Field Investigation and Laboratory Testing of Exposed Poly(Vinyl Chloride) Roof Systems

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Abstract

In 1999, a major manufacturer of thermoplastic membranes set out to "quantify and qualify" how their oldest roofs in the United States and Canada were performing. This information was critical for their Life Cycle Cost Data. The process was as follows: This manufacturer reviewed their internal project data base and project files to determine the oldest project in each of their regions. The regions attempted to contact each owner of the building. Approximately 70% of the owners were contacted because some of the buildings were vacant or torn down. A survey was sent to the building owners of 70 of their oldest projects in the U.S and Canada (range 17-22 years old). Some surveys were filled out over the telephone. The response rate was 63%. All surveys were collected and statistics created.

In 2001, the manufacturer sampled 25 of these projects in all regions and climates and invited roof consultants and architects to participate in field investigations and roof sampling. The specific roofs sampled in these different regions and climates were selected solely as a matter of convenience. That is, the roofs were samples when owners provided the manufacturer permission to do so and when the costs of accessing the selected roofs were reasonable. Samples were packaged and sent to the National Research Council of Canada (NRCC). The NRCC tested samples according to ASTM D4434 [1] (where appropriate) for thickness, tensile strength, elongation, linear dimensional change, low temperature flexibility and seam strength. It should be noted that D4434 [1] was established in 1985 and was the first ASTM standard for any single ply roof membrane in the U.S. Most of the roofs sampled were installed before the standard even existed. All of the roofs investigated and sampled were found to be in good shape. No immediate maintenance or repairs were needed. After sampling all of the existing roof membranes could be easily patched by hot air welding.

The laboratory testing confirms that although the products tested lost some of their initial physical properties (as expected), they generally held up well compared to the standard minimum values for testing new PVC roofing membranes according to ASTM D4434 [1]. 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 [1]. This is an interesting point because as materials age/weather, their properties are expected to degrade.

Introduction

Poly(vinyl chloride) – also known as vinyl -- is one of the most versatile thermoplastics in use today. It is produced by polymerization of vinyl chloride monomer, a gas produced by the reaction of ethylene with oxygen and hydrochloric acid. This reaction produces a chemical bond that is saturated and hence, highly inert and strong. In its basic form, PVC resin is a rigid substance to which plasticizers, stabilizers, and other components must be added to provide the desired properties for the PVC's intended use. It has been used in roof coverings since the 1960's. The basic formula for today's PVC roof membranes is shown in Table 1.

There are three types of PVC roofing sheets: unreinforced, unreinforced with fibres or fabrics that act as carriers, and reinforced sheets that contain fibreglass and/or polyester fibres or

fabrics. Reinforcements may be composed of woven polyester or woven or unwoven glass fibers. Polyester reinforcement is used to increase the membrane's resistance to tearing in the wind. Polyester reinforcement is used mainly for sheets that are going to be fastened mechanically, while fibreglass reinforcements are used for adhered systems. Fibreglass reinforcement is used mainly for dimensional stability. The carrier facilitates manufacturing and may add to the dimensional stability of the sheet. Reinforcement provides tensile and other properties. Generally, unreinforced sheets are produced by calendering or extrusion. Reinforced sheets can be produced by laminating two plies of unreinforced sheet with a layer of reinforcement between them or by a coating process.

Table 1   Typical composition of a generic PVC roofing membrane.

Ingredients	% by Mass	Function
PVC resin	50 – 55	Basic material (powder or granular)
Plasticizers	25 – 35	Impart flexibility
Inorganic solids	5 – 10	Increase dimensional stability and mechanical properties
Pigments	0.5 - 1.0	Provide color and UV stability to the PVC compound
Processing oils and biocides	0.5 - 1.0	Improve processing and resistance to biological attack
Stabilizers	2 – 3	Provide resistance to heat and light during manufacture and use

Note: Based on technical notes and some related patent specifications

One main advantage of PVC sheets is that the entire roof membrane can be joined by welding the joints with solvent or with air heated to 425 °C. This membrane can also be welded to metal flashing that has been factory-coated with PVC. The result is a continuous roofing assembly. PVC sheets remain flexible at temperatures as low as -40 °C. They are ideal for re-roof and repairs, because of their high permeability. Moreover, white reflective vinyl membranes contribute to reducing urban heat island effects, can be produced in a wide spectrum of colors to meet desired aesthetic features of building, have high resistance to puncture and impact and have excellent resistance to flame exposure and subsequent fire propagation.

Loss of plasticizers has been a concern with certain PVC roofing products [2, 3], as it caused embrittlement in the PVC sheets. This can be controlled by using high molecular weight plasticizers that have less of a tendency to volatilize or migrate out of PVC resin. Certain PVC roofing membranes utilizing a very stable formulation have over 40 years experience in Europe and close to 25 years throughout North America. Moreover, today all sheets are reinforced so that in case of cracking of the membrane, a local repair should suffice.

Vinyl roofing membranes should meet ASTM D4434 [1] or CAN/CGSB 37.54 recognized North American standards. PVC sheets have good resistance to industrial pollutants, bacterial growth and extreme weather conditions. Minor damage to the sheet during installation or in-service can be easily repaired by patching the hole using heat or solvent. PVC is incompatible with bituminous materials therefore care must be taken to avoid direct contact with asphalt.

Objectives

Physical properties of all roof systems change with age and outdoor exposure. The change in physical properties of a roof membrane may be a 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. The purpose of this investigation is to study the performance and physical properties of reinforced PVC membranes throughout North America. This information is critical for true life cycle costing and analysis.

Methodology

In 1999, a major manufacturer of thermoplastic membranes set out to "quantify and qualify" how their oldest roofs in the United States and Canada were performing. This information was critical for their Life Cycle Cost Data. The process was as follows: This manufacturer reviewed their internal project data base and project files to determine the oldest project in each of their regions. The regions attempted to contact each owner of the building. Approximately 70% of the owners were contacted because some of the buildings were vacant or torn down. A survey was sent to the building owners of 70 of their oldest projects in the U.S and Canada (range 17-22 years old). Some surveys were filled out over the telephone. The response rate was 63%. All surveys were collected and statistics created.

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Thickness Measurements

The material adhered on the G-designated samples were removed by either peeling slowly by hand or scraping carefully using a brass putty knife. Care was taken during the material removal to minimize any damage to the samples. *(Note: For definitions regarding Type and Grade please refer to Reference 1.)*

1. The thickness of the fibreglass-reinforced roofing membranes (ASTM Type II Grade 1) was measured according to ASTM D638 [4]. A hand held micrometer with a ratchet was used which has an accuracy of 0.025 mm (0.001 in.). The diameter of the contact foot was 6.35 mm (0.250 in.) and a pressure of 25kPa (3.6 psi) was used. Five measurements were taken at randomly selected points over the sample surface. The average and standard deviation of the thickness are reported in Table 3.

2. The thickness of the polyester reinforced roofing membranes (ASTM Type III) was measured according to ASTM D751 [5]. A dead weight dial gauge that was graduated to read to 0.025 mm (0.001 in.) was used. The presser foot had a diameter of 9.52 mm (0.375 in). Five measurements were taken at randomly selected points over the sample surface. The average and standard deviation of the thickness are summarized in Table 3.

The roofing membranes that met the minimum thickness requirement for new membranes (1.14 mm) as stated in ASTM D4434 [1] are 3A, 4B, 10B, 11B, 13A, 14A, 17B, 23A and 26. Samples 7A and 8A, which may have been Type IV membranes, were significantly below 1.14 mm. The other samples were very close to the thickness specified in ASTM D4434 [1] for Type II Grade I and Type III membranes.

Table 2   Summary of all PVC samples received.

Sample ID	Project Location	Membrane Type	Year Installed	Years Exposed
1A	Canton MA	G	1979	22
1D	Canton MA	S	1979	22
2A	Wenham MA	G	1984	17
2D	Wenham MA	S	1984	17
3A	Woburn MA	G	1983	18
4B	Dickson TX	G	1984	17
5B	Tyler TX	G	1981	20
5C	Tyler TX	S	1981	20
6A	Euless TX	S	1984	17
7A	City of Industry CA	G	1979	22
8A	El Segundo CA	G	1982	19
9B	Mountainview CA	S	1983	18
10B	Lacey WA	G	1982	19
11B	Ft. Steilacoom WA	G	1983	18
12A	Atlanta GA	S	1986	15
13A	Jacksonville FL	S	1982	19
14A	Appleton WI	S	1985	16
15B	Mt. Prospect IL	G	1981	20
15D	Mt. Prospect IL	S	1981	20
16A	Park Ridge IL	S	1984	17
17B	Hackensack NJ	S	1986	15
18A	Englewood NJ	G	1985	16
18C	Englewood NJ	S	1985	16
19A	Iowa City IA	S	1982	19
20B	Davis CA	G	1981	20
21A	Haileybury ON	G	1981	20
21C	Haileybury ON	S	1981	20
22A	Hamilton ON	S	1984	17
23A	Alouette QC	G	1983	18
25A	Sarnia ON	G	1984	17
26	Calgary AB	G	1982	19

Notes:
1. 31 samples, 25 locations
2. S refers to synthetic polyester reinforced, typically installed in mechanically fastened applications
3. G refers to fibreglass reinforced, typically installed in adhered applications
4. 12 refers to 1.2 mm or 47.4 mils in thickness

Tensile Properties

The tensile properties of the polyester reinforced roofing membranes were measured according to ASTM D751, Procedure B – Cut Strip Test Method [5]. The samples were cut into specimens of 25 mm X 150 mm (1 in. X 6 in.), using a utility knife with the aid of a plastic template. The specimens were tested in an Instron model 4502 machine with a gauge length of 75 mm (3 in.) at a constant crosshead speed of 300 mm/min (12 in./min). A minimum of five specimens were tested in both machine and cross directions.

The tensile properties of the glass reinforced roofing membranes were tested according to ASTM D638 [4]. The samples were cut into specimens using a dumb bell shaped die # C in a hydraulic press. The specimens were tested in an Instron model 4502 machine with a gauge

length of 65 mm (2.5 in.) at a constant crosshead speed of 50 mm/min (2 in./min). A minimum of five specimens were tested in both the machine and the cross directions.

Table 3   Summary of thickness results with single standard deviation

	Thickness	
Sample ID	Average (mm)	Average (in.)
1A	1.13 ± 0.02	0.044 ± 0.001
1D	1.09 ± 0.01	0.043 ± 0.000
2A	1.12 ± 0.02	0.044 ± 0.001
2D	1.12 ± 0.02	0.044 ± 0.001
3A	1.21 ± 0.13	0.048 ± 0.005
4B	1.17 ± 0.04	0.046 ± 0.002
5B	1.13 ± 0.04	0.044 ± 0.002
5C	1.12 ± 0.02	0.044 ± 0.001
6A	1.11 ± 0.02	0.044 ± 0.001
7A	0.98 ± 0.05	0.039 ± 0.002
8A	0.93 ± 0.03	0.037 ± 0.001
9B	1.13 ± 0.01	0.045 ± 0.001
10B	1.16 ± 0.07	0.046 ± 0.003
11B	1.19 ± 0.03	0.047 ± 0.001
12A	1.08 ± 0.02	0.042 ± 0.001
13A	1.20 ± 0.01	0.047 ± 0.000
14A	1.18 ± 0.02	0.046 ± 0.001
15B	1.12 ± 0.01	0.044 ± 0.001
15D	1.10 ± 0.01	0.043 ± 0.000
16A	1.12 ± 0.01	0.041 ± 0.001
17B	1.17 ± 0.01	0.046 ± 0.001
18A	1.12 ± 0.01	0.044 ± 0.001
18C	1.09 ± 0.01	0.043 ± 0.000
19A	1.13 ± 0.01	0.045 ± 0.000
20B	1.01 ± 0.02	0.040 ± 0.001
21A	1.13 ± 0.01	0.045 ± 0.000
21C	1.08 ± 0.02	0.042 ± 0.001
22A	1.10 ± 0.02	0.043 ± 0.001
23A	1.22 ± 0.01	0.048 ± 0.000
25A	1.09 ± 0.02	0.046 ± 0.001
26	1.15 ± 0.01	0.045 ± 0.000
Average	**1.12 mm**	**0.044 in.**

Note: ASTM D4434 [1] Type II Grade 1 and Type III requirement is
       1.14 mm (45 mils)
       ASTM Type IV requirement is 0.91 mm (36 mils)

Polyester Reinforced Samples (ASTM Type III)

Typical force-displacement curves for the tensile testing of the polyester reinforced roofing membrane are displayed in Figure 1. The load increased with displacement almost linearly at the beginning as the specimen stretched until the reinforcement broke, which caused an abrupt drop in load. No delamination was observed between the polyester fibre and the PVC matrix.

The tensile properties of the polyester reinforced roofing membrane samples are summarized in Table 4. None of the samples met the minimum breaking strength requirement (35 kN/m) as stated in ASTM D4434 [1] except Samples 13A in the cross direction. The samples retained 70-90% of the minimum breaking strength required for new membranes as specified in ASTM D4434 [1] and over 60% of the samples retained more than 80% of that requirement. However, all samples exceeded the minimum elongation at break value (15%) specified by ASTM D4434 [1]. Note at the time the membrane was made for most of these projects the ASTM Standard did not exist.

Figure 1 Typical Force displacement curve for tensile test of polyester reinforced roof membrane (Sample *21C*) in the machine (MD) and cross directions (CD)

Machine Direction   Cross Machine Direction
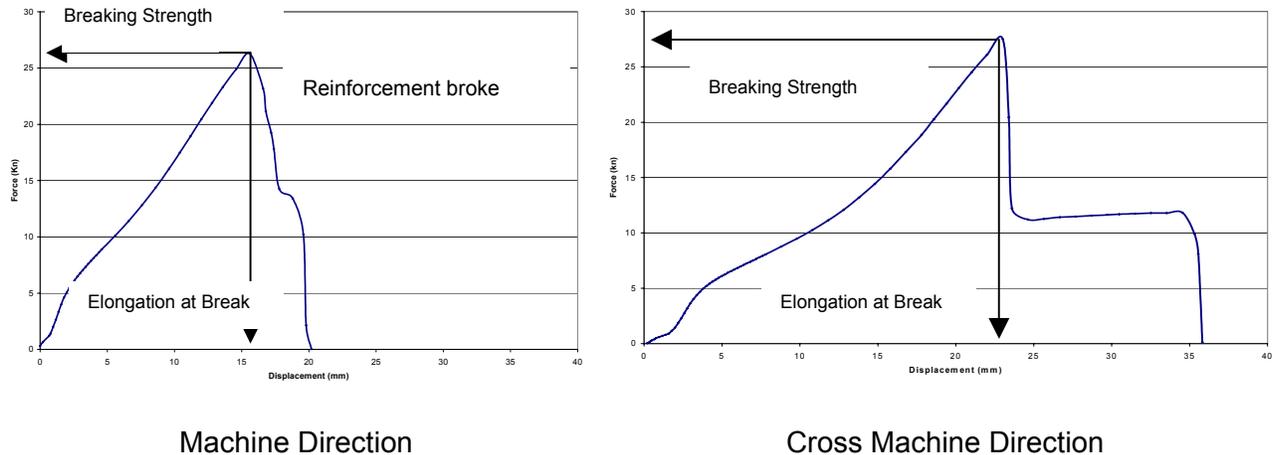
Glass Reinforced Samples (ASTM Type II, Grade 1)

Figure 2 shows a typical force-displacement curve for the tensile testing of the fibreglass reinforced roofing membranes. The load increased linearly with displacement at the beginning. The specimen then started to yield and neck as indicated by the change in slope in the force-displacement curve. It stretched to a high degree (over 100% in general) and finally broke with a snap. No delamination was observed between the fibreglass reinforcement and the PVC matrix.

The tensile properties of the fibreglass reinforced roofing membranes are shown in Table 5. All samples exceeded the minimum requirement (10.4 MPa) but did not meet the minimum elongation at break value (250%) as specified by ASTM D4434 [1]. The elongation at break for the samples ranged from 45-150%, which corresponded to 18-60% of the minimum value specified for new membranes in ASTM D4434 [1]. 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).

Linear Dimensional Change

The samples were cut making two specimens of 250 mm X 250 mm (10 in. X 10 in.) using a utility knife with the aid of a plastic template. The material adhered on the G-designated samples was removed by either peeling slowly by hand or scraping carefully using a brass putty knife. Care was taken during the material removal to minimize any damage to the samples. For this test, sample 21A was not evaluated due to limited materials.

Figure 2 Typical Force displacement curve tensile test for fibreglass reinforced roofing membrane Sample 18A).
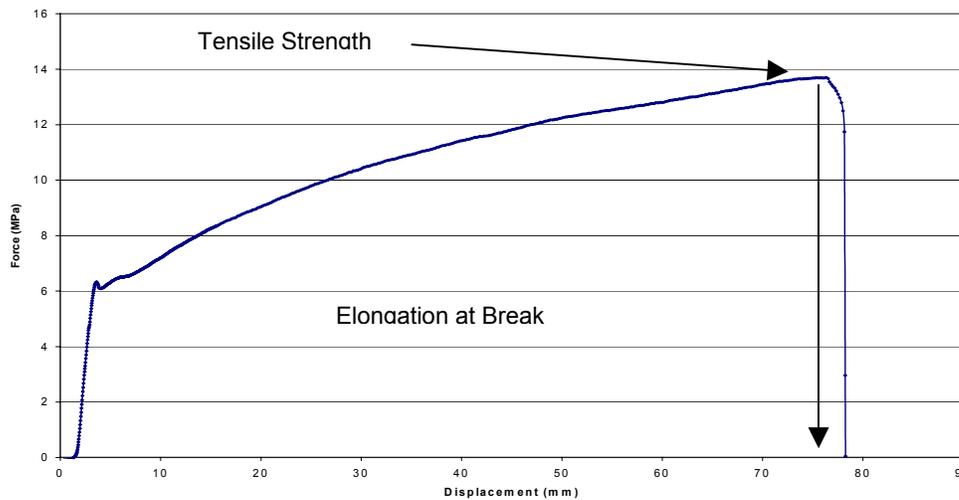
Table 4 Tensile strength and elongation at break properties of polyester reinforced roofing membranes (ASTM Type III) with single standard deviation

Sample ID	Years Exposed	Breaking Strength (kN/m)		Elongation at Break (%)	
		MD	CD	MD	CD
1D	22	27.0 ± 3.5	26.0 ± 2.5	22.2 ± 1.8	28.0 ± 3.7
2D	17	25.2 ± 2.1	26.3 ± 2.3	22.7 ± 1.7	27.8 ± 2.4
5C	20	30.2 ± 2.0	31.6 ± 1.4	19.0 ± 2.3	27.5 ± 1.04
6A	17	28.4 ± 0.9	30.0 ± 2.0	27.7 ± 0.6	21.4 ± 1.2
9B	18	26.8 ± 3.2	29.0 ± 1.6	25.1 ± 1.6	19.1 ± 1.9
12A	15	28.3 ± 1.7	28.7 ± 0.7	20.4 ± 1.5	18.7 ± 1.5
13A	19	29.2 ± 2.6	35.0 ± 1.4	28.1 ± 2.4	22.1 ± 1.3
14A	16	24.0 ± 2.4	25.9 ± 3.6	22.6 ± 1.7	17.3 ± 1.8
15D	20	26.6 ± 1.3	27.8 ± 1.7	25.1 ± 0.7	31.7 ± 1.7
16A	17	29.3 ± 3.3	29.6 ± 1.7	21.1 ± 2.3	29.4 ± 1.4
17B	15	26.5 ± 1.3	26.7 ± 1.4	23.3 ± 0.5	26.4 ± 3.7
18C	16	29.6 ± 1.4	26.0 ± 0.06	21.9 ± 3.2	36.8 ± 1.1
19A	19	29.2 ± 2.4	29.4 ± 1.6	23.3 ± 1.9	23.3 ± 1.9
21C	20	30.2 ± 1.9	30.2 ± 1.9	23.4 ± 1.6	22.5 ± 0.9
22A	17	29.0 ± 1.9	31.7 ± 0.8	22.0 ± 2.8	20.0 ± 1.4
Average	**19 Years**	**28.0**	**28.9**	**21.7%**	**24.8%**
ASTM D4434 [1]		**35**	**35**	**15.0%**	**15%**

Notes:
1. ASTM D4434 [1] approved in 1985
2. 11 projects installed before the standard even existed
3. Changes in scrim have occurred since introduction of the standard

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The samples were tested according to ASTM D1204 [6] as specified by ASTM D4434 [1]. Two specimens of dimensions 250 mm x 250 mm (10 in. x 10 in.) were cut from each sample. Before conditioning, each specimen was marked and measured at the midpoint in both the machine and cross machine directions. The specimens were measured using a 450 mm Mitutoyo vernier caliper that has an accuracy of 0.01 mm (0.0005 in.). The specimens were dusted with talc and placed between two pieces of Teflon™ coated paper, which were secured together with paper clips. The assemblies were placed in a convection oven at 80±1°C for 6h. They were then removed from the oven and conditioned at 23±2°°C, 50% relative humidity for at least 1 hour before the final measurements were made. The linear dimensional change is the change in dimension as a percent of the original dimension:

$$\text{Linear dimensional change} = [(D_f - D_o)/D_O] \times 100\%$$

Table 5   Tensile strength and percent elongation properties of fibreglass reinforced PVC roofing membranes (ASTM Type II Grade 1) with single standard deviation

Sample ID	Years Exposed	Tensile Strength (MPa)	Elongation at Break (%)
1A	22	15.2 ± 0.4	125 ± 5.6
2A	17	13.5 ± 0.5	119 ± 9.7
3A	18	14.8 ± 0.5	146 ± 18.8
4B	17	15.2 ± 1.1	85.3 ± 18.5
5B	20	16.0 ± 0.6	98.1 ± 13.2
7A	22	16.8 ± 0.6	124 ± 8.2
8A	19	17.3 ± 1.0	44.5 ± 14.3
10B	19	13.9 ± 0.5	133 ± 9.2
11B	18	14.7 ± 0.5	148 ± 3.3
15B	20	15.0 ± 0.6	139 ± 7.0
18A	16	13.1 ± 1.7	111 ± 36.1
20B	20	20.7 ± 2.0	56.0 ± 18.3
21A	20	13.7 ± 0.4	134 ± 6.2
23A	18	11.4 ± 0.3	115 ± 8.3
25A	17	15.7 ± 0.4	131 ± 11.8
26	19	12.4 ± 0.3	151 ± 8.6
Average	**18.8 Years**	**14.9**	**116**

Notes:
1.   ASTM D4434 [1] approved in 1985
2.   14 projects installed before the standard even existed
3.   Elongation affected by adhesive and preparation of sample
4.   Still over 100% elongation after 18+ years

Where D_f is the final length (or width) of the specimen after the test and D_O is the initial length (or width) of the specimen. A positive linear dimensional change indicates expansion while a negative value denotes shrinkage.

The results of the linear dimensional change of the samples after conditioning at 80 ± 1°C for 6h in a convection oven are shown in Table 6. All polyester reinforced roofing membranes except Sample 13A met the linear dimensional change requirement of 0.5% as stated in ASTM D4434 [1]. All the fibreglass reinforced samples met the linear dimensional change requirement of 0.1% as stated in ASTM D4434 [1].

Table 6   Linear dimensional change, cold temperature flexibility and seam strength

Sample ID	Years Exposed	Linear Dimensional Change (%)		Cold Temperature Flexibility at:	Seam Strength***	
		MD	CD	-20°C (-4°F)	(MPa)	(psi)
1D	22	-0.41	-0.36	Pass	18.15	2632
2D	17	-0.08	-0.06	Pass	19.42	2817
5C	20	-0.33	-0.15	Pass	--	--
6A	17	-0.48	-0.16	Pass	21.36	3098
9B	18	-0.23	-0.03	Pass	19.39	2812
12A	15	-0.10	-0.08	Pass	21.14	3066
13A	19	-2.26	-1.17	Fail*	22.60	3278
14A	16	-0.16	-0.06	Pass	19.95	2894
15D	20	-0.19	-0.46	Pass	--	--
16A	17	-0.14	-0.02	Pass	18.30	2654
17B	15	-0.10	-0.11	Pass	--	--
18C	16	-0.10	-0.03	Pass	18.06	2619
19A	19	-0.22	-0.09	Pass	--	--
21C	20	-0.07	-0.06	Pass	--	--
22A	17	-0.23	-0.12	Pass	--	--
1A	22	+0.01	-0.02	Pass	9.95	1443
2A	17	+0.05	+0.04	Pass	10.20	1479
3A	18	+0.02	-0.03	Pass	10.59	1536
4B	17	+0.01	0.00	Fail*	--	--
5B	20	-0.01	-0.01	Fail**	--	--
7A	22	-0.11	-0.07	Fail**	13.77	1997
8A	19	-0.02	-0.01	Fail**	11.73	1701
10B	19	+0.01	+0.02	Pass	10.17	1475
11B	18	+0.03	+0.02	Pass	9.11	1321
15B	20	-0.03	+0.01	Pass	10.13	1469
18A	16	+0.04	+0.01	Fail*	10.30	1494
20B	20	-0.05	+0.09	Fail*	--	--
21A	20	N/A[a]	N/A[a]	Pass	9.29	1347
23A	18	+0.06	-0.03	Pass	--	--
25A	17	-0.01	+0.01	Fail*	--	--
26	19	-0.08	-0.02	Pass	9.16	1330

*Specimens exhibited coating cracks **Specimens fractured ***Median of at least 3 specimens per sample

<u>Low Temperature Flexibility</u>

The samples were cut into specimens of 25 mm X 100 mm (1 in. X 4 in.) using a utility knife with the aid of a plastic template. The material adhered on the G-designated samples was removed by either peeling slowly by hand or scraping carefully using a brass putty knife. Care was taken during the material removal to minimize any damage to the samples.

The samples were tested according to ASTM D2136 [7] at -20°C. The specimens were sandwiched between two glass plates in a freezer at -20°C for 4 hours. They were then removed from the glass plates one at a time and placed inside the environmental chamber, which housed the bending apparatus (Figures 1 and 2). The specimens were placed into the bending apparatus and allowed to equilibrate in the chamber for one minute. When the trigger

pin was released, the flexing plate made a free fall, which bent the specimen. A minimum of three specimens per sample were tested.

After three specimens had been tested, they were removed from the environmental chamber and examined for surface cracks using a 5X-magnifying glass. During the inspection, each specimen was folded 180° in the same direction as the specimen was bent during the test. If all three specimens showed no cracks in the coating and no fractures, then the sample was considered to have passed. If all three specimens displayed cracks or fracture, the sample failed. However, if only one or two specimens showed cracks, three additional specimens were tested. If any of these exhibited coating cracks or fractures, then the material failed; otherwise, it passed. Typical failed and passed specimens are shown in Figures 3 and 4, respectively.

The results of the cold temperature flexibility test conducted at -20°C (-4°F) are shown in Table 6. All samples passed except 13A, 4B, 5B, 7A, 8A, 18A, 20B and 25A.

Environmental Chamber

Bending Apparatus

Specimen

Test specimens placed in the bending apparatus were allowed to equilibrate in the environmental chamber

Bending Apparatus

Trigger Pin

Specimen

Cold Chamber

A specimen in the bending apparatus
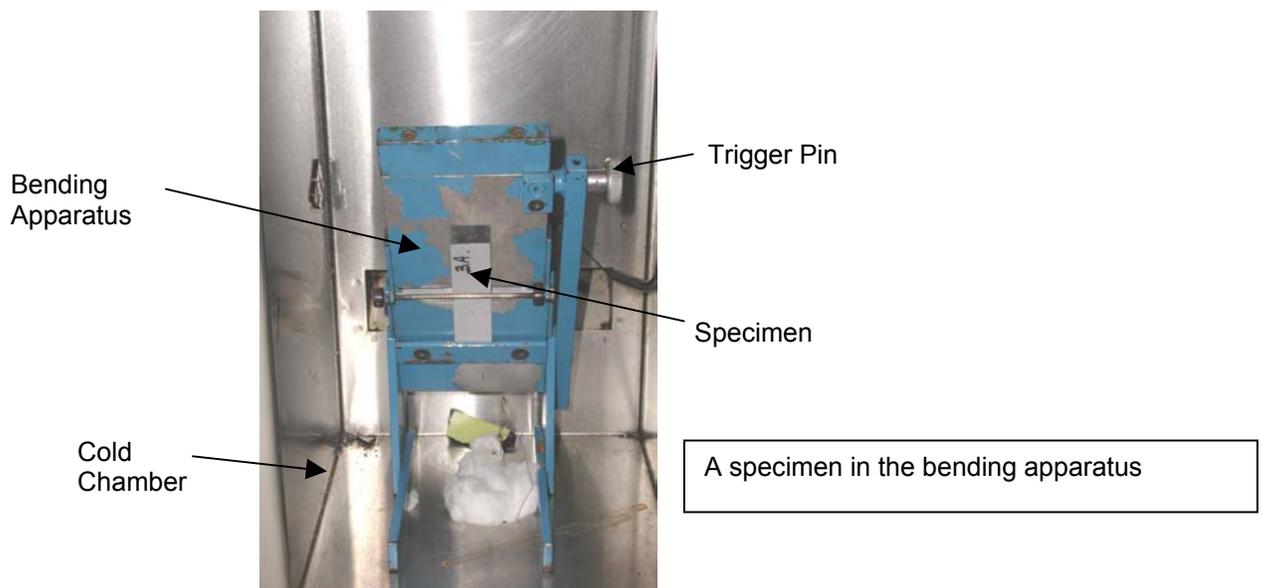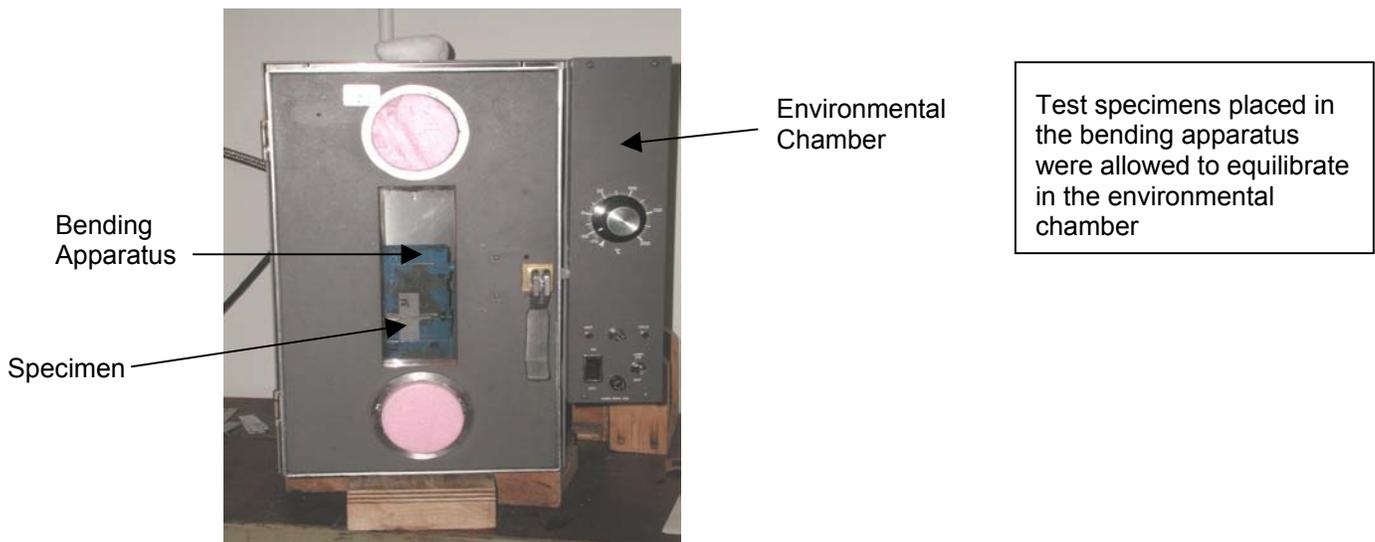
Figure 3   Typical failed specimens showing (a) fracture, (b) surface crack
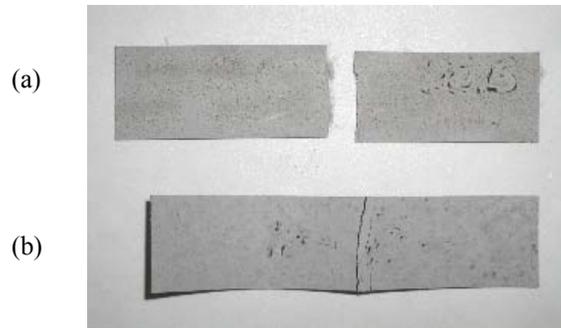
Figure 4   Typical passed specimens

Seam Strength

The seam strength of the reinforced PVC roofing membrane samples was measured according to ASTM D5868 [8] in a lap shear configuration. The samples were cut into specimens of 50 mm X 200 mm (2 in. X 8 in.), using a utility knife with the aid of a plastic template. The specimens were tested in an Instron machine (model 4502) at a constant crosshead speed of 13 mm/min (0.5 in./min). The distance between the grip and the edge of the seam was 27 mm (1 1/16 in.). Two pieces of sand paper (number 100) were placed between the grips and the specimen to prevent slippage. A minimum of three specimens were tested for each sample.

The seam strength of each specimen was calculated by dividing the maximum tensile load by the original cross-sectional area of the specimen (i.e., width X thickness). The seam strength of the reinforced PVC roofing membrane samples was reported as the median of at least 3 specimens and is summarized in Table 6. The seam strength of the glass reinforced membrane samples ranged from 9 to 14 MPa (1300 to 2030 psi) and that of the polyester reinforced membrane samples ranged from 18 to 23 MPa (2610 to 3340 psi).

Typical force-displacement curves for the seam test of the glass and polyester reinforced roofing membrane samples are displayed in Figure 5. The load increased with displacement as the specimen stretched. The slope of the curve then decreased slightly as the stretched zone started to neck and the surrounding material was drawn into this zone. The membrane stretched further and finally broke, which caused an abrupt drop in load. Both the glass and the polyester reinforced PVC membranes failed in similar manner. However, the glass samples stretched and necked to a higher extent because the random short glass fibres moved more freely with the PVC matrix.

The failure of all specimens occurred in the membrane outside the seam area with the seam remained intact (Figure 6). This indicated that the seam did not deteriorate after the membranes had been in-service for various periods of time and that the seam strength was governed by the tensile strength of the membrane.

Sand —————→
Upper grip —————→
Specimen —————→
Seam area —————→
Lower grip —————→

Figure 5

Force (kN) vs Displacement (mm)

Maximum Tensile Load

Polyester Reinforced
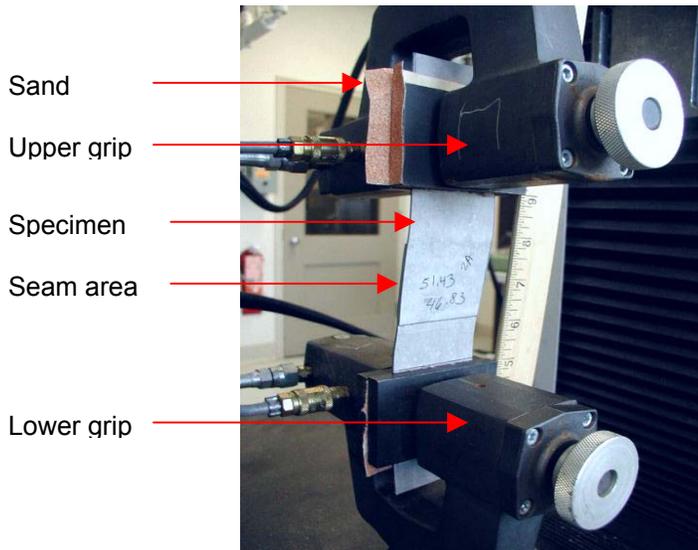
Glass Reinforced PVC
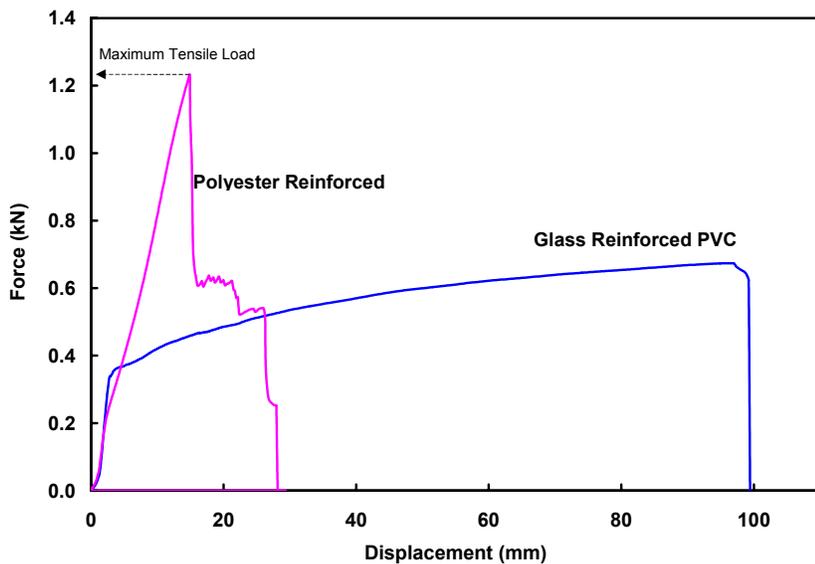
Typical force-displacement curves for the seam test of the reinforced PVC roofing membrane samples.

Conclusions

Overall, the field performance of these fibreglass and polyester reinforced vinyl membranes, which were analyzed, and found to be without problem. The roofing systems averaging 19 years of age were performing well and without leakage. All membranes were capable of being welded to even after 19 years of weathering.

The laboratory testing confirms that although the products tested lost some of their initial physical properties (as expected), they generally held up well compared to the standard minimum values for testing new PVC roofing membranes according to ASTM D4434 [1]. 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 [1]. This is an interesting point because as materials age/weather, their properties are expected to degrade.

(a)   (b)
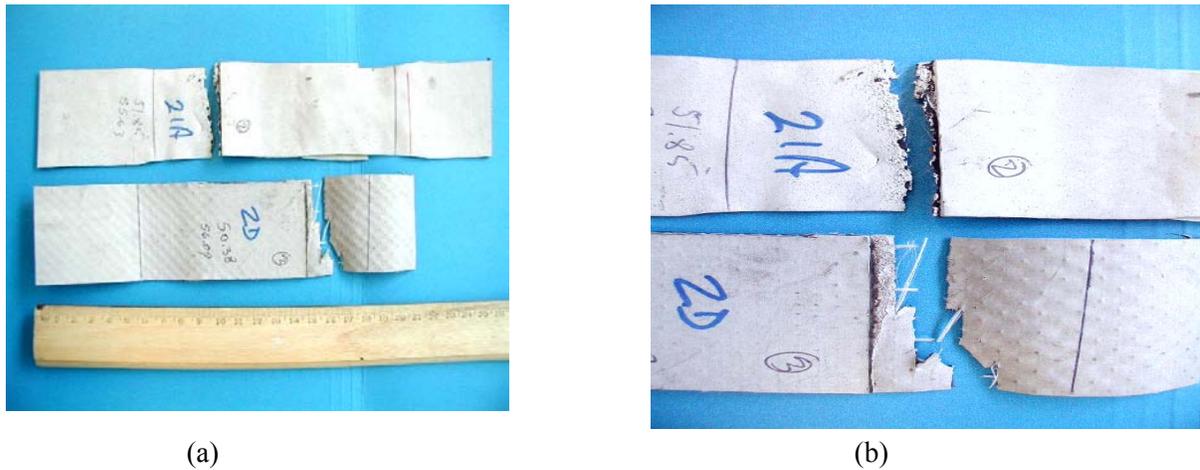
Figure 6   Typical failed glass and polyester reinforced seam test specimens (a) failure occurred in the membrane outside the seam area while the seam remained intact (b) close up at area of failure.

No prediction can be made as to how long these roof systems will last. But roofs have been in place for 40 years in Europe and this data would indicate that a properly formulated, properly maintained, reinforced PVC roof membrane system could perform in excess of 20-30 years in various climates throughout the Continental U.S. and parts of Canada. Obviously, the exact climate conditions could affect the overall longevity. [9]

Additional testing, such as wind uplift testing, fire testing and hail impact testing would be worthwhile but was not part of this test program.

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