PVC ROOFING MEMBRANES—FACTORS AFFECTING TENSILE TESTS

O.M. DUTT and H.E. ASHTON

National Research Council of Canada
Ottawa, Canada

SUMMARY

Many standard requirements for the evaluation of roofing membranes involve tensile testing and various methods are specified or have been used for these tests. In this study, some test parameters, such as temperature, speed of loading, gauge length and strain variation within a specimen, that affect the tensile test results, were examined for three types of PVC membrane. Over two hundred specimens were subjected to tensile tests. The results show that some of the test methods used for evaluating roofing membranes need to be carefully selected in relation to the material under test.

A roofing membrane is subjected to various stresses during manufacture, application and performance in service. The stresses related to the manufacturing and application generally are predictable and controllable. Those that occur in service are quite complex and extend over a long period of time. They are caused by many factors, such as heat, cold, wind, rain, snow, ice, moisture, occupancy loads, and structural movements, that prevail at different times in various combinations and unpredictable cycles.[1]

The various forms of loads in the roof-service environment are related to chemical, physical and/or mechanical action, which cause tension, compression, bending, shear, peel, fatigue, etc.[2] Of all the stresses that cause damage, tensile stress occurs most frequently in practice. Consequently, tensile tests are widely used to evaluate roofing materials. In the Canadian General Standards Board standard for plastic sheet roofing,[3] seven out of twelve physical and mechanical requirements are related to the tensile stress-strain behavior of the material. This also is recognized in other standards and publications, as shown in Table 1.[1,4]

Because membranes vary in chemical and material composition, different test methods are prescribed in various standards, which specify different specimen shapes, sizes, grip lengths and loading speeds. Some of these "standard" test methods, frequently referred to in testing roofing membranes or similar materials, are presented in Table 2. There is considerable variation among them. A review of these tests indicates that the differences among the methods may not have a rational basis. It is common to find a test developed for one type of material applied to a completely different type apparently without realization that the test may not be appropriate.[5] An example in the field of roofing is use of the very high extension rate from the test developed for rubbers (ASTM Method D 412) in evaluating much less elastic materials, such as bituminous roofing materials.[6]

The effect of some tensile test factors, such as temperature, speed of loading and gauge length, and the strain variation within a specimen, on the results of tests with roofing membranes was examined using three types of polyvinyl chloride (PVC) membranes to determine if certain conditions are more relevant for roofing materials. This part of the study is concerned with how tensile tests should be performed. The different responses of the three materials to the tensile tests after accelerated weathering and fatigue cycling and their relevance to field performance will be presented in a future publication.

TEST CONSIDERATIONS

The study was designed to determine the response of PVC roofing membranes when subjected to tensile testing under various test conditions. The samples represented the three basic types: PVC sheets with polyester fabric reinforcement, with integral non-woven glass fiber mat carrier and without any reinforcing materials. The three types were labelled A, B and C, respectively. Values of their strength, elongation and other parameters were obtained to relate them to the tests.

In general, dumbbell-shaped specimens were cut with die A of ASTM Method D 412, which has a width of 12mm, instead of the recommended die C[3] with a width of 6mm as given in Table 2. For specimens of different dimensions, the test values were adjusted to take into account the differences in width where results were compared.

TESTING AND RESULTS

Tensile Tests at Low Temperatures

For this test, 45 specimens of PVC membranes were cut using die A of Method D 412. They were subjected to the tensile test on an Instron test machine (model 1122) at 22C and at 0, -10, -20, and -30C in an environmental box. Gauge length of each specimen was 60mm and the crosshead speed was constant at 10mm per minute. Typical load-elongation curves for polyester-scrim reinforced membrane (A) are shown in Figure 1a, glass-mat reinforced membrane in Figure 1b, and non-reinforced membrane (C) in Figure 1c. Mean values of the test results are given in Table 3.

The curves in Figure 1a and the results from Table 3 indicate that when the temperature decreases, the load at break increases, while the overall elongation at break decreases. This behavior could normally be predicted for a PVC sheet because of greater intermolecular friction at cold temperatures, but the results show a marked difference between the three types. Comparing their values at room temperature and at -30C, membrane A shows a loss in elongation from about 230 to 20 percent, whereas the breaking load more than doubles. Also, the rupture of reinforcement and matrix occurs simultaneously at -30C and also at -10 and -20C. With membrane B, the glass mat breaks at low load and negligible elongation but the resin continues to extend after the reinforcement breaks. The resin decreases in elongation from about 220 to 80 percent, while the ultimate load increases to about 2½ times the original value. For the non-reinforced membrane, the changes in load-elongation values are similar to those of material B after the fracture of glass fibres.

Tensile tests conducted at low temperatures provide more information on the tension failure of the material than the low temperature bend test *(Table 1)*. In the bend test a specimen, cooled to -30C and bent over a specified curvature, is visually inspected for any tension cracks. This test depends solely on visual inspection, which could miss microcracks on the membrane surface. The tensile test gives quantitative information of the stress, which can be related to the tension cracks due to bending using principles of flexural mechanics. Because there are significant variations in the load-elongation properties of different membranes at cold temperatures, tensile testing at cold temperatures should be considered an essential method in evaluating PVC, as well as other roofing membranes intended for use in cold climates.

Speed of Loading

In various standards, the speed of loading, or grip separation, varies from 1.3 to 550mm per minute *(Table 2)*. For PVC membranes, it is 500mm per minute. To study the influence of this factor on behavior during tensile testing, twenty-four specimens cut with die A of ASTM D 412 from each of the three types of membrane were tested at crosshead speeds of 2, 5, 10, 20, 50, 100, 200 and 500mm per minute.

The effect of speed of loading on the resulting load at break of the specimens can be seen in Figure 2. At low speeds there is a steep rise in the values of breaking loads, but at speeds beyond 100mm per minute, strength is not very dependent on the rate of loading for a given type of PVC. It indicates that the 500mm per minute speed is not necessary to obtain a reasonably accurate value of the maximum strength in tension. A lower speed is adequate and is closer to the conditions imposed in the field by variable weather conditions. Also, lower speed is convenient for making meaningful observations during the test. Thus, a loading speed of not more than 10mm per minute is recommended for evaluating PVC membranes at room temperature.

Gauge Length Variation

Gauge length is another aspect that may influence the result of tensile tests of materials, particularly when the test specimens are rectangular and the initial spacing of jaws is considered the gauge length. Jaw slippage, deformation due to jaw pressure and higher strain at the neck of the specimen contribute to the error. In order to study this factor, different roofing materials, non-reinforced PVC membrane, asphalt felt and asphalt shingle, were included in the experiment. Because reinforced membranes suffer excessively high strains where necking occurs, they are discussed under strain variation.

Five sets of 24 specimens each were obtained from the samples, with specimens cut to gauge lengths of 5, 10, 20, 50, 100 and 200mm. The PVC specimens were specially cut with dumbbell ends, so that they provided wider ends for proper gripping, but only the straight section extended out of the jaws. The felt and shingle specimens were 25mm wide rectangular strips. They did not need wider grip ends because of the materials' low ultimate strength. Each set was cut along the machine direction or cross-machine direction and was tested either at a constant crosshead speed or at a constant rate of strain, using the separation of grips as a measure of elongation. The results and test conditions are shown in Figure 3.

From the curves in Figure 3, it is evident that the recorded elongation of shorter specimens is significantly greater than the true value because of the relatively greater contribution of the neck and end effects. A small change in the gauge length of less than 50mm causes a large change in elongation. With increasing lengths, the effect of these factors becomes less significant and is relatively negligible above 100mm gauge length. However, from the point of view of the time required to perform the test and the size of specimens of highly elastic material which requires long travel of the machine cross-head, a gauge length of 50 to 70mm should be acceptable. Specimens cut with Die A of ASTM D 412 fall within this range. For membranes with widely spaced reinforcing mesh, a wider specimen containing a representative number of strands is required for repeatability of results. For this purpose, the 25mm wide die of ASTM Standard D 2523 could be considered. Any specimen found to be short of a representative number of reinforcing strands is discarded.

In the case of dumbbell-shaped specimens subjected to tensile tests, elongation of gauge length commonly is measured by hand held scales, due to the lack of a simple and accurate extensometer for highly stretchable materials. In the test the ungripped portion of dumbbell ends, having variable width, elongates differently from the straight portion, where gauge length has been defined between bench marks. In order to compute the elongation of gauge length from the total elongation, a mathematical model can be developed for numerical integration of the elongation of end portions, taking into account their varying widths and the non-linear stress-strain property of the material. This model is applicable only to non-reinforced membranes, as the deformation of other types is governed by the reinforcement.

Strain Variation

In this test, 15 dumbbell-shaped specimens, each 25mm wide, were specially cut from the three PVC membrane samples and tested at a loading speed of 10mm per minute. In order to study, separately and together, the behavior in tension of the two components, reinforcement and matrix, of the reinforced PVC membrane, a test was designed in which a steel tape was attached to the jaws alongside the specimen being pulled. The assembly was photographed at intervals and the load-extension chart was marked the instant each photograph was taken. The elongations were measured from the prints *(Figure 4)*, and are reported in Table 4. The non-reinforced PVC specimens showed only small strain variation, and are not included in the table.

The percent elongations in various segments of the specimen are not equal. Once the reinforcement breaks, the elongation in the now unreinforced segment becomes much greater than in the remaining reinforced portion. This condition gives a 129 percent average value of elongation of the material over the gauge length rather than the true elongation of 215 percent *(Table 4)* at the site of potential break. This effect is significant with reinforced membranes only. It implies that an elongation requirement in specifications for the reinforced type, has a factor of safety incorporated in it. This is seen in the example cited above, which has a factor of safety of 1.67 over the average elongation for the matrix.

CONCLUSIONS

The present study looks at the methods of tensile testing the three basic types of PVC roofing and waterproofing membranes. From the results of these tests, it is concluded that:

1. Tensile tests at low temperature give significant information about the variability of the load-elongation properties between materials at different temperatures. One material's elongation changed from about 230 percent at room temperature to 20 percent at -30C. This information can supplement the cold bend test, which is based on visual observation.
2. Load at break of a membrane is influenced by loading speed. It becomes essentially independent of load speeds beyond 100mm per minute. It therefore is necessary that the strength of a membrane be defined in relation to the speed of loading. A rate of grip separation in that vicinity should be adopted in place of the existing 500mm per minute.[3]
3. Elongation at break of specimens where jaw separation is used for gauge length is significantly affected by slippage and deformation of specimen at the jaw as well as the neck formation in the vicinity of the fracture. Its relative significance decreases with increasing gauge length and becomes negligible for lengths greater than 100mm.
4. In a reinforced membrane, reinforcement breakage causes localized strain which is higher than the strain over the gauge length. This must be taken into consideration when specifying strain requirements of such membranes.

The information presented indicates the importance of factors affecting tensile tests on PVC membranes. The observations show that careful consideration must be used when defining test methods and procedures for evaluating material behavior.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to G.A. O'Doherty for his assistance in the experimental work. This paper is a contribution of the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director.

REFERENCES

[1] Mathey, R.G., and Cullen, W.C., Preliminary Performance Criteria for Bituminous Membrane Roofing, U.S National Bureau of Standards, Building Science Series Publication No. BSS 55, November 1974, pp. 2-9.

[2] Mathey, R.G., and Rossiter, W.J., Single Ply: Evaluating Tensile and Elongation, 1982 Handbook of single-ply roofing systems, published by RSI Magazine, New York, pp. 52-54.

[3] Canadian General Standards Board (CGSB) 37-GP-54M, Standard for Roofing and Waterproofing Membrane, Sheet Applied, Flexible, Polyvinyl Chloride, CGSB, Hull, Quebec, January 1979, pp. 2-5.

[4] Rosenfield, M.J., An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Roofing Systems, Technical Report M-284, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois, March 1981, pp. 9-11.

[5] Ashton, H.E., Evaluating the Performance of Organic Coatings and Building Materials, Symposium on Permanence of Organic Coatings, January 1981, ASTM STP 781, August 1982, pp. 67-85.

[6] CGSB 37-GP-56M, Standard for Membrane, Modified, Bituminous, Prefabricated and Reinforced for Roofing, CGSB, Hull, Quebec, July 1980, pp. 2-7.

Property	CGSB Standards for Roofing Membranes									NBS[3] BSS #55 Ref. 1		U.S. Army Tech. Report M-284 (Evaluation of PVC Roofing) Ref. 4		
	Elastomeric 37-GP-52M			Plastomeric 37-GP-54M			Modified Bituminous 37-GP-56M							
	Clause	**TT[1]**	**ASTM Ref.**	**Clause**	**TT[1]**	**ASTM Ref.**	**Clause**	**TT[1]**	**ASTM Ref.**	**No.[2]**	**TT[1]**	**No.[2]**	**TT[1]**	**ASTM Ref.**
Tensile Strength (stress)	5.2.1	✓	D412	5.2	✓	D412				1	✓	6	✓	D638 D882
Breaking Strength	5.2.2	✓	D751				5.1	✓	D412					
Lap Joint Strength	5.3	✓	D412	5.3	✓	D412	5.1	✓	D412			7	✓	D638
Ultimate Elongation/ Elongation at Break	5.4	✓	D412 D751	5.4	✓	D412	5.2	✓	D412			8	✓	D882 D638
Load-Strain Product							5.3	✓	D412					
Tensile Set	5.5	✓	D412											
Dynamic Impact	5.12			5.5			5.8			7	15			
Heat Aging	5.9	✓	D412 D751	5.6	✓	D412						13 14	✓	D638 D882
Thermal Stability				5.11			5.7			2		10		
Low Temperature Flexibility	5.6	Ø		5.7	Ø		5.5	Ø		14	Ø			
Accelerated weathering	5.11	✓	D412 D751	5.8	✓	D412	5.12	✓	D412	17				
Permeability				5.9			5.6			15		12		
Water Absorption	5.7	✓	D412 D751	5.10	✓	D412				9	✓			
Moisture Expansion	5.8						5.4			16	✓			
Cone Penetration				5.12										
Ozone Resistance	5.10													
Tear Resistance	5.13	✓	D624							13 8	✓	9	✓	D1004
Tearing Strength	5.14	✓	D751							8	✓			
Static Puncturing Test (Shear Stress)							5.9			6				
Granule Embedment (Abrasion)							5.11			12				
Crack Bridging/ Tensile Fatigue							5.13	✓		4	✓			

[1] Where tensile testing involved.

[2] Numbering of tests in reference publication.

[3] National Bureau of Standards, Building Science Series #55.

Ø Related to tensile stress in flexural loading.

Table 1 Test requirements for roofing membranes according to CGSB and NBS. (Evaluation of PVC membranes by CERL (Ref. 4) is included for comparison.)

No. of ASTM Standard	ASTM Designation	Shape	Specimen Width mm	Gauge or Grip Length mm	Rate of Grip Separation mm/min	Approx. Operating Time sec
D 146	Bitumen-saturated felts and woven fabrics for roofing and waterproofing	Rectangular	25	100	51	15
D 412	Rubber properties in tension	Dumbbell	6	33	510	30
D 624	Rubber property-tear resistance	Curly and notched	19	58	450-550	25
D 638	Tensile properties of plastic	Dumbbell	6	25	50-500	30-300
D 751	Coated fabrics	Rectangular (grab)	100	75	300	30
D 882	Tensile properties of thin plastic sheeting	Rectangular	5-25	50-125	12.5-500	15-120
D 1004	Initial tear resistance of plastic film and sheeting	Curly and notched	19	25	51	20
D 2523	Load-strain properties of roofing membranes	Dumbbell	25	76	1.3-500	3-1500
D 2707	Hard rubber in tension	Dumbbell	12.5	75	5-10	90
D 4073	Tensile-tear strength of bituminous roofing membranes	Rectangular and notched	75	100	2.5	30

Table 2 ASTM standards applicable to properties of roofing materials where tensile testing is involved

Description of PVC Membranes	Test Temp. °C	Load at Break (N) per 12.5mm width		Elongation at Break (%)	
		First	Final	First	Final
Polyester-scrim reinforced (A)	22	216	196	20	233
	0	280	255	19	150
	− 5	376	294	19	82
	−10	412	412	19	19
	−20	417	417	20	20
	−30	507	507	19	19
Glass-fiber mat reinforced (B)	22	54	140	3.0	218
	0	92	201	3.0	153
	−10	125	250	3.2	123
	−20	180	309	3.7	102
	−30	255	365	4.0	81
Non-reinforced (C)	22	—	280	—	275
	0	—	353	—	147
	−10	—	471	—	145
	−20	—	572	—	138
	−30	—	638	—	83

Table 3 Load and elongation at break for PVC membranes at different temperatures (first value is when reinforcement breaks).

Membrane	Load (N)/25 mm	Overall Elongation (%)	Segmental[1] Elongation (%)			
			1-2	3-4	5-6	7-8
Polyester reinforced	430	17	17	—	—	17
	128	21	15	—	—	45
	196[2]	95	16	—	147	195
	230	129	25	90	195	215
Glass reinforced	171	110	75	—	—	145

[1] Each segment 10 mm.

[2] Refer to Figure 4.

Table 4 Strain variation in different segments

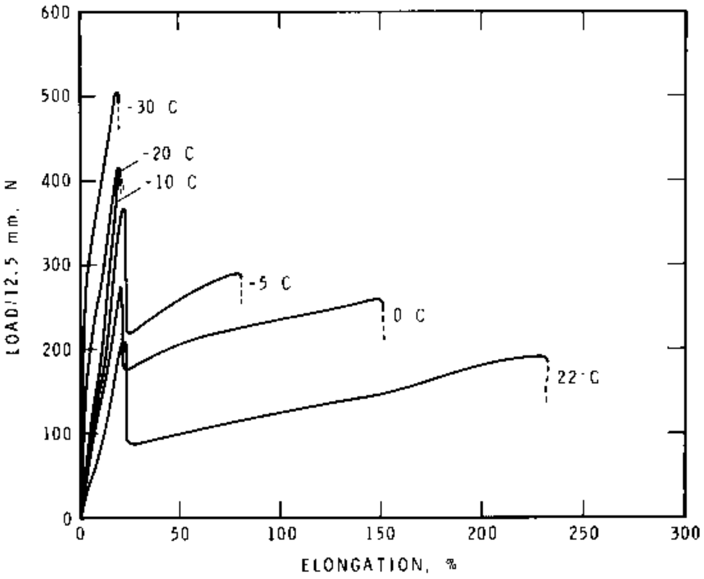


***Figure 1a** Load-elongation curves for polyester-scrim reinforced PVC membrane at different temperatures. First peak—reinforcement breaks, second peak—total section breaks. At -10, -20 and -30C, both break simultaneously.*

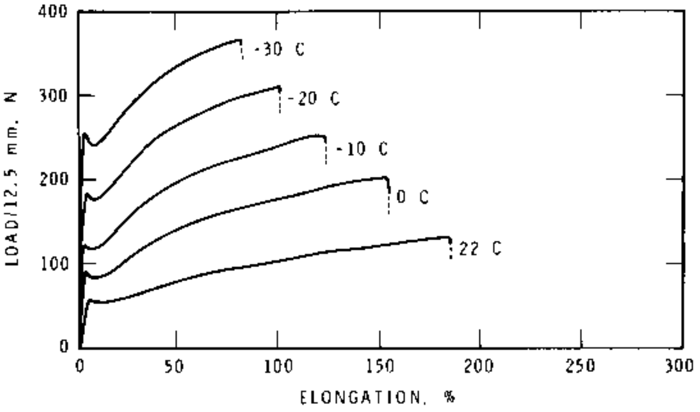


***Figure 1b** Load-elongation curves for glass-mat reinforced PVC membrane at different temperatures. First peak—reinforcement breaks, second peak—total break.*

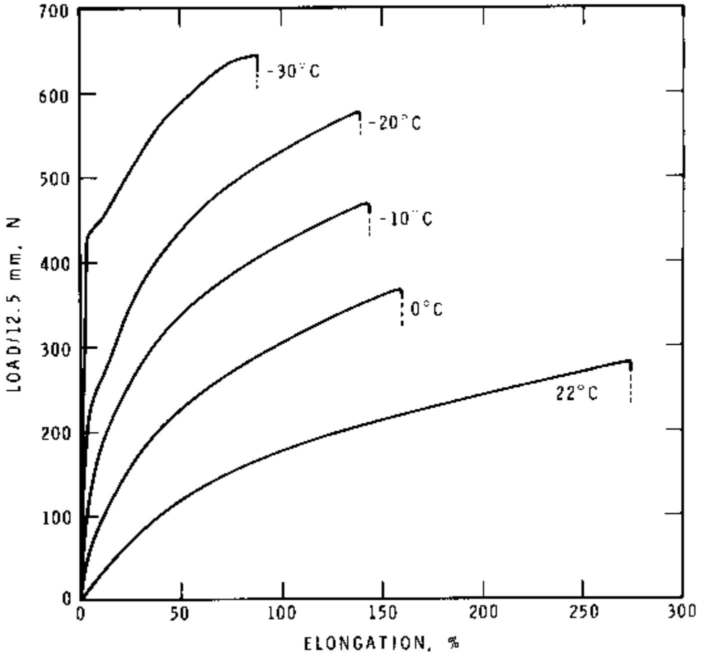


***Figure 1c** Load-elongation curves for non-reinforced PVC membrane at different temperatures*

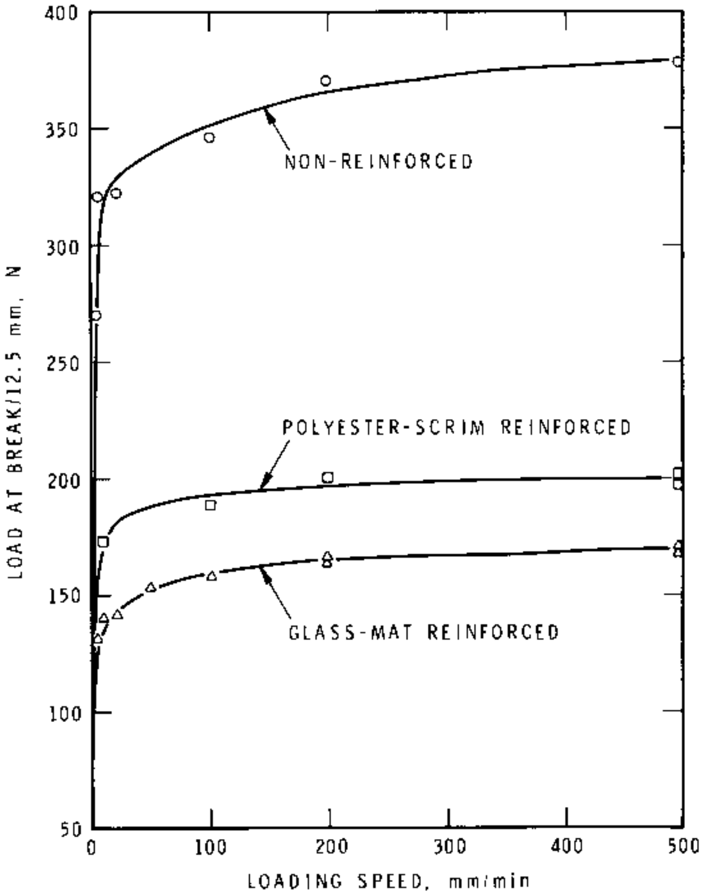
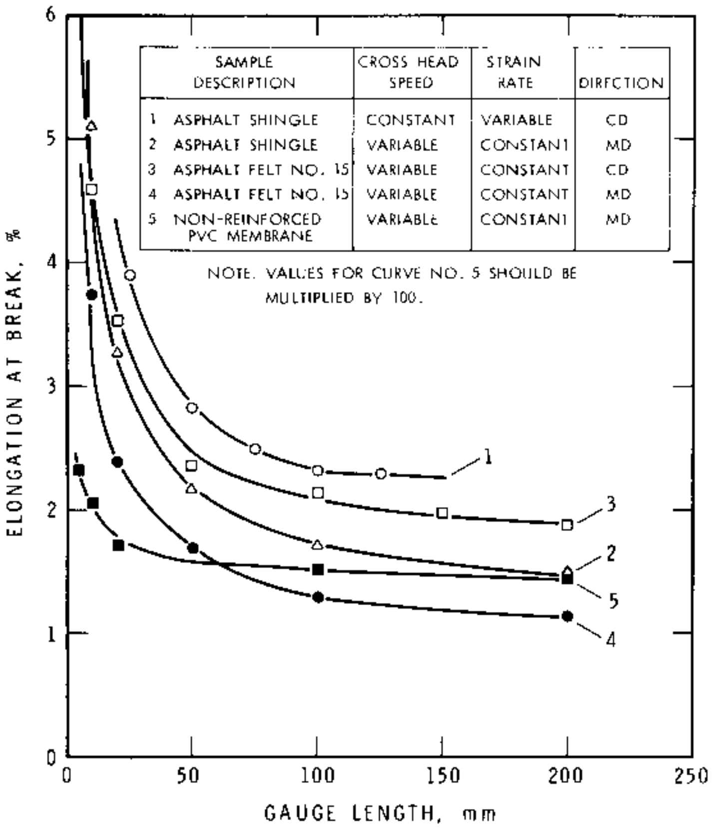


***Figure 2** Effect of loading speed on load at break for PVC membranes*



SAMPLE DESCRIPTION	CROSS HEAD SPEED	STRAIN RATE	DIRECTION
1 ASPHALT SHINGLE	CONSTANT	VARIABLE	CD
2 ASPHALT SHINGLE	VARIABLE	CONSTANT	MD
3 ASPHALT FELT NO. 15	VARIABLE	CONSTANT	CD
4 ASPHALT FELT NO. 15	VARIABLE	CONSTANT	MD
5 NON-REINFORCED PVC MEMBRANE	VARIABLE	CONSTANT	MD

NOTE. VALUES FOR CURVE NO. 5 SHOULD BE MULTIPLIED BY 100.

Figure 3 Effect of gauge length, or initial jaw separation, on elongation at break

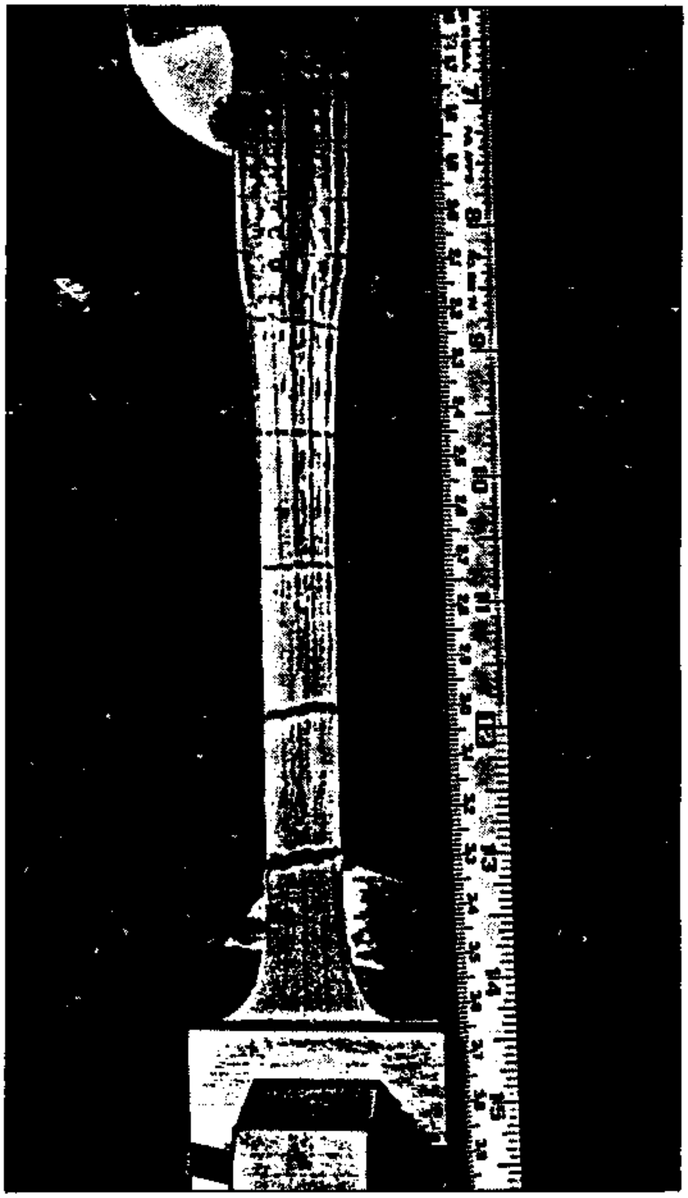


Figure 4 Example of strain variation in different segments of polyester-scrim reinforced PVC membrane. Refer to line 3 in Table 4.