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Predictive Service Life Tests for Roofing Membranes

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ABSTRACT

Twelve roofing membranes, including poly [vinyl chloride], asphalt glass-felt built-up, thermoplastic polyolefin, atactic polypropylene polymer modified asphalt, styrene-butadiene-styrene block copolymer modified asphalt, and ethylene-propylene-diene rubber membranes were exposed to oven heat, ultra-violet and condensing humidity environment, and two and four-year outdoor exposure at United States Department of Defense sites in Phoenix, Arizona (hot and dry climate); Key West, Florida (hot and moist climate); and Champaign, Illinois (moderate mid-continent climate). Selected mechanical properties were measured before and after each exposure. Each membrane was rated before and after exposure and the membranes were ranked as to relative performance in these physical tests.

The physical tests performed include load-strain, dynamic impact resistance, moisture absorption, and glass transition temperature. Identical test methods were used for each membrane to make the physical properties directly comparable.

With the exception of the TPO (thermoplastic polyolefin) membrane samples, the mean changes in the load to first peak of the membranes at each site had a 0.994 correlation with the before exposure, after oven heat aging, and after condensing ultra violet exposures. The TPO membrane load to first peak more than doubled after two years of exposure and then dropped dramatically after four years of exposure.

The over all results show that testing membrane samples before and after oven heat aging and condensing ultra violet exposures do not accurately predict the final ratings of a dissimilar group of membranes exposed outdoors in a broad variety of climates. These accelerated aging techniques have shown to often be valuable when used to evaluate similar membranes.

The single parameter that seems most useful in tracking weathering is the water absorption test. The average percent water absorbed by the membranes increase in direct proportion to exposure time with a linear coefficient of 0.999.

We hope to be able to conclude this six-year study as soon as the samples finish weathering and report our results to interested parties.

KEYWORDS

Relative durability, roofing membranes, test methods, weathering

INTRODUCTION

This research continues the work previously reported (Cash et al 1993, 2001, 2004 and Bailey et al 2002, 2003). We measured selected mechanical properties and the glass transition temperature of 12 roofing membranes before and after two-year and four-year outdoor exposure at Phoenix, Arizona, Key West Florida, and Champaign, Illinois. We report the unexposed and the exposed data. We used a rating system to enable us to include all the diverse physical values measured (such as tensile load at first peak, water absorption, glass transition temperature, and impact resistance) into a single value for each pre-exposure membrane and each post-exposure membrane modified by the change exhibited after exposure. We then ranked the membranes from the "best" to the "worst" in each exposure used.

Membranes tested

Table 1 lists the 12 popular membranes that are at the core of this on-going study. With the exception of some polymer-modified membranes that were prepared by the manufacturer, the multi-ply bituminous membranes were prepared in the laboratory under controlled conditions.

Sample	Description	Sample	Description
A	TPO - thermoplastic polyolefin	G & H	APP - atactic polypropylene - 2 ply polymer modified asphalt
B	PVCa - poly [vinyl chloride] alloy		
C & D	Asphalt-glass fiber felt BUR - 3 ply with steep asphalt	J & K	EPDM - ethylene-propylene-diene terpolymer rubber
E & F	SBS - styrene-butadiene-styrene 2 ply - polymer modified asphalt	L & M	PVC - reinforced PVC poly [vinyl chloride]

Table 1. Membrane sample designators and descriptions.

Test methods

For a given test, the same personnel tested all the samples using the same equipment under identical conditions in an effort to avoid some of the errors inherent in testing. Table 2 lists the test methods used to measure the parameters we selected.

Parameter	ASTM Method	Test Conditions
Load-strain properties	D2523	25 mm (1 in.) wide strips, 100 mm (4 in.) jaw gap, 0.85 mm/s (2 in./min) extension, 23oC (73oF).
Load at first peak		
Elongation		
Energy to first peak		
Water absorption	D570	1 week in water @ 60oC (140oF).
Glass transition temperature	DMA(D6382)	Change in free volume.
Dynamic puncture resistance	D5635	-18oC (0oF).
Thermal expansion	TMA	-20oC (-4oF) to 90oC (194oF).

Legend: DMA=dynamic mechanical analysis; TMA=thermo mechanical analysis

Table 2. Test methods and test conditions used for these evaluations.

Accelerated exposures

As previously reported (Bailey et al 2003), we tested pre-exposure samples before and after heat conditioning in a forced draft oven at 70ºC (158ºF) for 28 days, and before and after 1500 hours of cycles of 20 hours of ultra-violet light at 60ºC (140ºF) and 2 hours of condensing humidity.

Rating method

We used an arbitrary rating system to estimate the physical condition of each sample. We rated the "best" sample in each test as "100" and the "worst" as "0". As examples: the sample with the greatest tensile strength was rated "100"; the weakest sample was rated "0"; and all the other samples rated linearly in between these extremes. The sample with the highest water absorption was rated "0"; the sample that absorbed the least water was rated "100". We averaged the ratings for each parameter to get a single rating for each sample without using any weighting factors. Table 3 shows the ratings the unexposed samples. These ratings are different from those reported earlier (Bailey et al 2003) because two of the tests, cyclic fatigue and static puncture resistance were not performed on the samples after outdoor exposure. These two tests showed little change in our previous work.

Sample	Rating	Sample	Rating	Sample	Rating
A TPO	31	E SBS	35	J EPDM	71
B PVCa	43	F SBS	69	K EPDM	68
C BUR	28	G APP	45	L PVC	52
D BUR	37	H APP	55	M PVC	57

Table 3. Ratings for unexposed samples.

We rated the change due to exposure. We rated a parameter "100" when a change was not statistically significant and "0" for the parameter that showed the greatest change. We averaged these change ratings with the pre-exposure ratings to obtain the post-exposure rating for each sample after each exposure. We then averaged the pre-exposure rating with the two-year change and the four-year change ratings to find the final rating for the four-year exposure. We then ranked these membrane samples from the one with the highest to the membrane with the lowest rating at each outdoor exposure location.

RESULTS

Space limitations preclude publication of the testing details; the final ratings of each membrane are shown in Table 4. The performances of the membranes in the various parameters tested are discussed in individual paragraphs. Composite ratings: M PVC, H APP, and L PVC are in the top quartile of the rankings at Phoenix and Key West. Samples G APP, M PVC, and H APP are the top quartile of the samples exposed in Champaign.

Samples A TPO, J EPDM, and C BUR occupy the lowest quartile of the samples exposed at Phoenix. Samples H APP, and both BUR samples are at the bottom of the samples exposed at Key West. Samples A TPO, B PVCa, and F SBS were lowest in ranking of the exposures made at Champaign.

Phoenix		Key West		Champaign	
Sample	Rating	Sample	Rating	Sample	Rating
M PVC	83.9	M PVC	82	G APP	80.1
H APP	78.7	G APP	78.6	M PVC	78.7
L PVC	78.6	L PVC	77.7	H APP	75.9
F SBS	77.89	K EPDM	77	J EPDM	73.4
G APP	77.9	J EPDM	74.9	L PVC	71.1
K EPDM	74.6	F SBS	73.6	C BUR	71.1
E SBS	72.6	B PVCa	73	K EPDM	69.4
B PVCa	71.9	E SBS	70	D BUR	68.9
D BUR	66.3	A TPO	66.7	E SBS	68.3
A TPO	65.4	H APP	65.7	A TPO	67.6
J EPDM	59.4	D BUR	64.7	B PVCa	67.1
C BUR	54.3	C BUR	62.7	F SBS	61.7
Mean	71.8	Mean	72.2	Mean	71.1

Table 4. Relative ratings for each membrane after four years of outdoor exposure.

Load to first peak - These data show different weathering patterns. The load-to-peak of the TPO and BUR membranes' increase during the first two years of exposure and then decrease after four years of exposure. In particular, the TPO membranes strength increased an average of 112% after two years of exposure, then lost ~40% of that after two more years of exposure. The load-to-first-peak of the TPO membrane exposed at Key West for two years showed the greatest change.

The PVCs, APPs, and SBSes membranes show a relatively linear decline in strength with exposure time. The changes in average values were modest and may not be statistically significant, but the trend lines are quite linear – some with a least squares regression coefficient of up to 0.998 and one even of 1.0.
The average load-to-peak for EPDM specimens forms a trend line with a slight increase in strength with time of exposure – again, these differences may not be statistically significant.

The changes in load-to-peak were quite consistent with each other (with the exception of the change shown by TPO – mentioned previously). The changes varied with time – not exposure location. There is a 0.994 coefficient of correlation between the average of the unexposed, heat exposed and UV exposed ratings with the average rating for the membranes after four years exposure at all three locations.

Strain to first peak - These data show the BUR membranes and the TPO membrane tend to slightly increase their elongation-at-first-peak after two years of exposure and then decrease thereafter. The balance of the membranes' average elongation declined linearly - the least squares regression coefficients range from 0.940 to 1.0. We found no significant correlation between the average of the unexposed, heat exposed, and UV exposed strain ratings and the average strain rating of the membranes exposed to the weather for four years.

Energy to first peak - These data show the energy-to-first-peak increases after two years of exposure for the TPO, BURs, and the EPDMs; it drops off in the fourth year of exposure. The balance of the membranes shows a linear decline in the energy-to first peak with age at each location. The regression coefficient ranges from 0.931 to 1.0. Again, we found no correlation between the average of the ratings of the unexposed, heat exposed, and UV exposed "energy" ratings and the average "energy" ratings of the samples exposed to the weather for four years.

Water absorption - These data show that the water absorption increases as the weather exposure increases. These increases, for the average of each type of membrane, are linear with exposure time, with coefficients of correlation ranging from 0.82 for EPDM samples and coefficients in excess of 0.99 for the other membranes.. The samples exposed in Phoenix show the greatest increase; the samples exposed in Champaign the least increase. This water absorption test seems to be the most useful in tracking the weathering path of organic membrane samples. We found no correlation between the pre-exposure, heat exposure or condensing ultra violet exposure and the ratings on samples exposed for four years.

Thermal expansion - These data show the thermal expansion coefficient declines as the samples are aged outdoors. The average decline in the thermal expansion coefficient is roughly the same for thee exposure sites, and the decline is relatively linear. There is no correlation between these four-year exposure test data and the accelerated test data performed earlier.

Glass transition - These data show the glass transition temperature gets higher for many of the membranes as they weather. The TPO, PVCs, and BURs show linear increases of approximately 1ºC per year. At this time, age causes little change in the glass transition point of the other membranes. Of special note – we were unable to cut the small specimens required for this test from sample BUR D because the membrane crumpled into dust.

Dynamic puncture resistance - On the average, puncture resistance tends to increase with outdoor exposure time, but many samples show an increase in puncture resistance after two years of exposure, followed by a decline in resistance after four years of exposure. This probably related to the tensile strength that shows an increase after two years of exposure, followed by a decline after four years. There is no direct correlation between tensile strength and dynamic puncture resistance in these samples.

CONCLUSIONS

The following conclusions are preliminary; they may be modified by the additional data obtained from the samples after six years of exposure.

- Neither the unexposed, heat nor UV rankings adequately predicted the rankings of the samples after four years of outdoor exposure.
- The water absorption test appears to be very useful in tracking weather exposure in any of the samples under test. The average water the samples absorbed increased as the outdoor exposure time increased at each location.
- The BUR samples faired very poorly in these ratings, probably due to the lack of gravel or other protective coating on the samples to shield them from the weather.

These rankings are based solely on the change in physical properties measured and may not reflect the long-term weather performance of these products.

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REFERENCES

Bailey, DM, CG Cash and AG Davies Jr., "Predictive Service Life Tests for Roofing Membranes – Phase II Investigation of Accelerated Aging Tests for Tracking Degradation of Roofing Membrane Materials," USACERL TR-01, April 2002.

Bailey, DM., CG Cash and AG Davies Jr., "Update: Service Life Test for Roofing Membranes*,"* *Roofing Research and Standards Development: 5th Volume, ASTM STP 1451,* W.J. Rossiter and T.J. Wallace, Eds., ASTM International, West Conshohocken, PA, 2003.

Cash, CG and DM Bailey, "Predictive Service Life Tests for Roofing Membranes, Phase 1" USACERL Interim Report FM-94/03, December 1993.

TT4-213, Predictive Service Life Tests for Roofing Membranes, C.G. Cash, D.M. Bailey, A.G. Davies, Jr., A. H. Delgado, D.L. Niles, R.M. Paroli

Cash, CG, DM Bailey and AG Davies Jr., "Predictive Service Life Testing of Low Sloped Roofing Systems, Phase 1" *International Conference on Building Envelope Systems and Technologies,* National Research Council Canada, Ottawa, 2001

Cash, CG, DM Bailey, AG Davies Jr., AH Delgado, DL Niles, and RM Paroli, "Update 3: Service Life Tests for Roofing Membranes," CIB World Building Congress, Toronto, Canada, May 2004