

testing

In “A study of longevity,” February 2014 issue, page 44, TPO membranes’ long-term performance was discussed. The article also reviewed the general history of TPO and concluded the material generally is performing well in the almost 30 years it has been in service. However, some manufacturers have had issues when membranes were installed in high-heat situations. Problems occurred typically on roofs located in extremely hot, sunny climates or on roofs that had an unusual amount of dirt buildup, leading to loss of reflectivity. As the industry learned about these issues, ASTM International made the accelerated testing requirements in ASTM D6878, “Standard Specification for Thermoplastic Polyolefin Based Sheet Roofing,” more stringent.

It’s important to note accelerated testing subjects a material to conditions (ultraviolet [UV] light, heat, etc.) in excess of normal service parameters to uncover faults and failure modes. These often harsh conditions are used to get what would take years in the real world in a matter of months. The results of an accelerated aging test are an important proxy for the expected service life of a TPO membrane. For example, a poorly formulated and/or manufactured membrane will not even pass a low bar when subjected to accelerated aging while a well-formulated and manufactured sheet can last three to four times as long in accelerated aging tests.

Conditions and membrane failure

For the purposes of this article, membrane failure refers to either cracking or erosion down to the scrim in the field of the material. Once either of these things happens, membrane breakdown occurs rapidly. There are two in-situ temperatures the industry needs to be concerned about:

- 160 F—Many manufacturers’ design guides reference this temperature as an upper limit for sustained roof temperatures. It’s worth noting most roofs don’t exceed this; white membranes



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An unprecedented study shows surprising variations among TPO membranes

by Helene Hardy Pierce, Christopher McGroarty and Thomas J. Taylor, Ph.D.

are designed to stay cool, and most don't exceed 140 F to 150 F even after several years in the field.

- 195 F—There are several circumstances that can lead to membranes reaching temperatures this high for sustained time periods. These include membranes with directly attached solar panels, significant dark dirt buildup that blocks reflectivity, high-altitude locations and nearby highly reflective surfaces such as parapet walls.

There are recommendations for test requirements to ensure TPO can be specified correctly in terms of categories as shown in Figure 1. In addition, we have now predicted years of service in the real world for these categories for the two temperatures discussed.

Real-world performance

Anecdotal evidence clearly suggests there are many 10- to 15-year-old roof systems that perform in hot climates and still are in good condition (see the photo on page 40). However, the five- and seven-year-old roof systems in the photo show significant breakdown and an inability to weather under the conditions of their particular installations.

Throughout the years, ASTM International's TPO task group has continued to improve the

D6878 requirements that relate to weathering performance. In 2006, the UV test requirement doubled the exposure to 10,080 kJ/(m²·nm). In 2012, the heat-aging test was increased to 32 weeks' exposure at 240 F after which the breaking strength, elongation at reinforcement break and tear strength are to be at 90 percent or higher of the original values and the weight change less than +/- 1 percent.

In 2013, the TPO standard was raised by improving the thickness above scrim requirement to a minimum of 30 percent of the total thickness. The thickness over scrim is the weathering layer, and field failure is the point at which the weathering layer is cracked or eroded down to the scrim.

TPO category	Heat aging days to failure		Weather resistance kJ/(m ² ·nm) @ 340 nm	Projected performance at service temperature ¹	
	240 F	275 F		≤160 F	≤195 F
1	224	27	10,080	15 years	Not recommended
2	490	90	20,160	30 years	Not recommended
3	750	150	40,320	35 years	35 years

1. Actual warranties would need to consider wear and tear expectations, attachment method and several other system factors.

Figure 1: Recommended TPO test requirements and predicted years of service



Clockwise from upper left: A five-year-old roof showing cracking; a seven-year-old membrane showing erosion to the scrim; a 10-year-old 60-mil membrane; and a 12-year-old 45-mil membrane. The latter two roof systems showed negligible signs of weathering and were located in Las Vegas.

The TPO task group has repeatedly discussed the heat-aging requirement in terms of test temperatures and durations. In addition to the requirement for testing at 240 F, many industry professionals are using 275 F as another test temperature because it is faster and has been shown to predict product performance just as well as using 240 F.

There has been a lot of debate within the TPO industry about weathering performance. However, until now there has been an absence of a systematic and broad study of TPO membranes. Many studies have only looked at one or two rolls from each manufacturer. Such studies are useful, but they only provide a limited snapshot about the performance of the rolls tested.

The study

At the request and sponsorship of GAF, a study of the performance of commercially available TPO membranes was undertaken by Structural Research Inc., Madison, Wis. The goals were to study the accelerated aging of TPO, determine whether membrane performance has changed since earlier studies and compare surface cracking as a result of heat aging with weight loss.

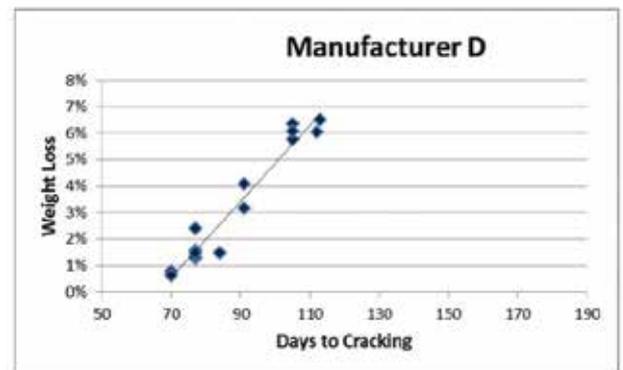
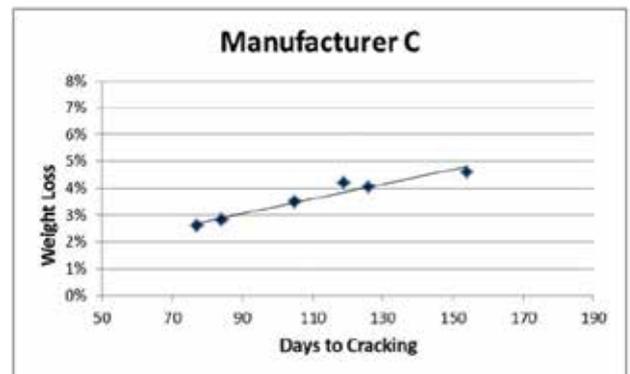
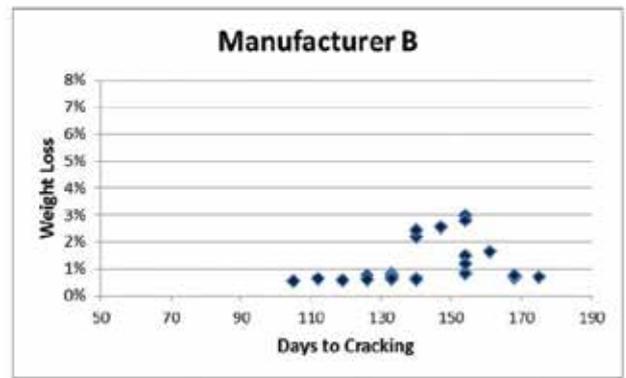
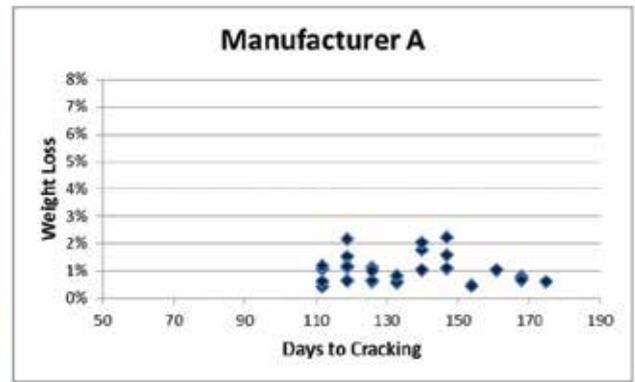


Figure 2: Number of days before TPO membrane showed surface cracking versus weight loss at that time

To avoid the common shortcoming of drawing conclusions from the testing of only a few rolls, the study attempted to obtain the broadest, most representative sampling of material possible. Multiple rolls from each of the manufacturer's plants, representing different manufacturing dates, were independently obtained by Structural Research from roofing distributors and contractors. The study included TPO membranes from four principal U.S. manufacturers that have a total of seven plants. Structural Research obtained 45 rolls of 50- and 60-mil TPO membranes that were produced between January 2013 and January 2014.

The four manufacturers' standard 60-mil products were designated A through D. Samples of one manufacturer's high-heat TPO product (60- and 50-mil versions) were included and designated E1 and E2, respectively.

For the heat-aging testing, three samples measuring 2 by 6 inches were taken from uniform spacing across the field of each roll. These were mixed randomly and hung in a laboratory oven at 275 F. The samples were taken out periodically, weighed, placed over a 3-inch mandrel and visually inspected for cracking while using a 7x eyepiece. A general visual inspection also was done to note curling, discoloration and any other physical change.

Failure Mode 1

The number of days each sample took to show surface cracking is shown in Figure 2.

Samples A and B went beyond 100 days before any cracking was observed whereas samples C and D started to crack at 70 to 75 days. Using cracking as the test failure, clearly Figure 2 indicates samples A and B are superior to samples C and D by a considerable margin. The E1 and E2 samples (the high-heat formulations) did not show any cracking until beyond 200 days. This supports the manufacturer's claims that this formulation can be expected to perform exceptionally well in demanding situations.

Failure Mode 2

Weight loss, indicated as a percent of the original weight, versus time is shown in Figures 3 to 6 for the four manufacturers. Note once an individual piece showed surface cracking, it was removed from the study.

The differences between competitors regarding the amount of time it takes to reach significant weight loss

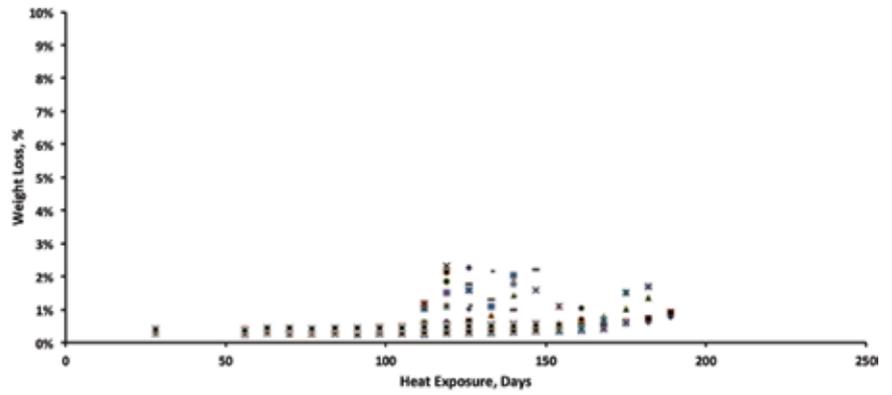


Figure 3: Weight loss of sample A

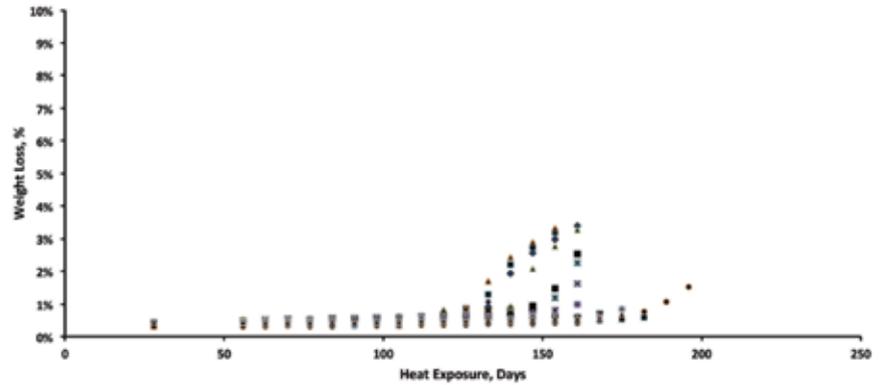


Figure 4: Weight loss of sample B

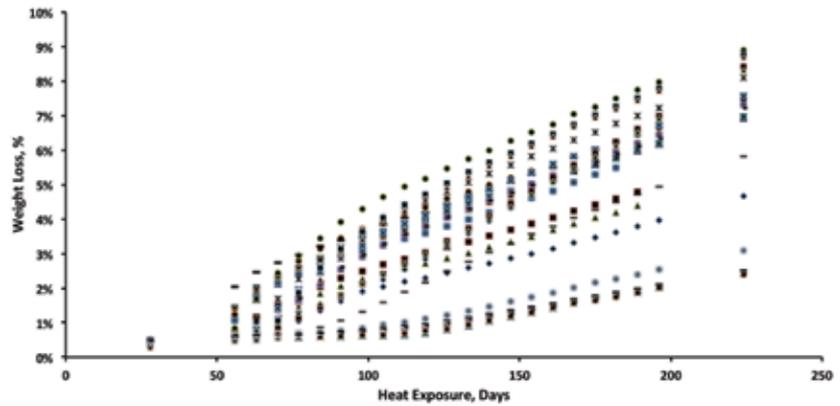


Figure 5: Weight loss of sample C

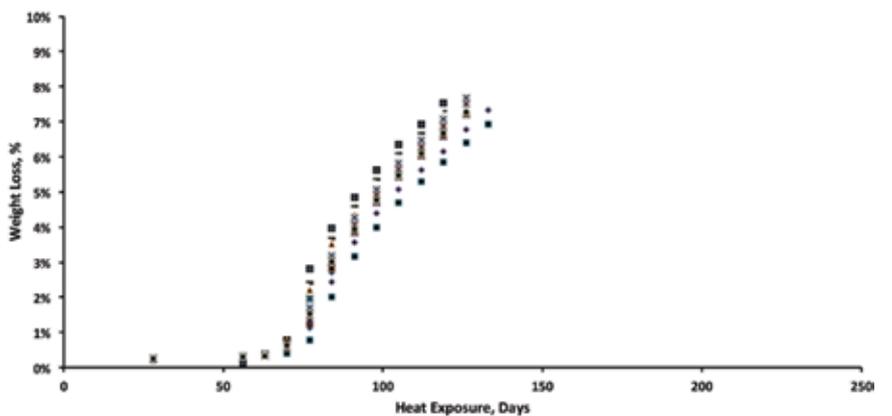


Figure 6: Weight loss of sample D

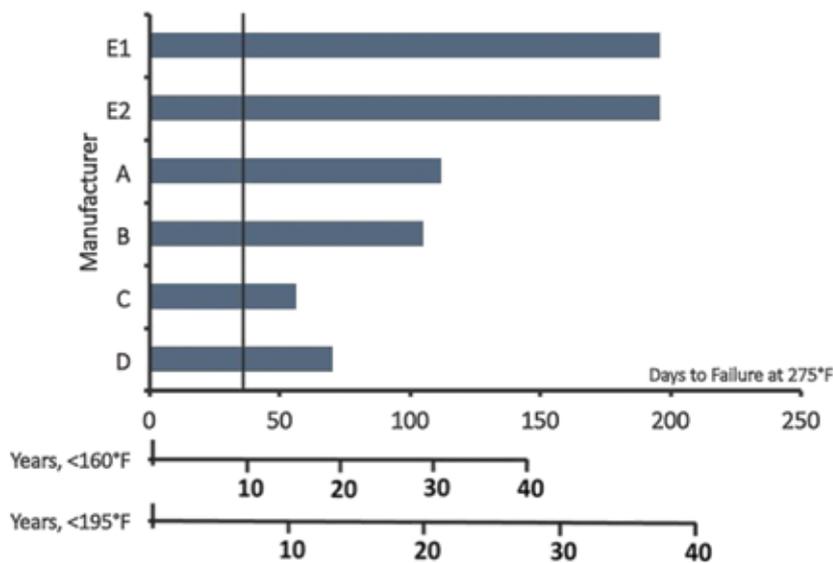


Figure 7: Time to failure, defined as cracking and/or weight loss greater than 1.5 percent for all TPO membranes. The vertical line represents ASTM D6878.

and the amount of weight loss are substantial. Samples C and D showed weight loss up to 8 percent while samples A and B were below 3 percent for all samples. Note the initial weight loss of around 0.5 percent, seen in the charts for all samples, is believed to be a result of loss of surface moisture. However, the larger amounts of weight loss likely are caused by a polymer breakdown and subsequent volatilization of the resulting low molecular weight species. Therefore, even though cracking might not have been observed, a strong argument can be made that a membrane with significant weight loss is not going to survive for an extended duration in the field and that samples with high weight loss correlate with instances of the cap layer eroding down to the scrim. It was observed that once the membranes had experienced just 1.5 percent weight loss, degradation occurred rapidly and the membranes were considered to have failed.

Another feature of the weight loss data was the variability seen among different rolls, particularly for sample C. In this case, some samples lose up to 9 percent while others lose about 2 percent. With such variation, it would be difficult for a building owner or roofing contractor to know what type of performance to expect from any installation.

Specifying TPO

From the results of this testing program, one may reasonably conclude there are two or three distinct grades of TPO on the market, notwithstanding all

the products meet ASTM D6878. These grades can be used to properly specify TPO based on the particular roofing application.

However, rather than using cracking as the only criteria, cracking and/or weight loss greater than 1.5 percent may be the better criteria to differentiate performance levels because the 275 F heat-aging test clearly shows two failure modes—cracking of the surface and/or weight loss greater than 1.5 percent. When the data are combined, it appears as shown in Figure 7.

Drawing conclusions

There are significant differences between TPO membranes from the various manufacturers in terms of resistance to accelerated aging. Although this testing showed all TPO membranes perform at levels significantly above where they were as a product class 10 or 15 years ago, any impression that TPO membranes are all the same, regardless of manufacturer, is wrong. The testing results led us to the following conclusions:

- TPO membranes fall into one of three distinct grades. Specifiers should be aware of their end use expectations when selecting a particular membrane. Demanding applications should require membranes that perform well in extended heat-aging and weight-loss tests.
- During accelerated heat-aging testing, TPO fails via one of two mechanisms. One of these is surface cracking, and the other is significant weight loss. During weight loss, a TPO membrane shrinks in thickness. It could be this failure mode accounts for the cracking and erosion of the top layer of the TPO sheet exposing the reinforcement seen in some instances.
- Three of the four manufacturers' TPO membranes showed remarkably consistent results, which indicates discipline in formulation and manufacturing.

This study conclusively demonstrates all TPO membranes do not perform equally, and more demanding applications require careful TPO membrane selection to ensure satisfactory performance and minimize potential risks of failure. 🏠🔧

HELENE HARDY PIERCE is vice president of technical services, codes and industry relations for GAF, Parsippany, N.J.; **CHRISTOPHER MCGROARTY** is GAF's senior product manager; and **THOMAS J. TAYLOR, PH.D.**, is GAF's executive director, single-ply systems product development.