSERVATIONS COMPARED TO REFERENCE DATA (a) (b)

TRACK SECTION	TYPE/TREAT.	W.P.1 (c) GARNET SNOW	W.P.2 STUDDED SNOW	NO TRAVEL	W.P.3&4 GARNET TRUCK	W.P.5 "SOFT",CAR,WINTER	W.P.6	W.P.7 STD.,WINTER CAR	W.P.8	SURFACE TEMPS COMMENTS
11	AC/Petroset (d)	63(3)	69(1.5)	79(4)	66(1)	60(1)	60(1)	76(1)	75(1)	7&8 much rougher
12	AC/None	67(0)	79(0)	79(1)	55(0)	64(1)	63(1)	73(1)	78(1)	
		85	*90*	*81*	*76 to 75*	*74*	*76*	*81*	*87*	
13	AC/L	65(2)	74(2)	77(5)	66(1)	65(2)	62(2)	74(3)	77(3)	28C
					71 to 68					
14	AC/None	66(0)	77(0)	81(1)	60(0)	62(0)	66(1)	70(1)	74(1)	
15	AC/I	64(3)	73(0)	84(5)	65(0)	63(1)	65(1)	72(1)	72(2)	34C
					73 to 70					
				74						
16	AC/G	64(2)	72(1)	67(5)	56(1)	63(2)	61(3)	69(4)	74(4)	
					54 to 55					
17	AC/F	61(3)	74(0)	71(5)	65(2)	70(3)	64(2)	67(3)	67(3)	
					61 to 64					
18	AC/C	65(1)	77(0)	68(5)	63(2)	75(4)	70(4)	75(4)	76(3)	34C
					78 to 75					
		83	*90*		*80 to 90*	*90*	*90*	*88*	*88*	
19	AC/B	64(2)	76(0)	68(5)	63(1)	70(3)	73(3)	71(2)	75(3)	
					65 to 66					
				88						
20	AC/None	63(0)	82(0)	82(1)	68(0)	70(0)	72(0)	74(0)	77(0)	
				88						

(a) Numbers in ( ) indicate beading code: 0 = zero beading, 1 = very slight beading, 2 = fair beading, 3 = good beading, 4 = good to excellent beading, 5 = excellent beading

(b) Top line in each section: 4/26 - 4/27/77 data (temperature indicated at right)
2nd line " " " : 1/19/77 data just after coating application (concrete 10C, asphalt = 7C)
3rd line " " " : 1/17/77 data just prior to coating (surface = 7C)

(c) W.P. = wheel path numbered from inside of track

(d) AC = asphaltic concrete

TABLE 22

FINAL TRACK SKID DATA AND BEADING OBSERVATIONS COMPARED TO REFERENCE DATA (a) (b)

TRACK SECTION	TYPE/TREAT.	W.P.1 (c) GARNET SNOW	W.P.2 STUDDED SNOW	NO TRAVEL	W.P.3&4 GARNET TRUCK	W.P.5 "SOFT",CAR	W.P.6 WINTER	W.P.7 STD.	W.P.8 WINTER CAR	SURFACE TEMPS COMMENTS
21	Open AC/None Graded	67(0)	80(0)	85(0)	64(0)	67(0)	68(0)	73(0)	74(0)	
22	Open AC/L	68(3)	83(3)	76(4) 83	70(3) 47 to ?	71(3)	68(3)	74(3)	75(3)	20C
23	Open AC/None	68(0)	84(0)	85(0) 83	61(0) 76 to 75	65(0)	61(0)	66(0)	75(0)	
24	Rubberized AC/None	71(1)	78(2)	81(2)	66(1) 72 to 73	72(1)	72(1)	72(1)	74(1)	
25	Rubberized AC/None	72(2)	81(2)	79(2) 23	73(1) 80 to 73	69(1)	73(1)	73(1)	81(1)	22C
26	Rubberized AC/None	68(1)	74(1)	83(1)	58(1) 74 to 75	79(1)	71(1)	73(1)	81(1)	
27	Overlay /8 -1/3Pet.	73(1)	84(1)	88(1) 83	64(1) 79 to 80	71(1)	72(1)	72(1)	78(1)	
28	Overlay /25 Pet.	67(1)	87(0)	87(2) 28	65(1) 78 to 80	72(2)	69(2)	71(2)	78(2)	24C
29	Overlay /4 Visco	68(0)	75(0)	87(0) 88	65(0) 78 to 73	72(0)	67(0)	72(0)	80(0)	
30	Overlay /8 Visco	69(0)	79(0)	84(0) 82	61(0) 81 to 77	69(0)	68(0)	75(0)	73(0)	

(a) Numbers in ( ) indicate beading code: 0 = zero beading, 1 = very slight beading, 2 = fair beading, 3 = good beading, 4 = good to excellent beading, 5 = excellent beading

(b) Top line in each section: 4/26 - 4/27/77 data (temperature indicated at right)
2nd line " " " : 1/19/77 data just after coating application (concrete 10C, asphalt = 7C)
3rd line " " " : 1/17/77 data just prior to coating (surface = 7C)

(c) W.P. = wheel path numbered from inside of track

The radial direction uniformity is quite poor - again judging from the before-coating data. We cannot, therefore, judge coating/tire-type effects from skid data.

We can assume that the degree of beading is indicative of the presence of the coating.

Beading on untraveled sections can be used as a baseline for at least some coating remaining - compared to untreated beading and final beading observations.

Where reasonable beading remains and skid value has changed significantly, good pavement penetration is indicated.

Portland Cement Data

Table 20 summarizes the Portland Concrete pavement data. Our conclusions are as follows:

Petroset AT:

1. Material appears to protect substrate from the severe wear caused by the studded snow tires noted on virtually every other section.

2. Penetration, in general, looks good.

3. Dri-Sil 73/DC 732 (Sections 3 and 5): For wear resistance and penetration, Formulation K appears slightly better than J.

LR 8652/DC 732 (Sections 6 and 7)

1. Formulation G is equal or superior to F in most cases.

LR 8198/DC 732 (Sections 8 and 9)

1. Based on beading observations, Formulation C is clearly superior to B.

2. Both of these formulations appear better than F and G - somewhat of a surprise based on our tests. Wear resistance obviously can only be evaluated by real-life testing.

Asphaltic Concrete Data

Table 21 summarizes the data on Asphaltic Concrete. Our conclusions are as follows:

Petroset AT (Section 11):
Comparing Sections 11 and 12, no specific trends are evident. The "no travel" data do again suggest the tendency for this material to become more effective with exposure.

Dri-Sil 73/DC 732 (Sections 13 and 15):

1. Based on beading observations, Formulation L is superior to Formulation I with no significant difference in skid resistance.

2. From the "no travel" data, skid resistance does not deteriorate with time.

LR 8652/DC 732 (Sections 16 and 17):

1. Based on beading, Formulations F and G are about the same.

2. Formulation G <u>may</u> present a slightly greater skid hazard but significance here is limited to the garnet truck tire wear path.

LR 8198/DC 732 (Sections 18 and 19):

1. Based on beading, Formulation C is marginally better than B.

2. No significant difference in skid hazard exists in skid measurements for the two formulations.

3. Penetration is poor, based on the studded snow tire data.

<u>Overlay and Other Track Section Data</u>

Table 22 summarizes the data for the remaining sections and the overlays. Our conclusions are as follows:

Formulation L on open graded asphalt (Section 22):

1. As would be expected, excellent penetration is indicated.

2. Virtually no change in beading occurred with wear.

3. Though not statistically significant, skid resistance is not degraded by this particular formulation/pavement-type combination.

Petroset AT Overlays (Sections 27 and 28):

1. On a skid basis, no difference exists between the two overlay concentrations.

2. Based on beading data, we must rank the higher concentration superior. This contradicts ice release data (Table 16).

Viscospin B Overlays (Sections 29 and 30):

1. Since Viscospin B remains water soluble for extended periods (the reason it is not used for coating purposes), no judgment can be made from beading observations.

2. No significant difference exists in skid values for the two concentrations.

Track Data Conclusion

Test track skid and beading data have been presented. In most cases, differences in the characteristics of similar formulations (same components) can be detected. It remains to determine what, if any, correlation exists between these differences and the snow/ice adhesion observations made by WSU personnel.

TENTATIVE RECOMMENDATIONS

1. Whether the WSU pavement is abnormally rough or not, longer duration tests are required (perhaps with intermittant coring and ice-adhesion tests) to determine the real-life durability of the coatings and overlays.

2. We feel that one further modification of the LR 8198 paint could produce impressive results.

3. More investigation of the overlay incorporation technique is indicated.

HAUSER LABORATORIES
[illegible] CENTRAL AVE. P.O. BOX [illegible], BOULDER, COLORADO [illegible] • PH. [illegible]

October 27, 1976
Test Report No. 76-475

CLIENT: Ball Brothers Research Corporation
P.O. Box 1062
Boulder, Colorado 80306
Attention: George Ahlborn P.O. No. 15585

MATERIALS: Sixteen coated steel plates supplied and identified by client.

TEST: Ice Adhesion in Shear. Two teflon rings 0.50 inch I.D. by 0.25 inch high were located on each plate, filled with water, then frozen. These specimens were allowed sixteen hours temperature soak at approximately 10°F. Specimens were tested by attaching a 0.025 inch diameter, nylon jacketed, steel cable to the upper or fixed crosshead member of a tensile test machine. The cable was looped around the teflon ring. Then the specimen plate attached to the moveable crosshead member was pulled away at a crosshead rate of 0.50 cm/seconds (11.8 inch/minute). Load was measured by a 500 pound load cell with electronic readout to an X-Y recorder. Tests were conducted at precisely $-12° \pm 1°C$. This procedure was repeated with three tests at each location.

RESULTS:

Coating No.	Sequence	Force lbs.	Shear Strength psi	Remarks
A 1	1a	22.1	113	
	1b	26.0	133	
	2a	33.2	169	
	2b	27.9	142	
	3a	27.0	138	rust severely under coating on test side
	3b	17.6	89.8	rust severely under coating on test side
A 3	1a	14.7	75.0	
	1b	12.3	62.8	
	2a	16.5	84.2	
	2b	16.6	84.7	
	3a	30.1	154	
	3b	28.9	147	
A 4	1a	16.6	84.7	
	1b	7.75	39.5	
	2a	16.3	83.2	
	2b	15.0	76.5	
	3a	17.0	86.7	
	3b	7.25	37.0	

Coating No.	Sequence	Force lbs.	Shear Strength psi	Remarks
A 6	1a	4.90	25.0	
	1b	6.15	31.4	
	2a	4.00	20.4	
	2b	6.55	33.4	
	3a	13.3	67.9	
	3b	22.5	115	
A 9	1a	3.65	18.6	
	1b	3.00	15.3	
	2a	2.40	12.2	
	2b	1.45	7.40	
	3a	2.65	13.4	30% coating removed, 15% damaged *
	3b	1.95	9.95	20% coating removed, 10% damaged *
A 11	1a	14.7	75.0	coating marked but not removed, 20%
	1b	17.8	90.8	coating marked but not removed, 80%
	2a	12.8	65.3	70% coating removed, 5% damaged
	2b	9.95	50.8	40% coating removed, 20% damaged
	3a	6.40	32.7	85% coating removed, 5% damaged
	3b	7.50	38.3	60% coating removed, 5% damaged
A 12	1a	8.00	40.8	
	1b	5.60	28.6	
	2a	7.05	36.0	
	2b	6.00	30.6	
	3a	11.8	60.2	
	3b	12.1	61.7	
A 15	1a	14.7	75.0	
	1b	19.0	96.9	10% coating removed, 30% damaged
	2a	28.7	146	80% coating removed, 5% damaged
	2b	23.0	117	20% coating removed, 10% damaged
	3a	27.8	142	85% coating removed, 5% damaged
	3b	26.0	133	55% coating removed, 15% damaged
A 16	1a	5.65	28.8	20% coating removed, 5% damaged
	1b	6.10	31.1	25% coating removed, 5% damaged
	2a	5.85	29.8	30% coating removed, 10% damaged
	2b	5.95	30.4	45% coating removed, 5% damaged
	3a	4.70	24.0	45% coating removed, 5% damaged
	3b	4.40	22.4	60% coating removed, 5% damaged

Coating No.	Sequence	Force lbs.	Shear Strength psi	Remarks
A 17	1a	7.10	36.2	40% coating removed, 2% damaged
	1b	4.95	25.3	25% coating removed, 10% damaged
	2a	5.65	28.8	50% coating removed, 10% damaged
	2b	5.60	28.6	60% coating removed, 5% damaged
	3a	6.10	31.1	55% coating removed, 5% damaged
	3b	5.20	26.5	65% coating removed, 5% damaged
A 18	1a	2.20	11.2	
	1b	2.50	12.8	
	2a	3.00	15.3	
	2b	3.15	16.1	
	3a	4.50	22.9	
	3b	4.55	23.2	
A 19	1a	3.40	17.3	
	1b	2.35	12.0	
	2a	3.55	18.1	
	2b	1.75	8.93	
	3a	6.35	32.4	
	3b	3.25	16.6	
A 20	1a	1.30	6.63	
	1b	1.90	9.69	
	2a	1.50	7.65	
	2b	2.45	12.5	
	3a	1.95	9.95	
	3b	2.50	12.8	20% coating damaged but not removed
A 21	1a	7.75	39.5	
	1b	6.05	30.9	
	2a	5.75	29.3	
	2b	5.90	30.1	
	3a	7.70	39.3	
	3b	7.10	36.2	
A 22	1a	5.05	25.8	
	1b	2.90	14.8	
	2a	6.55	33.4	15% coating removed, 10% damaged
	2b	4.10	20.9	
	3a	12.5	63.8	35% coating removed, 5% damaged
	3b	10.9	55.6	

Coating No.	Sequence	Force lbs.	Shear Strength psi	Remarks
A 23	1a	4.35	22.2	
	1b	3.40	17.3	
	2a	4.35	22.2	
	2b	4.15	21.2	
	3a	6.55	33.4	
	3b	·6.10	31.1	

* Coating peeling in areas other than test area.

Tests Supervised and Certified By:

Ray L Hauser

Dr. Ray L. Hauser, Research Director

HAUSER
LABORATORIES

560 CENTRAL AVE. P.O. BOX G, BOULDER, COLORADO 80302 • PH. 303-443-4 62

November 5, 1976
Test Report No. 76-498

CLIENT: Ball Brothers Research Corporation
P.O. Box 1062
Boulder, Colorado 80306
Attention: George Ahlbo n — P.O. No. 15584

MATERIAL: Ten 3 inch by 6 inch coated coupons, E prefix #1, E #7-15.

TESTS: pH, Total Solids, BOD, and COD.

METHOD: Per US EPA.

RESULTS: Samples were soaked 48 hours in 800 ml distilled water per sample. Tests were performed on portions of the water solutions. Blank was treated in a manner identical to the samples. pH of Blank was less than 7.0 due to absorbed CO_2.

Sample	pH	Total Solids (grams/sample)	mg/liter BOD (5 day at 20°)	mg/liter COD
Blank	5.86	0.0027	3	11
E 1	6.66	0.0074	6	16
E 7	7.05	0.0051	11	25
E 8	7.16	0.0103	9	25
E 9	7.09	0.0115	10	25
E 10	6.02	0.0033	4	11
E 11	5.89	< 0.0015	4	11
E 12	5.97	0.0026	4	14
E 13	5.82	0.0068	6	18
E 14	5.88	0.0073	4	13
E 15	7.65	0.342	252	791

Tests Supervised By:

Dr. T. D. Zieborth, Chief Chemist

RESULTS FROM DESIGN AND RESEARCH

HAUSER
LABORATORIES
5880 CENTRAL AVE. P.O. BOX G, BOULDER, COLORADO 80302 • PH. 303-443-4662

December 14, 1976
Test Report No. 76-569

CLIENT: Ball Brothers Research Corporation
P.O. Box 1062
Boulder, Colorado 80306
Attention: George Ahlborn P.O. No. 15655

MATERIALS: Fourteen concrete and nineteen asphalt pavement cores, supplied and identified by client.

TESTS: Ice Adhesion Shear Tests were devised to duplicate as nearly as possible the test conditions in previous tests of adhesion to coatings on pavement cores. (Test Report No. 74-343)

After cooling cores to proper temperature, two teflon rings 0.50 inch I.D. by 0.25 inch high were located on each core, filled with distilled water, and then frozen. The cores were allowed approximately 16 hours temperature soak at proper temperature. Specimens were tested by attaching a 1/16 inch diameter steel cable to the fixed crosshead member of a tensile machine. The cable was looped around the teflon ring where upon the core, attached to the movable crosshead member, was pulled away at the prescribed rate. The load was measured by a 500 pound bytrex load cell with electronic readout to an X-Y Recorder. Tests were conducted at the four following prescribed conditions:

(1) -5°C at 0.5 cm/sec.
(2) -12°C at 0.5 cm/sec.
(3) -5°C at 0.05 cm/sec.
(4) -12°C at 0.05 cm/sec.

New test locations were used for each of the four conditions.

RESULTS: Data are listed on the attached tables; failure modes are abbreviated as follows:

A - Adhesive
S - Shear through the ice
A/S - Combination of adhesive and shear failures in which the greater part was adhesive
S/A - Combination with more shear
Number eg. 25 - Test in which coating was removed from core, number indicates estimated percentage of test area from which the coating was removed
R - Tests in which part of the core was removed, number indicates percentage of test area from which the core was removed.

Testing Supervised and Certified By:

Ray L. Hauser

Dr. Ray L. Hauser, Research Director

RE$ULTS FROM DE$IGN AND RE$EARCH

Core I.D.	Test Position	-5°C at 0.5 cm/sec.			-12°C at 0.5 cm/sec.			-5°C at 0.05 cm/sec.			-12°C at 0.05 cm/sec.		
		Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode
1	1	36.8	187	A/S	35.2	179	A	41.1	209	A	45.9	234	S
		40.7	207	A/S	36.8	187	A	40.4	206	A/S	42.4	216	S
	2	39.9	203	A/S	18.8	95.7	A	42.4	216	A	38.1	194	S
		29.7	151	A/S	34.1	174	A	41.2	210	A/S	44.7	228	S
3	1	47.3	241	A/S,15	15.0	76.4	A	22.5	116	A,5	15.1	76.9	A
		27.1	138	A/S,20	20.8	106	A,10	12.9	65.7	A,20	28.8	147	A,5
	2	44.7	228	A/S,25	11.5	58.6	A	33.1	169	A	47.3	241	A,15
		30.2	154	A/S,35	23.9	122	A	15.9	81.0	A,15	28.6	146	A,90
4	1	47.3	241	A/S,50	14.0	71.3	A	17.1	87.1	A	19.0	96.8	A
		24.9	127	A/S,50	27.2	139	A,20	20.1	102	A,90	47.5	242	A/S,20
	2	24.7	126	A	10.4	53.0	A	17.0	86.6	A	14.4	73.3	A/S
		20.0	102	S/A,30	32.9	168	A	19.7	100	A,25	37.8	193	S/A,10
5	1	9.1	46.3	A	18.3	93.2	A	20.5	104	A	25.1	128	A/S,20
		37.0	188	S/A,60	28.0	143	A/S,5	19.0	96.8	A,10	26.2	133	A,25
	2	6.0	30.6	A	24.5	125	A/S	21.9	112	A	14.9	75.9	A,10
		41.5	211	S	39.1	199	A,5	16.0	81.5	A,10	40.9	208	A,75
6	1	30.7	156	A,30	8.0	40.7	A	14.5	73.8	A	13.1	66.7	A,10
		23.9	121	A,60	33.0	168	A,15	15.2	77.4	A	24.3	124	A,50
	2	7.7	39.2	A	10.5	53.5	A	12.9	65.7	A	8.6	43.8	A,5
		20.6	105	A,5	16.1	82.0	A/S,15	8.4	42.8	A	15.9	81.0	A,15
7	1	24.6	125	A/S	12.7	64.7	S	18.3	93.2	A	24.5	125	A
		18.5	94.2	A	17.5	89.1	A	15.2	77.4	A	20.4	104	A
	2	31.0	158	A/S	22.3	114	A/S	21.3	108	A	23.9	122	A
		12.2	61.9	A	17.5	89.1	A	17.5	89.1	A	19.2	97.8	A
8	1	17.0	86.6	A	6.3	32.1	A	17.0	86.6	A	16.5	84.0	A
		21.9	111	A/S	16.7	85.1	A	13.4	68.2	A	16.1	82.0	A
	2	19.0	96.8	A	16.1	82.0	A	15.0	76.4	A	12.6	64.2	A
		17.2	87.3	A/S	12.0	61.1	A	11.0	56.0	A	13.5	68.8	A

		-5°C at 0.5 cm/sec.			-12°C at 0.5 cm/sec.			-5°C at 0.05 cm/sec.			-12°C at 0.05 cm/sec.		
Core I.D.	Test Position	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode
9	1	15.4	78.4	A/S	5.1	26.0	A,5	10.5	53.8	A	15.7	80.0	A/S
		15.2	77.4	A/S	12.1	61.6	A,10	13.5	68.8	A	18.9	92.3	A/S
	2	15.5	78.7	A/S	11.6	59.1	A	12.0	61.1	A	13.1	66.7	A
		12.5	63.4	A/S	13.1	66.7	A	14.9	75.9	A	17.5	89.1	A
10	1	11.9	60.4	A	11.8	60.1	A	9.0	45.8	A	19.6	99.8	A
		13.3	67.5	A	18.0	91.7	A	11.0	56.0	A	17.5	89.1	A
	2	16.2	82.3	A	9.9	50.4	A	10.5	53.9	A	15.5	78.9	A
		13.0	66.2	A	10.3	52.5	A	11.2	57.0	A	16.3	83.0	A
11	1	29.8	152	A/S	36.0	183	A/S	46.9	239	A	35.4	180	A/S
		41.0	209	A	44.7	228	A/S	36.0	183	A	46.0	234	A
	2	36.8	187	A/S	34.9	178	A/S	40.0	204	A/S	47.5	242	A/S
		30.0	153	A	42.9	218	A/S	37.7	192	A/S	47.5	242	A
13	1	38.1	194	S/A	34.8	177	A/S	24.0	122	A/S	29.7	151	A/S
		18.7	94.2	A/S	31.7	161	A	28.1	143	A/S	48.0	244	A/S
	2	42.1	214	S/A	37.0	188	A/S	15.9	81.0	A/S	23.3	119	A
		20.7	105	S/A	28.5	145	A/S	19.9	101	A/S	34.9	178	A/S
14	1	47.3	241	A/S	37.7	192	S/A	18.4	93.7	A	32.2	164	A/S
		7.8	39.7	A/S	47.4	241	A/S	19.2	97.8	A	32.9	168	S/A
	2	30.8	157	A	35.2	179	A	19.3	98.3	A	31.0	158	A/S
		32.0	163	A/S	36.0	183	A/S	22.8	116	A	46.2	235	S/A
15	1	20.5	104	A/S	17.6	89.6	A	18.2	92.7	A	23.0	117	A
		26.1	133	A/S	13.0	66.2	A	27.2	139	A	31.1	158	A/S
	2	26.1	133	A/S	15.7	79.9	A	17.4	88.6	A	17.4	88.6	A
		13.6	69.0	A/S	13.8	70.3	A/S	15.2	77.4	A/S	27.6	141	A
16	1	26.4	131	A	17.6	89.6	A	18.7	95.2	A	25.7	131	A
		28.6	146	S	14.7	74.9	A/S	18.2	92.7	A	43.8	223	S/A
	2	27.1	138	A	24.4	124	A	15.2	77.4	A/S	27.4	140	A
		18.8	95.7	A/S	12.1	61.6	A/S,5	15.9	81.0	A	40.0	204	A/S

Core I.D.	Test Position	-5°C at 0.5 cm/sec.			-12°C at 0.5 cm/sec.			-5°C at 0.05 cm/sec.			-12°C at 0.05 cm/sec.		
		Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode
25	1	23.5	119	100R	21.0	107	S	30.0	153	A/S	28.5	145	A/S
		36.9	188	S	11.6	59.1	S/A	19.1	97.3	S	24.2	123	S/A
	2	36.9	188	S	30.9	157	S/A	19.9	101	S	22.0	112	A/S,20R
		20.0	102	S/A, 15R	36.0	183	S/A,40R	25.2	128	S	28.2	144	S/A
27	1	28.6	145	S/A	36.8	187	A	34.5	176	A/S	35.3	180	S/A
		25.8	131	S/A	11.0	56.0	S/A	33.5	171	S	42.6	217	A/S
	2	20.0	102	S/A	47.4	241	S	36.8	187	A/S	29.6	151	S/A
		26.3	134	S/A	29.6	151	S/A	39.0	198	S	30.1	153	A/S
28	1	31.1	158	S/A	33.5	171	S/A	25.7	131	S	43.5	222	S
		45.3	231	S	38.5	196	A	45.1	230	S	46.4	236	A/S
	2	29.9	152	A/S	47.5	242	A	46.0	234	S/A	48.5	247	S
		47.4	241	S	40.0	204	A/S	28.2	144	S	38.4	196	A/S
29	1	11.0	56.0	S	34.2	174	S/A	39.1	199	S/A	44.2	224	S
		34.5	176	S/A	39.1	199	S/A	11.8	60.1	S/A	40.5	206	S
	2	9.5	48.4	S	30.3	154	S/A	35.5	181	S	42.4	216	S
		22.5	115	S/A	28.4	145	S/A, 15R	16.4	83.5	S/A	37.2	189	S
30	1	23.6	120	S/A	45.5	232	S	41.0	209	S	42.7	217	S
		36.5	186	S/A	40.0	204	S	33.2	169	S	44.2	225	A/S
	2	30.8	157	S	47.3	241	S	47.3	241	S/A	47.3	241	S
		24.1	123	A/S	47.5	242	S/A	35.5	181	S	47.3	241	A/S
A	1	42.0	214	S	33.4	170	A	36.4	185	S/A	40.5	206	A
		28.6	146	S	25.6	130	S	32.5	166	S/A	35.6	181	A
	2	47.4	241	S	48.2	245	A	50.0	255	A/S	49.7	253	A
		44.7	227	A/S	34.5	176	A	44.7	228	A/S	47.2	240	A/S
C	1	15.3	77.9	A/S	24.4	124	A	17.9	91.2	A	24.5	125	A
		39.8	203	S/A	15.7	80.0	A	15.9	81.0	A,5	24.7	126	S/A
	2	47.4	241	S/A	16.8	85.6	A	16.0	81.5	A,15	33.4	170	A/S
		32.6	166	A/S,5	24.5	125	A	15.9	81.0	A,30	38.0	194	S/A,5

Core I.D.	Test Position	-5°C at 0.5 cm/sec. Load lbs.	-5°C at 0.5 cm/sec. Shear Strength psi	-5°C at 0.5 cm/sec. Failure Mode	-12°C at 0.5 cm/sec. Load lbs.	-12°C at 0.5 cm/sec. Shear Strength psi	-12°C at 0.5 cm/sec. Failure Mode	-5°C at 0.05 cm/sec. Load lbs.	-5°C at 0.05 cm/sec. Shear Strength psi	-5°C at 0.05 cm/sec. Failure Mode	-12°C at 0.05 cm/sec. Load lbs.	-12°C at 0.05 cm/sec. Shear Strength psi	-12°C at 0.05 cm/sec. Failure Mode
D	1	45.0	229	S	36.0	183	A/S	28.1	143	A,20	47.5	242	S/A
		26.4	134	S,15	25.0	127	S/A,5	18.1	92.2	A,20	24.6	125	A,5
	2	46.2	235	S	43.4	221	A/S	28.6	146	A,40	47.5	242	A/S
		23.5	119	S,50	47.5	242	S	19.3	98.3	A,45	24.6	125	A
E	1	43.9	224	S/A	30.0	153	A,5	19.3	98.3	A/S	28.7	146	A,5
		20.8	106	A,10	27.2	139	S/A,5	17.3	88.1	A	17.7	90.1	A,10
	2	45.6	232	S/A	28.6	146	S/A	22.7	116	A/S	21.8	111	A,5
		11.7	59.3	A,15	24.8	126	A/S,10	9.2	46.9	A	21.0	107	A,20
F	1	33.0	168	S/A	36.0	183	S/A,5	23.5	120	A/S	31.4	160	S
		33.3	169	S/A,5	28.3	144	A,20	20.7	105	A,15	10.1	51.4	A,35
	2	42.4	216	S/A	33.0	168	A/S,10	47.4	241	S/A	38.9	198	S
		24.7	126	S/A,25	35.7	182	S/A,10	22.0	112	A,5	15.1	76.9	A,5
G	1	15.1	76.9	A/S	6.0	30.6	A	15.8	80.5	A	14.7	74.9	A
		15.5	78.9	A	7.3	37.2	S	12.0	61.1	A	14.0	71.3	A
	2	16.6	84.5	A/S	16.9	86.1	A	18.6	94.7	A	21.4	109	A/S
		15.0	76.1	A	19.0	96.8	A	11.8	60.1	A	17.2	87.6	A/S
H	1	8.50	43.3	A	17.5	89.1	A	12.5	63.7	A	11.2	57.0	A
		8,15	41.5	A/S	12.7	64.7	A	13.4	68.2	A	13.0	66.2	A
	2	16.9	85.8	A	15.1	76.9	A	11.6	59.1	A	12.5	63.7	A
		9,80	49.9	A/S	11.9	60.6	A	9.4	47.9	A	14.6	74.4	A
I	1	11.0	56.0	A/S	9.3	47.4	A	9.6	48.9	A	9.1	46.3	A
		11.3	57.3	A	9.5	48.4	A/S	11.7	59.6	A	9.4	47.9	A
	2	11.6	58.8	A/S	11.5	58.6	A	7.7	39.2	A	5.9	30.0	A
		7.6	38.5	A	11.0	56.0	A	7.5	38.2	A	10.6	54.0	A
J	1	18.9	96.3	A/S	9.5	48.4	A/S	12.6	64.2	A	13.0	66.2	A
		4.7	23.8	A/S	15.9	81.0	A	12.0	61.1	A	15.0	76.4	A
	2	25.0	127	A/S	22.3	114	A/S	10.1	51.4	A	13.2	67.2	A
		14.9	75.9	A/S	15.3	77.9	A	12.3	62.6	A	8.3	42.3	A

		-5°C at 0.5 cm/sec.			-12°C at 0.5 cm/sec.			-5°C at 0.05 cm/sec.			-12°C at 0.05 cm/sec.		
Core I.D.	Test Position	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode	Load lbs.	Shear Strength psi	Failure Mode
K	1	31.4	160	A/S	22.8	116	S/A	24.7	126	A/S	37.1	189	A/S
		37.1	189	A/S	37.5	191	A/S	38.6	197	A	38.5	196	A
	2	24.2	123	A/S	41.2	210	A	27.8	142	A/S	33.3	170	A
		37.6	191	A/S	28.1	143	A	22.0	112	A/S	40.8	208	A
M	1	42.1	214	S/A	22.9	117	A/S	37.9	193	A/S	20.8	106	A/S
		19.6	99.8	S/A	27.0	138	A	23.1	118	A/S	33.3	170	A/S
	2	28.9	147	A/S	23.2	118	A/S	33.4	170	S/A	24.6	125	A/S
		9.5	48.4	A/S	17.4	88.6	A	16.4	83.5	A/S	25.8	131	A
N	1	44.4	226	A/S	28.6	146	S/A	39.8	203	A/S	23.9	122	S/A
		33.9	172	S/A	44.2	225	S/A	20.4	104	A/S	39.2	200	A/S
	2	38.2	195	A/S	13.7	69.8	S/A, 10R	25.4	129	A/S	20.4	104	A/S
		25.0	127	A/S	14.8	75.4	S, 10R	14.2	72.3	A/S	31.9	162	A
O	1	31.7	161	S/A	25.3	129	A	27.6	141	A	24.1	123	A/S
		24.9	127	A/S	39.0	199	A	24.8	126	A/S	13.2	67.2	A/S
	2	36.9	188	A/S	31.4	160	A	28.5	145	A/S	14.8	75.4	A
		24.6	125	A/S	33.0	168	S	25.9	132	A/S	20.9	106	A
P	1	34.6	176	A/S	41.0	209	A/S	17.5	89.1	A	30.0	153	A
		20.0	102	A/S	15.9	80.9	A/S	24.5	125	A	21.3	108	A
	2	11.7	59.6	A/S	27.0	138	A/S	21.5	109	A	27.0	138	A
		28.3	144	A/S	10.8	55.0	A	16.8	85.6	A	26.5	135	A/S

APPENDIX B

TOXICITY OF NINE EXPERIMENTAL ROAD SURFACING MATERIALS TO *DAPHNIA PULEX*

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INTRODUCTION

The acute toxicity of eight hydrophobic and one non-hydrophobic road surfacing materials were tested with Daphnia pulex, a common aquatic crustacean. The test materials are experimental compounds formulated to prevent ice adhesion to road surfaces. The formulation of the hydrophobic compounds designated as formula B, C, F, G, I, J, K and L are given in Table 1. The non-hydrophobic test material was Petroset AT (Phillips Petroleum).

The assays were designed to simulate two possible toxic modes.

The materials in use will be spread as a thin layer on a road surface and the material is formulated for rapid drying time. The toxicity of a water leachate from contact with the dried material is of greatest concern.

The toxicity of a leachate from undried compounds simulate runoff from freshly applied material.

The assay objectives were to define relative short-term toxicity.

METHODS

The test organism was Daphnia pulex. Our laboratory culture has been cloned three times from a wild stock collected in Medical Lake, Washington. Daphnia pulex is cultured in aquaria at room temperature (20°to 24°C), under 16 hour artificial daylength (approximately 100 ft. candles). The feed is a mixture of Selanastrum capricornutum and Carteria quadrata which is batch cultured. The algae media is carbon filtered tap water (see below) with addition of nitrogen, phosphorus and manure extract.

The water used for culturing Daphnia pulex, as a base for the algae media, and for preparing leachates is carbon filtered well water. The chemical characteristics of this water are given in Table 2.

Leachates of dried materials were prepared by drying the materials in beakers for 24 hours at room temperature under a hood. The beakers were rotated at approximately 200 rpm to prevent a surface film from developing. The beakers were then placed in a 100°C oven for 48 hours. Although formulas B through L dry rapidly when spread in a thin layer (<1/2 hour) when large quantities are dried it forms a surface layer which prevents further drying. To promote drying the materials were stirred frequently while in the drying oven. Each of the dried materials (except Petroset AT) was placed in a blender with an equal weight of dilution water and blended until finely ground. Dried Petroset AT has the consistency of light tar so water was added to this material without blending. The water and ground materials were placed in a stoppered flask and rotated at 300 rpm for 2 days at room temperature. The leachate water was then filtered with a Whatman #2 filter which had been rinsed with distilled water.

Wet leachates were prepared from formulas B through L by simply adding an equal volume of water to the surfacing compound. The reagent bottle containers were placed on a shaker table and the speed adjusted to move the materials in the bottles but not to break down the boundary layer. Although the materials are hydrophobic they will emulsify with water with strong enough agitation. The materials were rotated for 2 days, then the water (wet leachate) was aspirated and collected.

Both dry and wet leachates were stored at 4°C until used for testing.

Test dilutions of leachates were prepared 8 to 16 hours before the assays were begun.

Wet Petroset AT solutions were made as simple water dilutions of the raw material. Fresh solutions were made for each test.

All glassware used in the assays were cleaned with detergent, rinsed with distilled water, rinsed with 1:1 HCL, and then rinsed twice with distilled water.

Assays were conducted in 50 ml beakers with aluminum foil caps to retard evaporation. Test volumes were 20 or 40 ml. Daphnia pulex were taken from cultures using a zooplankton bucket with a #10 mesh screen. Young Daphnia pulex (estimated one or two days old) were placed in test beakers with an eyedropper. Ten organisms were used in each test container. Carryover of culture water to test beakers was approximately 0.5 ml. Two control beakers containing 20 and 40 ml of diluent water and 10 Daphnia pulex were used for each test. The test animals were fed 3 drops of algea culture on day 2 of the assay.

The assays were run at room temperature (20-21°C). Occasionally when the daytime laboratory temperature rose above 21°C, the assay beakers were moved to a 20°C (+ .5) temperature controlled room.

The beakers were examined for mortalities by scanning with a 20x dissecting microscope. Death was counted and the organisms removed when all feeding and swimming motions ceased and the animal made no response to the eyedropper used to remove it. Assays were terminated at 96 hours.

LC_{50}'s were estimated by plotting the data on log-probit paper and drawing the line by visual best fit. The LC_{50} was read from the fitted line.

Table 1. Formulation of Surfacing Compounds
Mix Quantity/liter

Formula	LR8198[1] (cm^3)	LR8652[1] (cm^3)	Drisil 73[2] (cm^3)	DC732[3] (gm)	naptha (cm^3)	isopropanol (cm^3)
B	476			83	423	18
C	370			128	470	32
F		604		37	348	11
G		523		65	394	19
I			579	34	375	11
J			512	66	407	15
K			455	91	431	23
L			413	107	453	25

[1]Akron Paint and Varnish Company
[2]Texas Solvents and Chemicals Company
[3]Dow Corning Company

TABLE 2

CHEMICAL CHARACTERISTICS OF CULTURE AND DILUTION WATER

total hardness (mg/ℓ $CaCO_3$)	alkalinity (mg/ℓ $CaCO_3$)
120	169
Ca(mg/ℓ) Mg(mg/ℓ)	Specific conductance (pmhos/cm)
21.9 15.7	265
nitrate nitrogen (mg/ℓ)	nitrite nitrogen (mg/ℓ)
0.005	0.028
ammonia nitrogen (mg/ℓ)	pH
0.18	8.3 - 8.5
residual chlorine (mg/ℓ)	
<0.04	

Table 3. Percentage mortality of *Daphnia pulex* in leachates of dried surfacing materials.

Formula	Percent solution of dry leachates 100	75	67	56	50	42	32	18	10	estimated LC_{50} (96 hr)
B	100	--	100	100	91	--	100	0	0	24
C	100	--	100	100	89	0	0	0	0	49
F	100	--	90	100	78	--	33	25	30	40
G[1]	88	--	25	--	30	--	--	--	--	70
G[2]	--	--	100	--	--	--	100	100	--	--
I	0	--	--	--	--	--	--	--	--	>100
J	11	--	--	--	0	--	--	--	--	--
K	0	--	--	--	--	--	--	--	--	>100
L	100	85	90	0	10	--	0	0	--	60

[1]Test track preparation

[2]Laboratory preparation

Table 4. Percentage mortality (%) of *Daphnia pulex* in leachates of undried surfacing materials.

Formula	Percentage solution of undried leachate: 18	14	10	7.5	5.6	3.2	1.8	estimated LC_{50} (96 hr)
B	100 (7.9)[1]	60 (8.3)	70 (8.3)	40 (8.4)	22 (8.4)	0	--	8
C	100 (8.0)	100 (8.1)	30 (8.0)	20 (8.0)	--	--	--	9.4
F	100 (5.5)	5 (7.7)	0 (7.9)	14 (8.1)	0 (8.1)	--	--	13
G	--	--	100 (5.2)	40 (7.7)	30 (8.0)	10	0 (8.4)	5.8
I	100 (5.2)	40 (7.6)	0 (7.8)	0 (8.1)				14
J	--	--	100 (7.8)	0 (8.0)	0 (7.8)	0 (8.2)	0 (8.3)	8.6
K	--	--	100 (4.9)	100 (6.8)	0 (7.7)	0 (8.1)	0 (8.3)	6.4
L	--	--	100 (4.6)	--	100 (7.3)	15 (8.1)	0 (8.1)	3.4

[1]pH of test solution

TABLE 5

PERCENTAGE MORTALITY OF DAPHNIA PULEX IN WATER DILUTIONS AND DRY LEACHATE OF PETROSET AT

Petroset AT dilution υl/ℓ					estimated LC_{50} (96 hr)
0.32	0.18	0.10	0.056		
100	100	33	0		0.11 υl/ℓ
Dried Petroset AT leachate υl/ℓ					6.0 υl/ℓ
17.8	10	5.6	3.2	1.8	
100	90	30	8	0	

RESULTS

The estimated LC_{50}'s of the dry leachates varied from 24 percent to greater than 100 percent (Table 3).

The toxicity would probably be slightly higher if softer water were used for leaching the dried materials but even a moderate increase in toxicity would not alter the conclusion that this material qualifies as "practically not toxic" as defined in Cairns (1973).

Some change in the toxicity of formula G was noted for the material made at the test track and the material made in the laboratory.

The wet leachates are approximately 7 times more toxic than the dry leachates and the estimates of LC_{50}'s range from 3.4 to 14 percent (Table 4). These leachates are also of low toxicity. Low pH probably contributes to the toxicity of wet leachates F, G, I, K and L.

Petroset AT and the leachate of dried Petroset AT are very toxic with estimated LC_{50}'s of 0.11 $\mu l/\ell$ and 6.0 $\mu l/\ell$ respectively. This material mixes readily with water and drys slowly which means it is more susceptible to leaching into surface waters.

CONCLUSION

The hydrophobic materials (B-L) were tested under laboratory conditions designed to extract the maximum amount of toxic material into the water leachate. Both wet and dry leachates of these materials are practically nontoxic.

Petroset AT mixes readily with water. The dry leachate and water mixture is toxic to very toxic.

REFERENCES

Cairns, John Hr., and K. S. Dickson, (ed.) 1973, Biological Methods for the Assessment of Water Quality. ASTM Special Technical Publication 528.

APPENDIX C

INFRARED ABSORPTION SPECTROPHOTOMETRIC ANALYSIS OF TEST TRACK RUNOFF

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INTRODUCTION

Analysis of runoff, natural and artificial, from the WSU Test Track was carried out by infrared analysis to determine the amount of leaching from the experimental surfacing compounds and to correlate the runoff with the toxicity assays.

The materials of interest are components of experimental compounds formulated to prevent ice adhesion to road surfaces. These compounds are named LR 8198, LR 8652, Drisil 73, Petroset AT, and Viscospin B. By examining the spectra of the pure compound, wavelengths were found at which absorption was considerably greater than for other compounds present in samples. A comparison between sample spectra and the reference spectra allowed determination of the concentration of a compound within the sample.

An assumption was made for analysis that the binder in the mixtures (LR 8198, LR 8652, Drisil 73) would be the only part of the compounds to leach. Petroset was analyzed as Petroset.

METHODS

Because of extremely low precipitation during the test period (Winter 1976-1977), natural runoff was augmented by flooding the test track with well water. The well water is approximately the same chemical composition as given in Table 2 of the toxicity assays.

The identification of a compound in runoff waters required initial concentration of the samples. Samples from test holes at the track were dried in evaporation dishes, and the residue was weighed. The dried solids were dissolved in carbon tetrachloride solvent, and the sample was analyzed for pavement additive by infrared absorption spectrophotometry. The device utilized was a Beckman IR 8 infrared spectrophotomer. By comparison with a reference spectra, the percentage of additive within each sample was determined. Multiplication of the concentration of total solids by the percentage of additive contained yielded the concentration of additive contained within each sample.

Dry leachates from the toxicity assays were run by direct analysis of the aqueous solution for LR analysis.

RESULTS

The analysis of the runoff from 14 track sections on February 16, 1977 (Table 1) showed seven were below the detection limits of 0.5 percent. Concentrations above detectable limits ranged from four to thirty mg/l.

The analysis of runoff in test shows 1, 4, 7, and 9 on March 9, 1977 showed a decline in concentration from previous runoff samples analyzed on February 16, 1977. Four runoff samples were above detectable limits in the series of samples run on March 9, 1977.

The analysis of the aqueous leachates used for the toxicity assays by direct analysis gave results that were obviously much too high (Table 2) considering the limited solubility of these materials. Apparently, the aqueous solutions attenuated the absorptivity and gave erroneously high peaks.

CONCLUSIONS

The concentrations of road surfacing materials in the runoff samples was generally small. Analysis of runoff approximately three weeks apart indicated a decline in concentration. The analysis of water leachates gave concentrations that were obviously too high.

Table 1. Analysis of Test Track Runoff by Infrared Spectrophotometry.

DATA

Date of Samples: 2/16/77

Test Hole No.	Total Solids (mg/l)	Compound	% Compound	Conc. Compound (mg/l)
1	420	Petroset AT	7.1	30
2	444	Petroset AT	<0.5	< 3
4	240	Drisil	1.9	5
7	250	LR 8652	6.4	16
8	100	LR 8198	<0.5	<0.5
9	160	LR 8198	5.5	9
14	360	Drisil	3.9	14
15	60	Drisil	<0.5	<0.3
17	190	LR 8652	7.7	15
18	170	LR 8198	<0.5	< 1
19	260	LR 8198	1.4	4
27	130	Petroset AT	<0.5	< 1
28	340	Petroset AT	<0.5	< 2
29	240	Viscospin B	<0.5	< 2

Date of Samples: 3/9/77

Test Hole No.	Total Solids (mg/l)	Compound	% Compound	Conc. Compound (mg/l)
1	922	Petroset AT	1.0	9
2	592	Petroset AT	<0.5	< 3
3	300	Drisil	<0.5	< 2
4	362	Drisil	<0.5	< 2
5	462	Drisil	<0.5	< 3
6	516	LR 8652	<0.5	< 3
7	743	LR 8652	<0.5	< 4
8	266	LR 8198	<0.5	< 2
9	300	LR 8198	<0.5	< 2
10	246	Petroset AT	<0.5	< 2
15	583	Drisil	<0.5	< 3
16	334	LR 8652	<0.5	< 2
20	1,404	LR 8198	1.8	26
21	185	LR 8198	5.5	10
22	238	LR 8198	2.3	5
23	292	Blank	<0.5	
28	414	Petroset AT	<0.5	< 2
29	296	Viscospin B	<0.5	< 2

Table 2. Compound Concentration in the Dry Leachates used for Toxicity Essays.

Formula (1)	Compound (2)	Dry Leachate Concentration (%) (3)
B	LR 8198	76.4
C	LR 8198	18.2
F	LR 8652	71.8
G	LR 8652	66.7
I	Drisil 73	36.8
J	Drisil 73	18.4
K	Drisil 73	65.8
Petroset	Petroset	157

*U.S. GOVERNMENT PRINTING OFFICE: 1978 260-880/61 1-3

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-035	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE OPTIMIZATION AND TESTING OF HIGHWAY MATERIALS TO MITIGATE ICE ADHESION Interim Report		5. REPORT DATE March 1978 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) M. Krukar and J. C. Cook		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State University Pullman, Washington 99163		10. PROGRAM ELEMENT NO. 1BC611:SOS 2; Task: 05 11. CONTRACT/GRANT NO. R-804660
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Interim 10/76 - 4/77 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

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16. ABSTRACT This project optimized and evaluated hydrophobic materials developed by EPA research in 1974. Laboratory optimizing of materials was accomplished by Ball Brothers Research Corporation (BBRC) under contract with Washington State University (WSU).

Field tests at the WSU Pavement Test Facility augment BBRC laboratory tests with comparative results. Factors of concern included pavement type, tire type, environment and toxicity, wear, ice/snow adhesion and asphalt overlays which included the substances as a component of the mix.

Although the winter conditions were mild, the limited amount of tests and data did allow a ranking based on skid resistance change, water beading, and snow/ice removal properties of the different formulations. The most effective formulations were combinations of modified traffic paints and room-temperature-curing silicone rubber.

Of the formulations tested only one was deemed toxic. Other formulations showed little or no toxicity.

Routine application (including purchase cost) to medium-sized areas of the optimized mixtures is expected to cost $0.50/m^2$ to $1.00/m^2$.

Although definitive results were obtained in the study, unusually mild winter conditions in eastern Washington in 1976-1977 restricted completion of the desired operational parameters. In order to obtain research fulfillment, a repeat of the test program is planned during the winter of 1977-1978. Iteration will also increase the statistical validity of the results discussed in this project.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Deicers, Ice control, Ice breakup, Water pollution, Pavements, Economic analysis	Environmental impact, Hydrophobic materials, Pavement deicers, Water/ice phobicity, Test track facility	13B

18. DISTRIBUTION STATEMENT RELEASE UNLIMITED	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 156
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77)