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PROTECTED MEMBRANE ROOFING SYSTEMS

Also Inside:

LIGHTWEIGHT INSULATING CELLULAR CONCRETE

THERMOPLASTIC SINGLE-PLY MEMBRANES

Thermoplastic Single-Ply Roofing Membranes REVISITED

By Carl G. Cash

The October 1999 issue of *Interface* contained a reprint of a paper that was presented at the International Conference on Durability of Building Materials and Components in Vancouver, Canada. This article updates that data by including two more TPO samples, records observation on samples exposed to 10,000 hours in ultraviolet condensing equipment (the former paper included a comment based on only 3,000 exposure hours), and adds the thermal expansion coefficient measured for each of the samples. The code number for each sample has been changed to match its relative rating for these fifteen samples.

The sample procurement and test methods used were reported in the previous report.

Product Rating

The rating table (*Table* 2) has been altered by adding columns containing the 0 to 100 range for the specific test values and the average rating for each test.

These data in the 0 to 100 range column illustrate the group's range of the values in a specific test. For example, for water absorption in *Table* 2, the 0 to 100 range for the individual values is 16.14 to 3.38% water absorbed based on the dry weight of the membrane. Therefore, the sample with the 16.14% water absorption received a "0" rating, and the sample with a 3.38% water absorption received a "100" rating.

Data in the "average rating" column of *Table* 2 enable comparison of the performance of a specific sample in a test with the average performance of the group of 15 samples. Again, using water absorption as an example, Sample 6 has a 21 rating compared with an average rating of 71 for the group. This suggests that the manufacturer of Sample 5 should work to reduce the water absorption of the product. The 71 rating also suggests a skew of the data; data in a normal distribution would have a mean rating of 50.

UV-Condensing Humidity Exposure

Table 3 reports observations on 10,000 hours of ultraviolet condensing humidity exposure in 1,000-hour increments for the original thirteen membranes. ASTM Standard Test Method G-53 was used. The changes in all of the samples were modest after 10,000 hours of exposure, and the changes observed were not included in our rating because they are so difficult to quantify. All of the samples tested showed some yellowing except Samples 1 and 2. Samples 1, 2, 3, and 13 showed some loss of surface gloss, and there was some increase in stiffness in Samples 1, 2, 3, 4, 7, 8, 9, and 11. Samples 3, 8, and 11 showed some membrane shrinkage.

Sample Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Principal Polymer	PVC	PVC	PVC	PVC	PVC	PVC	TPO	PVC	PVC	PVC	TPO	PVC	TPO	TPO	TPO
ASTM Type, Grade	II/1	III	III	III	IV	IV	2/SR	III	III	IV	2/SR	IV	2/SR	2/SR	2/SR
Caliper															
mm	1.219	1.295	1.168	1.245	0.991	1.092	1.092	1.168	1.219	0.94	1.219	0.864	1.295	1.143	1.092
inches	0.048	0.051	0.046	0.049	0.039	0.043	0.043	0.046	0.048	0.037	0.048	0.034	0.051	0.045	0.043
Sheet Thickness, Optical															
mm	1.206	1.243	1.146	1.251	0.987	1.115	1.118	1.19	1.109	0.701	1.18	0.879	1.111	1.185	0.963
inches	0.048	0.049	0.045	0.049	0.039	0.043	0.044	0.047	0.044	0.032	0.046	0.035	0.044	0.047	0.038
Compound above reinforcing															
mm	dna	0.554	0.41	0.512	0.436	0.485	0.457	0.476	0.438	0.313	0.583	0.317	0.517	0.418	0.347
inches	dna	0.022	0.016	0.02	0.017	0.019	0.018	0.019	0.017	0.012	0.023	0.012	0.02	0.016	0.014
Compound below reinforcing															
mm	dna	0.425	0.49	0.38	0.25	0.483	0.427	0.406	0.359	0.199	0.346	0.302	0.372	0.471	0.383
inches	dna	0.017	0.019	0.015	0.01	0.018	0.017	0.016	0.014	0.008	0.014	0.012	0.015	0.019	0.015
Compound between reinforcing															
mm	dna	1.249	1.146	1.128	0.86	1.086	1.068	1.17	1.028	0.717	1.098	0.85	1.072	1.17	0.789
inches	dna	0.049	0.04	0.044	0.034	0.043	0.043	0.046	0.04	0.028	0.043	0.033	0.042	0.046	0.031
Linear Dimensional Change															
% machine direction	0	-0.15	-0.2	-0.15	-0.35	-0.15	-0.49	-0.1	-0.2	-0.15	-0.57	-0.2	-0.3	-0.55	-0.3
% cross machine direction	-0.05	0.05	-0.05	-0.05	-0.05	0.1	-0.1	-0.05	0.05	-0.05	-0.1	0	0	0.05	0
Percent Water Absorption	3.62	3.38	4.05	4.57	6.37	13.46	4.09	14.4	4.72	5.58	3.86	16.14	4.45	10.37	6.47
Analysis - TFH Extraction															
Mass, kg/m2	1.523	1.552	1.396	1.465	1.211	1.445	1.006	1.543	1.552	1.059	1.24	1.069	1.279	1.094	0.981
Mass, lb/100 ft2	31.2	31.8	28.6	30	24.8	29.6	20.6	31.6	31.8	21.7	25.4	21.9	26.2	22.4	20.1
Fabric or Reinforcement															
Mass, g/m2	55.56	69.32	90.81	89.34	115.22	94.22	na	na	127.91	155.74	na	na	na	na	na
Mass, lb/100 ft2	1.14	1.42	1.86	1.83	2.36	1.93	na	na	2.62	3.19	na	na	na	na	na
Cold Bend @ -40oC or F	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile Strength, Grab Method															
Machine Direction, kN	dna	1.397	1.299	1.459	1.535	1.597	1.477	2.366	1.868	2.108	1.116	2.313	1.312	1.059	1.481
pounds	dna	314	292	328	345	359	332	532	420	474	251	520	295	238	333
Cross Machine Direction, kN	dna	1.281	1.29	1.361	1.61	1.25	1.521	1.535	1.664	1.695	1.272	2.384	1.277	0.854	1.388
pounds	dna	288	290	306	362	281	342	345	374	381	286	536	287	192	312
Elongation @ Fiber Breaking, %															
Machine Direction	dna	34	33	43	44	36	36	30	38	35	31	25	26	26	36
Cross Machine Direction	dna	44	39	39	36	33	36	36	34	38	40	35	28	41	50
Elongation @ Sheet Breaking, %															
Machine Direction	dna	116	117	117	133	124	146	89	125	117	71	80	164	128	151
Cross Machine Direction	dna	107	150	153	90	130	180	86	92	89	135	94	154	803	235
Tensile Strength, Strip Method															
Machine Direction, kN	0.316	0.694	0.596	0.609	0.721	0.916	0.538	1.637	1.005	1.059	0.391	1.392	0.387	0.347	0.356
pounds	71	156	134	137	162	206	121	368	226	238	88	313	87	78	80
Cross Machine Direction, kN	0.311	0.56	0.649	0.614	0.907	0.703	0.614	0.77	0.765	0.707	0.436	1.25	0.391	0.191	0.302
pounds	70	126	146	138	204	158	138	173	172	159	98	281	88	43	68
Elongation @ Fiber Breaking, %															
Machine Direction	5	31	27	30	29	32	24	28	34	29	47	26	23	19	26
Cross Machine Direction	4	37	36	32	32	35	31	33	28	30	34	30	24	12	29
Elongation @ Sheet Breaking, %															
Machine Direction	310	44	75	83	60	125	323	28	60	55	262	26	233	245	265
Cross Machine Direction	304	112	158	113	32	188	383	33	75	41	446	30	260	554	499
Dye Wicking															
Machine Direction, mm	0	0	0	130	0	0	0	85	57	18	0	45	0	0	85
inches	0	0	0	5.12	0	0	0	3.35	2.24	0.71	0	1.77	0	0	3.35
Cross Machine Direction, mm	0	0	0	63	0	0	0	91	68	21	0	75	0	0	88
inches	0	0	0	2.48	0	0	0	3.58	2.68	0.83	0	2.95	0	0	3.46
Estimated Expansion Coefficient X 10-6															
Machine Direction/oC	16.7	8.9**	13.3	22.8		21.1	22.2	24.4	41.1	11.1	20	5.6	24.4	17.8	26.7
/oF	30	16**	24	41		38	40	44**	74	20	36	10	44	32	48
Cross Machine Direction/oC	11.7	24.4	8.9	15.6		21.7	21.7	27.2	17.2	26.1	14.4	11.7	21.7	19.4	17.2
/oF	21	44	16	28		39	39	49	31	47	26	21	39	35	31
Seam Strength, % tensile	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Effect of Heat Aging, 800C (176oF) for six weeks															
Low Temperature Bend @ -40oC & F	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Tensile Strength, % of Original															
Machine Direction	112*	89	115	98	108	101	77	105	102	94	123	97	79	115	81
Cross Machine Direction	99*	101	102	101	103	105	102	93	94	107	104	95	76	117	65
Elongation, % Original Fiber Breaking															
Machine Direction	dna	101	118	97	110	91	114	99	90	92	111	86	86	121	157
Cross Machine Direction	dna	100	97	101	96	102	111	104	87	97	87	83	84	92	124
Elongation, % Original Sheet Breaking															
Machine Direction	108*	85	83	88	105	113	96	105	139	98	395	82	72	40	101
Cross Machine Direction	113*	97	94	100	101	128	94	109	123	118	135	105	57	82	85

Legend: * = based on tensile on strips; na = extraction incomeplete; ** = slope of chord to 90oF; dna = does not apply.

Table 1: Test Data on All Samples

Sample Code Principal Polymer ASTM Type, Grade	0 to 100 Rating Range	1 PVC II/1	2 PVC III	3 PVC III	4 PVC III	5 PVC IV	6 PVC IV	7 TPO 2/SR	8 PVC III	9 PVC III	10 PVC IV	11 TPO 2/SR	12 PVC IV	13 TPO 2/SR	14 TPO 2/SR	15 TPO 2/SR	Average Rating
Caliper, mm	0.864-1.295	82	100	71	88	30	53	53	71	82	18	82	0	100	65	53	**63**
Sheet Thickness, Optical																	
Compound above reinforcing, mm	0.313-0.583	dna	89	36	74	46	64	53	60	46	0	100	1	76	39	13	**50**
Compound below reinforcing, mm	0.199-0.490	dna	78	100	62	18	98	78	71	55	0	50	35	59	93	63	**61**
Compound between reinforcing, mm	0.717-1.249	dna	100	81	77	27	69	66	85	58	0	72	25	67	85	14	**59**
Linear Dimensional Change																	
machine direction, %	0.57-0	100	74	65	74	39	74	14	82	65	74	0	65	47	4	47	**55**
cross machine direction, %	0.1-0	50	50	50	50	50	0	0	50	50	50	0	100	100	50	100	**50**
Percent Water Absorption	16.14-3.38	98	100	95	91	77	21	94	14	89	83	96	0	92	45	76	**71**
Analysis - Sheet Mass, kg/m2	0.981-1.552	95	100	73	85	40	81	4	98	100	14	45	15	52	20	0	**55**
Fabric or Reinforcing, g/m2	55.65-155.74	0	14	35	34	60	39			72	100						**44**
Cold Bend @ -40oC or F	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Tensile Strength, Grab Method																	
Machine Direction, kN	1.059-2.366	dna	26	18	31	36	41	32	100	62	80	4	96	19	0	32	**41**
Cross Machine Direction, kN	0.854-2.384	dna	28	28	33	49	26	44	45	53	55	27	100	28	0	35	**39**
Elongation @ Fiber Breaking, %																	
Machine Direction	25-44	dna	47	42	95	100	58	58	26	68	53	32	0	5	5	58	**46**
Cross Machine Direction	28-50	dna	73	50	50	36	23	36	36	27	45	55	32	0	59	100	**44**
Elongation @ Sheet Breaking, %																	
Machine Direction	71-164	dna	48	49	49	67	57	81	19	58	49	0	10	100	61	86	**52**
Cross Machine Direction	86-803	dna	3	9	9	1	6	13	0	1	0	7	1	9	100	21	**13**
Tensile Strength, Strip Method																	
Machine Direction	0.316-1.637	0	29	21	22	31	45	17	100	52	56	6	81	5	2	3	**31**
Cross Machine Direction	0.191-1.25	11	35	43	40	68	48	40	55	54	49	23	100	19	0	10	**40**
Elongation @ Fiber Breaking, %																	
Machine Direction	5-47	0	62	52	60	57	64	45	55	69	57	100	50	43	33	50	**53**
Cross Machine Direction	4-37	0	100	97	85	85	94	82	88	73	79	91	79	61	24	76	**74**
Elongation @ Sheet Breaking, %																	
Machine Direction	26-323	96	6	16	19	11	33	100	1	11	10	79	0	70	74	80	**40**
Cross Machine Direction	30-554	52	16	24	16	0	30	67	1	9	2	79	0	44	100	90	**35**
Dye Wicking, mm																	
Machine Direction	130-0	100	100	100	0	100	100	100	35	56	86	100	65	100	100	35	**78**
Cross Machine Direction	91-0	100	100	100	31	100	100	100	0	25	77	100	18	100	100	3	**70**
Expansion Coeficient, x 10-6/oC																	
Machine Direction	41.1-5.6	69	91	78	52	94	56	53	47	0	85	59	100	47	66	41	**63**
Cross Machine Direction	27.2-8.9	85	15	100	63	73	30	30	0	55	6	70	85	30	43	55	**49**
Seam Strength	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Effect of Heat Aging, 800C (176oF) for six weeks																	
Low Temperature Bend	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	**100**
Tensile Strength, % Change																	
Machine Direction	29-1	61	64	50	96	75	100	21	86	96	82	21	93	29	50	36	**64**
Cross Machine Direction	35-1	100	100	97	100	94	88	97	82	85	82	91	88	32	53	0	**79**
Elongation, % Change Original Fiber Breaking																	
Machine Direction	57-1	dna	100	70	96	84	86	77	100	84	88	82	77	77	64	0	**78**
Cross Machine Direction	24-0	dna	100	88	96	83	92	54	83	46	88	46	29	33	67	0	**65**
Elongation, % Change Original Sheet Breaking																	
Machine Direction	60-1	88	76	73	81	93	80	95	93	36	98	0	71	54	0	100	**69**
Cross Machine Direction	43-0	70	93	86	100	98	35	86	79	47	58	19	88	0	58	65	**65**
Average		**68**	**68**	**65**	**64**	**62**	**62**	**60**	**59**	**58**	**57**	**56**	**55**	**54**	**53**	**50**	**59**

Table 2: Test Data Rated for All Samples

Based on these exposure data, it might be possible to conclude that all these materials will give excellent service upon exposure, but it is more probable to conclude that ultraviolet condensing humidity exposure alone does not accurately predict service life of these products, or that the acceleration factor provided is inadequate. The acceleration factor for a test method designed to rapidly test the durability of a product is the time of outdoor exposure divided by the time under test for the product to reach the same condition. For example, if a test has an acceleration factor of 20, then one year under test represents 20 years of service. To date, the acceleration factor for ultraviolet condensing humidity tests of thermoplastic membranes has not been established.

Thermal Expansion Tests

The thermal expansion of each membrane was measured by TDA (thermal differential analyses) for -18 through 66 degrees Centigrade (0 degrees to 150 degree Fahrenheit). In many cases the measured increase in length per degree temperature rise was not constant over the whole range. The slope of the curve often dropped off significantly above 32 degrees Centigrade (90 degrees Fahrenheit). The slope of the secant line from -18 to 32 degrees Centigrade (0 to 90 degrees Fahrenheit) is reported as the thermal expansion coefficient in *Table 1*. It is currently our best estimate of the real value and should be used with caution until additional testing refines or confirms the value. The large observed differences are not consistent with either TPO or PVC

Sample Code:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Polymer:	PVC	PVC	PVC	PVC	PVC	PVC	TPO	PVC	PVC	TPO	PVC	TPO	PVC	TPO	TPO
Exposure										NT		NT			
Hours															
1,000	Gl	Gl	SlYe	Ye	Ye	SlYe	SlYe	Ye	Ye		SlYe		Gl	SlYe	Ye
2,000				Sc		C	SlC						SlYe		
3,000			Gl				C							Sc	
4,000			St						St						
5,000							St				SlSt				SlC
6,000		SlSt		SlSt				SlSt						P	
7,000	SlSt														
8,000			Sh					St	P					B	
9,000								Sh			Sh				
10,000	Sc														

Legend:

B	Brown edges	P	Pinking	Sl	Slight	NT	Not Tested
C	Chalking	Sc	Scrim Pronounced	St	Stiffer		
Gl	Gloss loss	Sh	Shrinkage	Ye	Yellowing		

Table 3: Observations Upon UV-Condensing Humidity Exposure - Changes

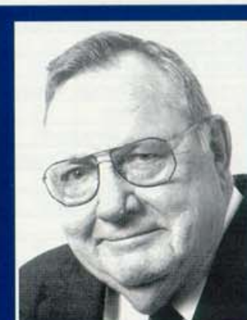
membranes; they may be related to the characteristics of the character and type of reinforcing in each membrane.

Conclusions

Most PVC membrane samples rate significantly higher than their TPO counterparts. For example, the top-rated six samples are all PVCs; four of the six lowest rating samples are TPOs. All of the five TPO samples have an average rating at or below the average rating for this group of fifteen samples. This suggests that the best choice for a durable membrane is PVC when PVC and TPO membranes are considered.

Not all PVC membranes have an equal rating. For example, PVC Samples 8, 9, 11, and 13 have a rating that equals or is less than the average rating. This suggests that their performance in the field may be unequal to the performance by the four membranes with the highest rating (Samples 1 through 4). Performance in the die and water absorption tests appears to be critical. ■

About the Author



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