EVALUATION OF CHANGES IN ROOFING MATERIALS AS A RESULT OF LONG-TERM EXPOSURE

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Samples of PVC, EPDM, and modified bitumen have been collected from roofs in various parts of Israel characterized with mild Mediterranean, mountain, and desert-like climates. All of the membranes studied were in service from four to 12 years, and their installations were relatively well-documented. The study also included four membranes exposed during five years at the authors' exposure site as part of the work done by the RILEM/CIB joint committee on roofing materials. New, unexposed membranes of types similar to the exposed ones have been used as reference materials.

The membranes taken from the roofs, as well as the new, unexposed samples, were tested concerning the following properties:

- mechanical properties in tensile
- three-dimensional extensibility under water pressure
- cold-temperature flexibility

The results suggest that the tensile properties of all of the materials and membranes suffered only minor changes. Changes were detected in the cold-temperature flexibility of the PVC and APP membranes, the latter exhibiting an undesirable change of 10°C to 15°C (50°F to 59°F). All of the exposed EPDM membranes burst immediately under water pressure, whereas unexposed samples were very flexible.

KEYWORDS

APP, EPDM, membranes, modified bitumen, PVC, roofing, SBS, waterproofing, weathering.

INTRODUCTION

Roofing materials and products are intended to perform without failure for many years while exposed to harsh deteriorating conditions such as solar radiation, precipitation, and high or low temperatures. Therefore, it is important to be able to estimate and predict, as much as possible and feasible, the performance of the materials for years ahead.

A variety of durability tests have been developed in the field of roofing and waterproofing, defining criteria for the characterization and evaluation of the expected weathering behavior of the products. Yet, most—if not all—of these tests and evaluations are performed on new products that have never been exposed to external weathering. Usually, all that these materials have been exposed to are artificial, laboratory weathering conditions. And so, in spite of all the true efforts made, there is seldom proper evidence for the real long-term performance. Furthermore, the external conditions to which the roofing materials are exposed differ very much from one geographical area to the other, from one application to the next. This paper's references relate to work done on the subject of performance and field studies of various roof systems.

It was the aim of this work to test and evaluate roof membranes that were in service on roofs for a few years under various conditions in different regions and to compare their properties with those of new, unexposed samples. By this, the authors hoped to learn what the real effect of the natural conditions on membrane properties is. The results can, it is hoped, serve as guides when artificial accelerated tests are used for the weathering predictions.

MATERIALS

Samples were collected from functioning roofs in different regions of Israel, including seashore, mountain, and desert areas. They were then tested in the laboratory, comparing their properties to those of new materials, as will be discussed later. Additionally, four samples that were exposed for five years in a controlled exposure site, as part of the weathering tests done in the framework of the activity of the Joint Committee on Membrane Roofing Systems, RILEM TC-120/CIB W.80, were incorporated as well.[1]

All the materials collected and tested were commercial membranes of the following types:

- PVC membranes of three different types: reinforced, supported (with a nonwoven polyester fabric on the lower side) and nonreinforced
- EPDM membranes: regular (i.e., black, nonreinforced)
- modified bitumen (MB) membranes containing SBS or APP polymers (although it was not documented in all cases whether the membrane was of the APP or SBS type)

The RILEM TC experimental membranes mentioned previously included one type of each of the four materials: PVC, EPDM, APP-MB and SBS-MB. These samples were clearly and accurately known and identified, and their unexposed, laboratory-stored reference samples were also tested.

The four RILEM samples were applied not on a normal roof substrate, but rather were exposed on stands, at a 45-degree angle (facing south). They all had a wooden substrate for support.

Description and details of the various samples tested are contained in Tables 1, 2, and 3, referring to the PVC, EPDM, and MB materials, respectively.

The exposure periods were approximately four to 12 years long. New (unused) samples of similar composition and structure were used for comparison, wherever the original reference samples were unavailable.

TESTING

The various samples were subjected to the following tests:

- *Mechanical properties in tensile (strength and elongation):* All reinforced and supported samples were tested as 50-mm- (2-inch-) wide strips, at an extention speed of 100 mm/min (4 inches/minute). The effective length between jaws was 200 mm (8 inches). The forces at break are reported in N/50 mm (N/2 inches). The EPDM and nonreinforced PVC samples were tested as dumbbell-shaped specimens. The EPDM was tested at an extention speed of 500 mm/min (20 inches/minute), and the PVC was tested at 200 mm/min (8 inches/minute). The results for these samples are reported in MPa. (Table 4 reports the results of all PVC samples; hence, the applicable units—MPa or N/50 mm—are given accordingly.)

  The results reported are an average of five tested specimens each.
- *Cold temperature flexibility (brittle point):* The test was done in accordance with the recommendations given in the appropriate UEAtc standards.[2,3,4] Strips cut out from the membrane were cooled down to the test temperature and bent over a cylindrical mandrel having a diameter of 20 or 30 mm (¾ or 1³⁄₁₆ inches). The highest temperature at which the specimen broke or cracked was regarded as the brittle temperature. The diameter of the mandrel over which the bending was done is given in the tables.
- *Three-dimensional extensibility and deformation under water pressure:* The water-pressure deformability was intended to test the flexibility and watertightness of the membrane at a water pressure of 1 bar (14.5 psi [0.1 MPa]) during 24 hours. The test was performed based on the recommendations in the European draft CEN/TG 116 Test No. I-1. Figure 1 shows the equipment used for testing. The water pressure caused the membrane to expand and deform like a blister, the extent of which was measured using an appropriate lever. The deformation level reached one minute after the desired water pressure was applied was considered the zero point. Only two or three specimens were tested for each membrane.

Membrane code	Membrane description	Site	Exposure period years	Remarks
PVC-N	Non-reinforced, non-supported	-	-	New membrane
PVC-S-N	Woven polyester reinforced	-	-	New membrane
PVC-F-N	Supported with polyester felt-mat	-	-	New membrane
PVC-R-N	Reinforced with chopped fibers	-	-	Reference membrane. RILEM TC project
PVC-R-5y	Identical to PVC-R-N	Shore region	5	RILEM-TC project. 45° exposure
PVC-HF-1	Supported with polyester felt-mat	Shore region	ca. 4	Unprotected
PVC-TLV-1	Non-reinforced, non-supported	Shore region	ca. 5	Protected with geotextile & gravel
PVC-TLV-2	Woven polyester reinforced	Shore region	ca. 7	Protected with geotextile & gravel
PVC-TLV-3	Supported with polyester felt-mat	Shore region	10	Protected with geotextile & gravel
PVC-TLV-4	Woven polyester reinforced	Shore region	10	Protected with geotextile & gravel

Table 1. The PVC membranes tested.

Membrane code	Membrane description	Site	Exposure period years	Remarks
EPDM-R-N	Standard, non-reinforced	-	-	Reference membrane. RILEM TC project
EPDM-R-5y	Identical to EPDM-R-N	Shore region	5	RILEM TC project. 45° exposure
EPDM-HF-1	Standard, non-reinforced	Shore region	ca. 12	Originally coated with a white coating
EPDM-HF-2	Standard, non-reinforced	Shore region	ca. 12	Under continuous stretching load*
EPDM-TLV-1	Standard, non-reinforced	Shore region	not known	-
* The tested membrane was taken from a corner where it was under constant stretching load due to membrane shrinkage.				

Table 2. The EPDM membranes tested.

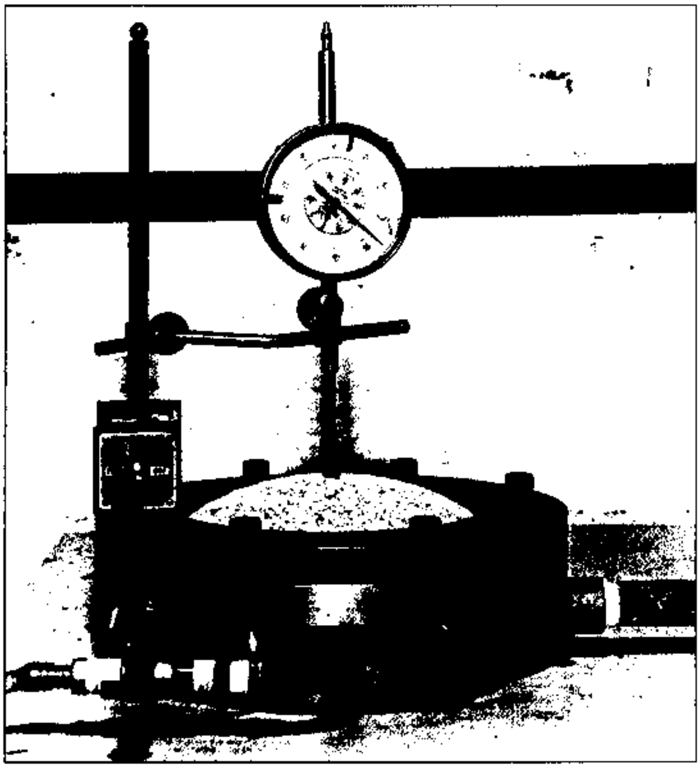

Figure 1. The equipment used to test the three-dimensional extensibility and deformation of a membrane under water pressure. The pressure was 1 bar, and the test lasted 24 hours.

RESULTS AND DISCUSSION

The detailed results of the various tests are presented in Tables 4, 5, and 6, concerning the PVC, EPDM and MB, respectively.

Most PVC membranes, whether reinforced, supported, or nonreinforced, did not exhibit any severe deterioration effects in spite of the long years of exposure. Yet, it has to be emphasized that the majority of the membranes were not exposed directly to solar radiation but rather were covered by geotextile and a layer of gravel.

The sample exposed at the exposure site for five years as part of the RILEM experiment (PVC-R-5y) showed some reduction in its machine-direction (MD) elongation, from 324 percent for a nonexposed membrane (PVC-R) to 202 percent for an exposed one. This is probably due to the release of the longitudinal stresses in the membrane during the years of exposure to high temperatures. These stresses are caused by the production process as a result of machine direction stretching during the manufacturing. No major changes were detected in the low-temperature brittleness or the water-pressure resistance.

A nonreinforced material (PVC-TLV-1) showed a sizable change in the brittleness temperature, losing its flexibility at about -17°C (1°F). Although the membrane was protected from the direct radiation of the sun, it probably lost some of its plasticizers during the years of exposure on a warm roof. Nevertheless, its resistance to water pressure did not change in spite of the change in flexibility.

The polyester-reinforced PVC membranes did not lose much of their mechanical properties nor their low-temperature flexibility, even after seven and 10 years of service, but all of these membranes were covered by a geotextile and gravel.

The nonwoven-fabric-supported PVC membranes also did not show major failures in their behavior after years of service. The strength and elongation of the composite did not differ much between the new and the used membranes, but the elongation of the PVC layer itself was strongly reduced (after the support itself had already yielded), from elongation in the order of 200 percent to elongation in the order of 70 to 80 percent. It occurred both in a sample that was exposed to sun and one that was protected from the sun, probably because of plasticizer loss.

Membrane code	Membrane description	Site	Exposure period years	Remarks
MB-APP-N	5 mm APP membrane	-	-	New membrane
MB-SBS-N	5 mm SBS membrane	-	-	New membrane
MB-APP-R-N	APP reinforced with polyester non-woven-mat and woven glass fibers. No coating	-	-	Reference membrane. RILEM TC project
MB-APP-R-5y	Identical to MB-APP-R-N	Shore region	5	45° exposure
MB-SBS-R-N	SBS coated with colored granules	Shore region	-	Reference membrane. RILEM TC project
MB-SBS-R-5y	Identical to MB-SBS-R-N	Shore region	5	45° exposure
MB-HF-1	Coated with granules	Shore region	ca. 4	Probably SBS
MB-D-1	Coated with granules	Desert region	ca. 7	Probably APP
MB-D-2	Coated with granules	Desert region	3.5	Probably APP
MB-D-3	Coated with granules	Desert region	8.5	Probably APP
MB-D-4	Coated with granules	Desert region	ca. 8	Probably APP
MB-JR-1	Coated with granules	Mountain region	ca. 6	Probably APP
MB-JR-2	Coated with granules	Mountain region	ca. 6	Probably APP

Table 3. The modified bituminous (MB) membranes tested.

Membrane Code		Tensile properties					Brittle temp. °C Ø=20mm	Water-pressure deformation, mm.		
		Force at break (N/50mm)*	Strength at break (MPa)*	Elongation at break (%)	Max. force (N/50mm)	Elongation at max. force (%)		1h	7h	24h
PVC-N	MD XD		16.7 16.4	165 215	= =	= =	> -25	6.85	10.61	13.77
PVC-S-N	MD XD	1530 1318		17.5 17.5	= =	= =	> -25	0.20	1.01	1.33
PVC-F-N	MD XD	700 700		170 204	925 900	59 80	> -25	Cannot be tested†		
PVC-R-N	MD XD		12.2 11.1	324 226	= =	= =	> -30	12.72	23.65	††
PVC-R-5y	MD XD		12.7 12.2	202 218	= =	= =	> -30	15.2	22.9	38.5
PVC-HF-1	MD XD	881 981		85 53	991 1170	57 48	> -30	1.54	2.60	3.02
PVC-TLV-1	MD XD		15.2 14.8	232 276	= =	= =	-17.5	8.31	13.30	18.54
PVC-TLV-2	MD XD	1473 1425		23 21	= =	= =	> -35	1.78	2.89	3.36
PVC-TLV-3	MD XD	1002 987		76 88	1244 1024	52 57	> -35	3.80	3.85	4.73
PVC-TLV-4	MD XD	1451 1552		25 22	= =	= =	> -35	1.61	2.66	3.11

MD - Machine direction, XD - Cross-machine direction
= the same value as at break
* The values for the non-reinforced samples are given as "strength at break (MPa)," while the values for the reinforced samples are given as "force at break (N/50 mm)."
† The membrane could not be water-sealed due to the non-woven support, and hence could not be tested.
†† The value is missing due to a technical problem.

Table 4. Test results for the PVC membranes.

Membrane Code		Tensile properties				Brittle temp. °C Ø=20mm	Water-pressure deformation, mm.		
		Strength at break (MPa)	Elongation at break (%)	Max. strength	Elongation at max. strength		1h	7h	24h
EPDM-R-N	MD XD	10.7 10.6	457 490	= =	= =	> -35	"Balloon" like expansion		
EPDM-R-5y	MD XD	10.2 10.4	417 402	= =	= =	> -25*	Burst		
EPDM-HF-1	MD XD	13.4 12.7	213 208	= =	= =	> -25*	Burst		
EPDM-HF-2	MD XD	12.7 12.1	347 350	= =	= =	> -35	Burst		
EPDM-TLV-1	MD XD	9.1 7.8	334 322	= =	= =	> -35	Burst		

MD - Machine direction, XD - Cross-machine direction
* was not tested at a lower temperature
= the same value as at break

Table 5. Test results for the EPDM membranes.

Membrane Code		Tensile properties				Brittle temp. °C		Water-pressure deformation, mm.		
		Force at break (N/50mm)	Elongation at break(%)	Max. force (N/50mm)	Elongation at max. force (%)	Ø=20 mm	Ø=30 mm	1h	7h	24h
MB-APP-N	MD XD	1290 1030	46 53	= =	= =	-10	-10	2.80	4.60	7.45
MB-SBS-N	MD XD	1340 1160	46 53	= =	= =	-20	-20	3.90	6.23	8.60
MB-APP-R-N	MD XD	615 500	4 49	710 581	2 Y 3 Y	-12	-15	Water passes through		
MB-APP-R-5y	MD XD	582 424	5 33	717 528	2 Y 2 Y	-5	-10	Water passes through		
MB-SBS-R-N	MD XD	962 735	43 47	= =	= =	-23	-22	4.74	6.54	9.33
MB-SBS-R-5y	MD XD	983 725	39 47	= =	= =	-10	-10	3.88		8.81
MB-HF-1	MD XD	1146 827	35 42	= =	= =	-10	-10	2.59	5.07	6.65
MB-D-1*										
MB-D-2	MD XD	508 477	21 22	610 537	3 Y 4 Y		+5	Water passes through, 5.12	 cracking	
MB-D-3	MD XD	1280 541	31 45	= =	= =		+7.5	Water passes through 4.29	 5.07	 8.80
MB-D-4	MD	873	32	=	=		+5	*		
MB-JR-1	MD XD	1028 742	32 35	= =	= =		+5	Water passes through 3.30		 5.66
MB-JR-2	MD XD	844 700	39 52	= =	= =		+5	4.31	5.98	7.81

MD - Machine direction, XD - Cross-machine direction
Y = Yield
* was not tested due to technical problems
= the same value as at break

Table 6. Test results for the modified-bituminous membranes.

A comparison between the properties of the EPDM membrane kept in the laboratory for five years (EPDM-R) and the one exposed at the exposure site (EPDM-R-5y) showed that there were hardly any differences in the mechanical properties and low-temperature flexibility. But a major change was detected in the water-pressure behavior: Although the unexposed sample expanded like a balloon under the water pressure, the exposed one burst with very little deformation, almost immediately when the water pressure was applied.

Similarly, all of the EPDM samples collected from the roofs burst under the water pressure. The exposed samples also showed a reduction, yet not a detrimental one, in their tensile elongation. It seems that the EPDM samples developed some stiffening while exposed, although the changes did not cause any problematic failure on the roof.

This finding also holds for a EPDM membrane that originally was applied over an existing layer of bituminous coating. Although some visual changes were seen on the membrane, the physical and mechanical deterioration was not more severe than the levels of change detected in the other membranes.

It is somewhat puzzling as to why the EPDM samples exhibited a visible stiffening and burst immediately in the water pressure test, but deformed and elongated in the uniaxial tensile stress and maintained a very low brittle temperature. One possibility is that it is the exposed surface that suffers the main deterioration damage while the bulk of the material still maintains many of its original properties. The deterioration and hardening of the surface is probably the detrimental factor causing the immediate failure when the membrane is subjected to the harsh three-dimensional deformation. However, the surface damage is not sufficient to cause such a premature failure under the less extensive unidirectional deformation.

The analyses of the tested properties of modified bitumen membranes show that the exposure of the membranes under normal service conditions has an important effect on the low-temperature flexibility. The unexposed SBS membrane (SBS-R-N) that was stored for five years in the laboratory had a brittle point of -22°C (-8°F), and the same material exposed at the exposure site (SBS-R-5y) had a brittleness temperature of only -10°C (14°F). There are almost no changes in the mechanical properties and water-pressure resistance. It seems, therefore, that the exposure hardly affects the properties that are determined by the reinforcement, but has a strong effect on the properties that are governed by the bitumen/polymer material.

The change in the low-temperature flexibility was particularly severe with the APP modified membranes. All of the exposed MB samples that were assumed to be APP modified showed relatively high brittle points: 5°C (41°F) and, in one case, even higher. On cold days when the temperature is near the freezing point, these membranes can crack and break under the load of a walking person or strong hail. Most of these APP membranes also leaked under the water pressure without bursting or visibly cracking.

In general, it seems that the SBS membranes remained flexible at much lower temperatures than the APP membranes, after similar periods of exposure to service conditions. Concerning the tensile properties, these did not change in any significant values in all of the tested MB membranes.

SUMMARY AND CONCLUSIONS

A variety of roof membranes—PVC, EPDM, and modified bitumens—that were exposed for years in different regions were tested to detect the changes in their original properties that resulted from their exposure.

The results of the mechanical and thermal tests suggest that, in general, the materials maintained much of their original properties even after long years of field exposure. Thus, for example, the tensile elongation and forces at break of all the membranes underwent only minor changes. It seems that the deterioration of the tested membranes was not detrimental under the exposure conditions. The membranes could have probably served for longer periods without material failure. The findings emphasize again the assumption that the problems usually do not lie with the materials.

Yet, two findings should be pointed out:

- A pronounced change was detected in the brittleness temperature of APP modified bitumen membranes; the membranes lost their flexibility at temperatures as high as 5°C (41°F). Furthermore, most of these exposed membranes gave way to water under the test conditions.
- The exposed EPDM membranes exhibited a visible stiffening, and they all burst under the water pressure test. But surprisingly, they all maintained a very low brittle temperature and a high tensile elongation.

It requires, no doubt, a very comprehensive study of this kind, testing a large number of membranes of each type of material, as well as using a wider range of chemical and physical tests, to come up with definite conclusions on the behavior of the materials.

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