Long-Term Field Performance of Exposed Polyvinyl Chloride Roof Systems

By Stanley P. Graveline

Thermoplastic PVC roof membranes have been in use in Europe since the 1960s and in North America since the 1970s. A number of early-generation, thin, unreinforced products did not live up to expectations, particularly when used in ballasted installations.[1] Reinforced sheets, on the other hand, particularly when used in exposed applications such as mechanically attached and adhered systems, have provided decades of problem-free performance.

A major international manufacturer of PVC membranes conducted a survey of a number of its oldest roofs (*Figures 1* and *2*) in Europe and in North America in order to quantitatively assess how well its products were performing after decades of exposure.

A total of 44 roofs were studied: 19 in Europe and 25 in North America. The North American roofs were distributed amongst all climatic areas of the U.S. and Canada. The European roofs were located in

Figure 2 – Charette, Woburn, MA, installed in 1977.

Figure 1 – Bogenhalle Reinhard, Sachseln, Switzerland, installed in 1967.

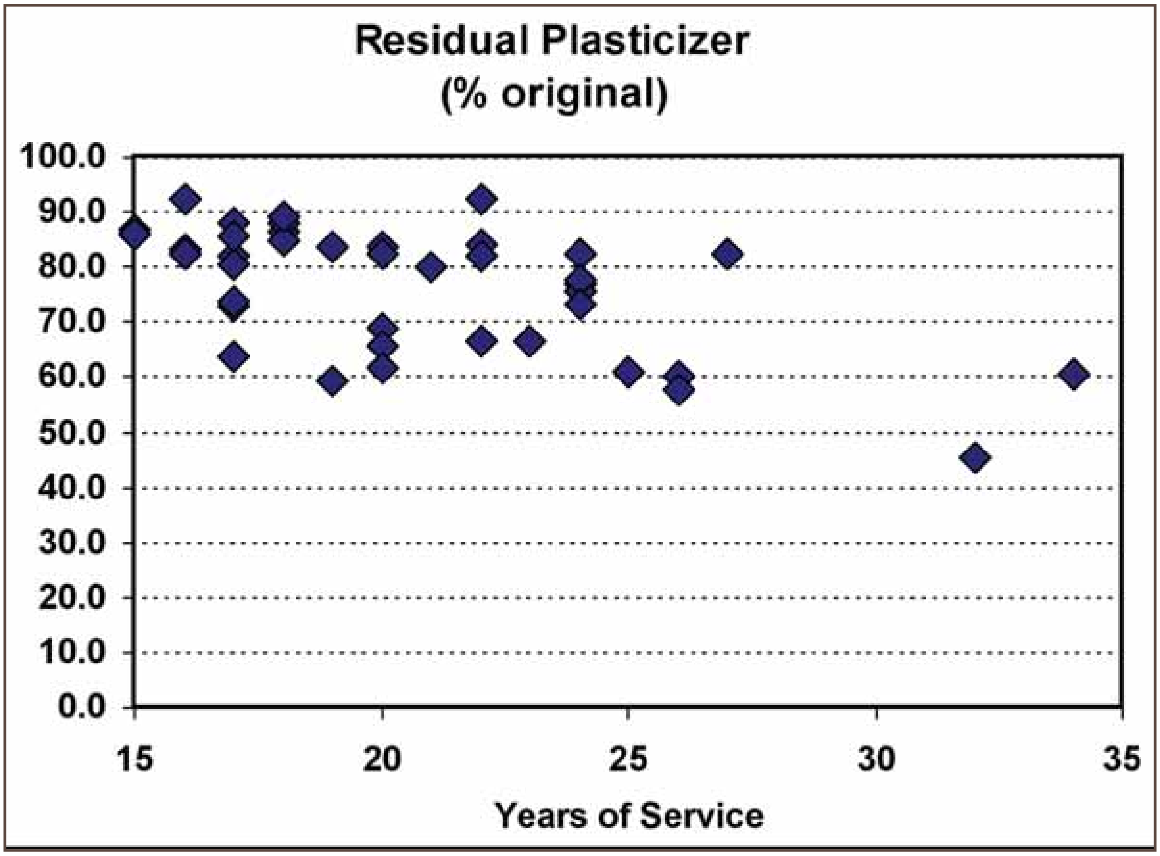

Figure 3 – Plasticizer content versus age.

ing occupancies vary appreciably. With one exception, even the oldest samples (up to 34 years old at the time of testing) still contain approximately 60 percent or more of their original plasticizer.

Possibly more important than analytical results is the fact that all the membranes had retained sufficient plasticizer to allow them to be hot-air welded. On every roof studied, a roughly 1m x 1m "patch" of new material was welded to the existing membrane to seal the sample removal area. Weldability is critical to the long-term performance of any thermoplastic roof, as welding allows permanent, watertight repairs or modifications to be made to the roof at any time during its service life.

Germany, Austria, Switzerland, and England. The oldest roof studied was 34 years old, and the average age of all the roofs was 20.3 years. Two types of material were studied: "S" membranes, which are polyester-reinforced and used in mechanically attached assemblies; and "G" membranes , which have a glass-mat internal carrier and are used in adhered applications.

A thorough visual inspection was conducted on each roof, and samples were taken. All samples were sent to the manufacturer's laboratory in Switzerland for testing. A second set of samples taken from the North American roofs was sent to the National Research Council Canada for analysis. A variety of physical properties was measured on all samples. When sufficient material was left over after the basic testing, the samples were subjected to hail resistance testing at the EMPA in Zurich, Switzerland. In a previous study, Foley et al.[2] identified plasticizer content and hail resistance of aged samples as key performance indicators, and these properties are the focus of this article. Additional qualitative and quantitative results have been reported in other papers.[3,4,5,6]

Plasticizer Content

Plasticizers are blended with the polymer during the manufacturing of vinyl roofing membranes to make them flexible. Some plasticizer is lost as vinyl membranes age. The plasticizers that migrate from the sheet are biodegraded. In the formulation of vinyl membranes, the choice of the appropriate types and grades of plasticizers and their use in sufficient quantities are critical to the long-term performance of the finished product, as they determine the material's ability to resist thermal cycling, structural movement, hail, etc.

The plasticizer content was determined by weighing each sample before and after boiling it in ethyl ether for one hour. The measured weight difference is the plasticizer that was extracted. The plasticizer content of each sample is reported as a percentage of the original plasticizer content of new material, based on production records.

The residual plasticizer content is plotted against sample age in *Figure 3*. As expected, plasticizer content decreases with age. As can be seen, the data correlate quite well, despite the fact that the samples were taken from roofs located in various European and North American climate zones and that the roof constructions and build-

It should be noted that all of the sampled roofs were light grey in color. It is assumed that the shift to highly reflective white color will result in even lower roof-surface temperature and will, if anything, slow the aging process even further.

Hail Resistance

Twenty-seven of the samples were large enough, after all other analytical procedures (minimum 0.5 m x 0.5 m), to be used for hail testing. The age of these 27 roofs ranged from 15 to 34 years.

For purposes of this investigation, the hail test method developed by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) was chosen for determination of hail resistance. It is based on pneumatically propelled spherical projectiles of polyamide (diameter 40 mm, mass 38.8 g). Polyamide has a density similar to ice; hence, the impact energies of an ice ball or a polyamide sphere of the same size and same terminal velocity are approximately the same. The test method is referenced in the Swiss Standard for Polymeric Waterproofing (SIA 280), and it has been adopted as a harmonized European Standard (BS EN 13583:2001).

	PARAMETERS OF TEST PROJECTILES					
Standard	**Shape and Material**	**Diameter (mm)**	**Mass (kg)**	**Sample Surface Cooling**	**Kinetic Control of Impact Tool**	**Impact Energy (Nm)**
ASTM D-3746	steel cylinder	50	2.27	no	h = 1355 mm	30
FM Class 1-SH	steel sphere	45	.360	yes	h = 5400 mm	19
FM Class 1-MH	steel sphere	51	.737	yes	h = 1500 mm	10.8
SIA280	polyamide sphere	40	.388	yes	v = 17 m/s (minimum velocity)	5.6

Table 1: Test parameters and kinetic energy of ASTM, FM, and SIA hail test methods.

Specimens to be tested are placed on the desired substrate and cooled with crushed ice for three minutes. The polyamide sphere is fired at the sample at a given velocity. The test is done five times at each velocity, targeting different points on the sample. The sample is then tested for "watertightness" using a soap solution and a suction device at each impact location. If no damage has occurred, the test is repeated at a higher velocity. The highest velocity at which no air leakage is detected is documented.

CEN (the European Committee for Standardization) does not provide minimum (or maximum) requirement values to be met. The Swiss standard requires a minimum impact velocity of 17 m/s for new roofing membranes. In order to determine how aged material would perform on substrates in use today, the aged membrane was tested over the most commonly used thermal insulations: polyisocyanurate (ISO) for North America and expanded polystyrene (EPS, density 20 kg/m^3) for Europe. Testing was also done on glass-fiber-reinforced gypsum boards. For comparison purposes, new membranes of the same PVC formulation and different thicknesses were also tested.

In North America, hail testing is typically done to the relevant ASTM or FM procedures. As can be seen in *Table 1*, there are numerous differences among the ASTM, FM, and SIA hail test methods.[7] Although it is not possible to directly compare data generated with the SIA methodology to the FM requirements, the following equation is useful to relate impact energy (FM) to impact velocity (SIA):

$$E_{kin} = 1/2 * m * v^2$$

where E_{kin} = kinetic energy, m = mass, and v = velocity. On this basis, the kinetic energy of a 40 mm polyamide sphere at velocities of 25 m/s and 33 m/s corresponds approximately to that of FM Class 1-MH and FM Class 1-SH,[8] respectively.

Data for new membranes is shown in *Figure 4*. All measured values exceed the three requirements. Not surprisingly, 1.8-mm thick membrane provides greater resistance than 1.2-mm membrane. Results over glass-faced gypsum board are roughly 1.5 times higher than those measured over polyisocyanurate boards for a given set of parameters.

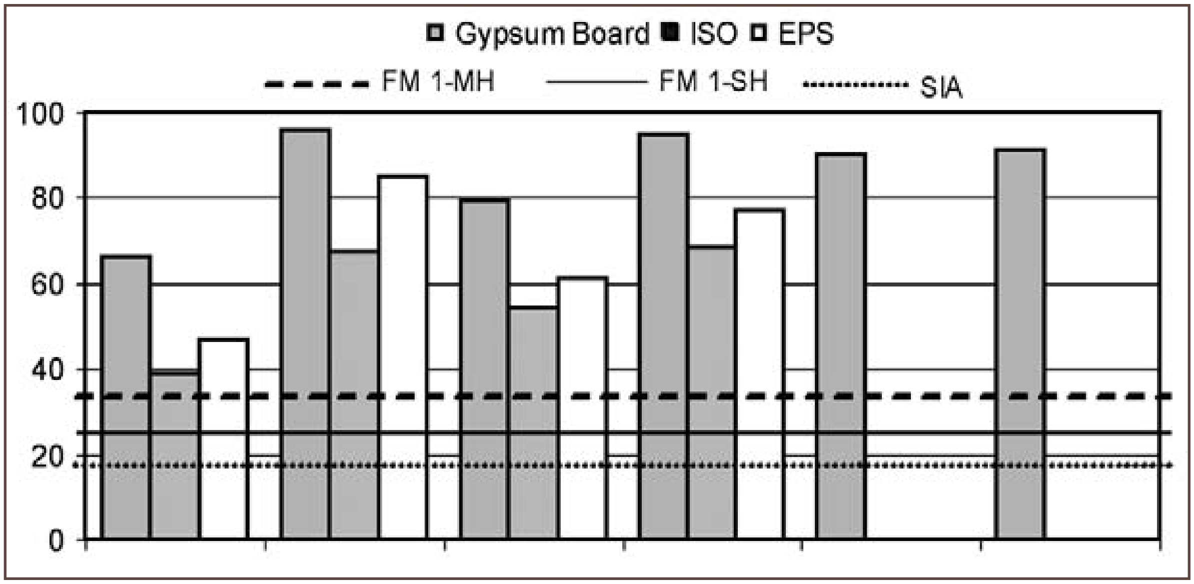

Figure 4 – Hail resistance of new samples.

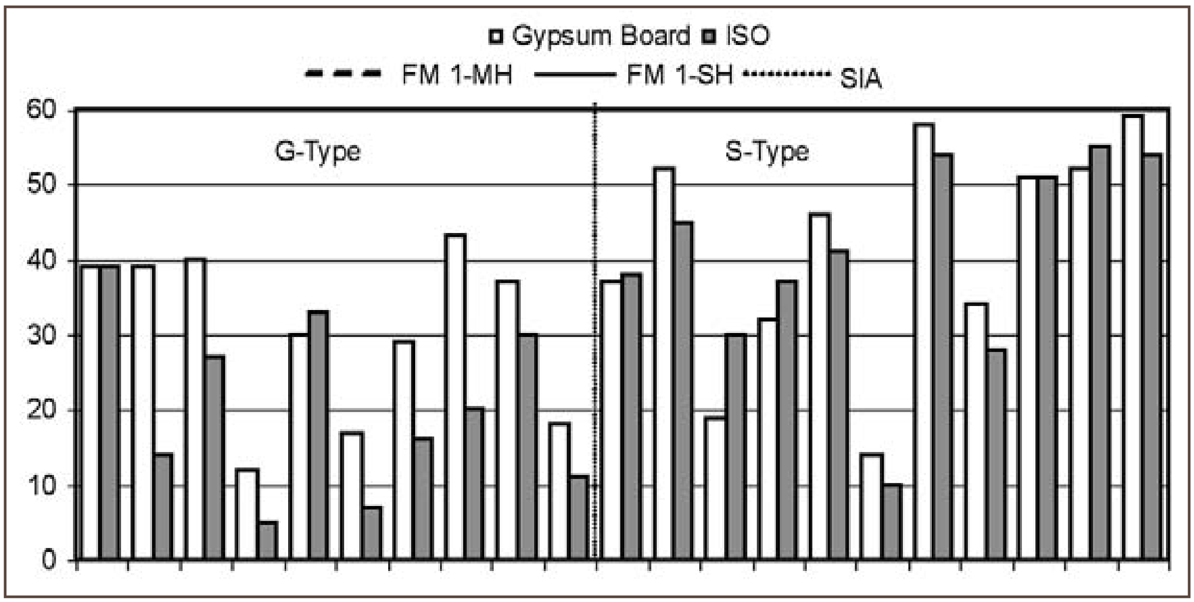

Figure 5 – Hail resistance, aged samples from North America on glass-faced gypsum and polyisocyanurate.

The data from the European samples are reported elsewhere.[9]

The data for the North American samples over both polyisocyanurate and glass-faced gypsum are presented in *Figure 5*. Although four samples show slightly higher values on ISO, glass-faced gypsum board generally is found to improve hail resistance. With an average age of 18.6 years, 16 out of the 21 samples still fulfill the requirement of FM Class 1-MH for new membranes, while 12 samples meet the requirement for FM Class 1-SH on glass-faced gypsum board.For ISO, 14 of the samples, aged 17 to 22 years, meet FM Class 1-MH, and 11 samples meet FM Class 1-SH. On glass-faced gypsum board, only one sample (13A) had a hail resistance value below the initial requirement of SIA280. All the others meet the requirement for new material. None of the roofs exhibited any signs of hail damage during the inspection.

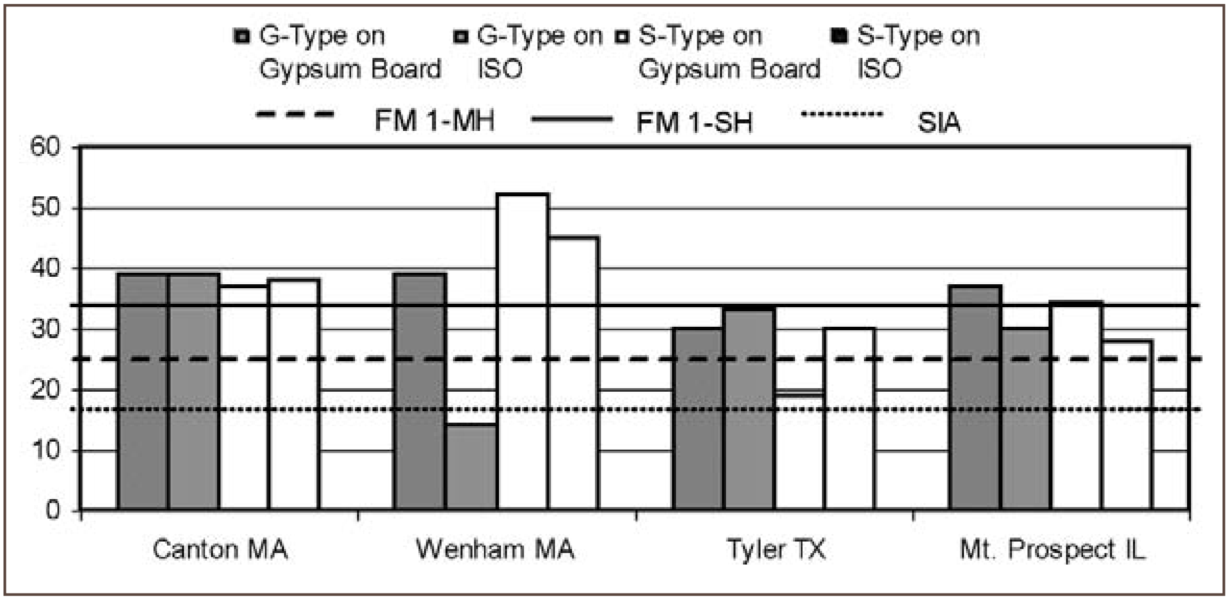

Figure 6 – Aged G and S membranes from the same roofs.

The results are also sorted by reinforcement type in *Figure 5*: fiberglass (G) and polyester (S). It should be noted that only the reinforcement varies between the two types; the polymer matrix is identical. The S materials appear to have a higher mean hail resistance. However, data from the four roofs on which both G and S membranes had been installed are presented in *Figure 6*. As can be seen, the data are inconclusive. Neither the G nor the S type can be said to provide better hail resistance than the other, based on this data.

Durability

The survey and the data generated in both the manufacturer's laboratories and at the National Research Council Canada indicate that properly formulated and maintained reinforced PVC roof membranes can perform for decades in various climates throughout North America and Europe.

The data were included in a submittal package to the British Board of Agrément (BBA) during the Agrément Certificate renewal process for the manufacturer's products. BBA-issued Agrément Certificates are used to demonstrate product compliance within the United Kingdom's Building Regulations. The BBA is somewhat unique amongst standards and testing agencies in that it provides a durability statement in its Agrément Certificates. It estimates each product's life expectancy after an exhaustive investigative process that includes site assessments of the manufacturer's oldest installations and thorough testing of relevant physical properties of the samples that are pulled during the inspections.

Prior to renewing the certificates for products covered by this study, the BBA visited roofs up to 40 years old in Switzerland and the UK. Samples from the roofs were tested "as received" and then conditioned at 80˚C for 200 days prior to testing, in accordance with the test standards for new membranes. On the basis of its testing and investigation and its own thorough analysis of the data generated in the study detailed in this article, it will include the following durability statement[10] in the certificate for these products: "All available evidence suggests that the durability of [the manufacturer's specific product designations] membranes when used in accordance with the relevant BBA Certificates should have a life in excess of 35 years," further supporting the conclusions of this study.

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Stanley P. Graveline

Stanley P. Graveline is vice president of technical services for Sika Sarnafil Inc., Canton, MA. He has worked in the roofing industry for more than 20 years in various technical, sales, and management capacities in Canada, Switzerland, and the U.S. He has participated in numerous technical committees and standards-writing bodies in North America and Europe. He is a member of Professional Engineers Ontario and RCI, Inc. He is currently active on various committees within the Cool Roof Rating Council, the Chemical Fabric and Film Association, and the National Roofing Contractors' Association. He has a bachelor of applied science (chemical engineering) degree from the University of Ottawa and an MBA from the International Institute for Management Development, Lausanne, Switzerland.