Durability of PVC Roofing Membranes - Proof by Testing After Long Term Field Exposure

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ABSTRACT

A leading supplier of thermoplastic roofing membranes inspected and removed samples from 44 different roofs in America, Austria, Canada, England, Germany and Switzerland. The roofs ranged in age from 9 to 34 years at the time of sampling. The dual European and North American survey is believed to be the most exhaustive ever conducted for PVC membranes.
The assessment on site was based on the general impression of the roof, constructive details, roof construction, surroundings, upstands, gutters, drains, connections and the status of the membrane seams. Comprehensive photographic evidence was collected and will be presented. For the laboratory evaluation a variety of physical properties were tested according to ASTM (USA), DIN (Germany) and SIA (Switzerland) standards. These properties are considered as essential in the estimation of the long term behaviour of plastic roofing membranes. Additionally, thermostability, glass transition temperature and hail testing were conducted on most of the aged samples. The paper will present the results of the testing. Relevant correlations which may exist between various physical properties, will also be looked at. These correlations may be useful in assessing the relevance of some tests in the context of material standards.
All of the 44 inspected roofs were fully functional and none was leaking. On none of them any repair work was necessary or advisory. The general impression on site was very positive. The laboratory evaluation of the field samples revealed the degree of material deterioration over the years. Although subject to a certain degree of aging, the majority of the determined material data revealed values better than the normative requirements for new materials. In conclusion the study proves the excellent durability of PVC roofing membranes in exposed applications.

KEYWORDS

roofing, pvc, longevity, weathering, waterproofing

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1 INTRODUCTION

Poly(vinyl chloride) – PVC, also known as vinyl - is one of the most versatile thermoplastics in use today. PVC roofing membranes can now look back to history of five decades of use in Europe. All roofs are expected to provide decades of problem free service. When new products are developed and introduced, there is little knowledge of how they will age beyond data generated in accelerated artificial weathering tests. Although testing the physical properties of new materials can be useful in trying to compare and even rank them against other similar products, nothing is more useful or informative than actual field experience [1].

Physical properties of all roof systems change with age and outdoor exposure. The change in physical properties of a roof membrane may be the result of many factors. A few factors that may affect the physical properties of a vinyl membrane include chemical formulation stability, thickness of the polymer, reinforcement, method of manufacturing, geographic location, heat and ultra violet radiation exposure, other products used in conjunction with the membrane and roof slope. These factors cannot adequately be simulated in any test program. The certainty of service life predictions increases with increasing application experience.

A major international supplier of PVC membranes with a vast inventory of roofs across Europe and North America, decided to survey a large sampling of their older roofs to assess how their materials were performing over time. The survey was expected to provide valuable insight on the ageing behavior of the products and will serve as a basis for life cycle costing (LCC) and life cycle analysis (LCA) evaluations.

2 METHODOLOGY

The manufacturer reviewed their internal project data bases and files in the various countries in which they operate to determine some of the oldest projects in each of their regions. 20 roofs were selected to be surveyed and sampled in Europe and 25 in North America. The roofs were chosen on the basis their age, geographic location (reasonable cost to access and to insure diversity of climate), and owner willingness to allow the company to access their roof and remove samples. A thorough visual inspection was conducted on each roof and samples were taken. In the USA local roofing consultants were invited to participate in every investigation. The North American roofs were surveyed in 2001 and the European roofs in 2002. Only roofs with exposed membranes were included in the survey. The manufacturer promotes the use of membranes with a glass mat carrier (G type) in adhered applications, and those with a synthetic polyester reinforcement (S type) in mechanically attached assemblies. Information on all inspected projects in Table 1. Unless otherwise specified, the installed thickness of all membranes was 1.2 mm.

All samples were sent to the manufacturer's research and development laboratory in Switzerland for testing. All samples were tested to the requirements of the German standard DIN16726 [2] or the Swiss standard SIA V 280 [3], the relevant standard for single ply PVC roofing membranes in each country.

A second set of samples taken from the North American roofs studied was sent to the National Research Council Canada for testing according to the requirements of ASTM D4434 [4]. Additional measurements not called for in the standard such as glass transition and reflectivity were also conducted on this set of samples. It is far beyond the limits of this paper to report the full set of data. More detailed information on the background of the study and the test methodologies can be found in previous papers by the same authors [5] [6]. A smaller sub set of all of the samples was subjected to hail resistance testing at the EMPA in Zurich, Switzerland.

Table 1: Summary of all projects. Samples 1-26: North America, samples 101-137: Europe

ID	Project Location	Type*	Instal-led	Age years	ID	Project Location	Type*	Instal-led	Age years
1A	Canton MA	G – 12	1979	22	21A	Haileybury ON	G - 12	1981	20
1D	Canton MA	S – 12	1979	22	21C	Haileybury ON	S - 12	1981	20
2A	Wenham MA	G - 12	1984	17	22A	Hamilton ON	S - 12	1984	17
2D	Wenham MA	S - 12	1984	17	23A	Alouette QC	G - 12	1983	18
3A	Woburn MA	G - 12	1983	18	25A	Sarnia ON	G - 12	1984	17
4B	Dickson TX	G - 12	1984	17	26	Calgary AB	G - 12	1982	19
5B	Tyler TX	G - 12	1981	20	101	Bregenz, A	S - 12	1978	24
5C	Tyler TX	S - 12	1981	20	102	Villach, A	S - 12	1981	21
6A	Euless TX	S - 12	1984	17	103	Hausmannstätten, A	S - 18	1984	18
7A	City of Industry CA	G - 12	1979	22	104	Vlotho, D	S - 12	1975	27
8A	El Segundo CA	G - 12	1982	19	105	Freiburg, D	S - 12	1977	25
9B	Mountainview CA	S - 12	1983	18	106	Memmingen, D	S - 12	1978	24
10B	Lacey WA	G - 12	1982	19	107	Niedergösgen, CH	S - 12	1978	24
11B	Ft. Steilacoom WA	G - 12	1983	18	108	Schwyz, CH	S - 12	1978	24
12A	Atlanta GA	S - 12	1986	15	109	Geneva, CH	S - 12	1978	24
13A	Jacksonville FL	S - 12	1982	19	110	Bursins, CH	S - 18	1993	9
14A	Appleton WI	S - 12	1985	16	111	Spreitenbach, CH	S - 18	1985	17
15B	Mt. Prospect IL	G - 12	1981	20	112	Canobbio, CH	S - 18	1985	17
15D	Mt. Prospect IL	S - 12	1981	20	131	Arnoldstein, A	G - 14	1986	16
16A	Park Ridge IL	S - 12	1984	17	132	Dortmund, D	G - 14	1979	23
17B	Hackensack NJ	S - 12	1986	15	133	Kempten, D	G - 12	1976	26
18A	Englewood NJ	G - 12	1985	16	134	Camorino, CH	G - 27	1976	26
18C	Englewood NJ	S - 12	1985	16	135	Personico, CH	G - 12	1968	34
19A	Iowa City IA	S - 12	1982	19	136	Lugano, CH	G - 12	1970	32
20B	Davis CA	G - 12	1981	20	137	Reading, UK	G - 12	1987	15

Note: *: Type of membrane, G: glass reinforced, S: polyester reinforced, "- xy": thickness in mm

3 ROOF CONDITION SURVEY

On one of the European objects the owner replaced the roof with the same material due to an external damage, and therefore the roof was nine years old at the time of the investigation, rather than 22 as expected. All of the roofs were in good condition. The roofs exhibited various degrees of soiling, the level of which depended on their location, surroundings, building occupancy/ activity, slope, etc. On some of the adhered roofs, there was evidence of insulation board shrinkage below the membrane. In some instances this resulted in localized areas of un-adhered membrane. There were patches on a few of the roofs indicating that the membrane had been punctured at some point. Typically when there were patches, they were found at access points and adjacent to mechanical equipment. Although various skill levels were observed, all welds, including field seams, patches and flashings were watertight. Samples were removed from all roofs. Without exception, new material was welded to the existing, aged membrane. Large weeds were growing in an area were soil had accumulated on one roof. The area was cleared for inspection. The roots had not had any effect on the membrane. On another roof, the skylights had been damaged by hail, although there was no damage to the membrane.

4 TEST STANDARDS

DIN and the SIA standards for roofing membranes were established in 1976 and 1977 respectively. The ASTM standard was first introduced in 1985. All were the first single ply standards introduced in their respective countries. It is interesting to note that many of the roofs surveyed were installed before these standards came into existence.

5 TENSILE PROPERTIES

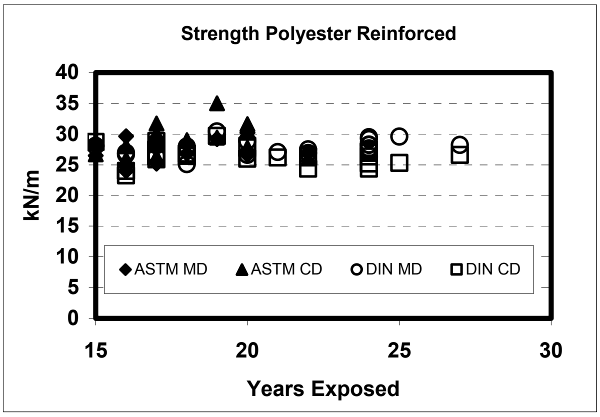
Test data for all the polyester reinforced samples, for both machine and cross directions, is shown in Figure 1. The North American samples were tested according to both the ASTM and DIN test procedures, while the European samples were only subjected to the latter.

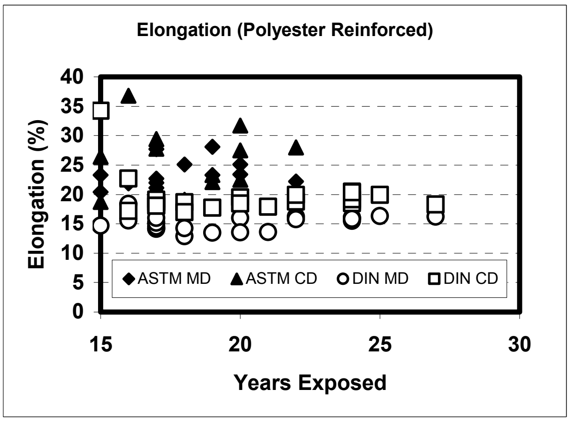
None of the North American samples met the minimum breaking strength requirement (35 kN/m) as stated in ASTM D4434 except Sample 13A in the cross direction. The samples retained 70-90% of the minimum breaking strength required for new membranes as specified in ASTM D4434 and over 60% of the samples retained more than 80% of that requirement. Note at the time the membrane was made for most of these projects the ASTM Standard did not exist.

All of the samples, European and North American exceeded the minimum requirements of the DIN standard for new materials (16 kN/m), by 60% to 75%.

The German requirement (16 kN/m) is less than half of the American minimum (35 kN/m). It is interesting to note however that despite the different test methodologies, the tensile results for a given sample correlate remarkably well between the two standards. Additionally, as can be seen in Figure 1, there is little variation in tensile strength as the membranes age beyond 15 years. It would appear that the polyester reinforcement is well encapsulated within the PVC matrix and is therefore very effectively protected. As mechanically attached membranes are subjected to countless cycles of wind uplift over their service lives, the maintenance of high tensile strength is a critical factor in the long term performance of these membranes.

Figure 1: Tensile strength (left) and elongation at break (right) of polyester reinforced membranes versus age





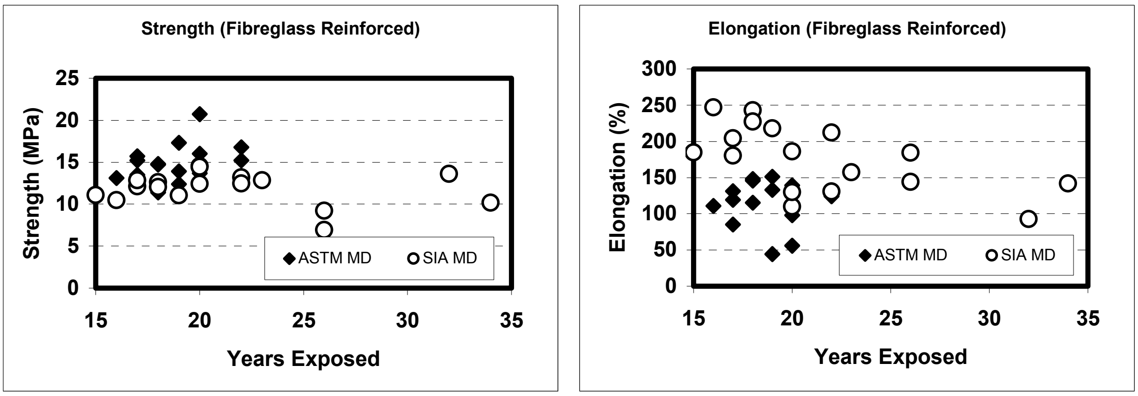
All the North American samples exceeded the minimum elongation at break value (15%) specified within ASTM D4434 for new material. All samples exceeded the minimum requirements of the DIN standard for new membranes (10%). As can be seen in Figure 1 however, unlike the tensile data, the elongation values generated by the two test methodologies do not correlate very well. The ASTM method appears to yield consistently higher results than the DIN test. The ASTM procedure not only results in higher values but also significantly greater data scatter. The DIN data conversely is quite consistent.

As would be expected, the membranes supported by the light weight, glass mat behave differently under tensile load than the much stronger polyester reinforced sheets. The glass mat in these membranes is there simply to insure dimensional stability. These membranes have the lowest level of shrinkage of any single ply membrane on the market. Test data for all glass mat supported samples is shown in Figure 2.

Whereas with polyester reinforced membranes, the strength of the sheet depends almost exclusively on the scrim, in glass mat supported membranes the strength comes from the polymer. To account for the thickness of the sample (i.e. greater strength with increasing membrane thickness), data is reported in MPa. All North American samples exceeded the ASTM minimum requirement for new material (10.4 MPa). The tensile strength of all the samples was greater than the DIN minimum (8 MPa). As can be seen in Figure 2, there is a tendency to increased tensile strength with age in the 15 to roughly 23 year range. This is expected as the sheet loses some flexibility over time. Beyond that range, there are insufficient data points to observe a clear trend.

A minimum elongation at break value of 250% is required for new materials in ASTM D4434. The measured elongation at break for the North American samples ranged from 45-150%, which corresponded to 18-60% of the minimum value specified for new materials. Samples 4B, 5B, 8A, and 20B had significantly lower elongation at break values (18-40% of ASTM minimum) than the rest (44-60% of ASTM minimum). The reasons for these values are not clear at this time. The DIN standard calls for new membranes to achieve a minimum of 150% elongation at break. As can be seen in Table 6.3, 4 of the 7 European samples achieved this value, one sample was at 95% of this value and another was at 92% of it (in the machine direction). Overall 11 of 17 samples (European and North American) surpassed this requirement for new products. Even amongst the samples with the lowest elongation values, all of the roofs were performing at the time of the survey and none showed any signs of any distress.

Figure 2: Tensile strength and elongation at break of glass mat supported membranes versus age

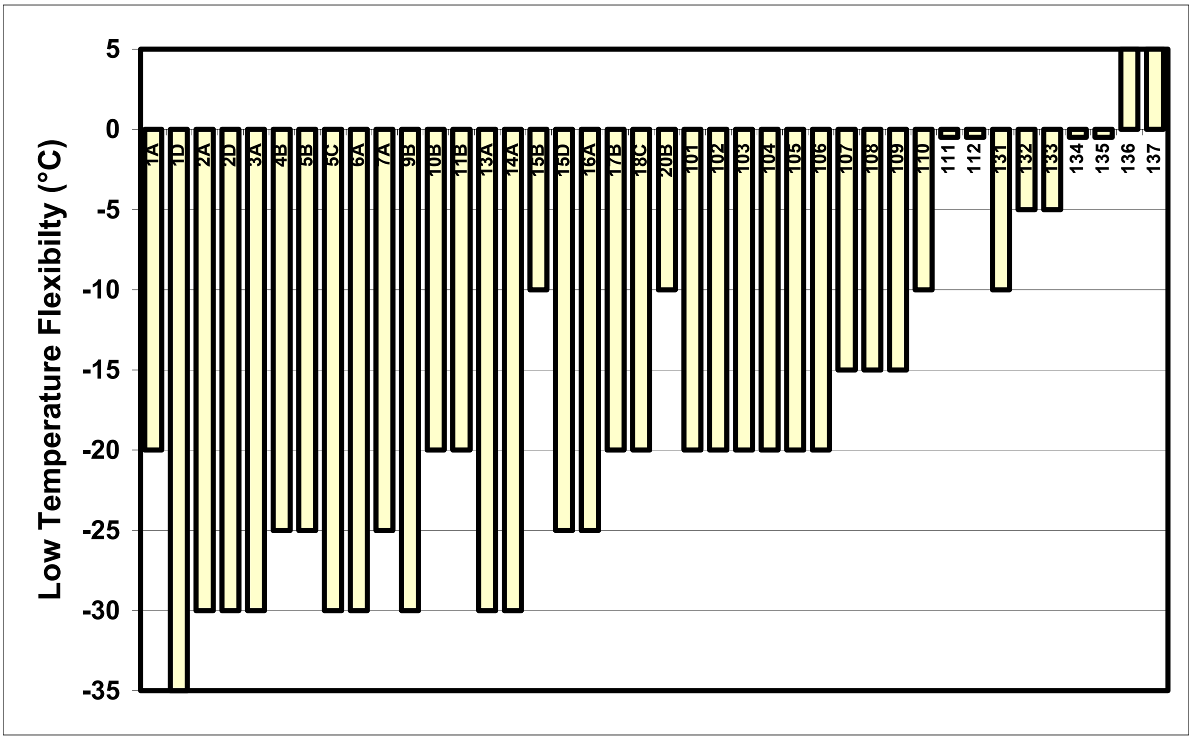


As can be seen in Figure 2, there is no correlation between the elongation data generated by the two different test methods. With the glass mat sheets, the SIA procedure results in higher values than the ASTM method, in many cases significantly higher. Once more, the different test parameters are assumed to be the reason for the differences. Perhaps not unexpectedly, for both types of membranes, the testing conducted at the lower cross head speed yields the higher elongations at break.

6 Low Temperature Flexibility

Flexibility is an important membrane property, particularly during the application phase. The flexibility of all types of roofing membranes decreases with temperature. For this study, the membranes' low temperature flexibility (LTF) was tested according to the procedure outlined in SIA 280. Five 10 mm wide rectangular specimens are folded with a bending radius of about 15 mm and fixed between two metal plates. The test device is then stored in a chamber and allowed to cool to the desired test temperature. When the samples have reached the required temperature the device is removed from the freezer and the two metal plates are instantly and quickly pressed together so that the samples are bent to a radius of 5 mm. The lowest temperature at which all five specimens do not break or crack is recorded. The reproducibility of the test method is ± 5°C. The SIA 280 requirement for new material is -20 °C. Test results are summarised in Figure 3.

Figure 3: Low temperature flexibility data



Remarkably 25 out of 40 samples still fulfill the requirement for new materials according to the SIA requirement of -20 °C or lower. Even the two samples with the highest values of 5 °C still show considerable flexibility. The testing conditions (rapid 180° bending around a small radius) are obviously severe and do not occur in real roof conditions. Membrane flexibility is an issue mainly during installation and roof maintenance. As can be seen even the aged installed membranes with a LTF value of 5 ° C continue to perform.
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The fact that a majority of all samples are tested with low temperature values above the requirements for virgin material reflects the manufacturer's efforts to formulate their membranes for long term behavior. Potential reduction in plasticizer content over long years of roof service is accounted for by the appropriate formulation of the base vinyl material.

7 Hail Resistance

Twenty seven of the samples received at the manufacturer's laboratory 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 the purposes of this investigation the hail test method developed by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) was chosen for the determination of the hail resistance. A detailed description of the test procedure and discussion of the results would be beyond the scope of this paper. They can be found in [7].

The Swiss standards SIA280 (polymeric) and SIA281(bituminous) require 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. Test results are summarized in Table 2.

Table 2: Hail resistance results. Blank fields indicate that no values have been determined.

ID	type thickness	age	hail resistance (impact velocity)			ID	type thickness	age	hail resistance (impact velocity)		
			Gypsum	ISO	EPS				Gypsum	ISO	EPS
	mm	years	m/s	m/s	m/s		mm	years	m/s	m/s	m/s
	G 1.2	new	66	39	47	10 A	G 1.2	19	29	16	
	G 1.8	new	96	67	85	11 B	G 1.2	18	43	20	
	S 1.2	new	79	54	61	13 A	S 1.2	19	14	10	
	S 1.8	new	95	68	77	14 B	S 1.2	16	58	54	
	G 1.2 [1)]	new	90			15 A	G 1.2	20	37	30	
	G 1.2 [2)]	new	91			15 C	S 1.2	20	34	28	
01 A	G 1.2	22	39	39		16 B	S 1.2	17	51	51	
01 C	S 1.2	22	37	38		17 A	S 1.2	15	52	55	
02 B	G 1.2	17	39	14		18 D	S 1.2	16	59	54	
02 C	S 1.2	17	52	45		20 A	G 1.2	20	18	11	
03 B	G 1.2	18	40	27		101	S 1.2	24			34
04 A	G 1.2	17	12	5		104	S 1.2	27			13
05 A	G 1.2	20	30	33		111	S 1.8	17			35
05 D	S 1.2	20	19	30		112	S 1.8	17			46
06 B	S 1.2	17	32	37		135	G 1.2	34			30
07 B	G 1.2	22	17	7		137	G 1.2	15			7
09 A	S 1.2	18	46	41							

[1)] membrane fully adhered to gypsum board;
[2)] felt backed membrane, fully adhered to gypsum board

All measured data of new membranes values exceed the minimum requirements by a multiple. 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.

Of the European surevy samples 101 and 135, 25 and 34 years old respectively, have hail resistance values below the requirement for new material. However, despite their age, and their locations in regions with high hail risk, these roofs exhibited no signs of hail damage. The other four samples, aged from 15 to 27 years, have hail resistance values far above the SIA280 requirement for new membranes.

Comparing the North American projects, the 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 FM Class 1-MH for new membranes, while 12 samples meet the requirement FM Class 1-SH on glass faced gypsum board (see [7] for a calculatory comparison between SIA and FM hail test values). On 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.

In a separate paper [7], one of the authors of this work studied the correlation between hail resistance (impact speed) and other physical properties. Both plasticizer content and low temperature flexibility were found to correlate reasonably well with hail resistance, with correlation coefficients around 0.6 in both cases. This area should be studied in greater depth. No correlation whatsoever was found between hail resistance and impact resistance, confirming that the latter cannot be used as a substitute for assessing the former.

8 Conclusions

Fourty four roofs, located in 6 countries in Europe and North America, were analyzed, and samples from each were subjected to a variety of physical property tests. Overall, the field performance of these fibreglass and polyester reinforced vinyl membranes, were found to be without problem. The roofing systems averaging over 20 years of age were performing well and without leakage. All membranes were capable of being welded to even after up to 34 years of weathering.

The laboratory testing confirms that although the products tested lost some of their initial physical properties, which is to be expected with any materials as they age, they generally held up very well compared to the standard minimum values for testing new PVC roofing membranes according to North American and European standards. It is important to note, however, that some of these membranes, which had been tested in the NRC laboratory about 15 years ago, exceeded the minimum requirements of the ASTM D4434. This is an interesting point because as all roofing materials age and weather, their properties are expected to degrade. Therefore, to ensure that the minimum property values are exceeded after aging/weathering, a new membrane, regardless of the type (i.e., polymeric, elastomeric or asphaltic) must exceed the minimum requirements listed in the standards.

As the roofs examined are essentially the oldest in place, it is not possible to predict how much longer they will perform. But considering the age and the condition of the roofs analyzed, this data would indicate that a properly formulated, properly maintained, reinforced PVC roof membrane system could perform in excess of 20 to 30 years in various climates throughout Europe and North America.

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