Testing the differences

Laboratory analysis of TPO membranes reveals differences in products

by Mark S. Graham

TPO membrane products first became widely distributed in the U.S. roofing industry during the early 1990s. But NRCA was aware TPO membranes were being manufactured and distributed in limited quantities in the United States as early as 1987—first as unreinforced membrane sheets and later as reinforced roof membranes.

Since the early 1990s, TPO membranes' acceptance and use have grown. According to *NRCA's 2000-2001 Annual Market Survey*, TPO membranes were used in 9.5 percent of all low-slope roofing projects (new construction and reroofing) in 2000, totaling about $970 million in installed costs.

At least four fundamentally different formulations of TPO membranes currently are in service on roof systems in the United States. NRCA believes this is a conservative estimate of the number of formulations, or generations, of TPO membranes currently in existence.

But there still is not a recognized material standard in the United States that applies to TPO membrane products. Such a material standard could define TPO roof membranes and provide minimum physical property values recognized as necessary for long-term field performance. Development of an American Society for Testing and Materials (ASTM) material standard currently is under way; however, it likely will be more than a year before this standard is finalized and published.

NRCA research

In 2000, citing a need for analytical data regarding TPO roof membranes, NRCA's Technical Operations Committee, with support from NRCA's Executive Committee, authorized an extensive study of TPO roof membranes currently available in the United States. The research's purpose was to determine physical characteristics of various TPO membrane sheets and provide baseline data for future evaluations of long-term performances of TPO products.

NRCA's research is not intended to highlight or single out any specific manufacturers or products. Therefore, product and manufacturer names are not reported.

Sampling

To begin the study, NRCA obtained full rolls of nine TPO roof membranes. The rolls were provided to NRCA by NRCA's technical committee members from throughout the United States; committee members purchased the products through typical distribution sources.

NRCA received the rolls with their original packaging and labels intact. Information from the packaging and labels was recorded, and the rolls were unrolled and visually inspected. Samples were taken from the rolls and labeled in a manner that did not identify manufacturer or product names.

The membrane samples included in the research represent products from six manufacturers. A light-colored (white) TPO membrane was analyzed from each manufacturer. A dark-colored (for example, black or dark gray) TPO membrane also was analyzed from three product manufacturers.

Eight of the products analyzed are identified on their package labels as being 45 mils (0.045 inches [1.1 mm]) thick. One product was identified as being 60 mils (0.060 inches [1.5 mm]) thick.

A	Reinforced TPO membrane; 0.045-inch nominal thickness; a white-colored top layer
B	Reinforced TPO membrane; 0.060-inch nominal thickness; a white-colored top layer
C	Reinforced TPO membrane; 0.045-inch nominal thickness; a white-colored top layer
D-1	Reinforced TPO membrane; 0.045-inch nominal thickness; a black-colored top layer
D-2	Reinforced TPO membrane; 0.045-inch nominal thickness; a white-colored top layer
E-1	Reinforced TPO membrane; 0.045-inch nominal thickness; a black-colored top layer
E-2	Reinforced TPO membrane; 0.045-inch nominal thickness; a white-colored top layer
F-1	Reinforced TPO membrane; 0.045-inch nominal thickness; a black-colored top layer
F-2	Reinforced TPO membrane; 0.045-inch nominal thickness; a white-colored top layer

Note: *IP units of inches can be converted to SI units of millimeters by multiplying inches by 2.54.*

Figure 1: *Descriptions of the TPO roof membranes analyzed.*

Figure 1 provides descriptions of the TPO roof membranes analyzed.

Testing

NRCA retained three nationally recognized testing laboratories to perform the laboratory analysis portion of the research. The TPO membrane samples were provided to the laboratories without identifying the products' manufacturers or brand names.

Laboratory analysis was conducted according to recognized test methods, including ASTM D751, "Standard Test Method for Coated Fabrics."

Thickness

Figure 2 reports the overall thicknesses and thickness-over-scrim measurements of the top and bottom coatings of the membrane samples in an as-received (not exposed or not weathered) condition. The reported values are averages of at least five measurements uniformly distributed across the rolls' full widths.

Each product, except membranes B and C, had overall thicknesses slightly less than those indicated by their

A	0.42	0.0171	0.0182
B	0.60	0.0379	0.0166
C	0.45	0.0185	0.0191
D-1	0.43	0.0206	0.0161
D-2	0.44	0.0201	0.0176
E-1	0.43	0.0150	0.0122
E-2	0.44	0.0152	0.0132
F-1	0.44	0.0172	0.0203
F-2	0.44	0.0177	0.0181

Note: *IP units of inches can be converted to SI units of millimeters by multiplying inches by 2.54.*

Figure 2: *Overall thicknesses and thickness-over-scrim measurements for tested membranes.*

manufacturers on their package labels. Assuming manufacturers intend package label values to be nominal thickness values, NRCA considers these slight variances generally acceptable.

The overall thicknesses for membranes B and C are identical to those indicated by their manufacturers on their package labels.

The thickness-over-scrim values for all tested membranes, except membrane B (the 60-mil- [0.060-inch- (1.5-mm-)] thick membrane), range from 0.0122 inches to 0.0203 inches (0.31 mm to 0.52 mm).

For membrane B, the additional thickness appears as a result of additional top-film thickness as compared with the 45-mil- (0.045-inch- [1.1-mm-]) thick membranes analyzed. The bottom-film thickness for membrane B falls within the range of the 45-mil- (0.045-inch- [1.1-mm-]) thick membranes analyzed.

NRCA considers a thickness-over-scrim value an important property—this value significantly can affect field seaming and field-seam strength. A relatively thick, consistent coating over scrim thickness generally is desired at top and bottom film surfaces to facilitate proper field seaming and provide adequate field-seam strength.

Water absorption

In Figure 3, water absorption values for the tested products in as-received conditions are shown. Water absorption is expressed as a percentage of change in mass after a membrane is immersed in water for 168 hours at 158 F (70 C). The reported values are averages of at least three measurements from each product.

Membranes D-1, D-2 and, to a slightly lesser extent, membranes E-2 and F-1 have significantly higher water absorption values than other samples. For example, membrane D-1's value is nearly twice that of membrane F-2's.

This large variability in water absorption values among products causes NRCA some concern. It remains to be determined whether these values significantly will affect the membranes' field performances.

Dimensional stability

Figure 4 reports the values for linear dimensional change for each product. The values are expressed as percentages of dimensional change after conditioning for six hours at 158 F (70 C); a negative value indicates a reduction, or shrinkage, in membrane size. The reported values are averages of at least five measurements for each product.

In general, the values appear to be comparable to or better than other single-ply roof membranes. However, membrane D-2 has a linear dimensional change value in the machine direction (MD) (long direction of a roll)

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A	4.5
B	·4.1
C	5.5
D-1	7.7
D-2	7.9
E-1	5.7
E-2	6.8
F-1	6.9
F-2	4.0

Figure 3: *Water absorption of tested membranes.*

A	-0.12	0.00
B	0.00	0.00
C	-0.06	-0.06
D-1	-0.25	-0.06
D-2	-0.44	-0.19
E-1	-0.31	-0.06
E-2	-0.12	-0.19
F-1	0.00	-0.06
F-2	-0.12	-0.12

Figure 4: *Linear dimensional changes of tested membranes.*

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noticeably greater than other membranes tested.

Brittleness

Figure 5 reports brittleness-point values for the membrane products in an as-received condition tested according to ASTM D2137, "Test Methods for Rubber Property—Brittleness Point of Flexible Polymers and Coated Fabrics." Brittleness point is expressed as a temperature.

Values of tested membranes' brittleness points range from -27 F (-33 C) to -62 F (-52 C). NRCA is concerned about products with brittleness points greater than -50 F (-46 C), namely membranes B, C, D-1, D-2 and F-1. It remains to be determined whether these values significantly will affect membranes' long-term field performances.

A	-51
B	-38
C	-31
D-1	-27
D-2	-36
E-1	-62
E-2	-54
F-1	-27
F-2	-51

Note: *IP units of degrees Fahrenheit can be converted to SI units of degrees Celsius as follows: C = (F - 32)/1.8.*

Figure 5: *Brittleness points of tested membranes.*

Breaking strength

NRCA also tested the values for breaking strength and elongation at break. The membranes were tested using the grab-test method defined in ASTM D751 in an as-received condition, as well as after seven days and 28 days of heat aging. In Figure 6, the values are reported in MD and cross-machine direction (XMD) (across a roll's width). Breaking-strength values are reported in pound force (lbf) units, and elongation is expressed as a percentage. The values are the averages of at least five measurements for each product.

For products tested in an as-received condition, breaking-strength values range from 232 lbf to 362 lbf (1.03 kN to 1.61 kN); this includes the 60-mil- (0.060-inch- [1.5-mm-]) thick product, membrane B. Elongation values range from 26 percent to 66 percent.

After seven days of conditioning, breaking-strength values range from 275 lbf to 383 lbf (1.22 kN to 1.7 kN) for all products and 275 lbf to 364 lbf (1.22 kN to 1.62 kN) for 45-mil- (0.045-inch- [1.1-mm-]) thick products only. Elongation values range from 27 percent to 38 percent. Generally, with the exception of membrane F-2, all breaking-strength values remained the same or increased slightly from their as-received values.

After 28 days of conditioning, the samples' breaking-strength values range from 253 lbf to 362 lbf (1.13 kN to 1.61 kN) for all membrane products and 253 lbf to 345 lbf (1.13 kN to 1.53 kN) for the 45-mil- (0.045-inch- [1.1-mm-]) thick products only. Elongation values range from 22 percent to 37 percent.

With the exception of membrane F-2, all breaking-strength and elongation values stayed the same or increased slightly during seven-day conditioning then decreased slightly during 28-day conditioning. Such a change in these values is not unusual for membrane products of this type, and NRCA considers the changes generally acceptable.

When membrane F-2 was tested in an as-received condition, its breaking-strength and elongation values were relatively high, but the values decreased significantly with conditioning. A change in physical properties of this magnitude concerns NRCA because it remains to be determined whether

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A	342	316	66	34	364	334	37	35	345	321	37	36
B	362	302	35	29	383	317	36	30	362	308	37	32
C	309	290	33	30	327	303	34	30	298	293	32	30
D-1	289	248	31	34	315	277	36	35	299	268	34	33
D-2	253	232	29	33	320	275	36	33	324	279	35	32
E-1	324	309	26	39	322	305	29	38	323	299	30	37
E-2	339	324	27	36	333	324	28	36	336	318	29	35
F-1	313	284	31	28	331	301	31	28	274	297	26	28
F-2	337	305	32	28	295	312	27	30	253	315	22	30

MD = Machine direction
XMD = Cross-machine direction
Note: *IP units of lbf can be converted to SI units of N by multiplying lbf by 4.448.*

Figure 6: *Breaking strengths of tested membranes.*

A	*	65	133	66	150	52
B	*	65	*	47	*	41
C	*	77	132	53	131	56
D-1	109	*	128	110	110	80
D-2	**	**	142	105	144	115
E-1	74	81	84	88	94	86
E-2	75	86	95	94	86	95
F-1	67	44	83	39	50	43
F-2	**	43	72	82	34	81

* Indicates samples did not tear in the direction of the original cut in sample preparation for testing.
** Indicates no tear.
MD = Machine direction
XMD = Cross-machine direction
***Note:** IP units of lbf can be converted to SI units of N by multiplying lbf by 4.448.*

***Figure 7:** Tearing resistances of tested membranes.*

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the change significantly will affect the product's long-term field performance.

Tearing resistance

Values for tearing resistance using the tongue-tear test method defined in ASTM D751 also were determined. Membranes were tested in an as-received condition and after seven days and 28 days of heat aging. In Figure 7, these values are reported in MD and XMD. Breaking-strength values are reported in lbf units. Reported values are averages of at least five measurements for each product.

For products in an as-received condition, tearing-resistance values range from 43 lbf to 109 lbf (190 N to 480 N).

For membranes A, B, C, D-1, D-2 and F-2, breaking-strength values could not be determined in MD, XMD or both. These products' test specimens did not tear conventionally (most products exhibit tearing of reinforcing scrim). Instead, the fibers of these products' reinforcing scrims bunched but did not necessarily tear. Bunching of reinforcing fibers typically is not considered to be a failure of the reinforcing scrim because the scrim did not break. However, such bunching does result in a membrane's failure.

After seven days of conditioning, the samples' values for tearing resistance range from 39 lbf to 142 lbf (170 N to 590 N). For membrane B, an MD breaking-strength value could not be determined because of bunching of the reinforcing scrim. After 28 days of conditioning, the values for tearing resistance range from 34 lbf to 150 lbf (150 N to 670 N).

For membranes E-1 and E-2, NRCA regards the tearing-resistance values and changes of these values after conditioning as generally acceptable. But NRCA is concerned about the changes in tearing-resistance values for membranes A, B, C, D-1, F-1 and F-2 after conditioning. It is unknown at this time whether the changes significantly will affect these membranes' long-term field performances.

A judgment regarding membrane D-2 has not been made—the membrane's tearing resistance in an as-received condition could not be determined because of bunching of the reinforcing scrim.

A	Bromine compound
B	Magnesium hydroxide
C	Magnesium hydroxide
D-1	Magnesium hydroxide
D-2	Magnesium hydroxide
E-1	Magnesium hydroxide
E-2	Magnesium hydroxide
F-1	Magnesium hydroxide
F-2	Bromine compound

***Figure 8:** Descriptions of tested membranes' primary fire retardants.*

Chemical analyses

To determine the formulations of the TPO membranes included in its research, NRCA conducted in-depth chemical analyses of the membranes. The analyses consisted of dynamic mechanical analysis, fourier transform infrared spectroscopy analysis and scanning electron microscopic analysis.

The primary purpose of conducting these types of analyses was to determine the TPO membranes' compositions as closely as possible and provide information for evaluating these membranes' long-term field performances. Such analyses also provide baseline information for analyzing and comparing data from this research with previous or future TPO membrane compositions.

Providing an in-depth report about the chemical analyses is beyond this report's scope because it may reveal certain information proprietary to TPO membrane manufacturers and, possibly, their raw material suppliers. However, information related to chemical additives used in TPO membranes to improve their fire-resistance properties yields data that NRCA considers necessary to report.

The use of certain chemical additives used as fire retardants (for example, bromine compounds) in TPO roof membranes may adversely affect membranes' physical properties after accelerated aging. As a result, some TPO membrane manufacturers have indicated they have switched to other fire-retardant additives.

Figure 8 reports the results of the chemical analyses for fire-retardant additives in TPO membranes. Membranes A and F-2 clearly contain bromine compounds. The other membranes contain other fire-retardant chemical compounds, most notably magnesium hydroxide.

Finding bromine compounds in membranes A and F-2 is viewed by NRCA as being significant because it may adversely affect the membranes' long-term performances.

Make informed decisions

TPO roof membranes are accepted and used in the U.S. roofing industry; however, it is apparent there are significant differences among some TPO membranes currently on the market and in service. Although the effects of some of these differences are unknown at this time, NRCA believes other differences will have notable effects on the useability and long-term field performances of TPO membranes.

The U.S. roofing industry needs a credible material standard for TPO membranes.

It is clear the U.S. roofing industry needs a credible material standard for TPO membranes that is based on the attributes necessary to ensure long-term field performance. Such a standard should differentiate products of questionable performance and those of known long-term field performance. A TPO material standard would be of great assistance to roof system designers, roofing contractors and building owners when specifying and purchasing TPO roof membranes. NRCA hopes the ASTM standard currently being developed can be such a material standard and will be available as soon as possible.

Until an appropriate material standard is available, NRCA encourages roofing professionals to closely evaluate product data and performance history of the specific TPO roof membrane products they consider using.

NRCA also recommends TPO membrane manufacturers readily provide information about their products. Such information should include physical property data, including data after accelerated weathering, such as heat aging; performance history of a membrane in its present composition; and building code compliance information. The information will help roofing professionals make informed, proper decisions regarding which TPO membrane products they should use.

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