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Project Summary

Evaluation of Flexible Membrane Liner Seams after Chemical Exposure and Simulated Weathering

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Strength and durability were tested in presently available seaming systems for flexible membrane liners (FML). The seams were exposed to selected, simulated environmental conditions over short periods of up to 52 weeks. A total of 37 combinations of supported and unsupported polymeric sheet materials joined by various seaming methods was subjected to 6 chemical solutions, brine and water immersion, freeze/thaw cycling, wet/dry cycling, heat aging, and accelerated outdoor aging. Effects of these environmental conditions were evaluated using shear and peel strength tests before and after exposure. The tests were performed under dynamic load at room temperature and under static dead load at 50°C. In addition six NDT (nondestructive test) methods were evaluated.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A considerable number of laboratory tests and pilot-scale studies have been conducted by various Government and private-sector groups to assess the effects of chemical waste products on the integrity of FMLs in hazardous waste containment facilities. However, little has been done to assess the performance of the various types of seams used in joining the manufactured roll goods in the factory and the panels seamed in the field. To learn more about the strength and durability of seams made by presently available seaming systems, the U.S. Environmental Protection Agency (USEPA) has funded research with the U.S. Bureau of Reclamation (USBR) to evaluate FML seams exposed to selected, simulated environmental conditions over short periods of up to 52 weeks. The seams listed in Tables 1 and 2 were subjected to six chemical solutions, brine and water immersion, freeze/thaw cycling, wet/dry cycling, heat aging, and accelerated outdoor aging.

Effects of the environmental conditions in this study were evaluated using shear and peel strength tests before and after exposure. The tests were performed under dynamic load at room temperature, and under static dead load at 50°C (122°F). In addition to seam testing, six nondestructive test (NDT) methods were evaluated in this study. The six NDT methods were:

- Acoustic method - ultrasonic pulse echo (5 to 15 MHz)
- Acoustic method - continuous wave resonant frequency (167 kHz)
- Air lance - 345 kPa (50 lb/in^2)
- Vacuum chamber
- Double seam pressurization
- Mechanical point stress

Exposure Methods

For chemical immersion, solutions were chosen to represent a wide range

Table 1. *Types of Factory Seams Evaluated*

Lining Material	Scrim reinforcement	Seaming method	Seam width (in)
36-mil CPE	6 × 6 leno polyester	Thermal-hot air	2.25
36-mil CPE	10 × 10 polyester	Thermal-hot air	1.00
30-mil CSPE	8 × 8 polyester	Thermal-hot air	2.50
36-mil CSPE	6 × 6 polyester	Thermal-hot air	3.00
36-mil CSPE	10 × 10 polyester	Thermal-hot air	2.00
36-mil CSPE	6 × 6 leno polyester	Thermal-hot air	2.25
36-mil CSPE	10 × 10 polyester	Bodied solvent adhesive	3.00
36-mil CSPE	10 × 10 polyester	Thermal-dielectric	1.25
38-mil EIA	polyester	Thermal-hot air	2.00
40-mil EPDM	10 × 10 nylon	Vulcanized/3/4 in. capstrip	1.50
30-mil CPE	—	Solvent adhesive	1.00
30-mil CPE	—	Thermal-dielectric	0.75
30-mil LLDPE	—	Thermal-hot wedge	0.62
30-mil PVC	—	Solvent adhesive	1.00
30-mil PVC	—	Thermal-dielectric	0.75
30-mil PVC	—	Thermal-dielectric	0.75

Table 2. *Types of Field Seams Evaluated*

Lining Material	Scrim reinforcement	Seaming method	Seam width (in)
36-mil CPE	6 × 6 leno polyester	Bodied solvent adhesive	3.00
36-mil CPE	10 × 10 polyester	Solvent adhesive	3.00
30-mil CSPE	8 × 8 polyester	Bodied solvent adhesive	4.50
36-mil CSPE	6 × 6 polyester	Bodied solvent adhesive	4.50
36-mil CSPE	10 × 10 polyester	Adhesive	3.00
36-mil CSPE	6 × 6 leno polyester	Bodied solvent adhesive	3.00
36-mil CSPE	10 × 10 polyester	Solvent adhesive	3.00
36-mil CSPE	10 × 10 polyester	Solvent adhesive	3.00
36-mil CSPE	10 × 10 polyester	Solvent adhesive	3.00
38-mil EIA	polyester	Thermal-hot air	2.00
40-mil EPDM	10 × 10 nylon	Gum tape/cement	6.50
30-mil CPE	—	Solvent adhesive	3.00
30-mil CPE	—	Solvent adhesive	3.50
30-mil HDPE	—	Extrusion fillet weld	N/A
80-mil HDPE	—	Extrusion fillet weld	N/A
80-mil HDPE	—	Extrusion lap weld	1.75
80-mil HDPE	—	Thermal-hot dual wedge	1.00
30-mil LLDPE	—	Thermal-hot wedge	0.63
30-mil PVC	—	Solvent adhesive	2.00
30-mil PVC	—	Solvent adhesive	3.50
30-mil PVC	—	Solvent adhesive	3.00

of chemical groups. These solutions were:

10 percent phenol (organic acid)

10 percent hydrochloric acid (inorganic acid)

10 percent sodium hydroxide (inorganic base)

10 percent methyl ethyl ketone (ketone)

5 percent furfural (aldehyde)

100 percent methylene chloride (halogenated hydrocarbon)

Methylene chloride is not soluble in water; therefore, pure solvent was used to avoid the problem of phase separation. Pure chemicals or aqueous chemical solutions were selected for testing rather than simulated or actual wastes from waste sites to simplify verification of testing procedures. The use of representative groups of chemicals also allows for reasonable interpretation of the data.

Chemical, brine, and water immersion of seam samples was accomplished in covered 170-liter (45-gal) capacity polypropylene and polyethylene tanks. These tanks were filled separately with each of the liquids and the seam samples were then suspended in the liquids. Three tanks of room-temperature tapwater and six tanks of saturated sodium chloride brine solution [three tanks at room temperature and three at 50°C (122°F)] were also set up for immersing samples at the USBR Laboratory. The samples, except for the room temperature brine, were removed and tested after 3, 6 and 12 months of immersion. Due to an error in scheduling, the room temperature brine samples were only tested after 3 and 12 months of immersion.

The remaining samples were either placed in running tapwater for 6-month saturation before beginning freeze/thaw or wet/dry cycling tests or set aside for heat aging tests. For heat aging, seam samples were subjected for periods of 4, 8, and 13 weeks to oven-aging at 70°C (158°F) in an effort to provide an accelerated test of long-term heat effects on the seam systems. Double-sided exposure of all samples was used to accommodate the large number of samples in minimum space. An advantage of double-sided exposure over single-sided exposure was the reduced time needed to see the effects of the liquids on the samples. In parallel with the tank immersions, smaller coupons of the parent materials were immersed in small, clear glass jars for periodic weight and thickness measurements. The smaller coupons allowed for easier inspection of the polymeric sheet materials for obvious excessive degradation, swelling, or change in color or surface texture. If any accelerated response was observed in the coupons, the seam samples were removed from the larger tanks before they were destroyed completely. The ratio of the volume of liquid to the surface area for each coupon was 6.2 mL/cm^2 (40 mL/in^2).

Thirty-two representative seam samples received accelerated outdoor sunlight exposure testing on accelerated weathering test machines located at the Desert Sunshine Exposure Test (DSET) Laboratories in Phoenix, Arizona. The machines are capable of tracking the sun and focusing the sun's rays on the 5-inch-wide seam specimens for optimum UV (ultraviolet) exposure. The accelerated rate of degradation of the sun exposure is approximately eight times that of conventional outdoor exposure. The samples were visually inspected and photographed after 6 months of exposure. After 1 year of exposure, the samples were again inspected and photographed, and then returned to the USBR where they were tested for peel strength retention and observed for any obvious deterioration.

Test Methods

Coupon samples of some parent materials were measured for weight and

thickness before immersion. The 21 coupon samples, each with dimensions of 50 millimeters by 125 millimeters (2 in by 5 in), were measured after 1, 2, 3, 4, 8, 12, 36, and 52 weeks of immersion.

Initial physical properties were tested on the unexposed seam samples for all lining materials. The data collected represent the virgin materials and seams in an unexposed state as received from the factory or the field fabrication.

After completion of the liquid immersions and the required environmental conditioning intervals, dynamic shear and peel testing and static dead load peel testing were performed to determine changes in physical properties. The dynamic shear and peel tests were conducted in accordance with the test procedures described in ASTM D 4545-86, "Standard Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes."

Test results of exposed seam samples were compared to the test results of original unexposed seam samples for all tests. The mode of failure was evaluated as well as the numerical results of shear, peel, and dead load in lbf/in of seam width.

Several methods are available for qualitatively testing seams without testing samples from a completed lining system. These nondestructive test methods can be used to measure the continuity of a seam but cannot be used to quantitatively measure the relative strength of the joint or the projected future performance. These methods should be used in conjunction with destructive methods in a quality assurance program. Table 3 summarizes the available NDT methods evaluated in this study.

Results

- Results of the study indicate that no direct correlation exists between the seam shear and seam peel strengths. For example, high shear strength does not guarantee high peel strength. The shear test appears to be more indicative of the strengths and weaknesses of the parent material, whereas the peel test is more a measure of the strengths and weaknesses of the seam bond.
- Dead load peel testing indicates that for the most part, no direct correlation exists between the results of this testing and the dynamic peel testing.
- For supported FMLs, the seam strength properties within the same generic group [CPE (chlorinated polyethylene) or CSPE (chlorosulfonated polyethylene) for example] varied depending on the particular FML chemical formulation and the type of scrim (reinforcing fabric).
- Chemical immersion tests indicate that changes in weight and thickness of the materials affected occur quite rapidly.
- In chemical immersion testing the performance of the FML seams was that essentially expected, based on the recommendations of the FML manufacturer and review of the available chemical compatibility data.
- Results of the accelerated outdoor sunlight exposure testing indicate that the one-year exposure may be too long, resulting in accelerated weathering conditions too severe for some materials.
- Of the three thermal methods used to field seam HDPE liners, evaluated in this study, the extrusion lap weld produced the highest shear and peel strengths. The extrusion fillet weld produced a slightly higher shear strength than the hot dual wedge, but the peel strengths of these two seams were nearly identical. In the peel tests, however, the hot dual wedge seam exhibited a failure within the seam area, and the other two field seams failed at the seam edge.
- Of the two factory seaming methods used for the unsupported PVC (polyvinyl chloride) and CPE liners, the seams made with the solvent adhesive exhibited higher shear strengths, whereas those made dielectrically produced higher peel strength values. The higher shear strength was primarily due to the wider factory seam for the solvent adhesive seam. In the shear tests, failure occurred in the parent material. The same was also true for the peel tests, except for the PVC solvent adhesive seam, where the failure occurred within the seam itself. No appreciable difference was noted in the performance of the two seaming methods.
- Studies on the NDT methods indicate that each method has particular strengths and limitations as a check for seam bonding. However, none of the methods determine seam strengths.
- The performance of the individual seams are summarized in tables for chemical immersion and other exposure conditions.

Conclusions

- Peel strength of a seam is an important property that should be tested along with the shear strength to evaluate the quality of a seaming method or operation.
- The dead load peel test, as conducted in this study, was not a valid procedure for evaluating the quality of a seaming method or operation.
- Generic-type material specifications are not sufficient to ensure satisfactory performance of FML seams when used for hazardous waste containment applications.
- Short-term chemical immersion tests of up to 6 months may not be of enough duration to determine the chemical compatibility of some FML seams.
- Existing publishing data and manufacturers' recommendations on chemical compatibility of FML materials give a reasonable basis to make an initial judgment on the expected performance of seams in a given chemical environment.
- The 1-year accelerated outdoor sunlight exposure may be too severe for some FML materials.
- The two factory seaming methods evaluated in this study for PVC and CPE produced satisfactory seams.
- As part of this study, the factory seam requirements listed in NSF Standard No. 54 were reviewed for the materials evaluated. Based on the results of this study, and other USBR studies, the shear requirements (breaking factor) are satisfactory, but the peel requirements (peel adhesion) for the unsupported materials such as CPE and PVC appear to be low.
- The air lance, vacuum chamber, and mechanical point stressing work well on most seam types with some specific limitations.

Recommendations

- The dead load peel test should be conducted utilizing a certain percentage of the ultimate peel strength. This will require additional testing to establish realistic dead load test values for the various FML seams.
- The specifications for hazardous waste containment should incorporate special provisions to ensure a specific FML formulation for chemical compatibility with the materials to be contained.

Table 3. *Recommended NDT Methods Based on This Research*

FML	Thickness (mils)	Ultrasonic pulse echo (5-15 MHz)	Continuous wave resonant frequency (167 kHz)	Air lance	Vacuum chamber	Double seam pressurization	Mechanical point stress
Supported	30		*	*	*		*
CSPE	36		*	*	*		*
and	45		*	*	*		*
CPE	60		*		*		*
Unsupported	20	*	*	*			
CPE	30	*	*	*	*		*
Unsupported	20	*	*	*			
PVC	30	*	*	*	*	*	
	40	*	*	*	*		*
Unsupported	20	*	*		*	*	
HDPE	30	*	*		*	*	*
HDPE-A	40	*	*		*	*	*
LLDPE	60	*	*		*	*	*
	80	*	*		*	*	*
	100	*	*			*	*
Supported	30			*	*		*
EPDM	45			*	*		*
and BUTYL	60				*		*
Supported EIA	38				*		*

1 mil = 0.0254 mm.

- The 120-day immersion period specified in EPA Test Method 9090, "Compatibility Test for Waste and Membrane Liner," should be reviewed to ensure that it is of long enough duration to determine chemical compatibility.
- Additional studies are recommended to determine if the accelerated weather test is truly representative of long-term weathering of FML's formulated for outdoor exposure.
- Additional studies are recommended to develop a method for testing HDPE seams for environmental stress cracking.
- Studies should be conducted on evaluating the thermal-hot air method for factory seaming PVC and CPE materials. This would provide an opportunity to document the results for future specification consideration.
- The NSF Joint Committee on FMLs should give consideration to increasing the peel adhesion values for CPE and PVC and for supported CPE and CSPE materials.

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***Mary Ann Curran** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of Flexible Membrane Liner Seams after Chemical Exposure and Simulated Weathering," (Order No. PB 87-166 526/AS; Cost: $24.95, subject to change) will be available only from:
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