

COMPARATIVE TESTING AND RATING OF THIRTEEN THERMOPLASTIC SINGLE PLY ROOFING MEMBRANES

Thermoplastic single ply roofing membranes

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Abstract

We tested samples of poly[vinyl chloride] (PVC), thermoplastic olefin (TPO), and other thermoplastic single ply roofing membranes using a battery of physical tests before and after heat aging and accelerated weathering tests. We cut all test from commercial products purchased on the open market.

We ranked all test results in descending order from the product with the most advantageous property (equaling 100%) to the least advantaged. The average of the test percentage ratings on each product were then ranked from the highest rating to the lowest rating.

We used this procedure previously to develop data for the preparation of ASTM consensus Standard D 6221, *Standard Specification for Reinforced Bituminous Flashing Sheets for Roofing and Waterproofing.*

Keywords: ABC, accelerated weathering, EP, EVA, performance ranking, physical testing, PVC, roofing, single ply, thermoplastic membranes, TPO.

1 Introduction

Product or system selection can be difficult for the designer who desires to use a thermoplastic single ply roofing system, because eight manufacturers offer thirty PVC (poly[vinyl chloride]) single ply roofing membranes and fourteen manufacturers offer forty-four “Other Prefabricated Sheet-Applied Membranes” according to the most recent NRCA materials guide (NRCA 1998). Two of these manufacturers offer both a PVC and an “other” membrane.

In the absence of an sufficiently long history of successful performance, there are very few ways a designer can objectively select a system for use. Some possibilities include:

- comparison of physical test data compared to appropriate standards, or
- comparison of physical test data obtained from testing competing materials,
- or reliance on data obtained from accelerated exposure.

We examine each of these three selection methods in this paper and contrast the advantages and disadvantages of each technique. Our data can also be used as a base line to compare the data obtained by testing other systems, as long as the same test methods are used.

2 Sample selection

We cut all of our test specimens from the inner convolutions of commercial products purchased on the open market. We tested specimens from one roll of each product. Because of the uniformity we expect in these factory made products, we feel that the specimens we obtained are a true representation of the products selected.

We would have preferred testing samples of all the available products, but economics required that we limit our study. We feel fortunate to have obtained thirteen different products for testing, and only two of these were from the same manufacturer. We obtained membranes based on the following polymers: eight rolls of PVC, two rolls of TPO (thermoplastic polyolefin), one roll of ABC (acrylonitrile butadiene), one roll of EP (ethylene-propylene), and one roll of PVC/EVA (poly[vinyl chloride] - ethylene vinyl acetate alloy).

We cut all the samples after the plastic sheets had been conditioned to equilibrium in the controlled temperature and humidity room of our laboratory. This room maintains a constant 50% relative humidity and a temperature of 23 C

3 Test methods

We used all the test methods required by ASTM D4434, except the puncture resistance tests. We do not currently own the puncture resistance equipment required. In addition, we performed some tests suggested by a manufacturer that are not now ASTM standard tests.

3.1 ASTM test methods

We used the following ASTM test methods in this study:

- D570 Standard Test for Water Absorption of Plastics
- D638 Standard Test Method for the Tensile Properties of Plastics [using D412 die C - 64 mm (2½ in.) jaw gap, 0.85 mm/s (2 in./ min.)]
- D751 Standard Test Methods for Coated Fabrics
Grab Tensile [76 mm (3 in.) jaw gap, 5 mm/s (12 in./min.)]
Thickness [dial caliper]
- D1204 Standard Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperatures [6 h at 80 C (176 F)]
- D2136 Standard Specification for Coated Fabrics - Low Temperature Bend Test [after 4 h at -40 C (-40 F)]
- D3045 Standard Practice for Heat Aging of Plastics Without Load [56 days at 80 C (176 F)]
- G53 Standard Practice for Operating Light and Water-Exposure Apparatus (Fluorescent UV Condensation Type) for Exposure of Nonmetallic Materials

3.2 Other test methods

We used the following non-ASTM test methods:

3.2.1 Sheet mass

We die cut specimen squares 45 mm (1.78 in.) on a side with a razor knife, and weighed each square using an analytical balance. Ten times the average mass in grams equals the mass in pounds per 100 square feet. Multiply the mass in pounds per 100 square feet by 48.82 to convert to grams per square metre.

3.2.2 Fabric mass

We extracted the polymer compound from the specimens in 3.2.1 with a micro extractor using THF (tetra-hydrofurane or tetra methylene oxide) as the solvent, and dried and weighed the reinforcing fabric recovered. We did not report the mass when the polymer extraction was incomplete.

3.2.3 Optical thickness

We photographed five vertical sections of each sample in the machine direction (the length) and the cross machine direction (the width) using a 1.6 X objective lens and a 1.6 X zoom setting on the microscope. We made the four measurements shown in Figure 1 in each photograph.

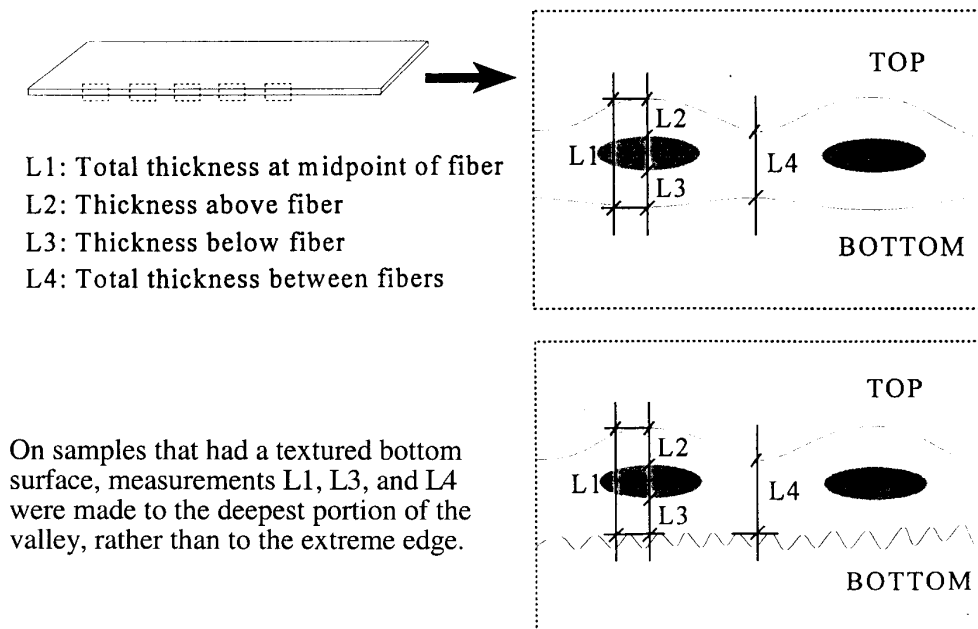


Fig. 1: Location of optical thickness measurements

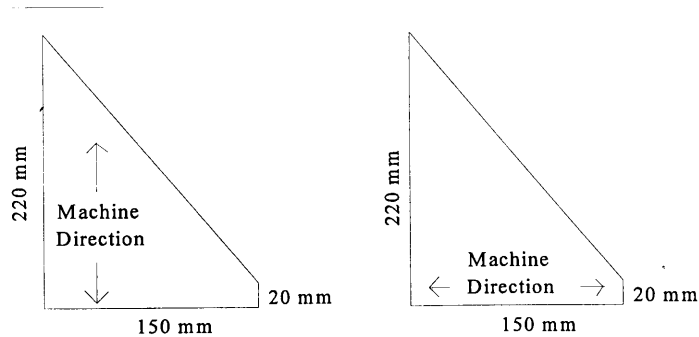


Fig. 2: Wicking test trapezoids

3.2.4 Wicking test

We cut the trapezoids shown in Figure 2 from each sample, and hung the lowest 20 mm in a water - methylene blue bath for 24 hours. We sectioned each specimen to measure the height of the wicking observed

3.2.5 Seam strength

We tested the strength of laboratory prepared heat welded 100 mm (4 in.) wide seams using the grab tensile test. We recorded that the seam strength was greater than the tensile strength if the sheet failed outside the lap area.

4 Results and discussion

These test data and our observations on samples placed in a ultraviolet condensing relative humidity apparatus are the basis for the following discussion and our conclusions.

4.1 Comparing test data to standards

Table 1 lists our test data on PVC membranes and the requirements of ASTM D4434. Table 2 lists our test data on membranes based on “other” polymers and the proposed ASTM requirements for TPO membranes. It is very difficult to select the “best” membrane from these data because different grades of the same product have different test requirements that are not comparable, most notably in the area of tensile properties.

4.2 Rating data

Table 3 lists all the data for samples 1 through 13. We rated these data by setting the maximum value obtained in each test to a rating 100, calculating the rating for each of the other products on a proportional basis. Where the “best” physical test result is zero, we set the rating at 100 for the test value zero and a rating of 100 for the maximum value obtained. These ratings are shown in Table 4. The ratings for each sample are averaged to measure the relative over-all rating of each product. In this series of tests the products average rating ranged from a high of 82 points to a low of 52 points.

4.3 Accelerated weathering

To the date of writing this paper, we have logged 3,000 hours in our ultra-violet condensing humidity equipment. To date, we have not noted any major change in these samples. We have noticed that some samples are changing color with a pink tinge. We have not observed this coloration in the field.

5 Conclusions

Of the three methods checked, comparing laboratory data with the requirements of ASTM standards does not permit the selection of the “best” membrane for use. Membranes represented by Samples 4, 11, 12, and 13, might be eliminated because of the loss of ~ 15% in elongation after heat aging, but this eliminates only one third of your candidates. This study shows that a core group of test requirements for all of the products serving the same use would enable the consumer to compare products offered for sale. Current ASTM standards do not permit this evaluation because they often use tests that cannot be compared, such as grab and strip tensile tests.

Rating these laboratory data and averaging these data provides an unbiased ranking, and a more rational approach to selection. Six of the PVC products rated highest of the 13 products tested.

Accelerated weather testing has little utility because it does not produce results fast enough to be practical (if useful results can be generated), does not take into account potential differences in failure mechanism (accelerated testing can influence one failure mechanism more than another), and the results achieved to date (such as the pinkish color seen in some samples) are not consistent with what we observed in the field.

The only rational system for selecting a roofing system is its past performance on the roof, in the same climate as the new project. If you must select a membrane system without the support of a history of excellent performance, an unbiased rating system may be of aid.

Table 1: Test data on PVC sheets and ASTM D4434 requirements

Sample number:	1	ASTM	2	3	4	5	ASTM	6	7	8	ASTM
ASTM type/grade:	II/1	II/1	III	III	III	III	III	IV	IV	IV	IV
<u>Physical</u>											
Caliper, mm	1.22	=/>1.14	1.30	1.24	1.17	1.22	=/>1.14	0.99	0.94	1.09	=/>0.91
(in.)	(0.048)	(=/>0.045)	(0.051)	(0.049)	(0.046)	(0.048)	(=/>0.045)	(0.039)	(0.037)	(0.043)	(=/>0.039)
Linear dimensional change											
% machine direction	0	=/<0.1	-0.15	-0.15	-0.2	-0.2	=/<0.5	-0.35	-0.15	-0.15	=/<0.5
% cross machine direction	-0.05	=/<0.1	-0.05	-0.05	-0.05	-0.05	=/<0.5	-0.05	-0.05	-0.1	=/<0.5
Water absorption, %	3.62	<+/-3	3.38	4.57	4.05	4.72	<+/-3	6.37	5.58	13.46	<+/-3
Cold Bend @ -40	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile strength, grab method											
machine direction, kN	10791*	10343*	1.24	1.43	1.50	1.91	=/>0.89	1.66	1.99	1.61	=/>1.00
(lbf)	(1565)'	(1500)'	(279)	(321)	(337)	(429)	(=/> 200)	(372)	(447)	(363)	(=/> 275)
cross machine direction, N	10673*	10343*	1.30	1.37	1.31	1.56	=/>0.89	1.67	1.82	1.31	=/>1.00
(lbf)	(1548)'	(1500)'	(291)	(309)	(295)	(350)	(=/> 200)	(375)	(408)	(294)	(=/> 275)
Elongation at sheet breaking, %											
machine direction	310	=/>250	-	-	-	-	-	-	-	-	-
across machine direction	304	=/>220	-	-	-	-	-	-	-	-	-
Elongation at fiber breaking, %											

machine direction	-	-	34	43	33	38	=/>15	44	35	32	=/>25
across machine direction	-	-	44	39	39	34	=/>15	36	38	35	=/>25
Seam strength, % of tensile	>100	=/>75	>100	>100	>100	>100	=/>75	>100	>100	>100	=/>75
Effect of heat conditioning, 80° C (176°F) for six weeks											
Low temperature bend	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile strength, % of original											
machine direction	112	=/>90	112	102	87	98	=/>90	93	106	99	=/>90
across machine direction	99	=/>90	99	99	98	107	=/>90	97	93	96	=/>90
Elongation, % of original or fiber breaking											
machine direction		=/>90	99	103	85	112	=/>90	91	109	109	=/>90
across machine direction		=/>90	100	99	103	116	=/>90	104	103	98	=/>90
Elongation, % of original or sheet breaking											
machine direction	108	=/>90	85	88	83	139	=/>90	105	98	113	=/>90
cross machine direction	113	=/>90	97	100	94	123	=/>90	101	118	128	=/>90

Legend: * value is in kPa - ' value is (psi)

Effect of heat conditioning, 80° C (176°F) for six weeks

Low temperature bend	pass	pass	pass	pass	pass	pass
Tensile strength, % of original						
machine direction	96	103	130	123	87.0	=/>100
across machine direction	107	105	98	153	86.0	=/>100
Elongation, % of fiber breaking						
machine direction	101	116	88	64	82	=/>100
across machine direction	96	121	90	80	109	=/>100
Elongation, % of sheet breaking						
machine direction	105	82	96	101	40	=/>100
across machine direction	109	105	94	85	82	=/>100

Table 3: Test data on all samples

Sample Number:	1	2	3	4	6	9	8	7	11	5	10	13	12
Principal Polymer:	PVC	PVC	PVC	PVC	PVC	ABC	PVC	PVC	TPO	PVC	PVC/ EVA	TPO	EP
<u>Physical Test</u>													
Caliper, mm	1.22	1.30	1.24	1.17	0.99	1.17	1.09	0.94	1.09	1.22	0.86	1.14	1.09
(in.)	(0.048)	(0.051)	(0.049)	(0.046)	(0.039)	(0.046)	(0.043)	(0.037)	(0.043)	(0.048)	(0.034)	(0.045)	(0.043)
Compound thickness, optical													
Above reinforcing, mm	nt	0.554	0.512	0.410	0.436	0.476	0.485	0.312	0.457	0.439	0.317	0.418	0.347
(in.)	nt	(0.022)	(0.020)	(0.016)	(0.017)	(0.019)	(0.019)	(0.012)	(0.018)	(0.017)	(0.012)	(0.016)	(0.014)
Below reinforcing, mm	nt	0.425	0.381	0.490	0.250	0.406	0.481	0.199	0.427	0.359	0.302	0.471	0.383
(in.)	nt	(0.017)	(0.015)	(0.019)	(0.010)	(0.016)	(0.019)	(0.008)	(0.017)	(0.014)	(0.012)	(0.019)	(0.015)
Without reinforcing, mm	nt	1.249	1.128	1.010	0.860	1.170	1.086	0.717	1.096	1.094	0.850	1.170	0.789
(in.)	nt	(0.049)	(0.044)	(0.040)	(0.034)	(0.046)	(0.043)	(0.028)	(0.043)	(0.043)	(0.033)	(0.046)	(0.031)
Sheet thickness, optical mm	1.206	1.249	1.251	1.146	0.987	1.187	1.115	0.808	1.118	1.109	0.879	1.185	0.960
(in.)	(0.047)	(0.049)	(0.049)	(0.045)	(0.039)	(0.047)	(0.044)	(0.032)	(0.044)	(0.044)	(0.035)	(0.047)	(0.038)
Linear dimensional change													
% machine direction	0	-0.15	-0.15	-0.2	-0.35	-0.1	-0.15	-0.15	-0.49	-0.2	-0.2	-0.55	-0.3
% cross machine direction	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.1	-0.05	-0.1	-0.05	0	+0.5	0
Water absorption, %	3.62	3.38	4.57	4.05	6.37	14.4	13.46	5.58	4.09	4.72	16.14	10.37	6.47
Analysis - THF extraction													

Mass, kg/m²	1.52	1.55	1.46	1.40	1.21	1.54	1.45	1.06	1.01	1.55	1.07	1.09		0.98
(lb/100 ft²)	(31.2)	(31.8)	(30)	(28.6)	(24.8)	(31.6)	(29.6)	(21.7)	(20.6)	(31.8)	(21.9)	(22.4)	(20.1)	
Fabric, kg/m²	0.06	0.07	0.09	0.09	0.12	nt	0.09	0.16	na	0.13	nt	nt	nt	
(lb/100 ft²)	(1.14)	(1.42)	(1.83)	(1.86)	(2.36)	nt	(1.93)	(3.19)	na	(2.62)	nt	nt	nt	
Cold bend @ -40°C (or F)	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	
Tensile strength, grab method														
machine direction, N	nt	1241	1426	1500	1656	2477	1614	1986	1136	1919	2252	1213	1205	
(lb)	nt	(279)	(321)	(337)	(372)	(557)	(363)	(447)	(255)	(429)	(506)	(273)	(271)	
cross machine direction, N	nt	1295	1374	1313	1668	1432	1305	1816	1559	1557	2260	999	903	
(lb)	nt	(291)	(309)	(295)	(375)	(322)	(294)	(408)	(350)	(350)	(508)	(224)	(203)	
Elongation at sheet breaking, %														
machine direction	nt	136	134	141	127	84	110	119	152	90	80	321	149	
across machine direction	nt	111	153	159	89	78	101	75	192	75	94	984	278	

Legend: nt = not tested because solvent extraction was incomplete, or test was not appropriate.

Table 3 (continued): Test data on all samples

Sample Number:	1	2	3	4	6	9	8	7	11	5	10	13	12
Principal Polymer:	PVC	PVC	PVC	PVC	PVC	ABC	PVC	PVC	TPO	PVC	PVC/ EVA	TPO	EP
<u>Physical Test</u>													
Elongation at fiber breaking, %													
machine direction		35	42	39	44	30	33	35	41	34	22	32	56
across machine direction		44	39	38	36	37	34	38	40	30	29	38	62
Tensile strength, strip method													
machine direction, kN/m	12	27	24	23	28	64	36	42	21	40	55	14	14
(lb/in. width)	(71)	(157)	(137)	(134)	(162)	(368)	(208)	(238)	(121)	(226)	(313)	(79)	(80)
cross machine direction, kN/m	12	22	24	26	36	30	28	28	24	30	49	8	12
(lb/in. width)	(70)	(126)	(138)	(146)	(204)	(173)	(156)	(159)	(138)	(172)	(281)	(43)	(69)
Elongation at break, %													
machine direction	310	31	30	27	29	28	32	29	24	34	26	19	26
cross machine direction	304	37	32	36	32	33	35	30	31	28	30	12	29
Die wicking													
machine direction, mm	0	0	130	0	0	85	0	18	0	57	45	0	85
(in.)	0	0	(5.12)	0	0	(3.35)	0	(0.71)	0	(2.24)	(1.77)	0	(3.35)

cross machine direction, mm	0	0	63	0	0	91	0	21	0	68	75	0	88
(in.)	0	0	(2.48)	0	0	(3.58)	0	(0.83)	0	(2.68)	(2.97)	0	(3.46)
Seam strength, % of tensile	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Effect of heat conditioning, 80° C (176° F) for six weeks													
Low temperature bend	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile strength, % of original													
machine direction	112	112	102	87	93	96	99	106	130	98	103	87.0	123
across machine direction	99	99	99	98	97	107	96	93	98	107	105	86.0	153
Elongation, % of original or fiber breaking													
machine direction		99	103	85	91	101	109	109	88	112	116	82	64
across machine direction		100	99	103	104	96	98	103	90	116	121	109	80
Elongation, % of original or sheet breaking													
machine direction	108	85	88	83	105	105	113	98	96	139	82	40	101
across machine direction	113	97	100	94	101	109	128	118	94	123	105	82	85

Legend: nt = not tested because solvent extraction was incomplete

Table 4: Test data ranked for all samples

Sample Number:	1	2	3	4	6	9	8	7	11	5	10	13	12
Principal Polymer:	PVC	PVC	PVC	PVC	PVC	ABC	PVC	PVC	TPO	PVC	PVC/EVA	TPO	EP
<u>Physical Test</u>													
Caliper	94	100	90	76	96	90	84	73	84	94	67	88	84
Thickness above reinforcing	nt	100	74	79	92	86	88	56	83	79	57	76	63
Thickness below reinforcing	nt	87	100	51	78	83	98	41	87	73	62	96	78
Thickness between reinforcing	nt	100	81	69	90	94	87	57	88	88	68	94	63
Optical sheet thickness	96	100	92	79	100	95	89	65	89	89	70	95	77
Thermal stability, length	100	73	64	36	73	82	73	73	11	64	64	0	45
Thermal stability, width	90	90	90	90	90	90	80	90	80	90	100	0	100
Water absorption	78	79	75	61	72	11	17	65	75	71	0	36	60
Total mass	98	100	90	78	94	99	93	68	65	100	69	70	63
Fabric mass	36	45	58	74	57	nt	61	100	nt	82	nt	nt	nt
Cold bend @ -40	100	100	100	100	100	100	100	100	100	100	100	100	100
Grab tensile strength. md	nt	50	61	67	58	100	65	80	46	77	91	49	49
Grab tensile strength. xmd	nt	57	58	74	61	63	58	80	69	69	100	44	40
Elongation at sheet breaking, md	nt	42	44	40	42	26	34	37	47	28	25	100	46
Elongation at sheet breaking, xmd	nt	11	16	9	16	8	10	8	20	8	10	100	28
Elongation at fiber breaking, md	nt	63	70	79	75	54	59	63	73	61	39	57	100

Elongation at fiber breaking, xmd	nt	71	61	58	63	60	55	61	65	48	47	61	100
Tensile strength, strip method, md	19	43	36	44	37	100	56	65	33	61	85	21	22
Tensile strength, strip method, xmd	25	45	52	73	49	62	56	57	49	61	100	15	24
Elongation at maximum stress, md	100	10	9	9	10	9	10	9	8	11	8	6	8
Elongation at maximum stress, xmd	100	12	12	11	11	11	12	10	10	9	10	4	10
Die wicking, md	100	100	100	100	0	35	100	86	100	56	65	100	35
Die wicking, xmd	100	100	100	100	31	0	100	77	100	25	18	100	3
Seam strength	100	100	100	100	100	100	100	100	100	100	100	100	100
+Heat, low temperature bend	100	100	100	100	100	100	100	100	100	100	100	100	100
+Heat, tensile strength, md	60	60	57	77	93	87	97	80	0	93	90	57	23
+Heat tensile strength, xmd	98	98	96	94	98	87	92	87	96	87	91	74	0
+Heat elongation @ fiber breaking, md	nt	97	58	75	92	97	75	75	67	67	56	50	0
+Heat elongation @ fiber breaking, xmd	nt	100	86	81	95	81	90	86	52	24	0	57	5
+Heat elongation @ sheet break, md	87	75	72	92	80	92	78	97	93	35	70	0	98
+Heat elongation @ sheet break, xmd	55	89	79	96	100	68	0	36	79	18	82	36	46
Average, all ratings	82	74	70	70	69	69	68	67	66	63	61	60	52

Legend: nt = not tested (does not apply); md = machine direction; xmd = cross machine direction.