SINGLE-PLY MEMBRANES—EFFECT OF COLD TEMPERATURES AND HEAT AGING ON TENSILE PROPERTIES

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Roofing membranes in Canada and other cold regions are exposed to very low temperatures. A study was undertaken to determine how single-ply membranes are affected by such climatic conditions. For this purpose, samples of two commercially available elastomeric (EPDM) and two PVC membranes were selected. Specimens of each material were tested for tensile properties, i.e., maximum strength and elongation at break in the machine and cross-machine directions at eight temperatures, from +22°C to −60°C.

Each sample was subjected to heat aging in an air circulating oven at 130°C, for three different time durations (one day, seven days and 28 days). The aged samples were then tested in the same manner as the unaged samples (i.e. at eight temperatures between +22°C to −60°C).

As expected with viscoelastic materials, the strength increases substantially at cold temperatures while the elongation decreases significantly compared to the values obtained at room temperature. Although these membranes, both EPDMs and PVCs, have tensile properties adequate from the point of view of relevant standards, they vary widely in their performance at cold temperatures. The results are useful for establishing cold temperature requirements that should improve roofing standards or provide guidance for the roof designer.

The results from the tensile testing of heat-aged samples show that some materials have been affected more than others. This information should improve understanding of the acceleration mechanism, and optimum conditions for accelerated aging (combination of temperature and duration) of different roofing materials.

KEYWORDS

Aging, cold temperature, EPDM, heat aging, low temperature, polymeric membranes, PVC, single-ply.

INTRODUCTION

A modern single-ply roofing membrane is polymeric in nature and is viscoelastic in behavior in response to loading. It is subjected to various forces during manufacture, application and service. The stresses developed in manufacturing and application are mostly predictable and controllable. Those that occur in service are quite complex. They originate from chemical, physical and mechanical changes occurring over a period of time. Stresses are caused by factors such as heat, cold, wind, rain, snow, ice, foot traffic loads and structural movements that prevail at different times and in various combinations and unpredictable cycles.

Of the various loads responsible for tension, compression, shear, flexure, etc., the most common is tensile load that may occur because of membrane shrinkage related to weathering, low temperatures, structural movements, wind uplift, etc.

Roofing membranes in Canada and other cold regions are exposed to much colder temperatures than those considered in the standards (CGSB, ASTM) or by the roof designers. These standards do not require low temperature tensile testing of heat aged samples, a combination closer to real performance situations. The low temperature flexibility test is more qualitative in nature.

The lowest temperatures that are adopted in the standards vary between 90°C and 130°C as shown in Table 1. In colder regions of Canada, the temperature of the roofs may reach as low as −60°C. They are also exposed to UV radiation.

One of the objectives of this investigation is to study the strength and elongation properties of roofing membranes at temperatures down to −60°C, and to compare the behavior of materials belonging to the same generic group and the other generic groups. A second objective is to establish acceptable criteria for the selection of roofing membranes for cold weather construction.

EXPERIMENTAL WORK

Specimen Preparation

The four membranes, tested for load-elongation behavior at different temperatures, included two commercially available products of non-reinforced ethylene-propylene-diene monomer (EPDM) and two of reinforced polyvinyl chloride (PVC).

Various aspects involved in the testing program were:

- Four membranes—Two non-reinforced EPDMs which are labelled A and B, and two reinforced PVCs labelled C and D.
- Eight Temperatures—22°, 0°, −10°, −20°, −30°, −40°, −50° and −60°C.
- Four Aging Preconditions—As received or control samples which were not heat aged, and others which were heat aged at 130°C for one day, seven days and 28 days.

- Two Directions—Machine direction (MD) and cross-machine direction (XD).
- Five Specimens—At least five replicates were tested for each test.

This required some 1300 specimens for testing.

Samples approximately 150mm x 200mm were taken from the "as received" sheets of EPDM and PVC for conditioning at room temperature or heat aging. The samples were placed in an air circulating oven preheated at 130°C. The first set was removed from the oven after one day, the second set after seven days and the third after 28 days.

The specimens were prepared after the samples had been conditioned at room temperature for at least 24 hours after heat aging.

EPDM membrane specimens were cut using a dumbbell-shaped die C of ASTM D412 (6.3mm wide). PVC specimens were cut with a rectangular die 25.4mm wide. It may be noted that since EPDM is non-reinforced, smaller width (6.3mm) of specimen would not affect the value of strength per unit width because of the homogeniety of the cross section. In the case of PVC which is reinforced, the specimen width must contain a representative number of reinforcing strands for accuracy of strength per unit width. Hence, specimens of 25.4mm width were used.

Each set of specimens was conditioned for at least 24 hours in the freezer at test temperature. Then each specimen was conditioned for over 10 minutes in the environmental cabinet before starting the tensile testing machine. The conditioning in the cabinet was necessary to compensate for the exposure to room temperature during shifting of specimen from the freezer and mounting it in the machine grips with the cabinet door open.

Specimen-Holding Clamps

Problems were encountered in the tensile testing of membranes at low temperatures using an environmental cabinet using liquid nitrogen as coolant.

It was not possible to use an extensometer for measuring the elongation since the specimen and grips were enclosed in the cabinet. Consequently, the travel of machine crosshead was used to measure the elongation. This, in some cases, affected the resulting elongation at break owing to specimen slippage close to the ends or the inner edges of the grips. This was particularly true for high-elongation elastomers. Any significant slippage, however, is detectable from sharp kinks in the load-elongation curves.

A constant pressure mechanism, consisting of pnuematic grips working at a line pressure of 400 kPa was used to reduce the incidence of slippage of specimens. This system failed at temperatures below −30°C as the moisture in the air inside the pneumatic system condensed, froze and jammed the movement of the grip plates. Subsequently, hydraulic grips with a low freezing point oil were used, but they too did not function below −30°C because the thickened oil slowed the grip movement and made them non-functional. Hand operated mechanical grips had limited elongation capability.

The available crosshead movement was limited with pneumatic, hydraulic and manual grips because their size was too large for the environmental cabinet. In order to use the environmental cabinet, a new clamp and gripping mechanism was developed and manufactured at the National Research Council. The new grips were manually operated and were of reduced size. That left more space in the environmental cabinet for accommodating higher elongation of specimens.

Testing

Each specimen was mounted in the grips of the tensile tester after heat aging and/or cooling at the desired temperature. The environmental cabinet was closed to let the inside temperature drop to the required level. The internal temperature was maintained by the liquid nitrogen. The test was initiated after allowing the temperature to stabilize for some 10 minutes.

The initial grip spacing was set at 60mm and the machine crosshead speed at 60 mm/min. for EPDM specimens. For PVC specimens, the grip spacing was set at 75mm and the crosshead speed at 75 mm/min.

The data was displayed and stored in the computer dedicated to the tensile tester, and was also graphed on the machine chart. Each data was monitored during the progress of the test. Any specimen breaking near the grips was closely examined and included in the results only if the break was considered valid.

Results

- All test data was recorded with the aid of a specially developed data acquisition program. The program has analysis and graphics capability.
- The resulting values of strength (kN/m) or elongation (%) vs. temperatures (°C) for materials A, B, C and D, and for various heat aging durations are presented graphically in Figures 1 through 4, in the following order:

		Sub-figure No.			
		Strength		Elongation	
Fig. No.	**Material**	**MD**	**XD**	**MD**	**XD**
1. EPDM	"A"	1.1	1.2	1.3	1.4
2. EPDM	"B"	2.1	2.2	2.3	2.4
3. PVC	"C"	3.1	3.2	3.3	3.4
4. PVC	"D"	4.1	4.2	4.3	4.4

- Photographic image (Figure 5) of breaking pattern of reinforced PVC at 22°C and −60°C.

DISCUSSION

Effect of Cold Temperature

The tensile strength results for the EPDM and PVC samples (Figures 1 through 4) show a general trend of increasing strength and decreasing elongation at break as the test temperature is reduced from 22°C to −60°C. This behavior is characteristic of all viscoelastic materials. The magnitude of change varies with each material.

The behavior is clearly depicted in the strength and elongation curves of EPDM sample A (Figure 1) because of the pronounced changes in the properties due to cold temperature changes and heat aging. Considering the case of a control sample MD (Figure 1.1), it is seen that its strength increases from 8 kN/m to 18 kN/m as the test temperature is reduced from 22°C to −60°C.

A sudden increase in strength of heat-aged materials at very low temperatures between −50°C and −60°C (Figures 1.1, 1.2, 2.1 and 2.2) for both EPDMs indicates that the materials have reached the glass transition state. A similar trend is not evident in the PVC results (Figures 3.1, 3.2, 4.1 and 4.2). Nevertheless, the difference in the breaking patterns of specimens tested at room temperature and at −60°C (Figure 5) does indicate the PVCs are close to their glass transition temperatures. The specimens tested at room temperature (RT) show a relatively clean break while those tested at −60°C show shattered mastic. It was not apparent as to whether reinforcement broke first or the PVC mastic.

Effect of Heat Aging

The two EPDM membranes differ as seen in Figures 1.3 and 2.3. The spread in the breaking strength for all test temperatures between the control and heat-aged samples is evident. For all durations of aging, the spread is greater for sample A (Figure 1.1) than for B (Figure 2.1). For example, consider the case of A; in the MD at −30°C (Figure 1.1) its strength after 28 days of heat aging increases from about 15 kN/m before aging to 25 kN/m or roughly 72 percent. The increase in the breaking strength of B, however, is less than 1.5 kN/m showing that this material is only slightly affected by heat aging. Small differences in the tensile properties between MD and XD are exhibited by both EPDM materials as they are non-reinforced and the matrix is nearly isotopic.

The elongation of the two products A and B is also affected, but in the opposite direction. After heating for 28 days at 130°C, the elongation of sample A at −30°C in the MD drops from approximately 198 percent to 18 percent, and for sample B the change is from 242 percent to 115 percent (Figures 1.3 and 2.3). These results show sample B is less affected (i.e, retains more of its elongation capability after heat aging) than sample A.

The trends are the same in the PVC samples (Figures 3 and 4), as with the EPDMs, but the effect is less pronounced. The comparatively lower slopes of the curves indicate the less effect of cold on the strength and elongation of these materials. This can be attributed to a number of factors. PVC materials are reinforced so that the maximum strength of the composite is determined by the reinforcement. Any anomaly would indicate the effect of reinforcement. Secondly, since the mastic or laminations are damaged or scarred by the breaking of the reinforcement within the membrane, the ultimate elongation is affected, making it unrealistic and inconsistent. This is evident from the inconsistency of graphics in Figures 3 and 4 as compared to those in Figures 1 and 2. Also, Figures 3.3 and 3.4 show the elongation values at room temperature are higher in MD than in XD, whereas in Figures 4.3 and 4.4 it is the reverse.

CONCLUSIONS

- Breaking strength values of EPDM and PVC roofing materials are higher and elongations lower at cold temperatures than their values at normal temperatures. This phenomenon is commonly associated with viscoelastic materials.
- Some roofing membranes are more sensitive to heat aging than others.
- The effect of heat aging and cold temperatures is more pronounced in non-reinforced EPDM than in reinforced PVC.
- Heat aging tests alone are not sufficient to evaluate reinforced roofing materials where reinforcement plays a dominant role in the membrane.
- The combined effect of heat aging and cold is quite severe for some membranes and should be adopted for their characterization. This aspect needs study for other generic types of roofing membranes.

ACKNOWLEDGEMENT

This is a part of joint research funded by Canada Post Corporation, Department of National Defence, National Research Council and Public Works Canada, Accommodation Branch, and is directed by a joint steering committee. Their support is gratefully acknowledged.

The authors also acknowledge with thanks the assistance of W.L. Lei and J.C. Margeson for conducting the laboratory tests and data acquisition. This paper is a contribution of the Institute for Research in Construction, National Research Council Canada.

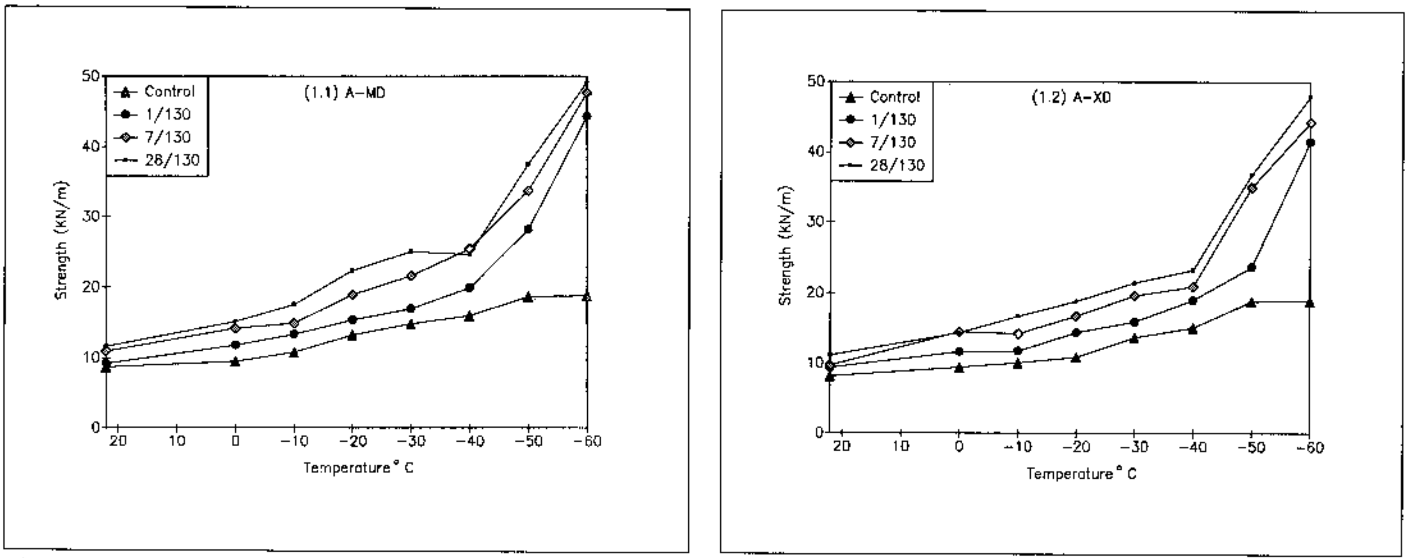

Figure 1.1 *A-MD, Strength-Temperature.*

Figure 1.2 *A-XD, Strength-Temperature.*

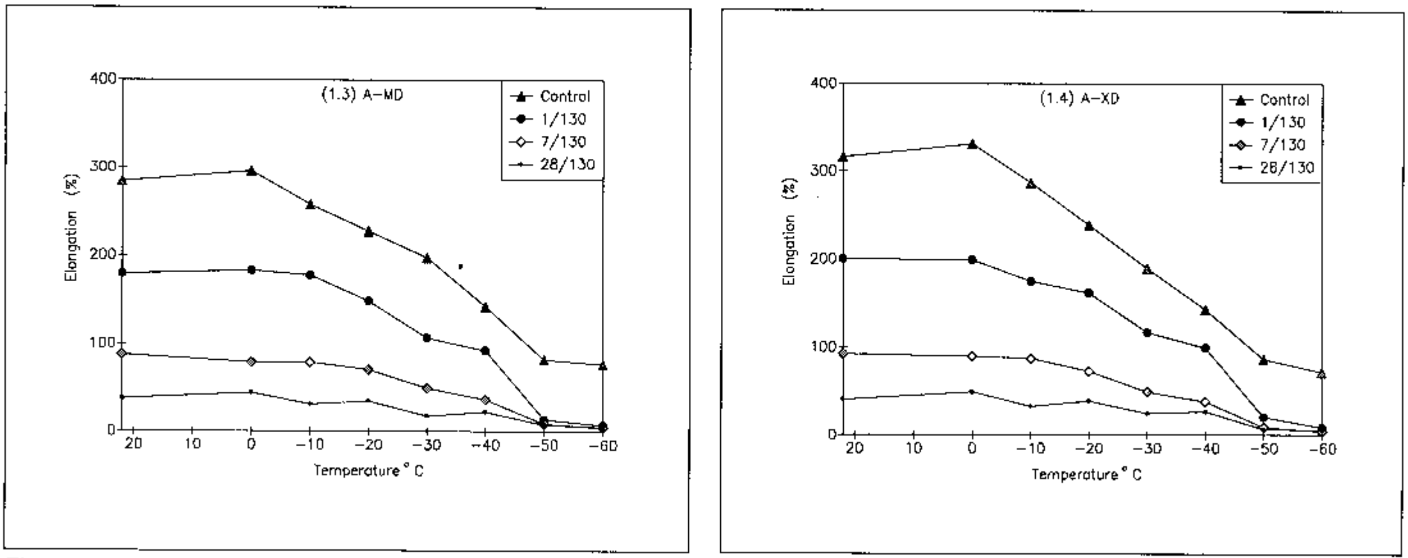

Figure 1.3 *A-MD, Elongation-Temperature.*

Figure 1.4 *A-XD, Elongation-Temperature.*

Figure 1 *EPDM Sample A (non-reinforced)—Control and heat aged at 130°C for one, seven and 28 days, tensile tests at eight temperatures.*

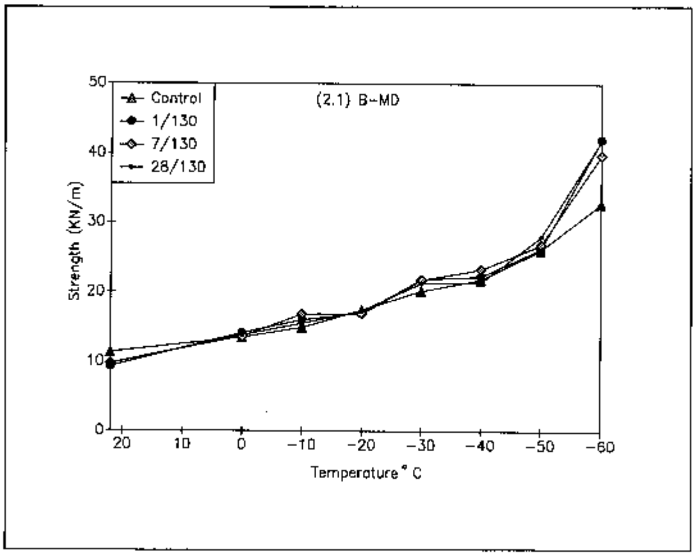

Figure 2.1 B-MD, Strength-Temperature.

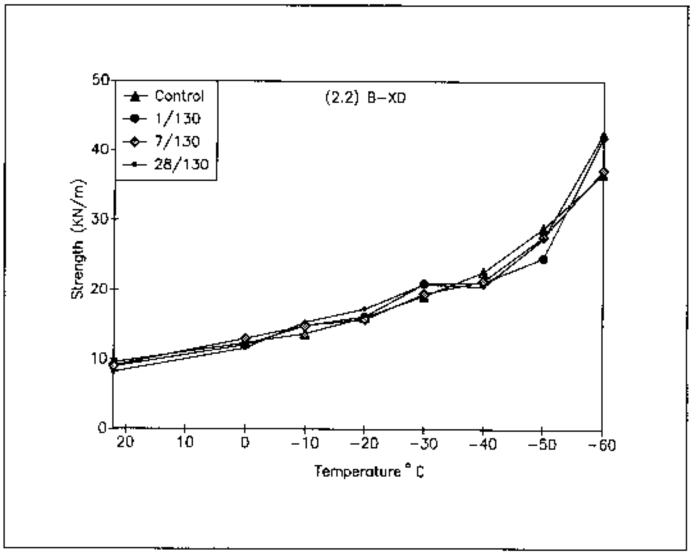

Figure 2.2 B-XD, Strength-Temperature.

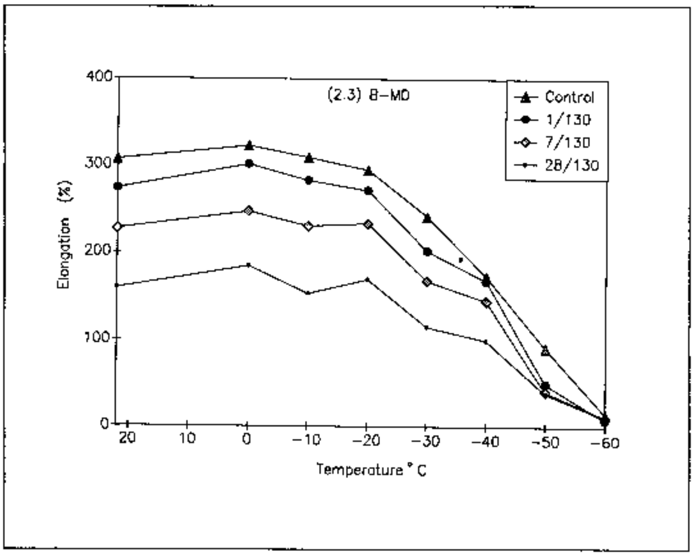

Figure 2.3 B-MD, Elongation-Temperature.

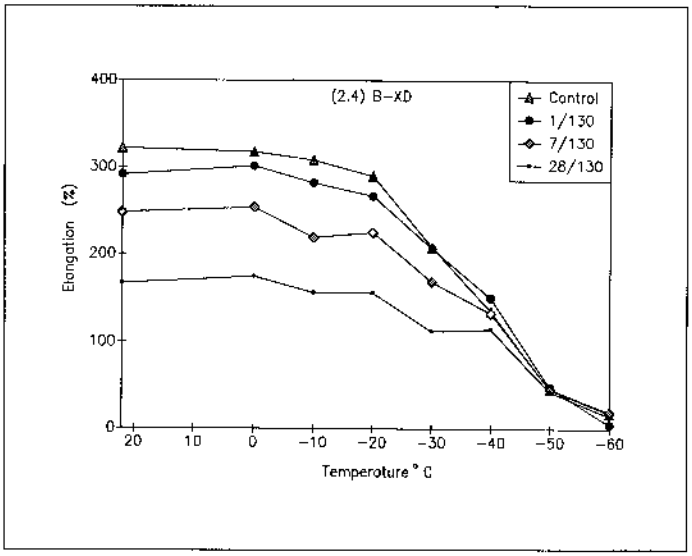

Figure 2.4 B-XD, Elongation-Temperature.

Figure 2 EPDM Sample B (non-reinforced)—Control and heat aged at 130°C for one, seven and 28 days, tensile tests at eight temperatures.

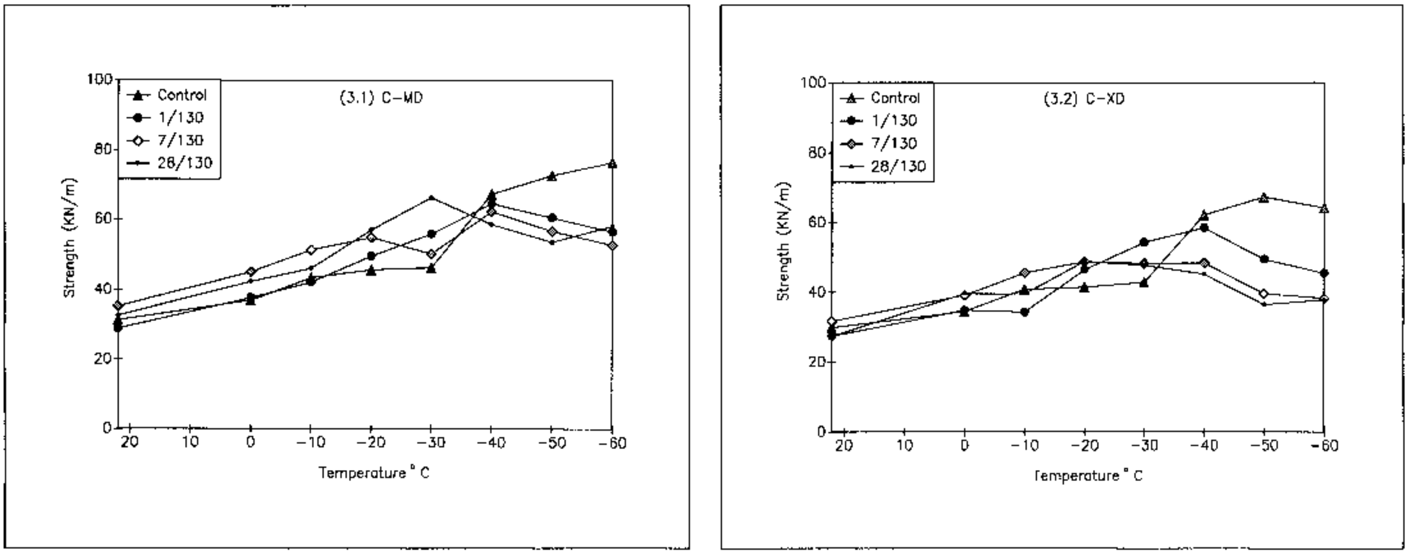

Figure 3.1 *C-MD, Strength-Temperature.*

Figure 3.2 *C-XD, Strength-Temperature.*

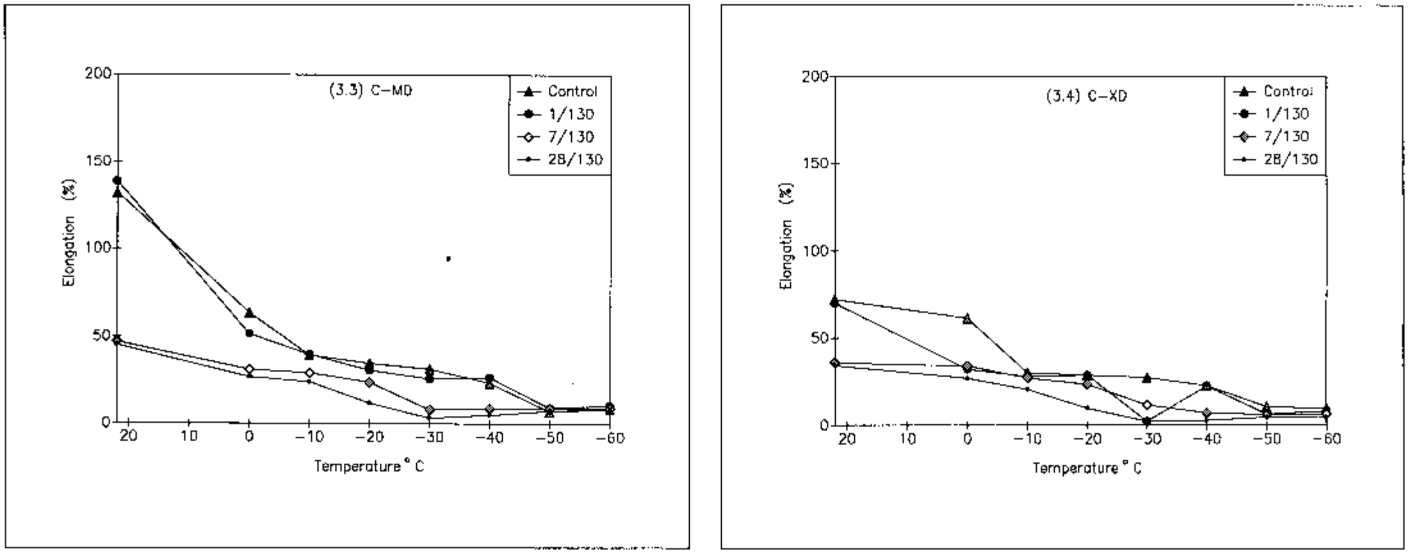

Figure 3.3 *C-MD, Elongation-Temperature.*

Figure 3.4 *C-XD, Elongation-Temperature.*

Figure 3 *PVC Sample C (non-reinforced)—Control and heat aged at 130°C for one, seven and 28 days, tensile tests at eight temperatures.*

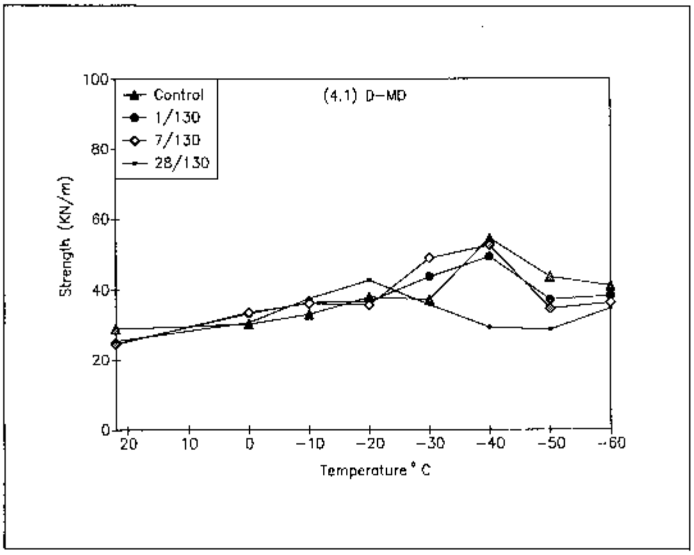

Figure 4.1 *D-MD, Strength-Temperature.*

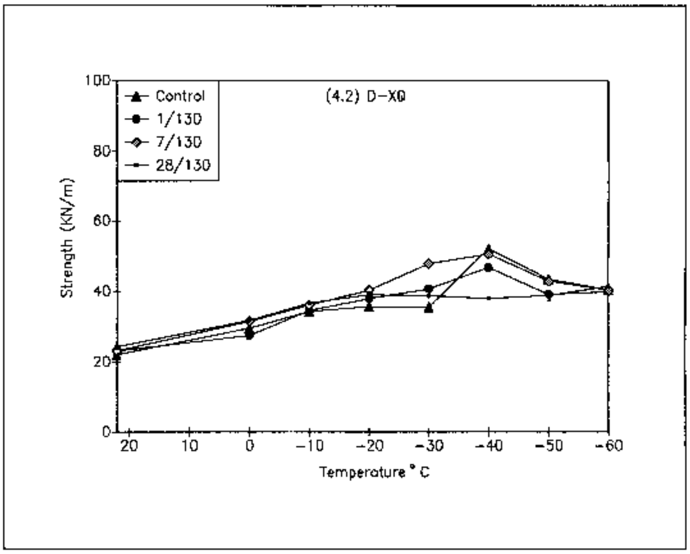

Figure 4.2 *D-XD, Strength-Temperature.*

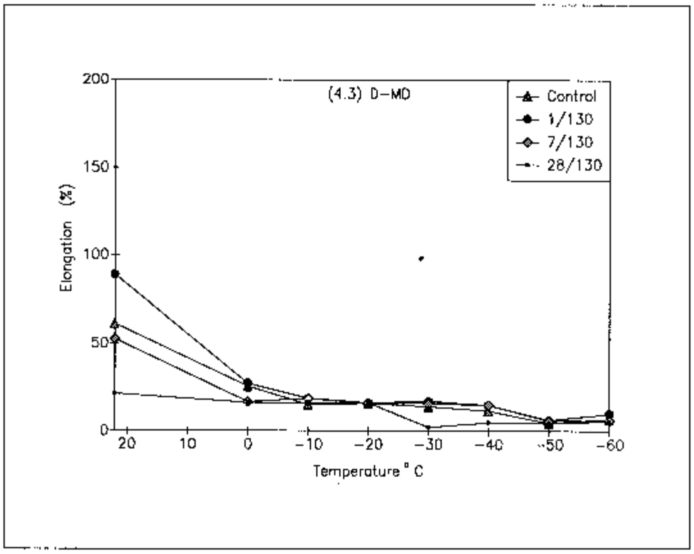

Figure 4.3 *D-MD, Elongation-Temperature.*

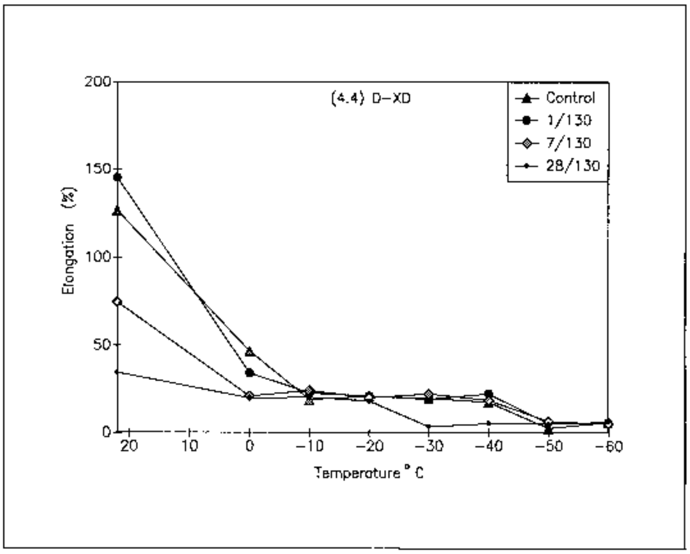

Figure 4.4 *D-XD, Elongation-Temperature.*

Figure 4 *PVC Sample D (non-reinforced)—Control and heat aged at 130°C for one, seven and 28 days, tensile tests at eight temperatures.*

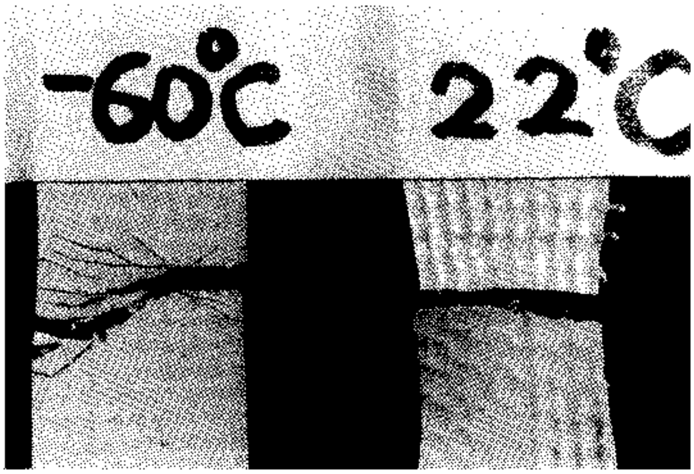

Figure 5 *Breaking pattern of a PVC sample at room temperature and at −60°C.*

Membrane	Reference	Aging	Conditioning	Testing	
		Temp/Duration (°C/h)	Temp/Duration (°C/h)	Temp (°C)	Title
Un-aged Samples					
EPDM	37-GP-52M[1]	—	−40/2	−40	LTF[2]
	D4637[3]	—	−45/4	−45	BPT[4]
PVC	37-GP-54M	—	−30/2	−30	LTF
	D4434	—	−40/4	−40	LTF
EPDM and PVC	Present Research	—	22 to −60/24	22 to −60	CTT[5]
Aged Samples					
EPDM	37-GP-52M	120/240	−40/2	−40	LTF
	D4637	115/670	22/24	22	OT[6]
PVC	37-GP-54M	130/24	22/24	22	OT
	D4434	90/168	22/24	22	OT
EPDM and PVC	Present Research	130/24, 168, 672	22 to −60/24	22 to −60	CTT

1. Canadian General Standards Board (CGSB)
2. Low temperature flexibility/bending/impact test
3. American Society for Testing and Materials (ASTM)
4. Brittleness point test
5. Cold temperature tensile test
6. Other tests e.g. tensile strength, tear strength, elongation, etc.

Table 1 *Exposure requirements for cold temperature testing of single-ply membranes before and after heat aging.*