

PUSHING THE LIMITS OF TPO TESTING

By Thomas J. Taylor

INTRODUCTION

Thermoplastic polyolefin roofing (TPO) is now the largest segment of the commercial roofing market. Its introduction in the early 1990s coincided with the increasing requirement for white reflective roofing. Also, as big-box architecture has become dominant in the retail markets, single-ply roofing in general has seen large growth.

TPO continues to be the newest membrane for commercial low-slope roofing, and is sometimes regarded as being “unproven.” It is important to recognize that the major manufacturers have produced many billions of square feet since the 1990s. In addition, ASTM International D6878, *Standard Specification for Thermoplastic Polyolefin-Based Sheet Roofing*,¹ published in 2003, has continually been strengthened.

This paper describes the weathering-resistance standards for TPO and how they have been increased. Some improvements have been incorporated into the ASTM D6878 standard, while others have been used by individual manufacturers. In addition, a new study using a combination of ultraviolet (UV) light and heat aging is described.

WEATHER-RESISTANCE SPECIFICATIONS

TPO is known to be very resistant to standing water; for example, it is used as both a pond and pool liner. Additionally, it is not affected by repeated freeze and thaw cycles. TPO weathers from the effects of UV and heat. Accelerated aging is an established science, exposing materials to conditions often far in excess of what is normally experienced, but for far shorter times. Heat is easy to simulate by using an oven. For UV testing, there are many options, including indoor and outdoor techniques.

UV Exposure

The ASTM D6878 specification requires the use of a xenon-arc apparatus, oper-

ated in accordance with practices G151 and G155. A xenon arc, operated in these ways, is widely recognized as producing a bright white light that closely mimics natural sunlight, including UV. When D6878 was first published in 2003, the exposure requirement was 5,040 kJ/m², measured at 340 nm. This was doubled to 10,080 kJ/m² in 2006 in response to some membrane failures, and remains at that level today. A review of marketing claims by manufacturers suggests that today's membranes are capable of passing twice this exposure level or better.

The use of other UV tests has been described elsewhere by Xing and Taylor.² In general, whether they use other types of indoor apparatuses or are based on some means of concentrating sunlight, these tests are regarded as being less severe or taking too long. The exception is the Ultra Accelerated Weathering System, or UAWS,³ which uses 29 reflective facets to direct sunlight onto a test specimen (*Figure 1*). The UAWS apparatus is unique in its ability to also focus a lot of heat energy onto the sample and was used by Xing and Taylor to develop a membrane for extreme conditions. However, work has not been done to quantify that heat energy and correlate it to typical annual exposures.

Heat Aging

The original ASTM D6878 specification called for heat aging at 115.6°C (240°F) for 28 days. During the December 2009 ASTM TPO task group meeting, premature failure of TPO roofs was discussed.⁴ One manufacturer described membrane failures that were found to be related to unanticipated high-heat loadings. In these conditions, the membrane was exposed to higher than normal temperatures due to situations such as

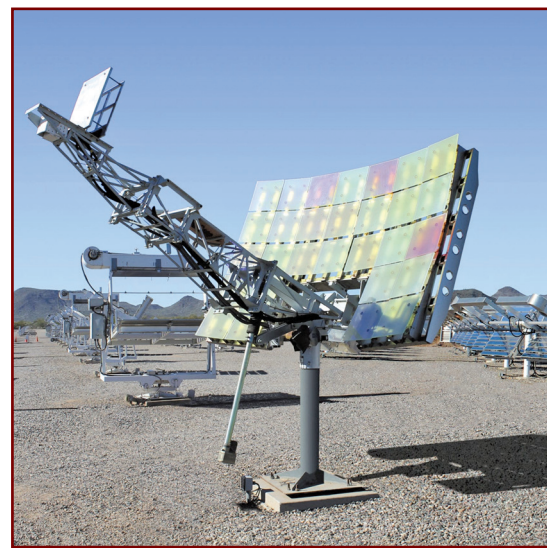


Figure 1 – The Ultra Accelerated Weathering System, used for testing material resistance to natural light. (Photo courtesy of Atlas Material Testing.)

reflections from nearby surfaces. An accelerated heat-aging test at 135°C (275°F) for 56 days was proposed (which would have raised the temperature from 115.6°C and doubled the time of exposure).

Such an increase was not agreed to, although significant anecdotal evidence exists to suggest that most manufacturers are using a heat-aging temperature of 135°C. The ASTM TPO task group decided to raise the standard to 115.6°C exposure for 224 days (32 weeks) and published this change on June 1, 2011.

A study by Deaton and Martin compared methods for predicting the long-term performance of membranes.⁵ They found that weight loss during heat aging correlated well with the onset of cracking, with similar results at various temperatures between 115.6° and 135°C. The ASTM TPO task group also conducted an interlaboratory study of TPO aging at these two temperatures. A statistical analysis of the data indicated that the relative ranking of samples remained the same at either temperature.⁶ The higher temperature simply achieved

Sample	Post-QUV Samples After Heat Aging, Days to Surface Cracking									
	7	14	21	28	35	42	49	56	63	70
A	60	70	80	90	90	90	100			
B	89	100								
C	67	67	67	67	67	67	67	67	67	67
D	100									
E1	20	30	30	50	60	80				
E2	0	0	0	20	20	40	40	60	80	

Note: Highlighted cells indicate when all samples failed due to surface cracking. The numbers indicate the percentage of failed samples.

Table 1 – Percentage of post-QUV samples failed during heat-aging exposure due to surface cracking.

results in a shorter time.

The study described here used a heat-aging temperature of 135°C in order to keep the test time reasonable. In the prior study by Xing and Taylor, several membranes took years to fail at 115.6°C. They noted an excellent correlation between the results for each temperature, indicating that degradation mechanisms are the same.

NEXT STEPS IN TESTING

It is clear that TPO continues to evolve. Warranties have been lengthened such that the typical original 10-year term has been replaced with 15- to 20-year terms, with some of the thicker membranes extended to 25 years. In fact, a membrane designed for high temperature and other demanding installations carries a warranty as long as 35 years, depending on thickness and installation method. It is therefore appropriate to challenge the existing standards and to continue to search for better test methods.

Combining UV and Heat Aging

In a recent study,^{7,8} 45 rolls of TPO membrane were sourced and tested independently by Structural Research Inc., Middleton, Wisconsin. These represented not just all manufacturers, but every factory, with each roll also having a different date code. 60-mil TPO that was produced between January 2013 and January 2014 was sourced through roofing distributors and contractors. Samples of TPO specifically designed for long life under demanding situations were included in the study. The four

manufacturers' products were designated A through D, with the long-life, 60-mil TPO being designated E1. In addition, samples of a 50-mil TPO version of E1 were included and designated as E2.

The testing included heat-aging, using both surface cracking and weight loss as the performance criteria. For this study, a subset of those rolls was used, this being one roll from each manufacturing plant.

Three 2- x 6-inch samples were taken across the field of each sheet, uniformly spaced. These were then exposed to 30,240 kJ/m² at 340 nm UV using a QUV, Q-Labs Inc.'s fluorescent UV apparatus. This was operated in accordance with ASTM G154 modified as follows: The exposure cycle was 700 minutes of light using UVA 340 lamps at 1.55 W/m² at 80°C, followed by 20 minutes of water spray.

After the UV exposure, all samples were examined for surface cracking while bent over a 3-inch mandrel, using 7x magnification. Those same samples were then placed in a SalvisLab Thermocenter TC400 oven, set at 135°C. They were taken out every seven days, allowed to cool, weighed, and examined for surface cracking. Weight measurements were carried out using an analytical balance and were recorded to three decimal places. The samples all initially

weighed around 11 grams each. Importantly, once a sample showed surface cracking, it was removed from further testing.

RESULTS AND DISCUSSION

None of the samples showed evidence of surface cracking after the UV exposure. Also, the weight change averaged a loss of 0.77%, with a standard deviation of ±0.20%. This supports the argument made previously that today's TPO membranes will not fail during their warranted life due to UV exposure alone.^{9,10}

After QUV exposure, the samples were heat-aged at 135°C as described earlier until they failed due to surface cracking. The percentage of samples failing the post-QUV heat-aging exposure due to cracking is shown in Table 1.

The correlation of UV exposure followed by heat aging to membrane life expectancy is not known. However, the data shown in Table 1 suggest that there are significant differences between the four standard membranes in terms of the amount and/or effectiveness of the stabilizers. Manufacturer D, having failed totally after seven days' heat exposure, would likely not have gone much further in the UV testing before failing.

It is notable that, with the exception of Manufacturer D and possibly Manufacturer B, the failures are spread out over a significant time period. This suggests that any specification such as ASTM D6878 should have some requirement as to sample size. Also, even though Samples E1 and E2 are the same formulation, it appears that the thinner of the two, E2, performs better. This might indicate that thicker samples crack more readily when bent over a mandrel.

Sample	Post-QUV Sample Percent Weight Loss After Heat-Aging, Days										
	0	7	14	21	28	35	42	49	56	63	70
A	0.6%	0.9%	0.8%	0.8%	0.8%	1.0%	1.7%	2.3%	1.3%		
B	0.7%	0.9%	0.8%								
C	0.8%	1.1%	1.1%	1.5%	3.2%	5.0%	6.4%	7.6%	8.5%	9.4%	10.1%
D	0.6%	1.2%									
E1	0.8%	1.1%	1.2%	1.3%	1.4%	1.2%	1.3%	1.5%	1.7%	2.0%	2.5%
E2	1.1%	1.3%	1.4%	1.4%	1.5%	1.4%	1.5%	1.4%	1.6%	1.7%	1.4%

Note: Highlighted cells indicate when all samples failed due to surface cracking or once weight loss reached >1.5%

Table 2 – Average percent weight loss of post-QUV samples during heat-aging exposure.


In terms of weight loss during the heat aging, significant differences existed between membranes. The average weight-loss data during heat aging is shown in *Table 2*.

There are a couple of instances where weight loss appears to have declined. However, that is an artifact of samples failing due to cracking and being removed from subsequent testing. Although ASTM D6878 allows for a maximum weight change of $\pm 1\%$, Taylor et al. have suggested that $>1.5\%$ might be more appropriate. This was based on an inflection point in weight versus exposure time, after which weight loss becomes rapid. That appears to be the case in this study, as well.

With one exception, the membranes generally did not lose more than approximately 2.5% weight before being withdrawn from testing due to surface cracking. However, in the case of Manufacturer C, the weight loss went as high as $>10\%$ without any evidence of cracking. This has also been seen for this manufacturer in a study based on heat aging alone.⁷ There has been relatively little anecdotal evidence for TPO failing due to cracking. However, that is not the case for so-called “surface erosion,” whereby the surface erodes down to the reinforcing scrim. It is very possible that the weight loss seen here is indicative of TPO that might also exhibit such erosion.

In some cases—specifically Manufacturers B and D—the results were very consistent among individual samples and rolls. However, there is strong evidence of considerable variability in other cases, especially with Manufacturer C.

CONCLUSIONS

1. Today’s TPO membranes survive UV exposure testing to 30,240 kJ/m², three times beyond current specification of 10,080 kJ/m², which is remarkable.
2. Heat aging of TPO after UV exposure shows that very significant differences exist among manufacturers’ products in terms of life expectancy.
3. The testing of large numbers of samples from manufacturers indicates that some have significant levels of product variability.
4. In the future development and improvement of product specifications, attention should be given to defining the number of specimens.
5. The use of weight loss as a pass/fail criterion warrants further attention. It may be an indicator of a real-world failure mode. 

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NEW FAA RULE ALLOWS UAS REGISTRATION ONLINE

The Federal Aviation Administration (FAA) has instituted a fast online registration system for those who use small unmanned aircraft systems (UASs, or drones) for personal or business purposes. Owners of small, recreational-use UASs (or those such as many engineering and construction firms might use on occasion) are required to register those devices by February 19 for a fee of \$5. Registration is required for aircraft that range from 0.055 pounds to 55 pounds.

An identification number must be put on the aircraft. Owners of multiple drones only have to buy one registration to cover all of their UASs.

A new registration for commercial UASs should be in place this spring, the FAA said.

The Management Association for Private Photogrammetric Services (MAPPS) helped to draw up the new registration recommendations. MAPPS members are in surveying, mapping, geospatial services, and other industries.

The FAA has enacted civil penalties of up to \$27,500 and criminal penalties of up to \$250,000 and three years’ prison time to enforce the regulation.