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LIMITATIONS OF PRESENT TEST METHODS FOR ROOFING MATERIALS
by H.O. Laaly and P.J. Sareda

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SOMMAIRE

Le perfectionnement des feuilles de polyester renforcé de fibres de verre et à résistance accrue au vieillissement, a suscité la mise au point de nouveaux essais de vieillissement accéléré qui permettent d'évaluer leur rendement et leur durabilité dans un laps de temps raisonnable. La nouvelle méthode de vieillissement artificiel soumet les matériaux de polyester renforcé de fibres de verre à un cycle de 2 h de radiation à un arc au xénon (deux fois l'intensité employée pour le cycle de radiation de 4 h et de vaporisation de 4 h à l'eau froide utilisé auparavant) et à une vaporisation de 0.67 h à l'eau froide. L'exposition des feuilles de polyester renforcé de fibres de verre ordinaires, des feuilles sans revêtement colloïdal et des feuilles ignifuges a produit une détérioration semblable à celle provoquée par les cycles de 4 h ainsi que par l'exposition à l'extérieur pendant une période de temps beaucoup plus courte. Le rythme d'accélération a été de 2.0 à 3.5 (par rapport aux cycles de 4 h) et de 5 à 30 (par rapport à l'extérieur).

Limitations of Present Test Methods for Roofing Materials

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ABSTRACT: A development study of test methods and criteria for evaluating new roofing materials is described: prefabricated polymeric and elastomeric sheets, prefabricated modified bituminous membranes, and liquid applied membranes. Results are summarized for a number of materials selected as typical of the three groups in order to illustrate the problems and the limitations associated with the different tests.

KEY WORDS: roofing, waterproofing, membranes, performance, durability, rubberized asphalt, poly(vinyl chloride), rubber, liquid elastomers, prefabricated, asphalt, bitumen, building materials

Bituminous built-up roofing (BUR) has been widely used in North America over the past 80 years with varying success. With the inclusion of insulation in flat roofs, however, problems have intensified and this has generated much interest internationally.^{2,3} The failure of traditional BUR and development of a range of plastic materials, including prefabricated ones, has led to the introduction of many new membranes for use on roofs. They range in composition from slight modifications of the original asphalt, also applied in liquid form, to prefabricated sheets of plastic or membranes containing several elements. The rapid introduction of these materials and their great variety have necessitated the establishment of suitable performance criteria to ensure a minimum service life in comparison with the conventional BUR system.

At the request of Central Mortgage and Housing Corporation (CMHC),

¹ Associate research officer and principal research officer, respectively, Division of Building Research, National Research Council of Canada, Ottawa, Ont., Canada.

² International Symposium of Roofs and Roofing, Society of the Chemical Industry/Agreement Board, Brighton, England, Vols. 1 and 2, Sept. 1974.

³ International Symposium on Roofing Technology, National Bureau of Standards/National Roofing Contractors Association, Gaithersburg, Md., Sept. 1977.

the Division of Building Research of the National Research Council of Canada has undertaken the task of establishing methods of evaluating these new roofing materials and of assisting in the preparation of standards. This paper outlines classification and description of products, and criteria for evaluation. It also presents a summary of the results of the tests for a number of materials selected as typical of the different classes. These examples illustrate the problems encountered and the limitations of the tests.

If it were possible to evaluate such a wide range of materials on strictly performance-based criteria, there would be no need for group classification. Ideally, one should be able to designate all as roofing and waterproofing membranes and consider them on that basis. This has not yet been possible, however, and it has been necessary to categorize them. It has been considered essential for the preparation of standards, which must be "prescriptive" to some degree, and based on generic class and method of application.

In discussing the durability of these materials, the following classifications were used:

Group 1—Prefabricated polymeric and elastomeric sheets, poly(vinyl chloride) (PVC) reinforced and unreinforced. Six flexible PVC samples were included in the evaluation.

Group 2—Prefabricated, modified, bituminous, reinforced membranes, multi-component. Thirty-six separate products were included under this category, representing a wide range of components formulated to give specific properties.

Group 3—Liquid-applied membranes (classified according to manner of application): *hot-applied*—These were represented by seven products that are formulations composed mainly of asphalt modified with rubber, resin or other materials, or *cold-applied*—This sub-group was represented by a total of 33 products, some of which were two-component systems requiring mixing, others, emulsions or solutions. Liquid materials are usually applied by trowel or spray.

Criteria for Durability Evaluation

In evaluating durability of roofing membranes it is necessary to specify the conditions of exposure, for example, to specify exposed or protected roofing systems. In an exposed system the membrane may experience the full range of temperature (-40 to $+70^{\circ}\text{C}$), may receive full solar irradiation, and moisture in the form of rain, snow, and ice. In the protected roofing system the membrane is covered by a layer of suitable insulation that shields it from solar irradiation. The yearly temperature change imposed on it is also moderated to about 25°C and it is subjected predominantly to liquid water.

The expected performance of conventional roofing materials is based on an average life of about 20 to 25 years. Therefore, it is logical that perfor-

mance of new roofing materials should be based on at least a similar life expectancy.

Each class of roofing membranes has very different chemical, physical, and mechanical properties. The capability of providing a water barrier is the only property that all classes have in common. At the present time the performance requirements of a roofing membrane cannot be defined in terms of any single property such as tensile strength, because two materials may have very different tensile strengths yet give adequate performance. However, individual properties may be used to characterize a material and permit control of quality.

Evaluation of new roofing materials has been based on the following criteria.

Mechanical Capability

(a) The material must withstand movements of the roof systems, wind action, penetration by sharp objects, and low temperatures. Therefore, the following properties were considered: tensile strength, elongation at break, elastic limit (recovery after stretching), low temperature flexibility, crack bridging, cone penetration resistance, and static and dynamic impact test at different temperatures.

(b) In order to maintain the capability defined in (a), properties should not change greatly after prolonged aging and weathering. Any change that does occur in a particular property after exposure to natural or artificial weathering conditions often gives the best indication of durability.

Resistance to Moisture

This requirement is clearly most important in evaluating the performance of roofing membranes: (a) moisture absorption (note any weight and dimensional change), and (b) moisture absorption (note mechanical property change, as in (b) under Mechanical Capability).

Resistance to Weathering

In addition to actual field experience involving recorded service performance and exposure of specimens to normal outdoor weathering, two machines were used in subjecting specimens to accelerated weathering cycles:

(a) *Climate Lab*—cycles of moisture and temperature: 2 cycles per day—7 h at 100 percent relative humidity, 56°C and 5 h at 25 to 100 percent relative humidity, 11 to 56°C (see footnote 4 for details). This method of

⁴Blaga, A. and Yamasaki, R. S., *Journal of Materials Science*, Vol. 8, 1973, pp. 1331-1339.

aging is suitable for the membranes used in inverted roofing systems where solar irradiation is not involved.

(b) *Weather-Ometer*—combined action of moisture-temperature-solar irradiation. Results of this test are applicable to materials that will be exposed to normal outdoor conditions.

Results

The following is a summary of data from the evaluation program chosen to illustrate the problems encountered in using the criteria and the reasoning behind the need for range of requirements rather than the lowest limit of one property which has to be considered in the development of material specifications.

Tensile Properties

Tensile strength and elongation for a membrane that is to serve as a roofing material can be considered only in relation to a group. Thus it is not possible to set an overall minimum requirement. This merely emphasizes that no one property can be taken alone to define the expected performance of the given material. For example, two materials from two groups could be considered to serve adequately as membranes while each will have very different tensile strengths.

The tensile strength and elongation of Group 1 specimens are higher than might be required of a roofing membrane, but this property is specified mainly for the purpose of determining the quality of the product and to measure the effect of aging or weathering. Tensile strength of PVC membranes varied with direction of manufacture (machine or cross-machine) and gave values ranging from 115 to 227 kg/cm² and elongations from 245 to 350 percent. When tensile strength was measured after certain aging and weathering exposures it did not change significantly although elongation at break did (Table 1).

Group 2 represents a large number of products, and tensile strengths varied widely from 6.5 to 92.9 kg/cm² in machine direction and 5.4 to 77.4 kg/cm² in cross-machine direction. As stated earlier, a single limit cannot be placed on tensile strength because of lack of performance data, and at this time values can serve only as an indicator of quality or evidence of changes following intervals of aging.

For rubberized asphalt (Group 3), tensile strength could not be determined at room temperature, using conventional strip or dumb-bell specimens. Instead, the toughness test was conducted using the cup and pulling head procedure described in CGSB Standard for Asphalt, Rubberized, Hot-Applied for Roofing and Waterproofing (37-GP-50M March 1978).⁵ Another procedure used ASTM Method for Ductility of Bituminous

⁵ Canadian Government Specification Board, Department of Supply and Services, Ottawa, Ont., Canada.

TABLE 1—Mechanical properties of flexible PVC (tensile strength in kg/cm², elongation at break, percent).

Accelerated Aging at 163°												
Specimen No.	Direction	Original		170 days in Water		75 mn		300 min		Natural Aging		
		Tensile Strength	Elongation	Tensile Strength	Elongation	Tensile Strength	Elongation	Tensile Strength	Elongation	Year	Tensile Strength	Elongation
1	MD	214	321	...	...	211	260	229	240	8	218	345
	CMD	196	338	...	...	184	257	176	233	...	...	...
	ND	...	...	231	292	...	...	...	...	...	...	...
2	MD	227	352	...	...	216	278	222	208	...	...	...
	CMD	218	340	...	...	219	295	207	212	...	...	...
	ND	...	...	233	311	...	...	...	...	...	...	...
3	MD	196	314	...	...	187	210	220	20	...	...	...
	CMD	178	340	...	...	165	234	172	10	...	...	...
	ND	...	...	...	...	...	...	...	...	...	...	...
4	MD	197	308	...	...	188	215	213	105	...	...	...
	CMD	180	353	...	...	159	232	162	97	...	...	...
	ND	...	...	...	...	...	...	...	...	...	...	...
5	MD	154	285	...	...	158	218	211	12	...	...	...
	CMD	146	245	...	...	157	39	226	16	...	...	...
	ND	...	...	...	...	...	...	...	...	...	...	...
6	MD	117	289	...	...	112	242	125	166	5	138	282
	CMD	...	...	...	...	...	...	...	...	10	155	215
	ND	...	...	...	...	...	...	...	...	11	230	19
	MD	...	...	...	...	...	...	...	...	5	148	308
	CMD	115	294	...	...	119	266	128	160	10	115	138
	ND	...	...	...	...	...	...	...	...	11	214	50

NOTE—MD = machine direction.

CMD = cross-machine direction.

ND = direction not determined.

Materials (D 113 - 76). Toughness (area under the curve) was determined at -25°C to show the influence of rubber on the brittleness of the asphalt (Fig. 1).

Low-Temperature Flexibility—Low-temperature flexibility can best be evaluated by a tension test at low temperature, but an alternative method is often referred to in standards, a bend test over a mandrel at a given temperature. This test is particularly important if the membrane has to be applied at below zero temperature. Low-temperature flexibility at -10 and -30°C has been considered for the standard and heavy duty materials, respectively (see CGSB 37-GP-56M).

Again, there is no criterion that can allow a limit to be set based on performance requirements. The test might be used to indicate quality and changes resulting from certain aging or weathering exposure, but the latter is difficult because of the low sensitivity of the test.

The materials included in this program yielded a wide range of results; where some elastomeric membranes passed the bend test over a 6.35 mm ($1/4$ -in.) mandrel at -60°C , other materials failed it over a 25.4 mm (1-in.) mandrel at -10°C . Of interest is the fact that conventional BUR failed a bend test over a 25.4 mm (1-in.) mandrel at 0°C . At this time there are few performance data to indicate which of the new materials will perform better in service and what common limits, if any, can be set on the low temperature flexibility of roofing materials.

Crack Bridging—This property is applicable to Groups 2 and 3 (where

FIG. 1—Toughness test (using ASTM D 113); testing temperature -25°C ; machine speed 1 cm/min; chart speed 5 cm/min.

they are fully adhered to a substrate). A test was devised to observe the tendency of the material to sag or break in bridging an opening of 3.18 mm (1/8 in.), either at room temperature or in an oven at 40°C for 24 h. The apparatus is shown in Fig. 2 and the test described in CGSB 37-GP-50M.

Cone Penetration—This property was measured for Groups 1 and 2 and defines limits to the thickness of the sheet that will withstand puncture such as that caused by falling objects or crushed stone grains driven into the surface under the weight of a man. This test is not valid for thick membranes, especially those that are self-healing such as rubberized asphalts (Table 2).

Resistance to Moisture

This is the most important property of roofing materials. It is their main function to serve as a moisture barrier and in this capacity they must retain

FIG. 2—Device and concrete blocks (CGSB 37-GP-50M) covered with hot-applied rubberized asphalt ready for crack-bridging test.

TABLE 2—Cone penetration
flexible PVC.

Specimen No.	Load, N
1	52.9
2	21.6
3	20.6
4	50.0
5	27.4
6	26.5

their physical and mechanical properties after continuous or cyclic exposure to water over their entire life cycle.

Various test methods for water absorption were considered, and that selected was immersion for a week at 50°C. The increase in temperature accelerated absorption rate, reducing the test period. It is believed that no abnormal effect was imposed on the materials at the chosen temperature. The amount of water absorbed and its effects were determined by measuring weight and dimensional changes.

Specimens of PVC materials (Group 1) absorbed 0.6 to 3.5 percent water (Table 3), and shrank up to 1 percent in the machine direction when exposed to the absorption cycle at 50°C, due to stress relaxation. This could be demonstrated by heating the material dry for 24 h at 60°C or for 10 min at 90°C (Table 4). This shrinkage presented a problem in evaluating the

TABLE 3—Weight and length changes of PVC immersed in water (mean of 3 tests).

Specimen No.	Weight Changes $\Delta W/W_o$ (%)				Length Changes $\Delta L/L_o$ (%)			
	Long-term at 25°C		Accelerated at 50°C		Long-term at 25°C		Accelerated at 50°C	
	170 days	233 days	7 days		170 days	233 days	7 days	
			MD	CMD			MD	CMD
UNREINFORCED								
1	1.68	2.38	0.78	0.59	0.68	0.93	-0.38	0.61
2	0.3	1.5	0.79	0.59	0.46	0.72	-0.28	0.55
3	...	...	2.93	2.33	...	...	-1.12	1.91
4	...	...	1.40	1.39	...	...	-0.88	1.02
REINFORCED								
5	...	...	2.49	2.54	...	...	-0.20	0.16
6	...	...	3.68	3.42	...	...	0.11	-0.03

NOTE—MD = machine direction.

CMD = cross-machine direction.

TABLE 4—Dimensional change of PVC with dry heating, percent.

Specimen No.	24 h at 60°C		10 min at 90°C	
	MD	CMD	MD	CMD
1	-0.69	0.76	-2.10	0.52
2	-0.60	0.41	-1.62	0.27
3	-2.08	1.10	-4.65	1.48
4	-0.88	0.78	-2.18	0.92
5	-0.06	0.05	-0.23	-0.02
6	0.02	0.03	-0.01	0.01

NOTE—MD = machine direction.

CMD = cross-machine direction.

material's resistance to moisture and this test should be carried out either at room temperature or after the heat relaxation.

Group 2 materials also gave a number of anomalous results for water absorption and dimensional change. There did not seem to be any consistency in the values; where one material absorbed 10.6 percent moisture and shrank 0.3 percent in machine direction, expanding 0.4 percent in cross-machine direction, another material absorbed only 0.9 percent water and expanded 1.3 percent (MD), 1.6 percent (CMD). Because of this, the results of these tests cannot be used alone in evaluating the materials, but must be combined with other tests such as tensile strength to identify any significant change in properties on absorption of water.

However, the absorption test does identify which materials will deteriorate visibly when exposed to water, for example, which will undergo large, irregular expansion resulting in buckling, delamination, etc. This is illustrated by the Group 3 materials in Table 5. It does not mean that other materials that absorb a certain amount of water with corresponding dimensional change but no visible damage will not, in time, undergo deleterious changes due to absorption. The hot-applied materials exhibited so little water absorption that dimensional changes were not even measured. Conversely, most of the cold-applied materials showed large losses or gains in weight with corresponding shrinkage or expansion.

Resistance to Weathering

Specimens of all the materials in this program were exposed to either or both of the two cyclic accelerated weathering machines:

(a) *Climate Lab*—Exposure of over 3 months was given to all specimens and the effect ranged from virtually no change to extreme deterioration and distortion (Fig. 3 and 4). It is believed that measurements of change in length and tensile strength may provide a quantitative indication of the effect of this

TABLE 5—Weight and length changes of Group 3 immersed in water (mean of three tests—7 days at 50°C).

Specimen No.	Weight Changes $\Delta W/W_0$, %	Length Changes $\Delta L/L_0$, %
HOT-APPLIED		
1	0	...
2	0.6	...
3	0.1	...
4	0	...
5	0	...
COLD-APPLIED		
6	-5.0	-2.7
7	27.2	8.4
8	-11.3	-4.6
9	2.6	0.7

FIG. 3—Liquid-applied, modified polyurethane membrane: (a) before exposure and (b) after 110 days' exposure in climate lab (temperature and moisture cycling). Note swelling and deformation.

FIG. 4—Rubberized asphalt: (a) unexposed, and (b) after 18 months' exposure in climate lab.

exposure, but these measurements have not yet been completed for all materials under investigation.

(b) *Weather-Ometer*—Specimens tested in this machine are being restricted to those materials that will be exposed to normal outdoor conditions, including solar irradiation. Testing is in progress.

Conclusions

Preliminary results of the program have revealed that evaluation of durability of new roofing materials is a complex task.

Owing to uncoordinated performance data it is not possible at the present time to define criteria for a roofing membrane in quantitative terms applicable to all of the variety of generic materials in use.

Comparison of individual properties of new roofing materials in the three

groups, or even within one group, is not justified because of wide variability and anomalous results for water absorption and dimensional change. Comparison of combinations of properties may yield useful results when performance data become available to provide the basis for such comparison.

Systematic evaluation of the large number of roofing materials is an involved, long-term study that will require combined laboratory and field work on an international level before realistic evaluation of performance can be achieved. For the present, evaluation of such materials must be done on an *ad hoc* basis to provide guidelines for quality control and standards to protect the consumer.

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