Comparative Testing And Rating Of Thirteen Thermoplastic Single Ply Roofing Membranes

By C. G. Cash

ABSTRACT

We tested samples of polyvinyl 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. The test specimens were all cut from commercial product purchased in the field and were tested using the same procedures.

The results from each test were ranked for performance from the product with the most advantageous property (equaling 100%) to the test result on the least advantaged product. The average of the test percentage ratings on each product was then ranked from the product with the highest rating to the product with the lowest rating.

This procedure was used previously to develop data for the preparation of ASTM consensus Standard D-6221, "Standard Specification for Reinforced Bituminous Flashing Sheets for Roofing and Waterproofing."

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 30 PVC single-ply roofing membranes and 14 manufacturers offer 44 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 a 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.

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/I	II/I	III	III	III	III	III	IV	IV	IV	IV
PHYSICAL TEST											
Caliper, mm	1.22	=/>1.14	1.30	1.24	1.17	1.22	=/>1.14	0.99	0.94	1.09	=/>0.91
Caliper, in.	.048	=/>.045	.051	.049	.046	.048	=/>.045	.039	.037	.043	=/>.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 blend @ -40	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile strength, grab method											
Machine direction, kN (lbf)	10791* (1565)‡	10343* (1500)‡	1.24 (279)	1.43 (321)	1.50 (337)	1.91 (429)	=/>0.89 (=/>200)	1.66 (372)	1.99 (447)	1.61 (363)	=/>1.00 (=/>275)
Cross machine direction, N (lbf)	10673* (1548)‡	10343* (1500)‡	1.30 (291)	1.37 (309)	1.31 (295)	1.56 (350)	=/>0.89 (-/>200)	1.67 (375)	1.82 (408)	1.31 (294)	=/>1.00 (=/>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 6 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
Across machine direction	113	=/>90	97	100	94	123	=/>90	101	118	128	=/>90

Legend: *value is in kPa ‡value is (psi)

In this paper, we examine each of these three selection methods 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.

SAMPLE SELECTION

We cut all of our test specimens from the inner convolutions of commercial products purchased on the open market. Specimens were tested 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 13 different products for testing, and only two of these were from the same manufacturer. Membranes were obtained 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 (polyvinyl 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 metrification room of our laboratory. This room maintains a constant 50% relative humidity and a temperature of 23° C (73° F).

TEST METHODS

All the test methods required by ASTM D4434, except the puncture resistance tests, were used. 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.

ASTM test methods

The following ASTM test methods were used in this study:

- D-570—Standard Test for Water Absorption of Plastics
- D-638—Standard Test Method for the Tensile Properties of Plastics [using D412 die C - 64 mm (2-1/2 in.) jaw gap, 0.85 mm/s (2 in./ min.)]
- D-751—Standard Test Methods for Coated Fabrics

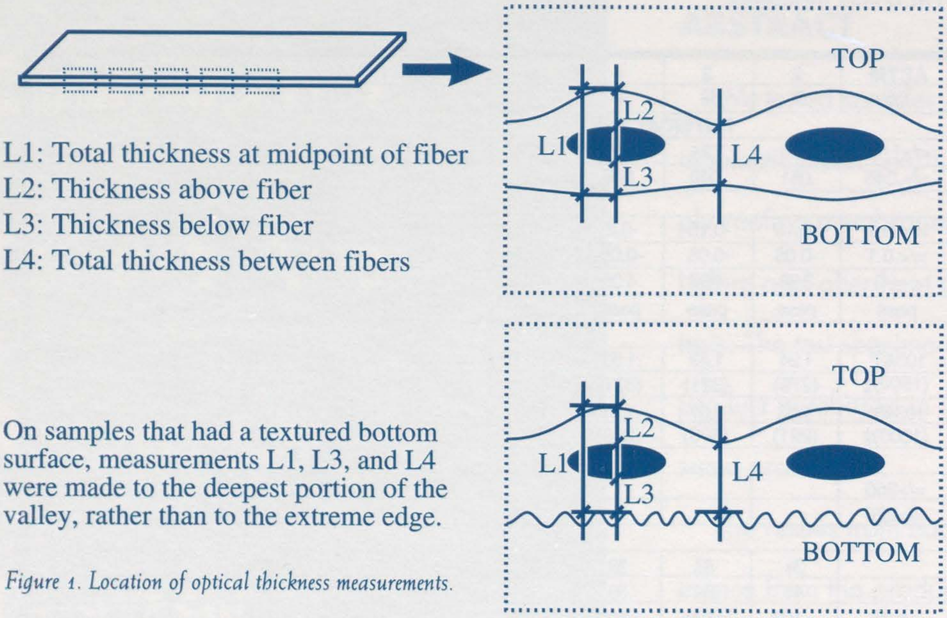

Figure 1. Location of optical thickness measurements.

Grab Tensile [76 mm (3 in.) jaw gap, 5 mm/s (12 in./min.)]
Thickness [dial caliper]

- D-1204—Standard Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperatures [6 h at 80°C (176°F)]
- D-2136—Standard Specification for Coated Fabrics - Low Temperature Bend Test [after 4 h at -40°C (-40°F)]
- D-3045—Standard Practice for Heat Aging of Plastics Without Load [56 days at 80°C (176°F)
- G-53—Standard Practice for Operating Light and Water-Exposure Apparatus (Fluorescent UV Condensation Type) for Exposure of Nonmetallic Materials

OTHER TEST METHODS

We used the following non-ASTM test methods:

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 meter.

Fabric mass

We extracted the polymer compound from the specimens in the sheet mass test with a micro extractor using THF (tetra-hydrofuran or tetramethylene oxide) as the solvent and dried and weighed the reinforcing fabric recovered. The mass was not reported until the polymer extraction was complete.

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.

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.

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

Table 2: Test data on "other" sheets and proposed TPO specification

Sample Number	9	10	11	12	13	ASTM
Principal Polymer	ABC	PVC/EVA	TPO	EP	TPO	TPO
PHYSICAL TEST						
Caliper, mm	1.17	0.86	1.09	1.09	1.14	=/>1.0
Caliper, in.	.046	.034	.043	.043	.045	=/>.039
Linear dimensional change						
% machine direction	-0.1	-0.2	-0.49	-0.3	-0.55	=/<2
% cross machine direction	-0.05	0	-0.1	0	0.5	=/<2
Water absorption, %	14.4	16.14	4.09	6.47	10.37	<+/-4
Cold bend @ -40° C (or F)	pass	pass	pass	pass	pass	pass
Tensile strength, grab method						
Machine direction, N	2477	2252	1136	1205	1213	=/>1001
(lbf)	(557)	(506)	(225)	(271)	(273)	(=/>225)
Cross machine direction, N	1432	2260	1559	903	999	=/>1001
(lbf)	(322)	(508)	(350)	(203)	(224)	(=/>225)
Elongation at fiber breaking, %						
Machine direction	30	22	41	56	32	=/>15
Across machine direction	37	29	40	62	38	=/>15
Seam strength, % of tensile	>100	>100	>100	>100	>100	=/>100
Effect of heat conditioning, 80°C (176°F) for 6 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
PHYSICAL TEST													
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
Caliper, 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
Above reinforcing, 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
Below reinforcing, 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
Without reinforcing, 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
Sheet thickness, 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/m^2	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
Mass, lb./100 ft^2	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/m^2	0.06	0.07	0.09	0.09	0.12	nt	0.09	0.16	na	0.13	nt	nt	nt
Fabric, lb/100 ft^2	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
Machine direction, 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
Cross machine direction, 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
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
Machine dir., lb/in width	71	157	137	134	162	368	208	238	121	226	313	79	80
Cross machine dir., kN/m	12	22	24	26	36	30	28	28	24	30	49	8	12
Cross mach. dir., 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
Machine direction, in.	0	0	5.12	0	0	3.35	0	0.71	0	2.24	1.77	0	3.35
Cross machine dir., mm	0	0	63	0	0	91	0	21	0	68	75	0	88
Cross machine dir., 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, or test was not appropriate greater than the tensile strength if the sheet failed outside the lap area.

RESULTS AND DISCUSSION

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

Comparing test data to standards

Table 1 lists our test data on PVC membranes and the requirements of ASTM D-4434. 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.

Rating data

Table 3 lists all the data for samples 1 through 13. We rated these data by setting the maximum value obtained in

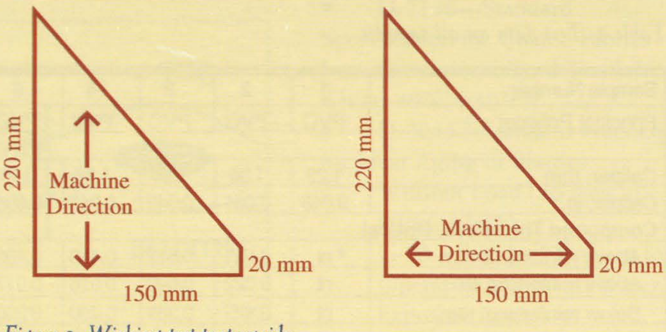

Figure 2. Wicking test trapazoids.

each test to a rating 100, calculating the rating for each of the other products on a proportion 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 overall 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.

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
PHYSICAL TEST													
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 @ 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 max. stress, md	100	10	9	9	10	9	10	9	8	11	8	6	8
Elongation at max. 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 break, md	nt	97	58	75	92	97	75	75	67	67	56	50	0
+Heat elongation @ fiber break, 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

Accelerated weathering

As of the writing of this paper, we had 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, to a pink tinge. We have not observed this coloration in the field.

CONCLUSIONS

Of the three methods checked, comparing laboratory data with the requirements of ASTM standards does not permit one to select the best membrane for a particular use. Readers may wish to eliminate the membranes represented by Samples 4, 11, 12, and 13, because of the loss of approximately 15% in elongation after heat aging, but this eliminates only one third of the candidates. This study shows, however, 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 them 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 (such as the pinkish color seen in some samples) are not consistent with what we observed in the field.

The only rational procedure for selecting a roofing system is its past performance on the roof in the same climate as the new project. When faced with selecting a membrane system without the support of a history of excellent performance, an unbiased rating system may be useful. ■

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