NRC Publications Archive Archives des publications du CNRC

Enhancement of the standard for PVC roof membrane material with the use of mechanical and chemical analysis

Paroli, R. M.; Dutt, O.; Smith, T. L.; Whelan, B. J.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

ASTM Special Technical Publication, 1224, pp. 116-122, 1994-05

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=67c10d5f-c52d-47f4-bde0-e983bea54c1a>
<https://publications-cnrc.canada.ca/fra/voir/objet/?id=67c10d5f-c52d-47f4-bde0-e983bea54c1a>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research
Council Canada

Conseil national de
recherches Canada

Canada

<http://irc.nrc-cnrc.gc.ca>

Enhancement of the standard for PVC roof membrane material with the use of mechanical and chemical analysis

NRCC-37762

Paroli, R.M. ; Dutt, O. ;

Smith, T.L. ; Whelan, B.J.

A version of this document is published in / Une version de ce document se trouve dans:
Building Envelope Performance and Durability, IRC Technical Seminar, Held in 11 Cities
across Canada, February through March 1995, pp. 116-122

National Research
Council Canada

Conseil national
de recherches Canada

Canada

Enhancement of the Standard for PVC Roof Membrane Material with the use of Mechanical and Chemical Analysis

REFERENCE: Paroli, R. M., Dutt, O., Smith, T. L., and Whelan, B. J., "Enhancement of the Standard for PVC Roof Membrane Material with the Use of Mechanical and Chemical Analysis," Roofing Research and Standards Development: 3rd Volume, ASTM STP 1224, Thomas J. Wallace and Walter J. Rossiter, Jr., Eds., American Society for Testing and Materials, Philadelphia, 1994.

ABSTRACT: Samples of reinforced and unreinforced PVC roofing membranes were studied using dynamic mechanical analysis and tensile testing. Preliminary work has shown that the glass-transition temperature provides an indication of the relative stability of the membranes and may assist in understanding the shattering phenomenon.

This study discusses the utility of using the glass-transition temperature in standards for the reinforced PVC roofing membranes. It is shown that T_g values are easily obtained from dynamic mechanical analysis (DMA) and that DMA should be considered in the standards for roofing membranes.

Based upon the characterization of samples from shattered roofs, as well as reinforced materials subjected to artificial weathering, recommendations for enhancing the ASTM Standard D4434 are presented.

KEY WORDS: PVC, poly(vinyl chloride), unreinforced PVC, shattering, reinforced PVC, glass-transition temperature, T_g , dynamic mechanical analysis, DMA, roofing membranes, thermal analysis, ASTM D 4434.

PVC roofing membranes have been used for many years and, overall, their performance has been reliable. Some problems with PVC membranes (mostly with unreinforced and ballasted) were reported in the United States. Shattering is one problem that can cause significant damage. The National Roofing Contractors Association (NRCA) and the Single Ply Roofing Institute (SPRI) issued a joint document addressing this issue [1]. NRCA and the Institute for Research in Construction (IRC) of the National Research Council of Canada began a cooperative research project in 1991 aimed at understanding the PVC shattering phenomenon. A detailed description of the shattering phenomenon describing causes and

providing recommendations to reduce the occurrence was presented elsewhere [2]. The application of thermal analysis, in particular dynamic mechanical analysis (DMA), in characterizing roofing membranes was outlined. An in-depth description is given in reference 2.

Traditionally, physical properties have been used as descriptors of aging (weathering) and performance of roofing membranes. Unfortunately, these properties yield very little information about the chemical processes which inevitably determine material failures. Substantial research on the performance of roofing membranes (including PVC-based membranes) has been carried out at IRC [3,4]. It focused on the evaluation of chemical and physical behaviour of roofing membranes after heat-aging. This work uses thermal analysis and mechanical testing. Potential for ranking the relative durability of roofing membranes was clearly demonstrated.

Additional considerations for enhancing the standard for PVC roofing sheets, ASTM Standard Specification for Poly(Vinyl Chloride) Sheet Roofing (D4434) are proposed in this paper.

EXPERIMENTAL

Sample Preparation

A typical composition for a generic unreinforced and reinforced PVC membrane is given in Table 1. It is important to note that this composition does not necessarily reflect the composition of unreinforced membranes that have shattered. The quantities given vary with each product.

All PVC membrane samples obtained from shattered roofs were unreinforced. A sample was taken from a seam area wherever possible. The unexposed (bottom portion of an "unbonded flap") as well as the exposed top shattered area [1] was included.

Three commercially available, unexposed, reinforced PVC roofing membranes were obtained and labelled as V1, V2, and V3. Each material was cut into seven pieces of about 150 x 250 mm. One piece was used as a control, three were placed in an air-circulating oven preheated to 100 °C, and the remaining three at 130 °C for heat-aging. One piece of each material was removed from the oven, in turn, after 1, 7, and 28 days, and specimens were cut out for thermal analyses and tensile testing [3].

Dynamic Mechanical Analysis (DMA)

A more detailed description of the procedure is presented elsewhere [3,4]. It is important to note that the DMA characterization was carried out at 1 Hz (6.28 rad/s) for the unreinforced membranes and 10 Hz (62.8 rad/s) for the reinforced membranes. The different frequencies will affect the actual T_g measurement. The higher the frequency, the more positive the glass-transition temperature will be. This, however, does not affect the outcome of the study since there is no attempt to compare the behaviour of unreinforced and reinforced membranes. The glass-transition temperature, T_g , (α -transition values) was obtained from the average of at least two measurements and reported as the maximum in the loss modulus (E'') vs. temperature curve. It is also possible to use the maximum of the $\tan\delta$ peak vs. temperature curve. It was found, however, that the application of the E'' curve maximum gave

¹Institute for Research in Construction, National Research Council of Canada, Montreal Rd., Ottawa, Ont., Canada K1A 0R6

²National Roofing Contractors Association, 10255 W. Higgins Road, Suite 600, Rosemont, IL 60018-5607

³Sarnafil Inc., 100 Dan Road, Canton, Mass. 02021

a better correlation with traditional mechanical data (e.g., tensile and elongation). The glass-transition temperatures of the various samples are summarized in Tables 2 and 3.

Tensile testing

The tensile testing of the unreinforced samples was carried out at room temperature on an Instron 4502. A pneumatic grip set at 586 kPa (85 psi) was used on samples cut into a rectangular shape of 12 mm by 75 mm. A grip distance of 50 mm and an extensometer (gauge length 25.4 mm) were used. The cross-head speed was set at 50 mm/min. The load and elongation curves were recorded on the machine chart recorder as well as stored in the computer. Specimens were tested in two directions, i.e., machine and cross-machine directions. The values of load and elongation-at-break were recorded and are listed in Table 4.

TABLE 1 -- Typical composition of a generic unreinforced and reinforced PVC roofing membrane.

Ingredients	% by Weight (Approx.)	% by Weight (Approx.)	Function
	Unreinforced	Reinforced	
PVC resin	50 - 55	55	Basic material (powder or granular)
Plasticizers	25 - 30	28	Impart flexibility
Fillers	5 - 10	7	Increase dimensional stability and reduce cost
Pigments	0.5 - 1.0	5	Provide color and UV stability to the PVC compound
Processing oils and biocides	0.5 - 1.0	3	Improve processing and resistance to biological attack
Stabilizers	2 - 3	2	Provide resistance to heat and light during manufacture and installation
TOTAL	100	100	

Note: The composition does not necessarily reflect the composition of the shattered membranes.

TABLE 2 -- Glass-transition temperatures of reinforced PVC membranes [3]

Heat-aging Schedule		T _g of Reinforced PVC Samples (°C)			ΔT _g (°C)		
Temp. (°C)	Days	V1	V2	V3	V1	V2	V3
Control	-	-28	-33	-29	0	0	0
100	1	-27	-34	-25	-1	+1	-4
100	7	-26	-34	-27	-2	+1	-2
100	28	-16	-33	-20	-12	0	-9
130	1	-21	-34	-25	-7	+1	-4
130	7	-18	-23	-19	-10	-10	-10
130	28	-5	-25	-14	-23	-8	-15

RESULTS AND DISCUSSION

PVC, in its natural form, is a rigid material with a T_g of +80 °C. To provide flexibility, PVC has to be heavily plasticized. Additionally, PVC is heat-sensitive as well as sensitive to ultraviolet radiation, therefore stabilizers are added to retard the effects of heat and UV-radiation. Heat may affect PVC in two ways: (a) it may affect the plasticizers and (b) may produce a chemical change in the composition of the PVC [5]. This results in increased rigidity or reduced flexibility. This change can be monitored by various parameters including T_g, modulus, elongation, etc. The advantage of using such a technique as DMA to determine T_g is that aside from the glass-transition temperature, Young's modulus (over a wide temperature range) is also obtained. This requires less specimen amount and time than for mechanical analysis.

TABLE 3 -- Glass-transition temperature and physical properties for unreinforced PVC membranes

Sample ID.		T _g (°C)	Shore-A Hardness	Specific Gravity	Plasti- cizer Content (%)	Cold Temperature Flex	
						Pass (°C)	Fail (°C)
88/89	2.1 A -TOP	-25	92	1.2701	27.83	-30	-40
88/89	2.1 A -BOTTOM	-36	82	1.2489	33.61	-40	
91/92	2.A -TOP	-28	95	1.2934	23.61	-20	-30
91/92	2.A -BOTTOM	-35	83	1.2467	30.67	-40	
91/92	3.1 A -TOP	-11	98	1.3416	16.78		-20
91/92	3.1 A -BOTTOM	-37	84	1.2681	30.37	-30	-40

Glass-Transition Temperature (T_g)

The T_g of the heat-aged, reinforced materials shifted to a higher temperature for all samples at 130 °C, Table 2. This was not the case for samples heated at 100 °C where sample V2 was not affected while the V1 and V3 samples had ΔT_g of +12 °C and +9 °C, respective. Overall, V2 was determined to be the most stable reinforced PVC and V1 the least.

The T_g values for the shattered membranes are shown in Table 3. It is interesting to note that the T_g values for the samples labelled "BOTTOM" (i.e., the unbonded flap) are always lower than the corresponding values for the "TOP" (i.e., exposed) samples. The difference varied from as little as 7 °C to as much as 26 °C. It should also be noted that, as could be expected from the T_g results, the plasticizer content was lower in the exposed samples as compared to the unexposed samples. Furthermore, similar results were observed using the Shore-A hardness test.

TABLE 4 -- Tensile strength and elongation values of reinforced PVC membranes at 23 °C [3].

Heat-aging Schedule		Strength (kN m ⁻²)			Elongation (%)		
T (°C)	Days	V1	V2	V3	V1	V2	V3
----Control----		31.1	28.9	29.7	124	65	229
100	1	27.5	28.8	29.1	149	47	153
100	7	31.9	23.4	33.0	124	54	175
100	28	33.6	27.5	33.7	51	47	158
130	1	28.9	24.7	30.7	139	89	201
130	7	35.2	25.2	34.0	47	54	165
130	28	32.6	25.4	29.8	45	22	183

Mechanical Testing of PVC Membranes

In the case of the reinforced membranes (see Table 4) [3], the molecular weight, amount and type of plasticizer, and reinforcement are important factors in the breaking strength and elongation of the membrane. Two types of membranes are available for use in conventional systems: glass-reinforced and polyester-reinforced. Glass-reinforced membranes can be used in ballasted and adhered assemblies, while the polyester-reinforced ones are used in mechanically fastened systems. The use of reinforcement of PVC membranes improves their dimensional stability and eliminates the possibility of shattering as defined by the NRCA/SPRI document [1] (but may not necessarily eliminate cracking or splitting). As expected, the strength increases as the temperature decreases, reflecting, in part, the hardening and loss of elasticity of the matrix. The increase in strength was much more pronounced for V3. The strength of the samples did not appear to be greatly affected by the T_g , but the maximum was found to occur between -40 °C and -50 °C. The PVC matrix of samples tested at temperatures below the T_g had a tendency to crack or split in the area of the break indicating that the material had lost its elasticity. The percent elongation results of the reinforced membranes, except those showing the effect of heat-aging, show a substantial drop between room temperature and -10 °C. This is probably due to a stiffening of the PVC matrix with decreasing temperature.

The tensile data for the unreinforced membranes shown in Table 5 reveals the following information. The bottom layer always had a higher percent elongation and percent strain than the top layer. Also, the bottom layer exhibited a smaller Young's modulus (calculated between 10% and 20% strain). This is indicative of the aging or weathering phenomenon.

Table 5 -- Tensile data for unreinforced PVC membranes

Sample I.D.	Direction	Max. Load (kg)	Modulus (MPa)	Max. Load/Width (kN/m)	Elongation (%)	Strain (%)
88/89 2.1 A -TOP	'A'	28.05	19.59	22.01	403.6	251.2
88/89 2.1 A -TOP	'B'	25.57	19.12	20.07	325.3	204.9
88/89 2.1 A -BOTTOM	'A'	26.35	13.92	20.68	500.4	298.8
88/89 2.1 A -BOTTOM	'B'	25.81	14.31	20.26	482.7	298.5
91/92 2 A -TOP	'A'	21.12	20.46	16.58	242.5	160.1
91/92 2 A -TOP	'B'	22.58	21.00	17.72	333.5	210.6
91/92 2 A -BOTTOM	'A'	23.74	13.38	18.63	446.6	269.7
91/92 2 A -BOTTOM	'B'	25.02	13.90	19.64	454.3	274.1
91/92 3 A -TOP, ah	MD	28.73	19.46	22.55	363.7	185.1
91/92 3 A -BOTTOM, ad	MD	30.66	18.59	24.06	451.5	266.1
91/92 3 A -TOP	MD	34.44	17.19	27.03	323.1	191.2

ASTM D4434

The unreinforced and reinforced PVC membranes were found to be sensitive to warm temperatures and their cold-weather performance to be affected by temperature-induced changes e.g., change in T_g . Thus it is important to include in the standard those parameters that reflect those changes. For example, the most recent draft contains heat-aging and accelerated weathering tests. The T_g of the materials should be tested before and after aging or weathering. The change in T_g (i.e., ΔT_g) should be noted because it does reflect changes in chemical composition, e.g., loss in plasticizer content. Determining the glass-transition temperature by DMA is simple and quick. Other thermoanalytical techniques, such as thermogravimetry (TG), could also be used to monitor changes in chemical composition. TG is a simple and rapid method that reveals important information.

The T_g of roofing membranes (before and after aging) should be a design consideration in cold climates. If PVC is the membrane of choice, only those PVC membranes exhibiting excellent stability should be considered for use in conventional (i.e., exposed) systems in cold climates. The T_g is influenced by the thermal stability of the material and the effect of aging must be evaluated by laboratory testing. Lack of stability also affects shrinkage and may have a direct bearing on the stresses induced in the membrane by cold weather.

It is important to realize that reinforcement of a membrane is not necessarily a solution to all the problems. The formulation, quality and quantity of plasticizer and other raw materials, play important roles in long-term performance of PVC membranes. PVC sample V2 was found to be more stable than V3 and V1. Incorporation of a means of differentiating between the reinforced PVC membranes that provide a longer service life and those that do not should be considered in revisions to the standard.

CONCLUSIONS

Mechanical and chemical methods of analysis should be used to monitor the stability of PVC roof membranes. The chemical techniques should include DMA as a means of measuring the T_g of samples. T_g can

be used to study the effects of aging or weathering on roofing materials. It is noted that in cases where naturally exposed samples are to be tested, the use of an unbonded flap can replace a control sample.

ACKNOWLEDGMENTS

The authors wish to thank P. McMahon, W. Lei, and A. Delgado for their assistance in obtaining the data presented in this paper; and R. Turenne, M. Mech, and H. Stenman for useful discussions. The authors also wish to thank those contractors, building owners and designers who sent in samples or reports of shattered jobs.

REFERENCES

- [1] "Shattering of Aged Unreinforced PVC Roof Membranes," NRCA/SPRI Joint Document, September 1990.
- [2] R. M. Paroli, T. L. Smith, and B. J. Whelan, "Shattering of Unreinforced PVC Roof Membranes: Problem Phenomenon, Causes and Prevention," Proceedings of the 10th Conference on Roofing Technology: "Problems: Issues and Answers", April 22-23, 1993, Gaithersburg, Maryland, pp. 93-107.
- [3] R. M. Paroli, O. Dutt, A. H. Delgado, H. K. Stenman, "Ranking Polyvinyl Chloride (PVC) Roofing Membranes Using Thermal Analysis," Journal of Materials in Civil Engineering, Vol. 10, No. 1, 1993, pp. 83-95.
- [4] R. M. Paroli, O. Dutt, A. H. Delgado, "The Characterization of Roofing Membranes using Thermal Analysis and Mechanical Testing," CIB World Building Congress, Montreal, Canada, May 18-22, 1992.
- [5] W. V. Titow, PVC Technology, 4th edition, Elsevier Applied Science Publishers Ltd., London, UK, 1984, pp. 256-260.