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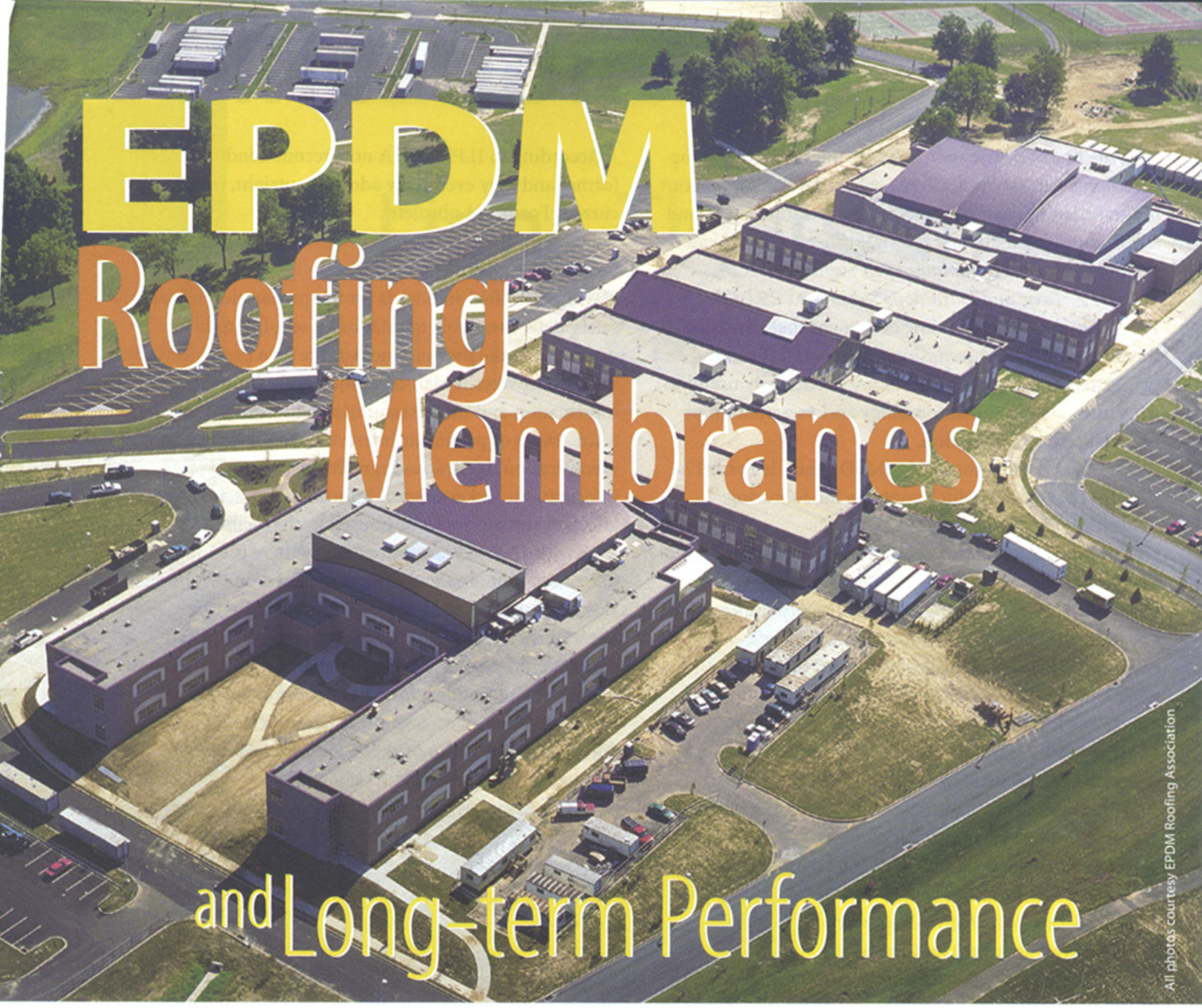


EPDM Roofing Membranes and Long-term Performance

All photos courtesy EPDM Roofing Association

by Tim Trial, Ph.D.

In the 1950s, ethylene-propylene-diene-monomer (EPDM) membranes were first used in waterproofing applications by being employed as pond/reservoir liners. The membrane was rolled out to line the tank, seamed, and held in place once water was added. From this came the use of EPDM membranes on roofs, which relied on stone, rather than water, for anchoring.

EPDM membranes were introduced in the single-ply roofing market in the 1960s. As with many new products, acceptance was slow. Initially, the market share for single-ply EPDM membranes lagged behind asphalt and built-up roofing (BUR) systems. However, during the oil embargo in the 1970s and the resulting shortages, the quality of available asphalt was diminished and became more expensive. (The end user also became more conscious of energy conservation.) Since this time, EPDM membranes have become the predominant roofing system selection for architects, specifiers, and contractors in both new construction and replacement roofing projects.[1]

To appreciate the long-term performance of these single-ply membranes, one must examine the chemical structure of the parent EPDM polymer, which is synthesized from three building block monomers—ethylene, propylene, and a diene.[2] The reactive or unsaturated diene is attached to the main chain of the polymer and protected. Since the unsaturation is protected, EPDM is inherently ozone-resistant as compared to other rubber materials. It is also resistant to acid and base attack, and possesses excellent weathering properties.[3]

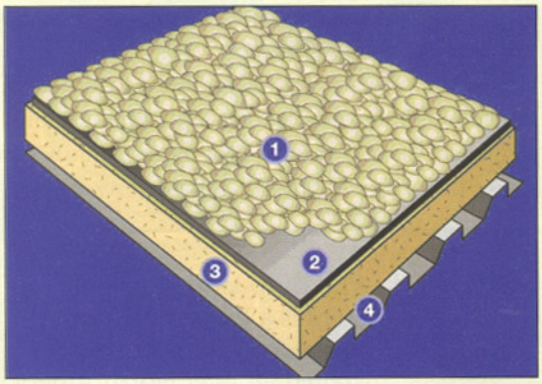
EPDM membranes are manufactured from complex formulations that improve the final properties of the product. In the case of black membranes, carbon black is added to the formulation to provide reinforcement, yielding improved physical and mechanical properties, along with ultraviolet (UV) radiation resistance. In white membranes, titanium dioxide is added for reinforcement and UV resistance. Ingredients such as oil improve the formulation's processing characteristics, while cross-linking agents are included in the mixture to facilitate vulcanization.

In 1839, Charles Goodyear discovered heating natural rubber with certain chemicals transformed an elastic material with little strength into a harder, resilient product with greater strength.[4] As mentioned, the diene is the reactive part of the EPDM molecule—cross-linking agents react with the diene to 'tie' the polymer molecules together, increasing physical and mechanical properties, such as heat and solvent resistance, tensile and tearing strength. Most importantly, cross-linking increases the membrane's service life.

The long-term performance of a roofing material is dependent upon its resistance to the combined effects of water ponding, UV radiation, ozone, heat, and thermal cycling. Additionally, the roof system design and site location can exploit or diminish the impact of the environmental factors. Generically, EPDM membranes are used in two types of roofing systems. In a protected or ballasted system (Figure 1, page 26), the system consists of an acceptable insulation on top of an approved roof deck. The membrane is loose-laid atop the insulation and seamed together. Finally, washed rock is applied on top of the membrane to hold it in place. The ballast also serves to provide additional protection from the effects of the sun's energy. In an exposed system (Figure 2, page 26), an acceptable insulation is placed atop an approved roof deck (such as steel, structural concrete, fibrous cement or gypsum) and secured with fasteners, while the membrane is held to the insulation with contact adhesive or metal fasteners. Although lighter than a ballasted system, the membrane is exposed to the effects of the environment.

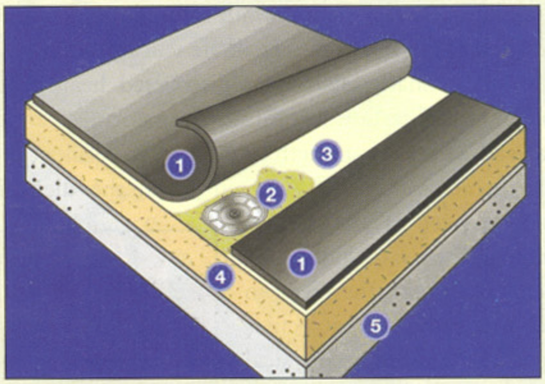
Perhaps the primary reason for EPDM's dominance in the single-ply roofing market lies in its superior long-term performance. Several studies have been published which describe the service life of EPDM membranes—the

Figure 1 Schematic of Ballasted Roofing System



1. Ballast. 2. EPDM membrane. 3. Insulation. 4. Roof deck.

Figure 2 Schematic of Exposed Roofing System



1. EPDM membrane. 2. Fasteners and plates. 3. Contact adhesive. 4. Insulation. 5. Roof deck.

resulting data is important for specifiers to consider when selecting appropriate roofing materials. This article briefly reviews some of these studies, including the most recent initiative of the EPDM Roofing Association (ERA).

Flexural fatigue of aged and unaged membranes

In 1991, J.C. Beech, of the U.K.-based Building Research Establishment (BRE), examined the aged and unaged properties of several roofing membranes, focusing on flexural fatigue, which was measured at 2 C (36 F), with a 1-mm (0.04-in.) flex amplitude and 12 cycles per second.[5] Unaged samples of reinforced and non-reinforced polyvinyl chloride (PVC), thermoplastic polyisobutylene with a fleece backing (PIB), chlorosulphonated polyethylene (CSM), and EPDM were subjected to 3 million flexural cycles, without observing failures. However, after heat-aging at 80 C (176 F), the reinforced PVC membrane failed after about 136,000 cycles, and the non-reinforced PVC membrane failed after approximately 63,000 cycles, unlike the more successful PIB and EPDM membranes.[6] (The CSM membrane was not tested.)

Samples of the membranes were also tested in an accelerated weathering apparatus at 70 C (158 F), which simulates the effects of outdoor aging by exposing the test sample to a constant temperature, while cycling UV radiation and water exposure. The reinforced and non-reinforced PVC samples failed after about 19,000 and 9500 cycles respectively. No evidence of failure was found in the PIB or EPDM samples. The membrane samples were also subjected to outdoor weathering in various climatic environments.

Samples sized 300 x 300 mm (11.8 x 11.8 in.) were cut from commercial products and placed in south-facing racks at a 45-degree inclination in the following environments:

- London, United Kingdom (a mild, wet environment);
- Dubai, United Arab Emirates (a hot, humid environment);
- Freetown, Sierra Leone (a hot, dry environment with significant temperature fluctuations.)

The membranes were aged for four years, and the flexural fatigue was measured at –20 C (–4 F).

The only PVC sample tested from London was the non-reinforced variety, which failed after about 63,000 cycles. The CSM sample failed after approximately 107,500 cycles, while the PIB and EPDM samples were tested to 500,000 cycles without evidence of failure.

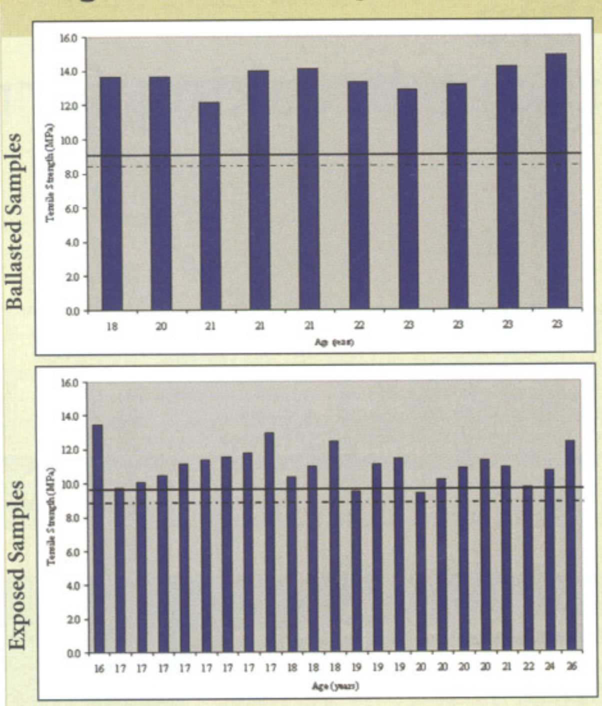
In the hot, dry environment of Freetown, the reinforced and non-reinforced PVC samples failed after about 6000 and 2000 cycles, respectively. The CSM sample failed after 8000 cycles, while the PIB sample failed after about 249,000 cycles. Again, testing of the EPDM sample was suspended when no evidence of failure was observed after 500,000 cycles.

The effect of the hot, humid Dubai environment was most noticeable on the CSM membrane, which failed after about 300 cycles. The reinforced and non-reinforced PVC membranes failed after about 11,500 and 13,500 cycles, respectively. The PIB sample failed after approximately 101,000 cycles, while no failure was observed with the EPDM sample after 500,000 cycles.

Warranty records as a measure of service life

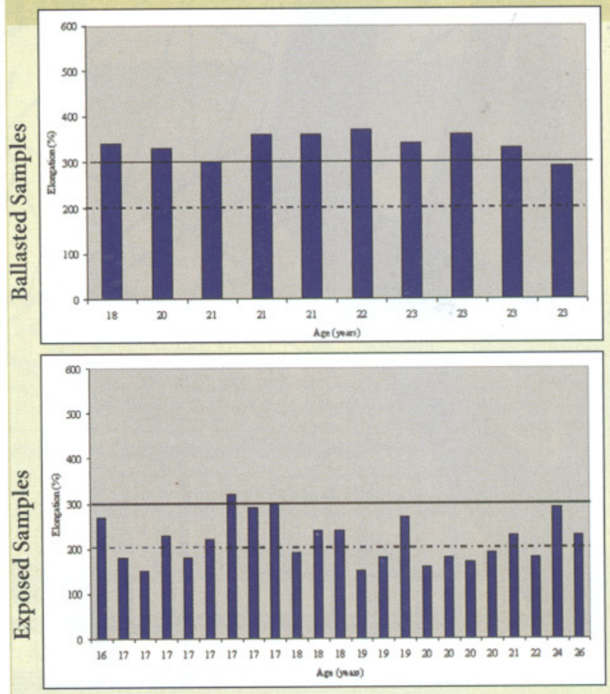
James Hoff has evaluated the performance of aged EPDM membranes though an examination of manufacturer warranty records.[7] Initially, these records were examined from 1982 to 1993, with maintenance costs normalized to

Figure 3 Tensile Strength



——— ASTM International D 4637 (New Membrane)
-------- ASTM D 4637 (Heat-aged Membrane)

Figure 4 Ultimate Elongation



——— ASTM D 4637 (New Membrane)
-------- ASTM D 4637 (Heat-aged Membrane)

1987 dollars. The repair costs over the first five years of service declined 84.6 percent. The study was updated in 2003 to include the repair costs over the first 10 years of service life (*i.e.* 1982 to 1993), demonstrating repair costs dropped 60 percent from 1987 to 1993, and 93 percent over the course of the study.[8] Hoff attributes the decline in the warranty repair costs to advances in several important roofing system component technologies:

- butyl-based splice adhesive replacement of neoprene-based adhesives (1985 to 1986);
- replacement of neoprene-based flashings with EPDM-based flashings (1985 to 1986);
- replacement of metal edge flashings with tape laminates (1987 to 1988);
- replacement of wood nailers and nails with metal battens and screw fasteners (1988 to 1989);
- introduction of perimeter fastening strips (1991 to 1992); and
- replacement of adhesive seams with seam tape with high-solids primer (1992 to 1993).

This conclusion is supported by the findings that repair costs associated with field seams and perimeter flashings respectively declined 92 percent and 95 percent from 1982 to 1993. Further supporting evidence can be found in examining the maintenance costs associated with specific EPDM roofing systems. Ballasted systems typically use larger sheets, and thus require fewer seams as compared to mechanically attached and fully adhered systems. For systems installed in 1982, maintenance costs (normalized to 1987 costs) for fully adhered systems were about 40 percent more per square foot as compared to ballasted systems. (The difference between mechanically attached systems and ballasted systems was even greater at approximately 70 percent.) By 1991, the maintenance cost difference between ballasted, fully adhered, and mechanically attached systems had equalized to a statistically insignificant difference, and was 60 percent lower as compared to the 1987 costs.

Physical properties of *in situ* roofing membranes

In 1991, Brian Gish and Kathleen Lusardi studied the aged properties of 45 *in situ* roof samples cut from various roof systems, ranging in age from five to 17 years.[9] In general, an increase in tensile strength, tear resistance, brittleness temperature, and Shore A hardness was observed, along with a reduction in ultimate elongation. No difference was observed in the glass transition temperature or appearance of the aged membrane, as compared to the unaged samples. The aged properties of eight to nine-year-old ballasted membranes were comparable to those of exposed (adhered) membranes with the exception of ultimate elongation.

Exposed membranes suffered the greatest decrease in ultimate elongation (25 percent to 40 percent reduction for five- to 12-year samples, 54 percent for the 17-year samples). A less pronounced reduction in the ultimate elongation (12 percent to 40 percent for five- to 10-year samples) was observed for the ballasted membranes. All samples met ASTM International D 4637, *Standard Specification for EPDM Sheet Used in Single-ply Roof Membrane,* and Midwest Roofing Contractors Association (MRCA) ME-20, *Recommended Performance Criteria for Elastomeric Single-ply Roof Membrane Systems,* specifications for heat-aged membranes, and 87 percent exceeded the requirements for new membranes.

In 2003, ERA conducted a study to update Gish and Lusardi's work, selecting 33 membranes—aged between 16 and 26 years—from in-service roofs in nine states.[10] Given these samples were obtained from two membrane manufacturers (relying on different personnel and potentially different equipment and raw material sources), they provide a good basis for determining the product's general long-term properties. The samples included 10 protected (ballasted) and 23 exposed (fully adhered and mechanically fastened) roofing systems, and were submitted to Architectural Testing Inc. in York, Pennsylvania, for unbiased testing.

Tensile strength

As shown in Figure 3 (page 28), the tensile strength for ballasted membranes ranged from 10.8 MPa to 14.9 MPa (1560 psi to 2160 psi), while exposed membranes varied from 9.4 MPa to 13.5 MPa (1350 psi to 1950 psi). ASTM D 4637 requires a minimum of 9.0 MPa (1305 psi) for new sheets, and 8.3 MPa (1205 psi) for heat-aged samples. MRCA ME-20 mandates new membranes meet a minimum of 6.0 MPa (850 psi), and aged membranes 5.5 MPa (800 psi). All samples were observed to meet the specifications for new membranes, and substantially surpass the requirements for heat-aged samples.

Elongation

The ultimate elongation values, depicted in Figure 4 (page 28), ranged from 290 percent to 370 percent (ballasted) and from 150 percent to 320 percent (exposed). ASTM D 4637's minimum specification for new sheet is 300 percent, with heat-aged samples needing 200 percent. MRCA ME-20 requires new membranes to meet a minimum of 250 percent, while aged membranes must reach 200 percent. While all ballasted samples met the minimum ASTM and MRCA for new and heat-aged membranes, most exposed membranes did not meet the minimum ASTM and MRCA ME-20 requirements for new membranes. Twelve samples were observed to exceed the minimum requirements for heat-aged samples.

Tear resistance

Figure 5 (page 32) illustrates that tear-resistance values ranged from 45.8 kN/m to 65.0 kN/m (261.7 lbf/in. to 371.2 lbf/in.) for ballasted membranes, and from 38.1 kN/m to 50.5 kN/m (217.7 lbf/in. to 288.2 lbf/in.) for the exposed samples. ASTM D 4637 requires that new sheets possess 26.3 kN/m (150 lbf/in.) and heat-aged samples to have 21.9 kN/m (125 lbf/in.). MRCA ME-20 requires at least 21.0 kN/m (120 lbf/in) for new membranes, but does not include a requirement for aged products. All samples were observed to meet the minimum ASTM and MRCA ME-20 requirements for new membranes and all ASTM requirements for heat-aged samples.

Weathering

Weathering resistance was assessed by visual inspection according to ASTM D 4637.

No crazing (*i.e.* network of fine surface cracks) was observed for ballasted membranes, regardless of age. About

At the Pixar Animation Studios building in Emeryville, California, a 10,229-m² (110,100-sf) fully adhered ethylene-proylene-diene-monomer (EPDM) roofing membrane helps protect the people—and computers—that brought forth Toy Story, The Incredibles, *and* Finding Nemo.

half the exposed membranes exhibited some degree of micro-crazing, but this could not be observed without the aid of 10x magnification.

To measure the width of any observed crazing, optical micrographs of the membrane samples were obtained. The width of the measured artifacts ranged from 0.015 mm to 0.043 mm (0.00059 in. to 0.0017 in.). To put this into perspective, the width of a razor's edge is 0.23 mm (0.009 in.), the diameter of a pinhead is 0.2 mm (0.008 in.), and the width of a human hair is 0.051 mm to 0.076 mm (0.002 in. to 0.003 in.)—all items thicker than the largest micro-craze observed in the study.

Discussion of results

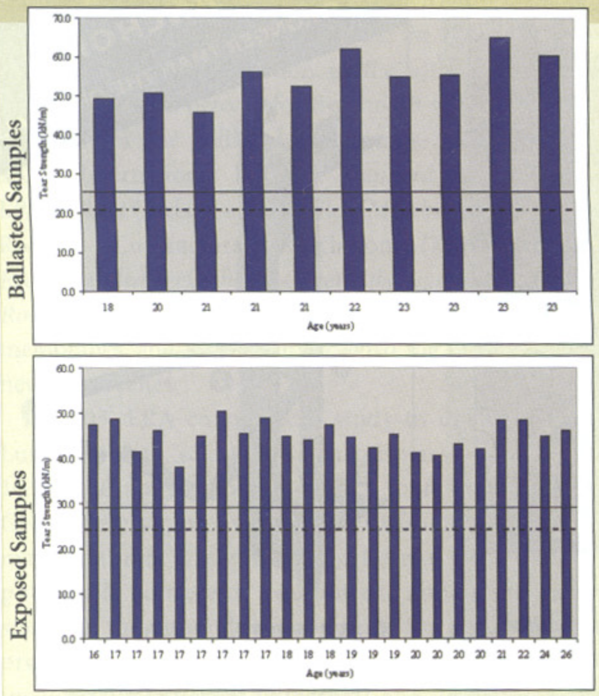
The tensile strength, ultimate elongation, and tear resistance of the ballasted membranes remained relativity constant, regardless of the membrane's age—within 23 years of service life, there was no significant, observable deterioration of EPDM's physical properties.

While the same general trend is observed in exposed membranes in terms of tensile strengths and tear-resistance values, a decrease in the ultimate elongation was observed. This is likely due to additional thermal cross-linking from thermal energy from the sun—since the ballast provides some degree of protection from solar energy, this phenomena is not observed in protected membranes.

By combining the results from the ERA study with the earlier Gish-Lusardi study, one can see the physical performance of EPDM roofing membranes over almost a quarter century (Figures 6 to 8, page 32), confirming the excellent field-aging performance of the material.

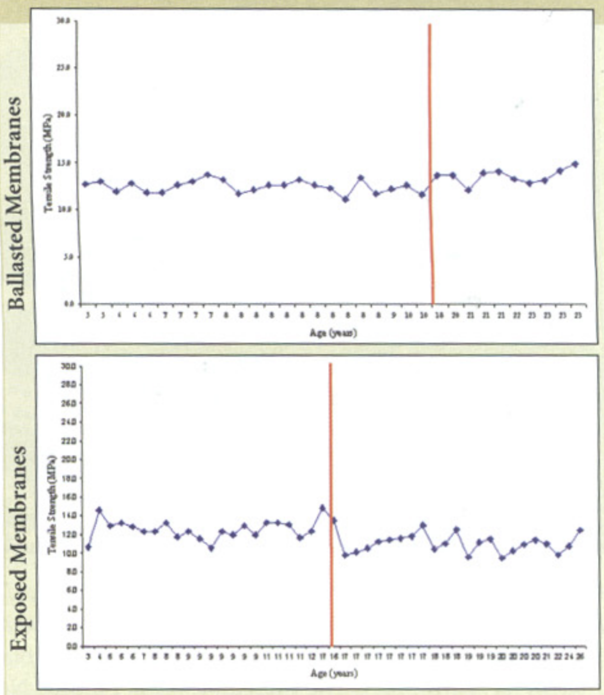
All physical properties of samples cut from ballasted and exposed roof systems exceeded the ASTM D 4637 specification for new and heat-aged membrane after 17 to 26 years of service life, with the exception of the ultimate elongation for exposed

Figure 5 Tear Resistance



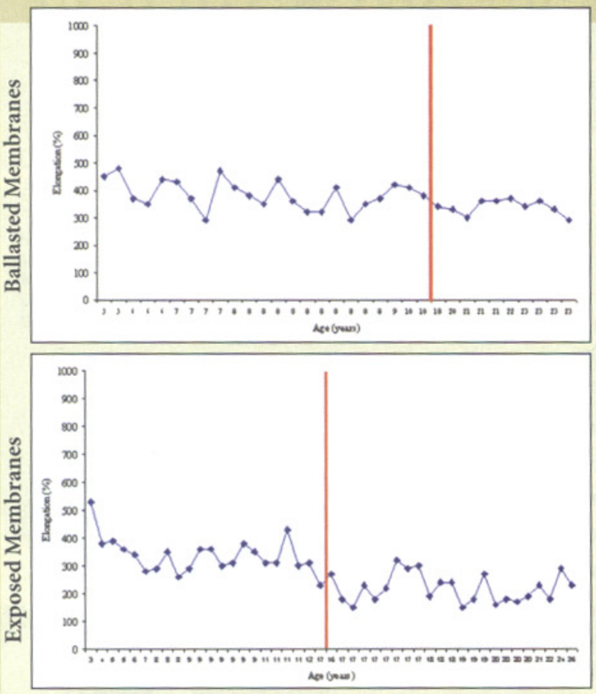
——— ASTM D 4637 (New Membrane)
-------- ASTM D 4637 (Heat-aged Membrane)

Figure 6 Tensile Strength (combined study)



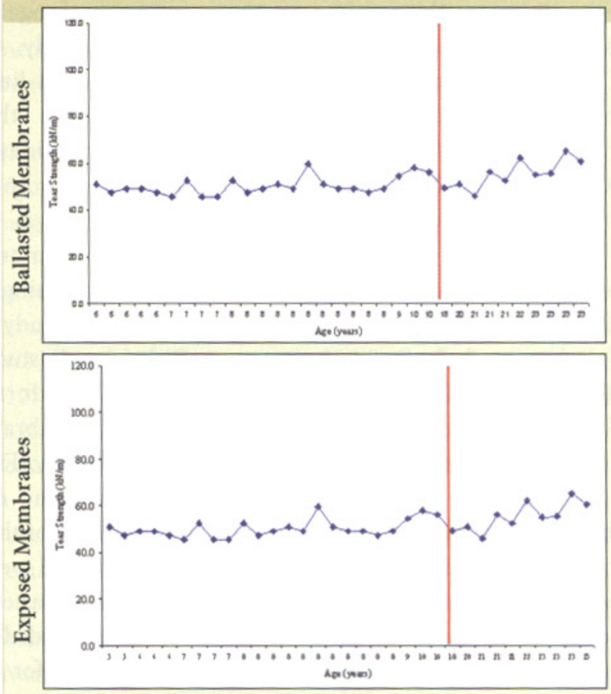
Horizontal line delineates the two studies highlighted in the article. (Gish and Lusardi for roofs aged five to 10 years, Trial et al *for roofs aged 18 to 23 years.)*

Figure 7 Ultimate Elongation (combined study)



Horizontal line delineates the two studies highlighted in the article. (Gish and Lusardi for roofs aged five to 10 years, Trial et al *for roofs aged 18 to 23 years.)*

Figure 8 Tear Resistance



Horizontal line delineates the two studies highlighted in the article. (Gish and Lusardi for roofs aged five to 10 years, Trial et al *for roofs aged 18 to 23 years.)*

membranes. While some samples cut from exposed roofs displayed ultimate elongations below the specifications for heat-aged membranes, it is important to remember these EPDM membranes can still stretch to almost twice their dimensions. Additionally, the membranes were found to be watertight and functional in all sampled roof systems. The tensile strength and tear resistance of the exposed systems are consistent with respect to age, while the decrease in the ultimate elongation and surface crazing are expected observations after long-term exposure to weathering, which results in additional roof-top cross-linking and exposure to the UV portion of solar radiation.

Although the ERA study solely examined the long-term performance of membrane properties, when coupled with the advances in accessory technology presented in the Hoff studies, it is reasonable to assume EPDM roofing systems will provide protection for the extent of the warranty period and beyond.

Notes

[1] For more information, see *Building Design and Construction* magazine and the National Roofing Contractors Association's (NRCA's) 2002–2003 market surveys.

[2] Typical dienes include ethylene norbornene (ENB), vinyl norbornene, and di-cyclopentyldienyl. Historically, 1-4 hexadiene was employed, but the material is not currently used by any major EPDM membrane manufacturer.

[3] American Chemical Society. *Basic Elastomer Technology.* Eds. K.C. Baranwal and H.L. Stephens (University of Akron, 2001) p. 42.

[4] For an interesting background on this, see Charles Slack's *Noble Obsession—Charles Goodyear, Thomas Hancock, and the Race to Unlock the Greatest Industrial Secret of the Nineteenth Century* (Theia, 2003).

[5] Beech, J.C. *Proceedings of the 3rd International Symposium on Roofing Technology* (1991).

[6] Heat-aging is based on a relationship known as the Arrhenus equation, which states the rate of a chemical reaction (*e.g.* decomposition) doubles with every 10-C increase in temperature. However, the equation only considers the effects of thermal energy, and does not take into account the other factors affecting the service life of a roofing membrane, such as UV radiation, thermal shocking, or ozone exposure.

[7] See J.L. Hoff's report in the July 1998 edition of the Roof Consultants Institute (RCI) *Interface* (1998), along with his piece in the *Proceedings of the Fourth International Symposium on Roofing Technology* (1992) on page 125.

[8] Hoff, J.L. *RCI Interface* (September 2003).

[9] Gish, B.D. and K.P. Lusardi. *Proceedings of the 3rd International Symposium on Roofing Technology* (1991). p. 159–166.

[10] Trial, T., R. Robinson and B. Gish. *Proceedings of the RCI 19th International Conference* (2004).

Additional Information

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Abstract

Ethylene-propylene-diene-monomer (EPDM) membranes have become a popular selection for design professionals, but specifiers should know the objective facts behind the material's physical properties and long-term performance. This feature provides a survey of research into the material's properties, ranging from flexural fatigue in varying climates and cost efficiency to the elongation and tensile/tear strength of aged membranes in the field.