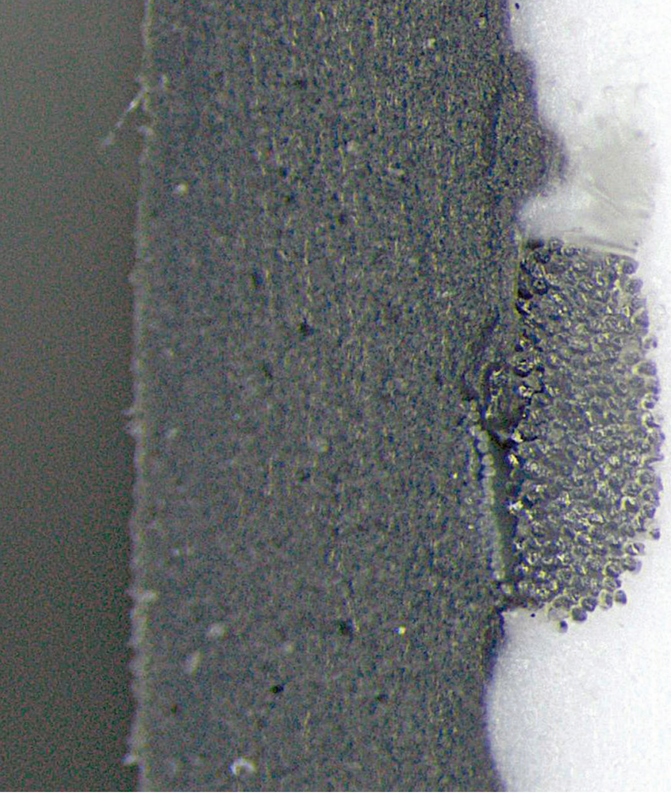


SPECIFYING SINGLE PLY

– *Testing for Roof Performance*

By Christopher McGroarty and Thomas J. Taylor, PhD

INTRODUCTION

In common with most construction industry practice, roofing specifiers rely on material specifications developed and published by the American Society for Testing and Materials (ASTM). Material standards such as ASTM D6878[1] for thermoplastic polyolefin (TPO), ASTM D4434[2] for polyvinyl chloride (PVC), and ASTM D6754[3] for ketone ethylene ester (KEE)-based sheet roofing include specifications for attributes such as the following:

- **Materials and Manufacture –** Requirements for the types of polymer and the amounts are specified in D6878 and D4434. Both specify a polymer content greater than 50% by weight. In the case of D6754, it is specified that the KEE content should be a minimum of 50% of the total polymer content. However, the amount of polymer in the sheet is not specified by D6754.
- **Physical Requirements –** Physical requirements of single-ply membranes can be divided into those that characterize the initial properties of the membrane and those that indicate resistance to stressors such as heat, ultraviolet light (UV), and ozone. The specifications include the minimum sheet thickness and the minimum thickness above reinforcement fabric of the weathering layer. In addition, a large number of properties are specified, ranging from various strength values to heat and UV resistance.
- **Dimensions –** Roofing material dimensions are typically left for agreement between buyer and seller, as is the case for the PVC and TPO standards. However, the ASTM specifications describe the length and width tolerances and note that the sheet must be allowed to relax prior to measurement.
- **Workmanship, Finish, and Appearance –** These characteristics generally relate to visual defects and such. The membranes are required to lay straight and be flat.

Many of the properties are measured using an ASTM test method. For example, the breaking strength specified in the D4434, D6754, and D6878 specifications is to be measured using ASTM test method D751. Some specifiers mistakenly write membrane requirements in terms of the test method, such as, "Must meet tensile strength requirements of ASTM D751." But the test methods do not have any requirements; they define sample size, number of samples to be tested, etc., but can be used for a great many materials.

In an effort to differentiate between TPO membranes, for example, specifiers sometimes write requirements that are more stringent than the ASTM material specification. However, going beyond the ASTM specifications does not necessarily translate to a membrane that will outlast others covered by the same basic specification. Also, due to manufacturing variability, a sample that, for instance, had a high tensile strength, might not actually be typical of what can be expected from that manufacturer.

KEY INDICATORS OF ROOF PERFORMANCE

Roof issues can generally be characterized as short- and long-term. Short-term issues—especially those occurring within the first few years—are generally due to installation issues. For thermoplastic single-ply membranes, these include welded seam problems plus issues that are common to most roof types, such as those associated with flashings, details, and terminations.

Longer-term roof membrane failure can be due to hidden installation issues, but is more frequently due to loss of integrity of the membrane itself. Examples include cracking and erosion of the membrane. Also, long-term failure can occur due to puncture of the membrane.

The authors are not aware of any thermoplastic single-ply roof failure that can be traced to insufficient breaking or tear strength. In fact, as has been previously noted by Taylor and Yang,[4] the initial properties in the ASTM D6878 TPO standard specification appear to be sufficient. Specifying higher individual targets for a property such as tear strength might actually be counterproductive, given the compromises that might need to be made.

Higher tear strength, as an example, can be achieved but is normally at the expense of cap-to-core lamination strength.

The characteristics that appear to indicate long-term roof performance are as follows:

- **Membrane Thickness** is an indicator of weather and mechanical abrasion (i.e., "wear and tear") resistance, and it has a small but positive effect on puncture resistance.[5,6] The National Roofing Contractors Association (NRCA) has recommended using thicker versions of TPO membranes.[7] Certainly thicker membranes have a greater "reservoir" of UV and heat stabilizers per unit area.
- **Thickness Over Scrim** is a measure of the thickness above the reinforcement fabric of the weathering layer. Membrane manufacturers put stabilizers into this top layer to provide resistance to UV and heat-initiated degradation. It could be argued that thickness over scrim is more important than total membrane thickness for weathering. However, total thickness offers an assurance that once the fabric is visible, there is possibly still enough membrane to allow sufficient time for repair or replacement to be carried out.
- **UV Resistance** uses intense laboratory UV sources that mimic the sun's UV spectrum to evaluate a membrane's ability to withstand high levels of UV energy. Many building materials used in exposed construction applications degrade over time due to UV exposure, and roof membranes are no different. UV energy breaks bonds within the polymer and creates free radicals that begin a degradation cycle leading to breakdown of the polymer backbone.[8,9]
- **Heat Aging** uses elevated temperatures to speed up membrane degradation that might normally take years or decades to be become sufficient to cause failure. For TPO, heat causes oxidation of the polymer and thereby a gradual loss of the original properties.[10] In the case of PVC, it has long been recognized that heat causes loss of the plasticizers and thus an increase in cold brittleness and a decrease in flexibility.[11,12]

MEMBRANE TESTING

Structural Research Inc. (SRI) carried out a large study of commercially available TPO produced during 2013.[13] That study included heat and UV resistance and a range of physical properties. This paper contains a more detailed examination of some of that data, including total membrane thickness and thickness over scrim.

Five rolls, each with a different date code, were obtained per manufacturing plant, the majority being 10 feet wide. Six measurements were taken, equally spaced across each sheet, with the edge points being one inch in. Care was taken to ensure thickness over scrim was measured to the uppermost yarns, excluding the tie yarn.

MEMBRANE INITIAL PROPERTIES

Sheet Thickness and Thickness Over Scrim

TPO and PVC (ASTM D4434-compliant) membranes come in a variety of thicknesses; however, the most popular thickness is

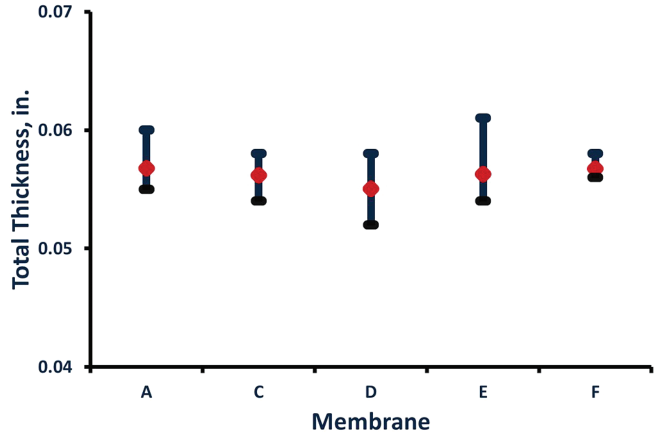


Figure 1 – Average thickness (inches) for all membrane samples. The range indicates the measured minimum and maximum values.

60 mils, whereas PVC KEE (ASTM D6754-compliant) membrane's most popular thickness is 36 mils. The ASTM sheet thickness for most single-ply membranes is specified as having a tolerance of +/- 10%. So, a nominal 60-mil sheet could actually be as low as 54 mils. In reality, manufacturers must target a thickness greater than the minimum such that no sample would go below the minimum.

Thickness over scrim for PVC is specified as being 16 mils in D4434, 6 mils for D6754, and the use of a single value was in the original D6878 TPO standard. However, in 2016, the TPO specification was changed to a minimum of 30% of the overall thickness. For a 60-mil membrane, that would be an 18-mil-thick weathering layer.

As indicated in *Figure 1*, the total thickness for all manufacturers is very similar.

The average values shown are all 56 mils, with the exception of membrane D, which is 55 mils, suggesting that one manufacturer targets a slightly lower nominal thickness than the others. Also, in the case of membrane D, some individual measurements are below the D6878 specification. However, the specification does not clearly indicate whether the thickness minimum applies to individual measurements, a roll average, or some other metric.

The thickness-over-scrim data are shown in *Figure 2*.

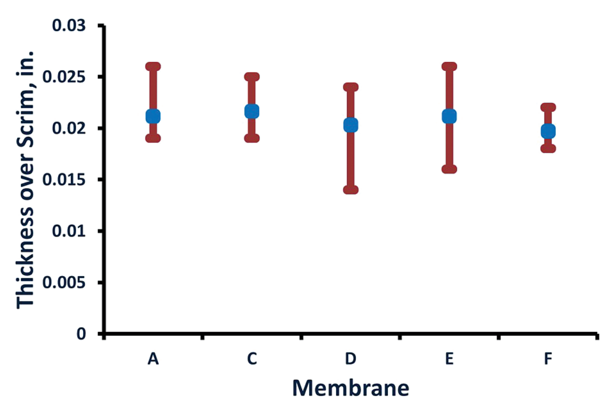


Figure 2 – Average thickness over scrim for all samples. The range indicates the minimum and maximum values.

In terms of real-world performance, the thickness over scrim is a critical parameter. Membrane failure is frequently viewed as the point in time when the surface has worn, eroded, or cracked such that scrim is exposed. It appears from this large sample set that all manufacturers are targeting >20 mils, but in two cases, individual samples fall below the D6878 minimum (18 mils for 60-mil nominal or 16.2 mils for 54-mil actual total thickness).

Thickness over scrim is measured using a calibrated microscope to view a polished cross section of the membrane, per test method ASTM D7635.[14] A closer examination of the membranes indicates that some differences exist that are not being captured in the data; for example, *Figures 3* and *4* show reinforcement that is forced into the top and bottom layers, respectively.

Also, in some cases, the reinforcement is approximately centered within the membrane, as shown in the example in *Figure 5*.

After examination of all of the micrographs, it is very apparent that even individual plants are not consistent with respect to reinforcement positioning within the membrane. There have been anecdotal reports of some manufacturers claiming a particular reinforcement positioning, but the data belie that.

MEMBRANE-AGED PROPERTIES

Accelerated Weathering

The ASTM PVC standard allows for the use of either xenon arc light or fluorescent UV to artificially weather membrane samples (using either test, the samples must pass at least 6,300 KJ/m^2), whereas the TPO standard specifies the use of xenon arc light only. The two light sources are different in that a xenon arc reproduces the entire solar spectrum, while fluorescent UV reproduces the UV region. The two methods also have differences in terms of moisture exposure, and each has its pros and cons.[15] The TPO study conducted by SRI used UVA 340 lamps to apply a 1.55 W/m^2 irradiance using a cycle of 700 minutes of light followed by 20 minutes of water spray. The black panel temperature was 176°F. Both ASTM standards define failure as the presence of surface cracks visible using a 7x eyepiece when the sample is bent over a 3-in.-diameter mandrel.

All the TPO samples from the multiple date codes from each manufacturing plant survived exposure to 30,240 kJ/m^2 without cracking. This

Figure 3 – Microscopic picture of a nominal 60-mil-thick membrane cross-section, showing the reinforcement positioned in the top (white) layer.

is well beyond the 10,080 kJ/m^2 requirement of ASTM D6878, even though the test method (fluorescent UVA versus xenon arc) was different. It supports industry anecdotal evidence that current-production TPO is very resistant to UV damage.

Heat Aging

Heat aging for PVC is done at 176°F for 56 days, with failure defined by ASTM D4434 as being if the tensile strength, breaking strength, and elongation at break fall below 90% of the original. For TPO, the aging is performed at 240°F with essentially the same mechanical tests and criteria at the end. However, in addition, failure includes weight change of greater than 1%. As noted elsewhere,[16] there has been an ongoing industry discussion of testing TPO at 275°F. Some of today's membranes are so heat-resistant that testing at 240°F can take well over a year. Testing TPO at 275°F has been shown to give similar results to 240°F[17] and was used in the SRI study to measure the time to cracking and weight loss.

Surface cracking during heat aging is indicative of membrane stiffening and embrittling. Heat promotes two degradation mechanisms in polyolefins: oxidative crosslinking and chain scission. Of these two, crosslinking of the polymer chains would stiffen the material and thereby increase the risk of cracking when bent over the mandrel. In the real world, the increased stiffness could lead to cracking in freeze-thaw conditions, for example. Also, stresses in membrane adjacent to welds or fixed attachment areas such as penetrations or fasteners could lead to cracking.

Weight loss during heat aging of polyolefins is due to breakdown of the polymer chains into smaller units that are, ultimately, volatile. In the field, this appears as surface erosion, which eventually exposes the reinforcement fabric.

The weight loss during heat aging at 275°F was typically small and gradual until some point at which weight loss became rapid. The presence of this "induction period" is well established for many stabilized organic and polymer systems. It is typically measured using differential scanning calo-

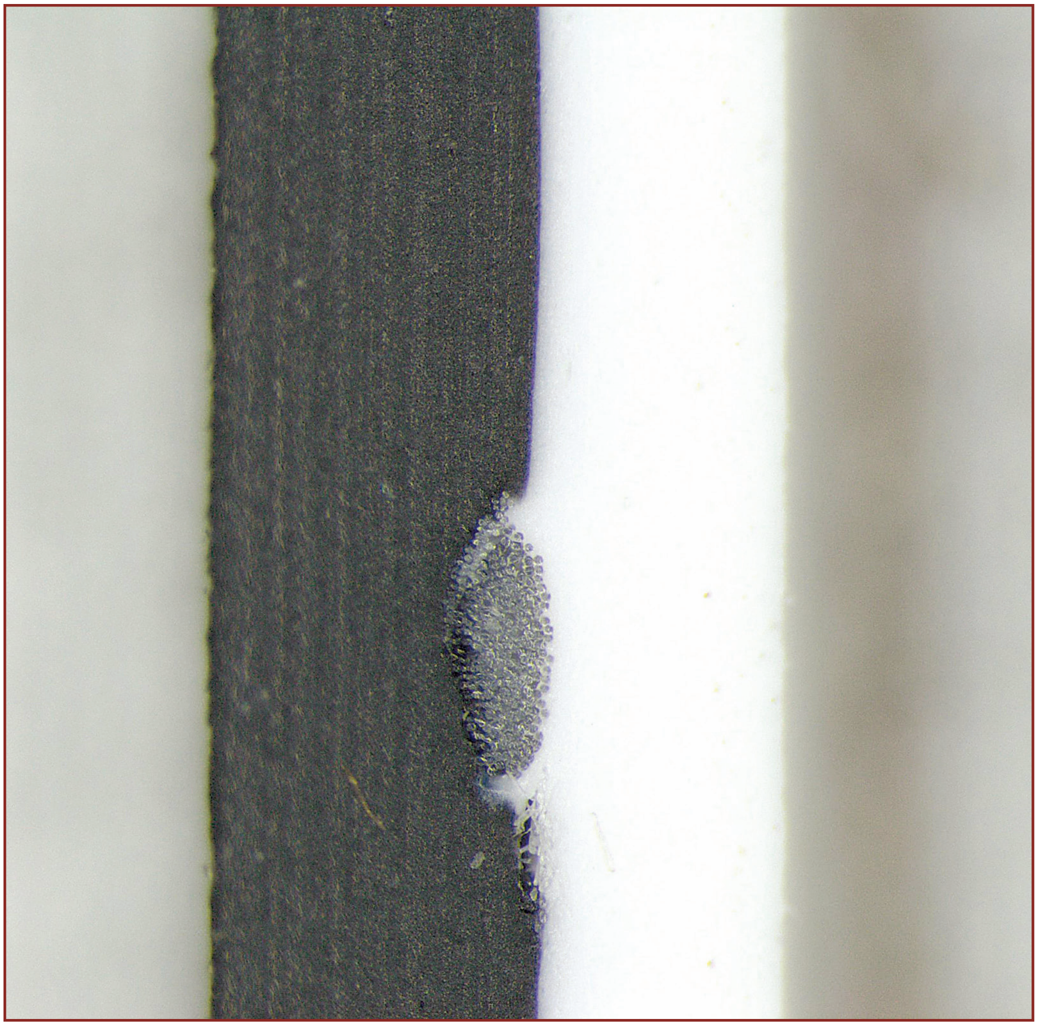


Figure 4 – Microscopic picture of a nominal 60-mil-thick membrane cross-section showing the reinforcement positioned in the bottom, gray, layer.

Figure 5 – Microscopic picture of a nominal 60-mil-thick membrane cross-section showing the reinforcement positioned approximately in the membrane center.

rimetry (DSC), whereby the oxidative-induction time (OIT) prior to oxidative breakdown and associated exothermic heat loss is measured[18] and has been standardized by ASTM D3895.[19] A typical DSC plot used to derive OIT is shown in *Figure 6*.

The OIT test is typically done at around 400°F for polyolefins, and it measures the time taken to deplete the antioxidants. In a similar way, the weight loss study of TPO membranes shows a long induction time until the stabilizers are depleted, at which point weight loss becomes rapid. A typical result for one of the membranes is shown in *Figure 7*.

As can be seen, there is an initial period of relative stability, followed by accelerated weight loss. The exact point at which loss becomes rapid varies depending on the sample, possibly indicative of some process variation. Such variation was very large for membrane E, as shown in *Figure 8*.

Some samples went beyond 1% weight loss before the rate of loss increased. A loss of 1.5% was taken as generally indicative of the start of rapid weight loss. *Table 1* shows the heat aging days to failure for the first

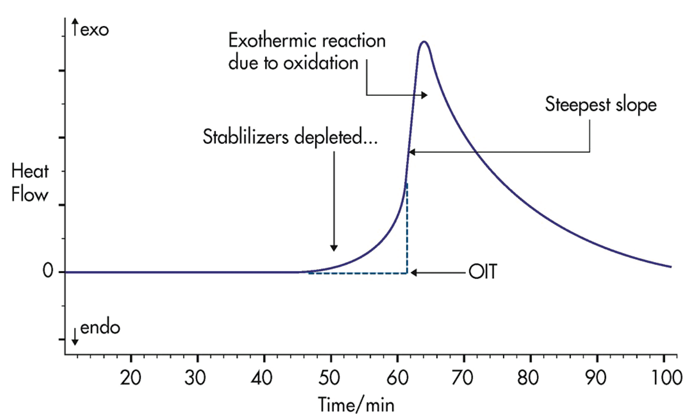


Figure 6 – Schematic of a DSC scan of a stabilized polyolefin in air.

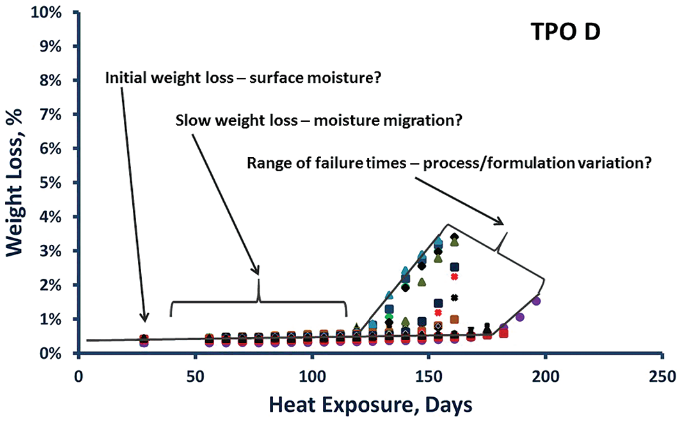


Figure 7 – A typical weight loss during accelerated aging study of TPO, shown for Membrane D. The data points represent four samples taken across each of the ten rolls (five per manufacturing plant).

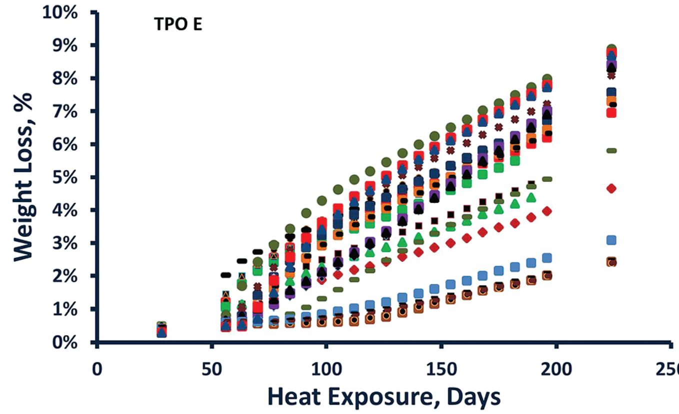


Figure 8 – Weight loss during accelerated aging of Membrane E. Each series of points represents one sample taken from across one of the 15 rolls (five per manufacturing plant).

appearance of surface cracking and the time to a weight loss of 1.5%.

Although the results shown in *Table 1* appear to clearly rank the membranes, they do not indicate the large variation shown for membrane D. This argues that, while the ASTM specifications are highly relevant to the specifier in providing general guidance, they do not address variability in a manufacturing process. Consideration of the results shown in *Figure 8* suggests that competitive studies do need to evaluate large numbers of samples. The use of single samples to evaluate differences between membranes is clearly not valid, but has been used in some other studies.[20]

ASTM D4434 VS. D6754; PVC VS. KEE

A comparison of the PVC and KEE specifications, D4434 and D6754, respectively, shows that the accelerated weathering and heat aging requirements are the same for each membrane. The specifications differ in terms of the polymer contents, thickness, and thickness above scrim, and the breaking and tear strengths, as noted earlier. These authors have not seen single-ply membranes fail due to poor strength, and so a specifier isn't provided with a performance-based specification that differentiates between these two membrane types.

CONCLUSIONS

1. Many material properties are specified in membrane ASTM standard specifications. However, those that are indicative of long-term roof performance are limited to membrane thickness, thickness over scrim, UV resistance, and heat aging.
2. A large study covering multiple rolls from all U.S. TPO manufacturing plants showed that total membrane thicknesses are generally equivalent, although there is some evidence that one manufacturer might be targeting a slightly lower thickness versus the other three.
3. Thickness over scrim is a measure of the depth of the weathering layer. The membranes studied were all generally equivalent, although some manufacturers were more variable than others.

Membrane	Days to Failure at 275°F	
	Cracking	Weight Loss >1.5%
A	196	196
C	112	119
D	105	133
E	77	56
F	70	77

Table 1 – Heat aging days to failure, using the first failure mode to occur in each case.

4. While all TPO appears to significantly exceed the ASTM specification for UV resistance, there are large differences in terms of accelerated aging by heat exposure. Not only do some membranes fail earlier than others, but some manufacturers exhibit large variations between plants and rolls from an individual plant.
5. Conducting competitive studies by focusing on single rolls clearly cannot identify those manufacturers that have consistent processes versus those that do not.
6. Manufacturers and others who participate in ASTM specification development are encouraged to include targets that enable differentiation in terms of actual real-world performance.

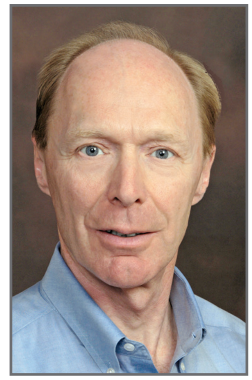
REFERENCES

1. ASTM D6878, *Standard Specification for Thermoplastic Polyolefin Based Sheet Roofing*. ASTM International, West Conshohocken, PA, www.astm.org.
2. ASTM D4434, *Standard Specification for Poly(Vinyl Chloride) Sheet Roofing*. ASTM International, West Conshohocken, PA, www.astm.org.
3. ASTM D6754, *Standard Specification for Ketone Ethylene Ester Based Sheet Roofing*. ASTM International, West Conshohocken, PA, www.astm.org.
4. T.J. Taylor and L.Y. Yang. "Physical Testing of Thermoplastic Polyolefin Membranes and Seams," *RCI Interface*. December 2010, pp. 4-9.
5. S. Bhawalkar and T.J. Taylor. "Puncture Resistance of Thermoplastic Single-Ply Roofing Membranes." *RCI Interface*. January 2015, pp. 22-25.
6. S. Bhawalkar, T. Yang, and T.J. Taylor. "Understanding the Puncture Resistance of Thermoplastic Polyolefin Membranes." *ASTM Eighth Symposium on Roofing Research and Standards Development. STP1590*. 2015, pp. 14-29.
7. M.S. Graham. "Is Thicker Better?" *Professional Roofing*. October 2009, p. 21.
8. C. Decker, F.R. Mayo, and H. Richardson. "Aging and Degradation of Polyolefins." *Journal of Polymer Science*, Polymer Chemistry, Vol. 11, 1973. pp. 2879-2898.
9. M. Tolinski. "Ultraviolet Light Protection and Stabilization," *Additives for Polyolefins: Getting the Most Out of Polypropylene, Polyethylene, and TPO*. Elsevier, 2nd Edition, Chapter 4. 2015. pp. 32-40.
10. M. Tolinski. "Antioxidants and Heat Stabilization," *Additives for Polyolefins: Getting the Most Out of Polypropylene, Polyethylene, and TPO*. Elsevier, 2nd Edition, Chapter 4. 2015. pp. 19-31.
11. R.G. Turenne, H.K. Stenman, M.N. Mech, and O. Dutt, "Single-Ply Membranes – Effect of Cold Temperatures and Heat Aging on Tensile Properties." Third International Symposium on Roofing Technology, Gaithersburg. 1991, pp. 7-14.
12. R.M. Paroli, O. Dutt, A.H. Delgado, and H.K. Stenman, "Ranking PVC

Roofing Membranes Using Thermal Analysis." *Journal of Materials in Civil Engineering*. 1993, Vol. 5, No. 1, pp. 83-95.
13. H.H. Pierce, C. McGroarty, and T.J. Taylor. "Testing TPO." *Professional Roofing*. August 2015, pp. 38-42.
14. ASTM D7635, *Standard Test Method for Measurement of Thickness of Coatings over Fabric Reinforcement*. ASTM International, West Conshohocken, PA, www.astm.org.
15. D.M. Grossman. "The Right Choice – UV Fluorescent Testing or Xenon Arc Testing?" *Paint and Coatings Industry*. March 2006, Vol. 22, Issue 3, p. 40.
16. T. J. Taylor and L. Xing. "Accelerated Aging of Thermoplastic Polyolefin Membranes – Prediction of Actual Performance." *Roofing Research and Standards Development, Vol. 8*. ASTM International. 2015, pp.139-152.
17. K. Deaton and N. Martin. "Putting Membranes to the Test." *Architectural Roofing & Waterproofing*, Vol. 2, 2013, pp. 14-18.
18. H. Rudin, H.P. Schreiber, and M.H. Waldman. "The Thermographic Study of Polymers." *Industrial and Engineering Chemistry*, Vol. 53, 1961, p. 137.
19. ASTM D3895, *Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry*. ASTM International, West Conshohocken, PA, www.astm.org.
20. Carlisle Syntech Systems, "TPO Competitive Test Programs Summary of Results." https://www.carlislesyntec.com/view.aspx?mode=media&contentID=1155, Nov. 11, 2016.

Chris McGroarty

Chris McGroarty has worked at GAF for over ten years in a variety of roles, including product manager for insulation and single ply. During that time, he has worked with cross-functional teams to develop products for both the residential and commercial roofing industry. In his current role, he manages the strategy for GAF's single-ply and asphaltic commercial product lines. He holds a BS in business administration from Rowan University and an MBA from Centenary University.



Tom Taylor

Tom Taylor is the executive director for Building & Roofing Science for GAF. This position is focused on the building enclosure and its impact on the indoor environment and energy efficiency. Tom has over two decades of experience in the building products industry, all working for manufacturing organizations in a variety of new product development roles. He received his PhD in chemistry and holds approximately 35 patents.

RCI Interface Seeks Project Profiles

Everybody likes a project profile!

RCI Interface is particularly interested in submission of project profile articles concerning unique building envelope projects. Profiles should be 1500 to 2500 words with five to 15 high-quality photos and should describe a building issue that is diagnosed or solved or an unusual building or condition worked on in the course of a building envelope consultant's work. Submit articles to Executive Editor Kristen Ammerman, kammerman@rci-online.org.

FAA Drone Registration Database Shot Down

The U.S. Court of Appeals for the District of Columbia Circuit in May struck down a Federal Aviation Administration (FAA) rule requiring owners of drones or unmanned aerial vehicles (UAVs) used for recreation to register their crafts. The three-judge panel said that safety was obviously important and making hobbyists register "may well help further that goal to some degree," but it was up to Congress to repeal a ban on FAA rules for model aircraft signed into law in 2012.

The Association for Unmanned Vehicle Systems International, whose members include big commercial drone operators and manufacturers, expressed disappointment with the court's ruling. The group's president, Brian Wynne, said registration "helps create a culture of safety that deters careless and reckless behavior." He vowed to seek a legislative fix in Congress.

