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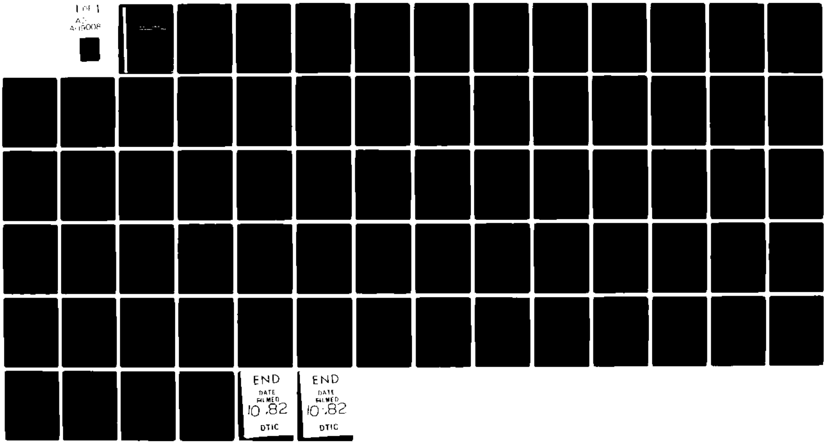

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RESEARCH AND DEVELOPMENT BRANCH
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CANADA

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Environmental Protection Section
Protective Sciences Division

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ABSTRACT

The effect of low temperatures on the shape of the load-elongation curve, the initial modulus, breaking load, percent elongation and work to rupture of 13 coated and uncoated fabrics was examined. It was found that the cotton/synthetic blends were least sensitive to low temperatures, the nylon fabrics, be they coated with polyurethane or neoprene, or uncoated, were more sensitive. The PVC-coated nylon scrims were the most sensitive and, for all practical purposes, completely inappropriate for use at temperatures below 0°C.

RÉSUMÉ

L'effet des basses températures sur la forme de la courbe de charge-allongement, le module initial, la charge de rupture, le pourcentage d'allongement et le travail à la rupture de treize tissus enduits et non enduits a été étudié. Il ressort que les mélanges coton-matières synthétiques sont moins sensibles aux basses températures alors que les tissus de nylon, enduits de polyuréthane ou de néoprène ou non enduits, sont plus sensibles. Les canevas de nylon enduits de chlorure de polyvinyle sont les plus sensibles et, à toutes fins utiles, complètement inutilisables à des températures inférieures à 0°C.

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INTRODUCTION

The purpose of this study is to determine the effect of low temperatures on the pertinent physical properties of a variety of coated and uncoated fabrics. This was undertaken because some fabrics, especially coated ones, are known to become hard and brittle at low winter temperatures. Their usefulness at low temperatures will be determined by their ability to retain their room-temperature properties at these temperatures.

The effect of low temperatures on fabrics can be characterized by changes in the basic shape of their load-elongation curves, and in other mechanical properties such as initial modulus, breaking strength, percent elongation at break, and work of rupture. Considerable previous work has been done to determine the load-elongation curves of fibres, especially at temperatures at and above room temperature, since most textile processing takes place at elevated temperatures. Occasionally low temperatures were included. Graphs reproduced by Morton and Hearle (1) show the effect of -57°C on the load-elongation curves of fibres. The low temperature made them stiffer, with a higher initial modulus, and stronger and less elastic at break.

Coplan and Singer (2) studied the effect of temperature on nylon yarns and fabrics at 177, 99, 21 and -57°C. They found an increase in breaking load and a decrease in extension as the temperature decreased. They gave stress-strain curves for a nylon yarn at +21 and -57°C. The curve at +21°C had no yield point, but a secondary yield point. At -57°C, the opposite was true, the yarn now had a yield point, but no secondary yield point, and they described this as "brittleness" of the yarn.

Two small studies carried out by Russian workers (3,4) looked at the effect of low temperature on the physical properties of fabrics. In the first of two studies, Bozov and Nikitin (3) compared the effect of low temperatures on the strength, elongation, stiffness, crease resistance and components of total deformation of a 70% wool, 30% staple rayon suiting fabric, a 66% wool and 34% polyester suiting fabric and a 100% cotton waterproofed tenting material. For the strength and elongation tests, the specimens were cold-soaked for 2 hours before they were broken. No actual data are given in the report, but they write that the reduction in temperature to -40°C increased the strength of the wool blends significantly (9 to 30%) and reduced that of the cotton fabric (up to 10%). They found that the breaking elongations varied in both the warp and weft direction, particularly for the cotton fabric. In discussing the effect of low temperatures on the various physical properties which they measured, they say that increased moisture content and subsequent formation of ice crystals in the fibre cause irreversible changes in the fibre structure and properties. They also comment that at low temperatures, there is a reduced mobility of the macromolecular chains in the structure of the fibres, resulting in a loss of elasticity.

In the second study (4), Nikitin, Bozov and Somova chose a 'plastic coated' 100% polyamide, a waterproofed 67% polyester, 33% viscose rayon and a "waterproof fabric with water-repellent impregnation" 65% polyester, 35% cotton. They measured the breaking strength and extension at +20, -20, -40 and -50°C. These specimens were cold soaked for 15 minutes before testing. Their results are given in Figure 1. They point out that there is a marked change in strength and extension of the blends at -20°C. They comment that fabrics have increased breaking strength at low temperatures and that viscose rayon or cotton in the blends lessen the effect of cold on the properties of fabrics.

Therefore, because of the lack of a comprehensive study of these effects, the present study was undertaken. A range of thirteen coated and uncoated fabrics were broken at four temperatures, 20, 0, -20 and -40°C, and changes in yield point, secondary yield point, initial modulus, breaking load, percent elongation at break and work to rupture were determined and compared.

METHOD

FABRICS USED

Descriptions of the fabrics used are given in Table 1. The fabrics were selected from existing or experimental Canadian Forces stock to include a range of coated and uncoated fabrics. Fabrics PE/C, N/C-G and N/C-F are uncoated, plain-weave fabrics, PE/C being a polyester and cotton blend, and N/C-G and N/C-F a nylon and cotton blend, N/C-F being the finished and dyed version of N/C-G. Fabrics N-R and N-R-PU are similar ripstop nylons, N-R with water-repellent finish and N-R-PU with one side coated with polyurethane. For this study, N-R is considered to be nominally uncoated. Similarly, N and N-PU are nominally the same fabric, N-PU being polyurethane coated, N not. Fabric N-PU-L is a lighter weight version of N-PU. Fabric N-NE was chosen because of its neoprene finish. Fabrics N-PVC-L, N-PVC-H, N-PVC-HT and N-PVC are all 1×1 nylon scrims laminated with polyvinylchloride (PVC), but of varying counts (about 6×6 or 9×9) and varying weights. They are constructed such that the yarns are imbedded in the PVC.

1. Warp "Plastic-coated"
   100% polyamide
2. Weft "Plastic-coated"
   100% polyamide
3. Warp 67% polyester
   33% viscose
4. Weft 67% polyester
   33% viscose
5. Warp Waterproof fabric
   65% polyester
   35% cotton
6. Weft Waterproof fabric
   65% polyester
   35% cotton

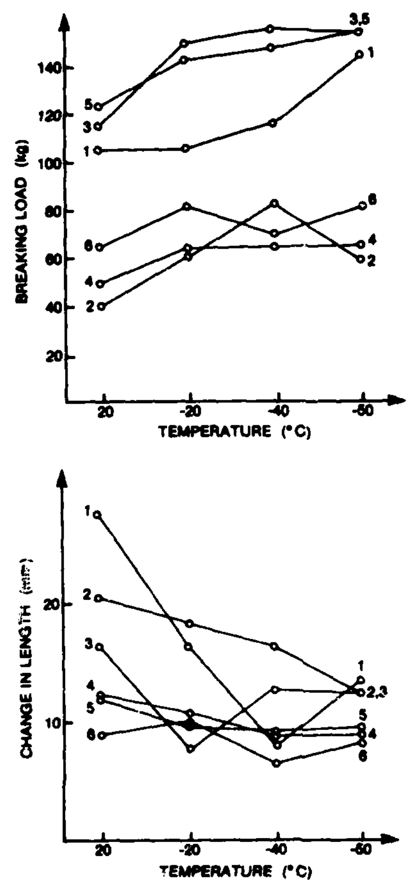

Figure 1: Changes in Breaking Load and Extension of Fabrics at Low Temperatures (Adapted from original (4)).

TABLE 1

Pertinent Physical Properties of the Fabrics

Fabric	Fibre Content	Construction	Finish	Mass (g/cm^2)*	Count (yarns/cm)** Warp	Count (yarns/cm)** Weft	Thickness† (mm)	Designatio
PE/C	65% Polyester 35% Cotton	1×1 poplin	-	167	46	23	0.28	CF-C-778
N/C-G	50% Nylon 50% Cotton	1×1 plain	greige goods	167	23	21	0.48	TEXT 7-6-5
N/C-F	50% Nylon 50% Cotton	1×1 plain	finished & dyed	168	25	20	0.41	X 73-411
N-R	100% Nylon	1×1 ripstop	water repellent	71	43	38	0.10	X 75-405A
N-R-PU	100% Nylon	1×1 ripstop	Polyurethane 1 side	110	43	38	0.13	X 75-404A
N	"	1×1 plain	-	183	21	17	0.30	TEXT 7-1-2
N-PU	"	1×1 plain	Polyurethane 1 side	283	25	16	0.38	CF-C-744
N-PU-L	"	1×1 plain	Polyurethane 1 side	172	29	17	0.20	D 80-001-002/ SF-001
N-NE	"	2×1 twill	Neoprene 1 side	169	47	44	0.18	X71-409
N-PVC-L	"	1×1 scrim laminated with PVC		330	9	9	0.30	X77-420
N-PVC-H	"	"		571	6	5	0.64	X77-421
N-PVC-HT	"	"		661	6	6	0.74	CF-C-698
N-PVC	"	"		586	9	8	0.53	MIL-C-20696C

* CAN 2-4.2-M77 Method 5.A.
** CAN 2-4.2-M77 Method 6
† Measured at 0.16 kPa, CAN 2-4.2-M77 Method 37.

EXPERIMENTAL METHOD

The tests were carried out in an environmental chamber fitted onto an Instron, Model 1102. The chamber was cooled with solid carbon dioxide placed in the bottom of the chamber. Since Buzov and Nikitin (3) point out specifically that moisture in the specimens can affect their breaking characteristics, an attempt was made to prevent moisture from penetrating into the fabrics, despite the fact that the tests had to be carried out in a conditioning room, set at 20°C ± 1°C, 65% R.H. ± 5%. The specimens were placed in a desiccator containing Drierite for 24 hours prior to testing. The specimens were removed from the desiccator, one at a time, and fitted into the jaws of the Instron inside the environmental chamber. At 20°C, the specimens were broken immediately. For the other temperature, the specimens were cold-soaked for 15 minutes before they were broken. At 0°C, it took 2 minutes of the 15-minute period for the chamber to come back down to this temperature after the opening and closing of the chamber door, 3 minutes at -20°C and 5 minutes at -40°C. The tests were carried out in accordance to CAN 2-4.2 M77, Method 9.1, Breaking Strength of Fabrics - Strip Method (Constant-Time-to-Break Principle), with, obviously, a modification to the conditioning procedure. In order to prevent the specimens from slipping, the jaws were lined with emery paper.

METHOD OF ANALYSIS

Figure 2 is an idealized load-elongation curve for a woven fabric. The "secondary yield point" has been added to the parameters which conventionally describe this curve because, for many of the fabrics, its presence or absence was temperature-dependent. Rennell (5) calls the secondary yield point "a 'hardening' point". However, we think that "secondary yield point" defines this point more accurately, as hardening occurs before this point and yielding after. (It may be that, for fabrics, gross changes in fabric and yarn structures contribute to the first yield point, and changes in polymer-chain configuration cause the secondary yield point.) In this study, the yield point is defined as occurring at a low load and low elongation and the secondary yield point at a high load and high elongation. For clarity, the yield point is occasionally called the conventional yield point. The method used to measure all the secondary yield points and most of the yield points was that proposed by Meredith (as reported by Morton and Hearle in Physical Properties of Textile Fibres (1)) for determining yield points, i.e., the yield and secondary yield points are the successive points at which the tangent to the curve is parallel to the line joining the origin to the breaking point as illustrated in Figure 3a. For a few curves whose yield points could not be found in this way, a modification of Coplan's construction (as reported by Morton and Hearle in Physical Properties of Textile Fibres (1))

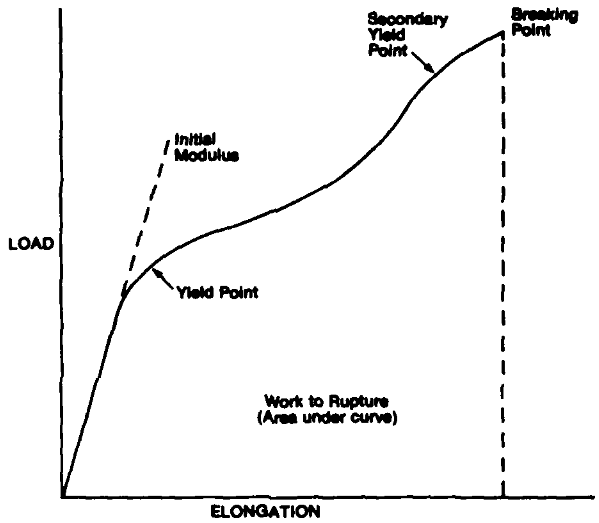

Figure 2: Idealized Load-Elongation Curve for a Woven Fabric.

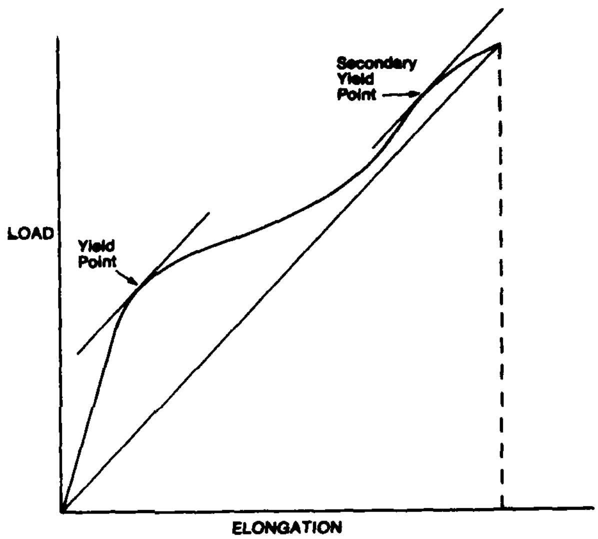

Figure 3a: Determination of Yield Point and Secondary Yield Point by Meridith's Method.

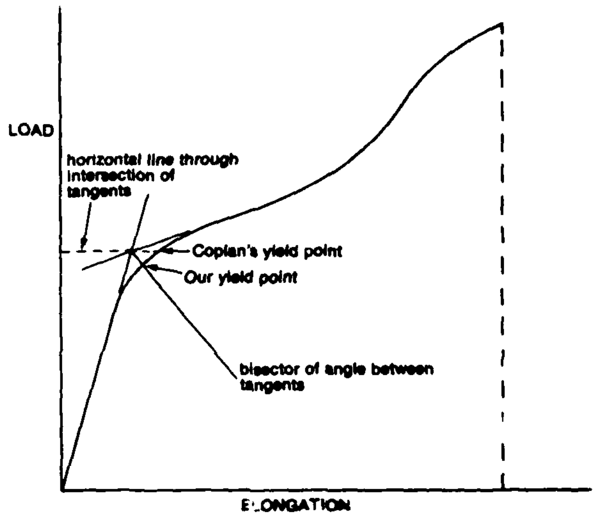

Figure 3b: Determination of Yield Point by the modified Coplan method. For this idealized curve, our yield point coincides with the one obtained by Meridith's method.

was used as illustrated in Figure 3b. By using the bisector of the tangents to obtain the yield point rather than using the horizontal line drawn through the intersection of the two tangents, one gets a yield point which is closer to the yield point as found by Meredith's method.

Examination of the results showed that there can be considerable variation in the behaviour between the warp and weft of the same fabric and among materials of nominally the same fibre content and coating. Therefore, the general characteristics of the load-elongation curves as shown by the presence or absence of yield and secondary yield points will be discussed qualitatively, the coordinates of these points being given in tables for completeness.

As stated earlier, considerable work has been done on the stress-strain characteristics of fibres, and to a lesser extent on yarns. Although there are variations in the shape of the curve for any one polymer, there is more or less a characteristic shape for a particular polymer. Figure 4 shows typical specific stress-strain curves for polyester, nylon and cotton fibres (6). The curve for polyester fibre can terminate at any point along the curve, depending on the type of polyester and its history, i.e., it can have a yield and a secondary yield point as shown here, or just the conventional yield point. Hearle et al (7) give load-elongation curves for polyester yarns which are similar to the curve for the polyester fibre, with only the conventional yield point. The load-elongation curves of nylon yarns as given by Hearle et al, have shapes similar to the curve given here for the polyester yarns.

Unlike the fibres, there is not really a 'standard' curve for the coatings, polyurethane, PVC and neoprene, because of the great variation in plasticizers, formulation, heat treatment, etc. of these materials.

The shape of the load-elongation curve of each fabric at 20°C will be compared to the shapes of the fibre or yarn curves.

The actual measurements of initial modulus, breaking load, percent elongation at break and work to rupture was quite straightforward. However, arriving at a method to compare the results was more difficult. In engineering, the breaking load, for instance, is normalized in order to compare materials of different shapes and composition. To do this, the breaking load is divided by the area of cross-section of the material to give specific stress. However, for textiles, the area of cross-section of fibres and yarns is not well defined and a more convenient quantity based on the mass of the specimen is conventionally used, i.e. the specific stress is the load divided by the mass per unit length. If the concept of using mass per unit length is applied to fabrics, the mass per unit area would be the normalizing factor. However, variables such as the type of weave, thread count, yarn twist and interyarn friction are ignored in this simplistic treatment. In this study, some fabrics had the added variable of a coated continuous film on one or both sides of the fabric, which, while adding substantially to the total mass of the specimen, may not have contributed proportionally to the strength. Thus it was concluded that normalization of this set of specimens based on mass per unit area is not appropriate.

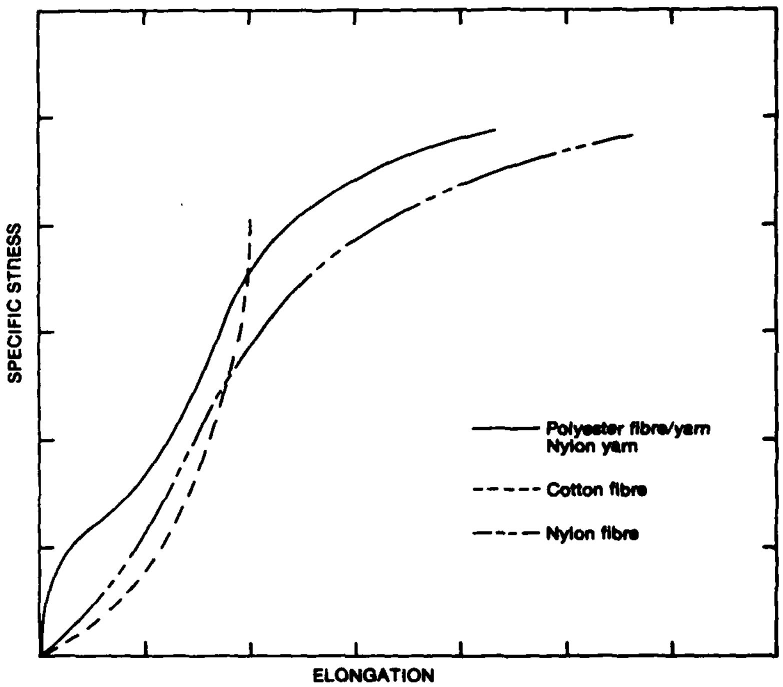

Figure 4: Characteristic Specific Stress-Elongation of Fibres and Yarns.

Therefore, the results of the effect of temperature on the initial modulus, breaking load, percent elongation and work to rupture for each fabric are only compared statistically here. This was done by using a paired t-test to compare the parameters at 20 and 0, 0 and -20, and -20 and -40°C. The maximum increase and minimum decrease in each of the four parameters, calculated as a percent of the 20°C value, are also given.

As mentioned earlier, the results show that there can be considerable variation in behaviour between the warp and weft of the same fabric. Further, the change in breaking load and the change in percent elongation with temperature were not always consistent. This resulted in changes in work to rupture, which, for the most part, reflected the product of changes in breaking load and in elongation. Therefore, because of the cumulative variability of the work-to-rupture results, these results are presented, but not discussed.

It is noted that some of the curves, especially for the uncoated fabrics at the higher temperatures, have a small 'run-in' which probably is the crimp being removed from the yarns as stress is applied to them. This 'run in' was included in the calculation of percent elongation and work to rupture because it tended to disappear as the fabrics were broken at the lower temperatures, and thus is a real part of the curve for the present comparisons.

RESULTS

Typical load-elongation curves for each fabric at the four temperatures are given in Appendix A. Also given in Appendix A are the mean values and coefficient of variation of the initial modulus, breaking load, percent elongation and work to rupture for each fabric at the four temperatures, and the related statistical analysis. The presence or absence of yield and secondary yield points is noted; if either is present, the mean of its coordinates for that temperature is recorded.

In Tables 2 to 4, the pertinent information from Appendix A is summarized.

COTTON BLENDS

The load-elongation curves of the 50% nylon-50% cotton blends, N/C-G and N/C-F, at 20°C are concave, similar to the cotton-fibre curve or the first part of the nylon fibre curve. As the temperature is lowered,

TABLE 2

Summary of Parameters for Cotton Blends

	Temperature/ Temperature Change	Fabric N/C-G Warp	N/C-G Weft	N/C-F Warp	N/C-F Weft	PE/C Warp	PE/C Weft
Yield Point	20°C	--	--	--	--	x	x
	0°C	--	--	--	--	x	x
	-20°C	--	--	--	vvsl	x	x
	-40°C	--	--	vvsl	vvsl	x	x
Secondary Yield Point	20°C	--	vvsl	--	--	--	--
	0°C	--	vvsl	--	--	--	--
	-20°C	vvsl	x	--	vvsl	--	--
	-40°C	vvsl	x	x	vsl	--	--
Initial Modulus	20 to 0°C	--	--	--	--	0	0
Breaking Load		+	+	+	+	+	+
Percent Elongation		+	+	+	+	+	0
Work to Rupture		+	+	+	+	+	0
Initial Modulus	0 to -20°C	--	--	--	--	+	+
Breaking Load		0	0	0	+	0	0
Percent Elongation		-	0	0	0	-	0
Work to Rupture		+	0	0	+	0	+
Initial Modulus	-20 to -40°C	--	--	--	--	+	+
Breaking Load		0	0	0	0	0	0
Percent Elongation		0	0	0	0	-	0
Work to Rupture		0	0	0	0	-	0

x = presence
-- = absence
vsl = very slight
vvsl = very very slight
\+ = statistically significant increase
\- = statistically significant decrease
0 = no significant change

TABLE 3

Summary of Parameters for Coated and Uncoated Nylons

	Temp./ Temp. Change	Fabric											
		N		N-PU		N-R-PU		N-R		N-PU-L		N-NE	
		Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Yield Point	20°C	--	x	x	x	x	--	x	--	x	--	x	x
	0°C	--	x	vsl	x	x	--	--	--	x	--	x	x
	-20°C	vsl	x	x	x	x	x	x	--	x	vsl	x	x
	-40°C	vsl	x	x	x(2)	x	x	x	--	x	x	x	x
Secondary Yield Point	20°C	vsl	x	x	x	x	x	x	x	x	x	x	x
	0°C	x	x	x	x	x	x	x	x	x	x	x	x
	-20°C	x	x	x	x	x	x	x	vvsl	x	x	x	x
	-40°C	vsl	x	--	x	--	--	x	--	vsl	--	vsl	x
Initial Modulus	20 to 0°C	0	0	--	0	0	--	--	--	0	--	-	-
Breaking Load		+	+	+	+	0	0	+	+	+	+	+	+
Percent Elongation		+	+	+	0	0	0	+	+	+	+	+	0
Work to Rupture		+	+	+	0	0	0	+	+	+	+	+	0
Initial Modulus	0 to -20°C	+	+	--	+	+	--	--	--	+	--	+	+
Breaking Load		+	+	+	+	+	+	+	+	0	+	0	0
Percent Elongation		-	-	-	0	-	0	-	-	-	-	-	-
Work to Rupture		0	0	0	0	-	+	0	-	-	-	0	0
Initial Modulus	-20 to -40°C	0	0	+	0,+	+	+	+	--	+	+	+	+
Breaking Load		0	0	-	0	-	-	0	0	0	-	0	+
Percent Elongation		0	0	-	-	-	-	0	0	0	-	0	0
Work to Rupture		+	0	-	-	-	-	0	0	0	-	0	0

TABLE 4

Summary of Parameters for PVC-coated Nylon Scrims

	Temp./ Temp. Change	Fabric							
		N-PVC-L		N-PVC-H		N-PVC-HT		N-PVC	
		Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Yield Point	20°C	x	x	x	x	x	x	x	--
	0°C	x	x	x	x	x	x	x	x
	-20°C	x	x	x	x	x	x	x	x
	-40°C	x	x	x	x	x	x	x	x
Secondary Yield Point	20°C	x	x	x	x	x	breaks	x	--
	0°C	x	x	x	x	x	x	vsl	--
	-20°C	breaks	breaks	breaks	x	x	x	vsl	--
	-40°C	breaks	breaks	breaks	breaks	vvsl	breaks	breaks	--
Initial Modulus	20 to 0°C	+	+	+	+	+	a.	0	--
Breaking Load		+	+	+	+	+	+	+	+
% Elongation		+	+	0	+	0	0	0	0
Work to Rupture		+	+	+	+	+	+	0	+
Initial Modulus	0 to -20°C	+	+	+	+	0	a.	+	+
Breaking Load		-	0	0	+	+	+	0	0
% Elongation		-	-	-	-	0	0	0	-
Work to Rupture		-	-	0	0	0	-	0	0
Initial Modulus	-20 to -40°C	+	+	0	+	+	a.	+	+
Breaking Load		0	0	0	-	0	0	-	0
% Elongation		0	0	0	-	0	0	-	0
Work to Rupture		0	0	0	-	0	0	-	0

a. Has measurable Initial Modulus at +20 and -40°C. Has 2 slopes at 0 and -20°C.

N/C-F developed a slight yield point and a secondary yield point. Fabric N/C-G did not develop a yield point as the temperature was decreased, but did develop a slight secondary yield point in the warp direction and a distinct one in the weft direction. Fabric N/C-F has been finished under tension, so its yarns are in an extended state. Therefore, it would seem that any stiffening of this fabric due to the lower temperatures is sufficient to cause yield and secondary yield points to appear. Fabric N/C-G is the greige goods of N/C-F, and has yarns which are still in a relatively relaxed state in the fabric. Although N/C-G did stiffen at the lower temperatures as indicated by its secondary yield points, it was still sufficiently relaxed that the low temperatures did not affect its ability to extend easily at low loads as shown by its lack of conventional yield point. Although N/C-F developed slight conventional yield points, it did not have measurable initial modulus. The breaking load and percent elongation increased significantly from 20 to 0°C for both fabrics and then remained more or less the same for further decrements in temperature.

The load-elongation curve of the 65% polyester, 35% cotton blend, PE/C, has a truncated polyester-fibre curve at 20°C. At all four temperatures, the curves have yield points, but not secondary yield points. However, as the temperature was decreased from 0 to -20 and from -20 to -40°C, there was a significant increase in the initial modulus of this fabric. The warp direction of this fabric behaved similarly to the nylon/cotton blends N/C-G and N/C-F with a significant increase in breaking load and percent elongation from 20 to 0°C. The breaking load remained the same and the percent elongation decreased as the temperature was lowered to -40°C. In the weft direction, the percent elongation remained incrementally unchanged as the temperature was decreased. The breaking load increased from 20 to 0°C and then it too remained unchanged through to -40°C.

NYLON FABRICS

As mentioned earlier, two pairs of polyurethane-coated and uncoated fabrics were selected. Fabric N is the uncoated version of N-PU, and N-R the nominally uncoated ripstop nylon version of N-R-PU. The other two fabrics in this series are N-PU-L, another polyurethane-coated nylon and N-NE, a neoprene-coated nylon.

At 20°C, the load elongation curves of N-R-PU warp, N-R warp, N-PU-L warp and N-NE warp and weft have yield and secondary yield points similar to the nylon-yarn curves. The weft directions of N-R, N-R-PU and N-PU-L have only secondary yield points, making them similar to the nylon-fibre curves.

The fabrics which had conventional yield points retained them through to -40°C, with the exception of N-R warp which lost its yield point only at 0°C. Fabric N-R-PU weft and N-PU-L weft acquired yield points at -20 and N-R weft did not stiffen enough to acquire one.

Fabric N-R-PU warp and weft, N-R weft, N-NE warp and N-PU-L warp and weft all stiffened sufficiently at -40°C to break before measurable secondary yield points were reached. N-R warp and N-NE weft retained their secondary yield points throughout.

Some of the load-elongation curves of the plain nylon, N, and its coated version, N-PU, were difficult to analyze. Apparent yield and secondary yield points, and initial moduli, were generally visible, but it was a matter of conjecture whether or not some of them were measurable or even whether or not they existed. Therefore, no conclusive comments will be made on these curves. Fabric N-PU weft did have two distinct yield points at -40°C. This may indicate that the polyurethane coating and the nylon fabric were yielding at different loads at this temperature.

When a comparison of initial modulus could be made, there was no change from 20 to 0°C for N, N-PU, N-R-PU and N-PU-L and a decrease for N-NE; as the temperature was lowered to -40°C, there was an increase in initial moduli for all fabrics except N which had no change from -20 to -40°C.

The behaviour of the breaking load and percent elongation with temperature decrease is identical for the two uncoated nylons, N and N-R. Their breaking load increased continually through to -20°C, then stayed the same to -40°C. Their percent elongation increased to 0°C and then decreased to -40°C. With the exception of the occasional difference between the warp and weft, the polyurethane-coated nylon, N-PU-L, followed the same pattern for breaking load and percent elongation, the polyurethane coated nylon, N-PU, for just the breaking load, and N-NE, the neoprene-coated nylon, just for the percent elongation. The change in percent elongation of N-PU differed for its warp and weft, but the trend was for an increase in percent elongation from 20 to 0°C and then a decrease to -40°C, as N and N-R. The breaking load of N-NE increased to 0°C and stayed the same to -20°C, then tended to increase to -40°C. The behaviour of this neoprene-coated fabric does not distinguish it from the other nylons discussed above.

Fabric N-R-PU's behaviour was dissimilar to the other five nylons. Its breaking load and percent elongation did not change from 20 to 0°C. Between 0 and -20°C, its breaking load increased and its percent elongation tended to decrease. From -20 to -40°C, both its breaking load and percent elongation decreased. Thus, it would appear that it is the polyurethane coating of N-R-PU which is more resistant to changes in temperature than the other polyurethane-coated fabrics, its properties not being affected until -20°C is reached.

PVC-COATED NYLON SCRIMS

The PVC-coated nylon scrims, N-PVC-L and N-PVC-H, had similar PVC coatings, with N-PVC-L being the lighter weight, more closely-woven scrim of the two. At 20°C, both had load-elongation curves similar to the nylon-yarn curve, i.e. they both had yield and secondary yield points. They both retained their conventional yield points as the temperature was decreased.

At the lower temperatures, the PVC coatings became brittle, shattered and flew off in all directions, coating the inside of the environmental chamber. The irregular breaks in their load-elongation curves show the sudden failures in the coating (Figure 5).

For N-PVC-L the initial modulus, breaking load and percent elongation increased significantly from 20 to 0°C with the initial modulus continuing to increase significantly through to -40°C. From 0 to -20°C, there was a decrease in breaking load and percent elongation, and then once the coatings started to shatter, there was no change in either parameter, indicating that N-PVC-L had reached its maximum brittleness at -20°C for the range of temperatures considered here.

Fabric N-PVC-H followed much the same pattern as N-PVC-L, with N-PVC-H weft reaching its maximum brittleness at -40°C rather than -20°C.

Fabric N-PVC-HT was the heaviest and thickest of the four PVC-coated nylon scrims. It had a PVC coating which appeared to have more plasticizer in it than the others. At 20°C, N-PVC-HT had load-elongation curves similar to N-PVC-L and N-PVC-H, the nylon-yarn curve. In the weft direction, it had irregular breaks at 20°C due to the fact that the nylon yarns in the middle of the specimen broke first, then the coating covering these yarns broke. The outer nylon yarns were then pulled back through the coating, at which point the coating covering these yarns broke. This type of break always occurred at the upper jaw and may have been avoided if larger jaws had been used. However, wider jaws did not fit into the environmental chamber which was required for the lower temperatures. The same type of break was observed, although to a lesser extent, on the chart trace for some of the specimens at 0 to -20°C, and was more distinct at -40°C. Actual observation was impossible because of frosting of the environmental chamber window.

When the curves of N-PVC-HT weft were analyzed, conventional yield points were present at all four temperatures. At 20 and -40°C, there was a distinct and measurable initial modulus, but at 0 and -20°C, there were two slopes in this yield region. Since the coating and scrim were acting independently at break, it is probable that the two were yielding independently of each other due to differences in hardening at the lower temperatures. At -40°C, both were either equally hard and yield together, or one of the two had become so stiff that its yielding masked that of the other, resulting in one distinct initial modulus.

The breaking load of N-PVC-HT warp and weft increased from 20 to -20°C, then remained unchanged. The percent elongation remained unchanged throughout.

The last PVC-coated nylon, N-PVC, was tactilely the most rigid of the series. At 20°C, it had a nylon-yarn type curve in the warp direction and a concave nylon-fibre type curve in the weft. In the warp direction, it retained its conventional yield characteristics throughout. At 0 and -20°C, its secondary yield point became slight, indicating that it was breaking before its secondary yield point was reached. At -40°C, a jagged trace was produced before the main break by shattering of the coating. However, this occurred with less violence than was the case with N-PVC-L and N-PVC-H.

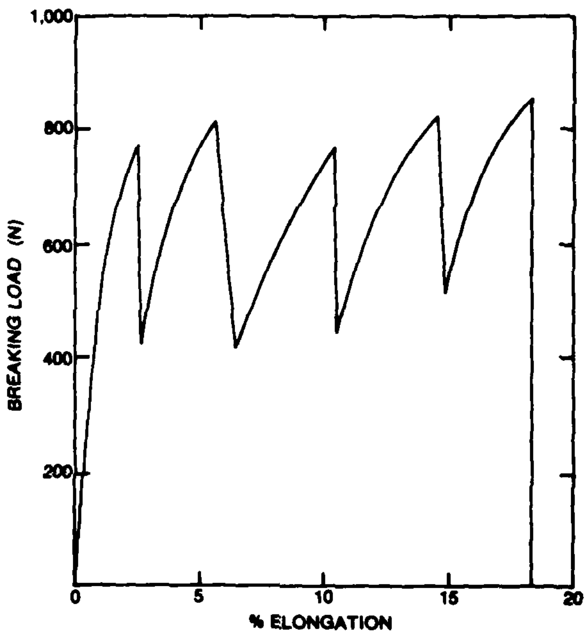

Figure 5: Load-Elongation Curve of N-PVC-L Weft at -40°C.

In the weft direction, it stiffened sufficiently for a yield point to appear at 0°C and remain through -20 and -40°C, but it did not acquire a secondary yield point as the temperature decreased. It is a matter of conjecture whether the weft was so hard that it broke before the secondary yield point was reached, or whether it just extended easily at high loads. Because of this distinct behaviour, N-PVC was examined carefully and it was found that it was relatively easy to delaminate the PVC manually from the scrim in the weft direction only; it was impossible to delaminate the PVC film manually from the other PVC-coated nylons, in either direction. Therefore, it is possible that the PVC film was delaminating from the nylon scrim of N-PVC weft under severe tension as experienced at the upper limit of the load-elongation curve and that this curve was, in fact, the resultant of the load-elongation curve of the PVC film and the nylon scrim. The fact that the PVC film did not break in the weft direction as it did in the warp direction supports this view. Since the PVC film was not in intimate contact with the nylon scrim in the weft direction, the two materials were able to break smoothly on their own. The load-elongation curve of N-PVC weft at -40°C is shown in Figure 6 because of its distinctive yield point. This curve is not typical of conventional textile materials, but rather similar to the ones given for plastics by Billmeyer (8) who describes such a curve as being characteristic of a "hard and tough" polymeric material.

Examining its measured properties, we found a significant increase in initial modulus as the temperature was decreased. Its breaking load increased from 20 to 0°C and then remained the same or decreased. The percent elongation either stayed the same or decreased with temperature.

MAGNITUDE OF CHANGES

The foregoing dealt, in part, with the statistically significant differences of initial modulus, breaking load and percent elongation for incremental decreases in temperature. Of equal interest are the gross changes in these three parameters from their initial values at 20°C. Tables 5 and 6 give the maximum increase and minimum decrease expressed as a percent of their 20°C value and the temperature at which these occur for the initial modulus, breaking load, percent elongation, and for completeness, work to rupture. Since we are looking at differences between <u>any</u> temperature and 20°C, the statistical patterns described previously do not necessarily apply here.

For the fabrics which had initial modulus at 20°C, there was never a decrease in this parameter, and the maximum increase always occurred at -40°C. The coated fabrics, polyurethane, neoprene and PVC, had increases in initial modulus of over 100%, the uncoated fabrics less than 75%, indicating that the coated fabrics are stiffening more than the uncoated ones at low loads.

Turning to the breaking load, we found that all fabrics had an increase in this parameter from their 20°C value, the temperature at which this occurred varying with the fabric, as it was statistically shown

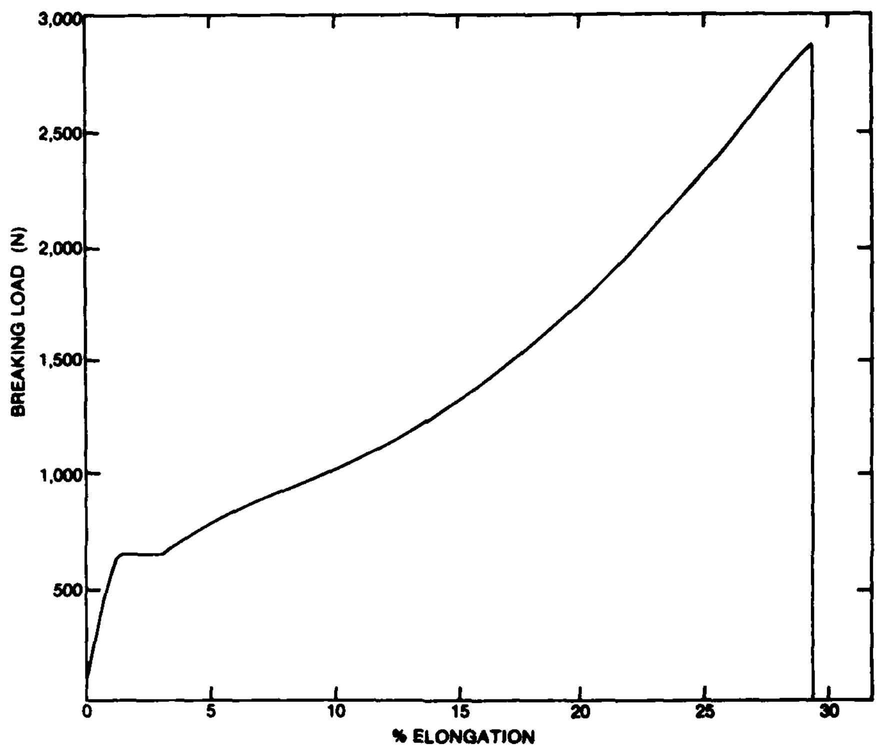

Figure 6: Load-Elongation Curve of N-PVC Weft at -40°C.

TABLE 5

Maximum Increase of Cited Properties, Expressed as a Percent of the +20°C Value

Fabric		Initial Modulus	Temp (°C)	Breaking Load	Temp (°C)	% Elongation	Temp (°C)	Work to Rupture	Temp (°C)
N/C-G	warp	-	-	29	-40	12	0	62	-40
	weft	-	-	34	-40	13	0,-40	98	-40
N/C-F	warp	-	-	26	-40	12	0	65	-40
	weft	-	-	39	-20	13	0,-20	66	-20
PE/C	warp	40	-40	27	0,-20	16	0	42	0
	weft	36	-40	19	-40	—	—	23	-40
N	warp	47	-40	39	-40	26	0	102	-40
	weft	74	-40	29	-20,-40	12	0	27	-20
N-PU	warp	117	-40	51	-20	41	0	105	0
	weft	23,119	-40	31	-40	—	—	5	0
N-R-PU	warp	133	-40	16	-20	—	—	0	—
	weft	none at	+20	24	-20	—	—	18	-20
N-R	warp	64	-40	34	-20	52	0	100	0
	weft	none		23	-20,-40	28	0	47	0
N-PU-L	warp	142	-40	28	-40	11	0	28	0
	weft	none at	+20	30	-20	24	0	58	0
N-NE	warp	360	-40	30	-40	17	0	34	0
	weft	510	-40	36	-40	—	—	12	-40
N-PVC-L	warp	800	-40	38	0	22	0	108	0
	weft	671	-40	24	0	7	0	46	0
N-PVC-H	warp	204	-40	30	-20	4	0	27	0
	weft	690	-40	36	-20	19	0	57	-20
N-PVC-HT	warp	102	-40	31	-40	—	—	25	-20
	weft	270	-40	64	-40	—	—	60	0
N-PVC	warp	175	-40	20	-20	0	0	27	-20
	weft	none at	+20	17	-40	3	0	19	-40

TABLE 6

Minimum Decrease of Cited Properties, Expressed as a Percent of the +20°C Value

Fabric		Initial Modulus	Temp (°C)	Breaking Load	Temp (°C)	% Elongation	Temp (°C)	Work to Rupture	Temp (°C)
N/C-G	warp	—	—	—	—	—	—	—	—
	weft	—	—	—	—	—	—	—	—
N/C-F	warp	—	—	—	—	—	—	—	—
	weft	—	—	—	—	—	—	—	—
PE/C	warp	—	—	—	—	14	-40	—	—
	weft	—	—	—	—	7	-40	—	—
N	warp	—	—	—	—	—	—	—	—
	weft	—	—	—	—	10	-40	—	—
N-PU	warp	—	—	—	—	16	-40	—	—
	weft	—	—	—	—	71	-40	160	-40
N-R-PU	warp	—	—	1	-40	120	-40	133	-40
	weft	—	—	—	—	52	-40	28	-40
N-R	warp	—	—	—	—	10	-40	—	—
	weft	—	—	—	—	21	-40	9	-40
N-PU-L	warp	—	—	—	—	13	-20,-40	—	—
	weft	—	—	—	—	50	-40	30	-40
N-NE	warp	—	—	—	—	16	-40	—	—
	weft	—	—	—	—	26	-20	14	-40
N-PVC-L	warp	—	—	—	—	92	-40	14	-40
	weft	—	—	—	—	59	-40	13	-20
N-PVC-H	warp	—	—	—	—	37	-40	—	—
	weft	—	—	—	—	16	-40	—	—
N-PVC-HT	warp	—	—	—	—	21	-40	—	—
	weft	—	—	—	—	8	-40	—	—
N-PVC	warp	—	—	1	-40	22	-40	1	-40
	weft	—	—	—	—	21	-40	—	—

previously. Within experimental error, none of the fabrics decreased in breaking load from that at 20°C.

The magnitude of the maximum increase in breaking load for all the fabrics was about the same, a mean increase of 29% for the cotton blends, 31% for the uncoated nylons, 30% for the polyurethane coated nylons, 33% for the neoprene coated fabric and for the PVC coated nylons.

The maximum increase in percent elongation for the majority of the fabrics occurred at 0°C. It was expected that since the breaking load of the fabrics was increasing from 20°C to 0°C, some stiffening of the fabrics was occurring, and so logically the percent elongation of the fabrics should decrease. Since this was not the case, samples of the fabrics were dried over a desiccant and the change in weight after 15 minutes exposure to approximately 20°C, 30-40% humidity (the equivalent saturation vapour pressure at 0°C) was measured. The 15-minute period was chosen as this was the length of time the specimens were cold-soaked at 0°C before being broken. All the samples picked up some moisture in that time, the PVC's the least (approximately 0.05%) and the cotton/nylon blends the most (approximately 1.5%). Because of the Russian studies of Buzov and Nikitin, the method for breaking the specimens was chosen to eliminate as much moisture from the specimens as possible. However, it appears that at 0°C there was sufficient moisture pickup by the specimens in the 15-minute cold-soak period to make the yarns and fibres slide easily over each other, although the majority of the fabrics were getting stiff in the cold. This would account for the increase in both the breaking load and percent elongation at this temperature, and the loss of yield point of N-R warp.

The minimum decrease in percent elongation occurred for the majority of the fibres at -40°C, with the exception of the cotton/nylon blends whose percent elongations did not decrease below their original value at +20°C. The variation in the percent elongation was much greater than that for the breaking load for fabrics within a group. The decrease for uncoated nylons ranged from 10 to 21%, polyurethane-coated nylons from 10 to 71%, the neoprene-coated nylon, 16 to 26%, and the PVC-coated nylon scrims from 8 to 92%.

GENERAL SUMMARY AND DISCUSSION

The load elongation curves of the fabrics at 20°C are typical of textile fibres or yarns, whether coated or not, indicating that either the load-elongation curves of the polyurethane, neoprene or PVC are similar to those of textile materials, or that the textile base structure determines the shape of the load-elongation curve. The second alternative is more likely as the coated nylon-based fabrics had curves similar to either the nylon fibre or nylon yarn curves.

The cotton blends have curves resembling the first part of the synthetic fibre-curves with which they were blended. The truncation of these curves shows the influence of the low extensibility and relatively lower breaking strength of the cotton on their general shape.

As the temperature decreased from 20 to -40°C, the basic shape of the load-elongation curve as defined by the presence or absence of yield and secondary yield points changed for all fabrics but the polyester/cotton blend, PE/C, whose curve remained basically the same. The first indication that a fabric was stiffening due to the low temperatures was the appearance of a yield or secondary yield point, if one did not exist at the higher temperatures. A further indication of stiffening was the disappearance of the secondary yield point, with the fabric hardening and breaking before the secondary yield point was reached. This behaviour is similar to that reported by Coplan and Singer for nylon yarns.

The most spectacular stiffening occurred with the PVC-coated nylon scrims, with breaks in their coatings and/or unsynchronized yielding or breaking of the coating and the scrim.

If the sensitivity of these fabrics to cold temperatures is judged solely on the change in the basic shape of the load-elongation curve, then the cotton/polyester blend, PE/C, would be considered insensitive, the cotton/nylon blends, slightly sensitive, and the set of coated and uncoated nylons, with the PVC-coated nylon scrims the most sensitive. As we have seen in the previous section, this last statement is not entirely true, as the measured parameters of the polyester/cotton do change significantly with decreasing temperature. However, the order of sensitivity, i.e. the cotton blends, then the nylons and finally the most sensitive PVC coated fabrics, is still valid and observations of change in the shape of the load-elongation curve, as outlined here, would be a quick and easy way of qualitatively determining the sensitivity of a fabric to temperature change.

The variability in the behaviour of the warp and weft of some of the fabrics was somewhat unexpected. It was considered that since the warp and weft were the same fibre(s), and for the coated fabrics, covered with the same polymeric film, they would react similarly to low temperatures and have similar changes in their load-elongation curves and similar increases or decreases in the measured parameters. Obviously, the difference in such things as yarn construction and number of threads per centimetre between the two directions were sufficient to override the effects of low temperatures on their physical properties.

The statistically analyzed parameters confirm the change in the load-elongation curves, i.e. all the fabrics were affected by a decrease in temperature. The increase in initial modulus from 20 to -40°C was common to all fabrics. This is the only parameter which really distinguishes the polyurethane-coated nylons from the uncoated ones, the former having changes in initial modulus greater than 100% from 20 to -40°C, the latter, less than 75%.

The breaking loads of all fabrics increased from the 20°C value, the maximum percent change being much the same for all fabrics, about 30%.

The temperature at which this maximum occurred varied from fabric to fabric and often from warp to weft.

The changes in percent elongation occurred independently of the breaking load, with the majority of the fabrics having their maximum increase at 0°C, and minimum decrease at -40°C. It has been hypothesized that the increase at 0°C was due to moisture in the specimens, which made them more plastic and extensible at large loads. The magnitude of the percent changes were not as consistent as were the ones for the breaking loads, the variation in warp and weft again reappearing.

The changes in breaking load and percent elongation confirmed work by others, namely, that the breaking load increased with a decrease in temperature, be it for fibres, yarns or fabrics, and the percent elongation varied in both the warp and weft directions. However, for this set of fabrics, there was not the marked change in breaking load and extension at -20°C, except for N-R-PU, the polyurethane-coated nylon, as found by Nikitin et al (4). However, this study does confirm their finding that the inclusion of cotton in a fabric makes this fabric blend less sensitive to low temperatures.

CONCLUSION

The purpose of this study was to determine the effect of low temperatures on the pertinent physical properties of coated and uncoated fabrics. It was found that all fabrics tested were affected at low temperatures, becoming stiffer as shown by an increase in initial modulus, an increase in breaking load and a decrease in percent elongation at break. Taking the change in the basic shape of the load-elongation curve into consideration, as well as the statistically significant differences in initial modulus, breaking load and percent elongation, and the magnitude of the changes, the cotton/synthetic blends were the least sensitive to low temperatures; the nylon fabrics, whether they were coated with polyurethane or neoprene or not, more sensitive; and the PVC-coated nylons scrims tested here, the most sensitive, and for all practical purposes, completely inappropriate for use at temperatures below 0°C.

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APPENDIX A

Tables A-I to A-XIII give the breaking load, percent elongation, work to rupture and initial modulus and their related statistical parameters. The percent change in each of these parameters from one temperature to the one below it is given. If the change is significant at the 95% level of confidence, it is underlined once; if it is significant at the 99% level of confidence, it is underlined twice. The presence or absence of yield and secondary yield points is noted and if present, their coordinates are given.

The following abbreviations are used:

$\bar{x}$ = the mean

cv = coefficient of variation (%)

vvsl = very, very slight

vsl = very slight

Figures A-1 to A-26 show typical load-elongation curves for each fabric in the warp and weft direction at the four temperatures.

NOTE:

The x-values for the yield points and the secondary yield points are elongation in centimeters and the y-values in pounds force $\times 10^{-1}$. The initial moduli were calculated using these units.

TABLE A-I

Fabric **N/C-G**

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	850	1010	1080	1100	860	1090	1090	1150
	cv	1	4	4	5	3	3	2	3
	% change		+19	+7	+2		+27	0	+6
% Elongation	$\bar{x}$	26	29	28	26	23	26	25	26
	cv	3	2	2	9	3	3	4	6
	% change		+12	-3	-8		+13	-4	+4
Work to (N.cm) Rupture	$\bar{x}$	1000	1200	1480	1620	1020	1320	1620	2020
	cv	2	5	4	16	5	7	12	13
	% change		+20	+23	+9		+29	+23	+25
Initial Modulus	$\bar{x}$	none	none	none	none	none	none	none	none
	cv								
	% change								
Yield Point	$\bar{x}$	none	none	none	none	none	none	none	none
Secondary Yield Point	$\bar{x}$	none	none	vvsl	vvsl	vvsl	vvsl	15.7,22.4	14.7,22.1
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-II

Fabric **N/C-F**		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	1100	1270	1380	1390	870	1060	1210	1140
	cv	1	1	5	2	2	2	3	3
	% change		+15	+9	+1		+22	+14	-6
% Elongation	$\bar{x}$	26	29	27	28	32	36	36	33
	cv	0	0	4	5	3	1	2	5
	% change		+11	-7	+4		+13	0	-8
Work to (N.cm) Rupture	$\bar{x}$	1600	1870	2160	2640	1290	1660	2140	2040
	cv	2	2	9	8	3	5	7	11
	% change		+17	+16	+22		+29	+29	-5
Initial Modulus	$\bar{x}$	none	none	vvsl	vsl	none	none	vsl	vvsl
	cv								
	% change								
Yield Point	$\bar{x}$	none	none	none	vvsl	none	none	vvsl	vvsl
Secondary Yield Point	$\bar{x}$	none	none	none	18.0,28.5	none	none	vvsl	vsl
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-III

Fabric **PE/C**

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	820	1040	1040	1020	480	530	570	610
	cv	3	1	4	2	3	3	6	3
	% change		+27	0	-2		+10	+8	+7
% Elongation	$\bar{x}$	25	29	26	22	30	30	29	28
	cv	2	1	5	5	4	3	1	2
	% change		+16	-10	-15		0	-3	-3
Work to (N.cm) Rupture	$\bar{x}$	1810	2560	2440	2140	1000	1060	1190	1230
	cv	5	2	7	6	7	6	3	6
	% change		+41	-5	-12		+6	+12	+3
Initial Modulus	$\bar{x}$	2.5	2.3	2.9	3.5	1.1	1.2	1.4	1.5
	cv	2	8	3	5	7	6	1	0
	% change		-8	+26	+21		+9	+16	+14
Yield Point	$\bar{x}$	7.0, 12.5	8.0,14.0	7.0,16.0	11.0,17.5	5.5,6.0	10.5,7.0	11.5,8.0	8.5,10.5
Secondary Yield Point	$\bar{x}$	none	none	none	none	none	none	none	none
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-IV

Fabric N-R

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	640	750	860	850	560	630	690	690
	cv	3	1	5	1	2	1	3	3
	% change		+17	+15	-1		+13	+10	0
% *Elongation*	$\bar{x}$	23	35	27	21	29	37	27	24
	cv	5	10	14	2	5	3	3	2
	% change		+52	-23	-22		+28	-27	-11
Work to (N.cm) Rupture	$\bar{x}$	1170	2340	1950	1370	1160	1700	1250	1150
	cv	10	15	23	3	9	3	8	4
	% change		+100	-17	-30		+47	-26	-8
Initial Modulus	$\bar{x}$	1.1	vsl	1.5	1.8	none	none	none	none
	cv	5		10	5				
	% change				+20				
Yield Point	$\bar{x}$	2.0,2.0	vsl	2.0,2.5	3.0,4.0	none	none	none	none
Secondary Yield Point	$\bar{x}$	12.0,11.0	14.0,13.0	11.5,15.0	12.0,15.0	17.0,11.0	19.5,12.0	vvsl	none
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-V

Fabric N-R-PU

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	760	790	880	750	620	630	770	650
	cv	1	4	3	5	2	6	7	5
	% change		+4	+11	-15		+2	+22	-18
% Elongation	$\bar{x}$	33	32	23	15	32	32	30	21
	cv	7	11	9	7	4	10	11	7
	% change		-3	-28	-35		0	-6	-30
Work to (N.cm) Rupture	$\bar{x}$	2310	2190	1660	990	1500	1390	1770	1170
	cv	10	19	12	10	8	20	20	6
	% change		-5	-24	-40		-7	+27	-34
Initial Modulus	$\bar{x}$	1.2	1.3	2.1	2.8	none	none	1.0	2.2
	cv	3	22	7	7			3	11
	% change		+8	+62	+33		-	-	+120
Yield Point	$\bar{x}$	2.0,2.5	2.0,2.0	2.5,4.5	2.5,6.5	none	none	2.0,1.5	2.5,4.5
Secondary Yield Point	$\bar{x}$	13.0,13.5	13.0, 13.5	11.0,9.5	none	17.5,11.5	18.0,12.0	18.0,14.5	none
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-VI

Fabric N		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	1490	1700	1930	2070	1380	1480	1780	1780
	cv	1	1	2	4	1	2	2	6
	% change		+14	+14	+7		+7	+20	0
% Elongation	$\bar{x}$	27	34	29	30	34	38	33	31
	cv	2	1	3	3	2	4	3	7
	% change		+26	-15	+3		+12	-13	-6
Work to (N.cm) Rupture	$\bar{x}$	2860	4330	4160	4780	3880	4780	4930	4860
	cv	3	2	6	6	3	8	1	17
	% change		+51	-4	+15		+23	+3	-1
Initial Modulus	$\bar{x}$	1.5	1.4	2.1	2.2	1.9	1.9	3.0	3.3
	cv	0	6	4	22	6	5	10	2
	% change		-7	+50	+5		0	+58	+10
Yield Point	$\bar{x}$	none	none	vsl	vsl	4.5,6.0	4.0,5.0	5.0,7.5	5.0,11.5
Secondary Yield Point	$\bar{x}$	vsl	18.5,33.0	18.5,39.0	vsl	17.0,26.0	18.5,28.0	17.0,33.5	17.0,33.5
Number of Specimens	=	6	6	6	6	6	6	5	6

TABLE A-VII

Fabric N-PU		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	1820	2430	2740	2350	1680	1900	2160	2200
	cv	5	1	2	10	2	1	2	1
	% change		+34	+13	-14		+13	+14	+2
% Elongation	$\bar{x}$	29	41	34	25	53	51	44	31
	cv	7	3	3	10	3	6	6	3
	% change		+41	-17	-26		-4	-14	-30
Work to (N.cm) Rupture	$\bar{x}$	3780	7750	7140	4870	9160	9590	9050	5700
	cv	12	5	6	19	4	10	11	5
	% change		+105	-8	-32		+5	-6	-37
Initial Modulus	$\bar{x}$	2.4	none	3.4	5.2	2.1	2.0	2.4	2.6 & 4.6
	cv	5		4	13	5		12	9 5
	% change		-	-	+53		+5	+20	+8 +92
Yield Point	$\bar{x}$	3.0,6.0	vsl	4.0,12.0	3.5,15.5	4.0,6.0	4.0,6.5	5.0,10.0	1.0,3.0 & 4.5,13.0
Secondary Yield Point	$\bar{x}$	18.0,36.5	21.0,22.0	20.0,52.0	none	18.5,31.0	19.0,35.5	18.0,39.0	16.5,40.1
Number of Specimens	=	6	5	6	6	6	6	6	6

TABLE A-VIII

Fabric N-PU-L

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	1350	1550	1615	1730	1080	1240	1400	1230
	cv	2	2	3	6	0	1	4	6
	% change		+15	+4	+7		+15	+13	-12
% Elongation	$\bar{x}$	27	30	24	24	33	41	31	22
	cv	3	5	4	7	3	4	9	6
	% change		+11	-20	0		+24	-24	-29
Work to (N.cm) Rupture	$\bar{x}$	2660	3400	2900	3330	2730	4300	3390	2100
	cv	7	9	7	13	4	7	16	11
	% change		+28	-15	+15		+58	-21	-38
Initial Modulus	$\bar{x}$	1.9	1.6	2.6	4.6	none	none	1.5	3.7
	cv	3	13	2	8			5	12
	% change		-16	+63	+77		-	-	+147
Yield Point	$\bar{x}$	2.5,4.5	3.0,4.0	3.0,7.0	2.5,10.0	none	none	vsl	1.5,4.0
Secondary Yield Point	$\bar{x}$	15.0,25.5	16.5,29.0	14.5,31.0	vsl	17.0,20.0	18.5,23.0	16.5,25.5	none
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-IX

Fabric **N-NE**

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	800	900	950	1040	740	830	900	1010
	cv	1	2	3	3	3	3	7	4
	% change		+13	+6	+9		+12	+8	+12
% Elongation	$\bar{x}$	29	34	26	25	39	39	31	32
	cv	2	5	7	8	13	9	12	7
	% change		+17	-24	-4		0	-21	+3
Work to (N.cm) Rupture	$\bar{x}$	1910	2560	2020	2300	2590	2730	2280	2910
	cv	3	8	12	11	19	17	23	12
	% change		+34	-21	+14		+5	-16	+28
Initial Modulus	$\bar{x}$	1.3	1.1	1.8	6.0	1.0	0.8	1.3	6.1
	cv	6	5	4	12	4	5	8	11
	% change		-15	+64	+233		-20	+63	+369
Yield Point	$\bar{x}$	2.5,3.0	2.5,2.5	3.0,4.5	2.5,6.5	4.0,3.5	3.0,2.5	4.0,4.0	3.0,6.0
Secondary Yield Point	$\bar{x}$	14.5,14.5	16.0,16.0	15.0,17.5	vsl	17.0,13.0	18.5,15.0	16.5,16.5	16.0,17.5
Number of Specimens	=	6	6	6	6	6	6	6	6

TABLE A-X

Fabric N-PVC-L

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	760	1050	910	920	780	970	900	850
	cv	2	1	4	4	2	1	8	6
	% change		+38	-13	±1		+24	±7	-6
% Elongation	$\bar{x}$	23	28	13	12	27	29	16	17
	cv	7	4	11	41	5	4	9	14
	% change		+22	-54	±8		+7	-45	±6
Work to (N.cm) Rupture	$\bar{x}$	1430	2970	1310	1250	1710	2490	1510	1640
	cv	8	4	12	51	7	5	14	17
	% change		+108	-56	±5		+46	-40	±9
Initial Modulus	$\bar{x}$	1.2	2.2	7.9	10.8	1.4	3.2	7.9	10.8
	cv	3	4	6	4	7	10	7	4
	% change		+8	+259	+37		+129	+147	+37
Yield Point	$\bar{x}$	2.0,3.0	2.5,3.5	2.0,13.5	1.0,12.0	2.0,2.5	2.5,5.4	2.0,13.0	2.0,16.5
Secondary Yield Point	$\bar{x}$	11.5,13.5	11.5,9.5	breaks	breaks	15.5,15.0	15.3,18.1	breaks	breaks
Number of Specimens	=	6	5	5	5	6	6	6	6

TABLE A-XI

Fabric N-PVC-H

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	2150	2510	2790	2540	1990	2280	2710	2260
	cv	2	2	9	2	4	3	2	2
	% change		+17	+11	-9		+15	+19	-17
% Elongation	$\bar{x}$	26	27	20	19	29	32	27	25
	cv	2	3	16	3	5	4	2	3
	% change		+4	-26	-5		+10	-16	-7
Work to (N.cm) Rupture	$\bar{x}$	4640	5890	5210	5000	4100	5740	6450	5090
	cv	8	4	26	4	7	7	5	5
	% change		+27	-12	-4		+40	+12	-21
Initial Modulus	$\bar{x}$	4.8	6.6	13.7	14.6	2.2	5.4	11.6	17.4
	cv	6	4	6	5	1	6	8	6
	% change		+38	+108	+7		+145	+115	+50
Yield Point	$\bar{x}$	1.5,7.0	2.0,11.0	2.5,23.5	2.2,32.5	3.5,7.5	2.5,10.0	2.5,21.5	1.5,24.3
Secondary Yield Point	$\bar{x}$	13.0,4.0	13.5,46.0	breaks*	breaks	18.0,39.5	19.0,44.0	16.0,52.0	breaks
Number of Specimens	=	6	6	6	6	6	6	6	6

* 3 of the specimens had breaks, 2 had measurable Secondary Yield Points, 1 had no Secondary Yield Point.

TABLE A-XII

Fabric **N-PVC-HT**

		WARP				WEFT			
		Temperature (°C)				Temperature (°C)			
		20	0	-20	-40	20	0	-20	-40
Breaking Load (N)	$\bar{x}$	2110	2370	2640	2760	1570*	1850*	2330*	2570*
	cv	1	1	4	7	5	2	5	9
	% change		+12	+11	+5		+18	+26	+10
% Elongation	$\bar{x}$	23	23	22	19	28	28	28	26
	cv	2	3	8	9	4	2	4	9
	% change		0	-4	-14		0	0	-7
Work to (N.cm) Rupture	$\bar{x}$	3540	4240	4430	4130	3400	5630	4920	5450
	cv	7	4	14	15	3	4	8	12
	% change		+20	+5	-7		+66	-13	+11
Initial Modulus	$\bar{x}$	4.4	5.1	6.2	8.9	2.0	**	**	7.4
	cv	1	5	12	6	11			6
	% change		+16	+22	+44		-	-	-
Yield Point	$\bar{x}$	1.5,5.5	1.5,8.0	1.5,10.0	2.5,15.0	4.0,5.5	4.0,7.5	3.0,8.0	2.5,13.5
Secondary Yield Point	$\bar{x}$	13.5,43.0	13.5,48.0	13.5,53.5	vvsl	breaks	20.0,40.0	18.0,47.5	breaks
Number of Specimens	=	6	6	6	5	6	6	5	5

* Not a clean break.

** Difficult to measure as 2 slopes.

TABLE A-XIII

Fabric **N-PVC**

		WARP Temperature (°C) 20	0	-20	-40	WEFT Temperature (°C) 20	0	-20	-40
Breaking Load (N)	$\bar{x}$	3340	3760	4000	3310	2400	2540	2740	2800
	cv	3	4	3	5	6	7	10	9
	% change		+13	+6	-17		+6	+8	+2
% Elongation	$\bar{x}$	22	22	21	18	34	35	29	28
	cv	3	6	4	6	4	5	7	9
	% change		0	-5	-17		+3	-17	-3
Work to (N.cm) Rupture	$\bar{x}$	5160	5790	6570	5140	5080	5810	5870	6070
	cv	8	12	6	8	10	10	14	13
	% change		+12	+13	-22		+14	+1	+3
Initial Modulus	$\bar{x}$	6.8	7.9	11.9	18.7	none	2.9	8.7	14.8
	cv	4	14	4	5		5	8	5
	% change		+16	+51	+57		-	+200	+70
Yield Point	$\bar{x}$	1.5,9.5	2.0,12.5	2.0,19.5	1.5,22.5	none	1.5,4.0	2.0,13.5	1.0,14.0
Secondary Yield Point	$\bar{x}$	14.5,69.5	vsl	vsl	breaks	none	none	none	none
Number of Specimens	=	6	6	6	5	6	6	6	6

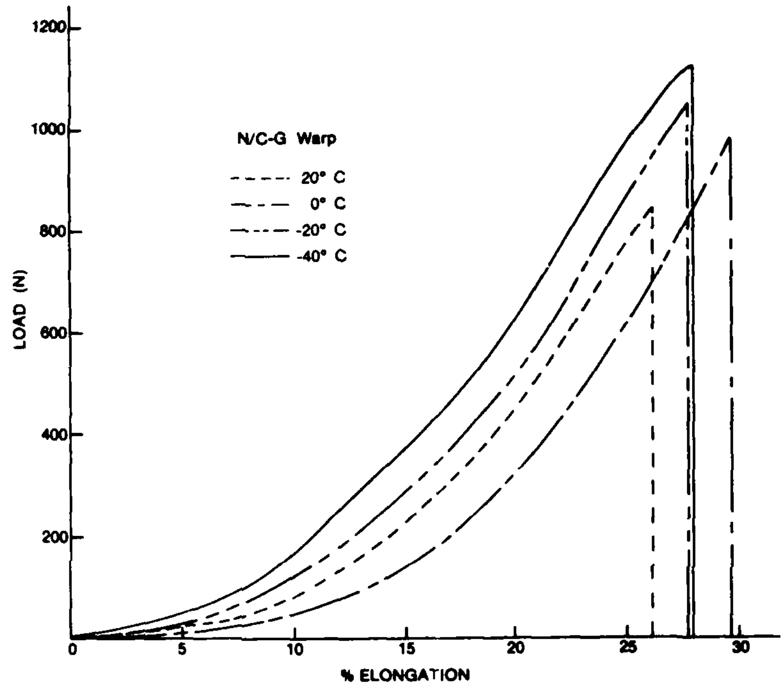

Figure A-1: Load-Elongation Curves of N/C-G Warp at the Four Temperatures.

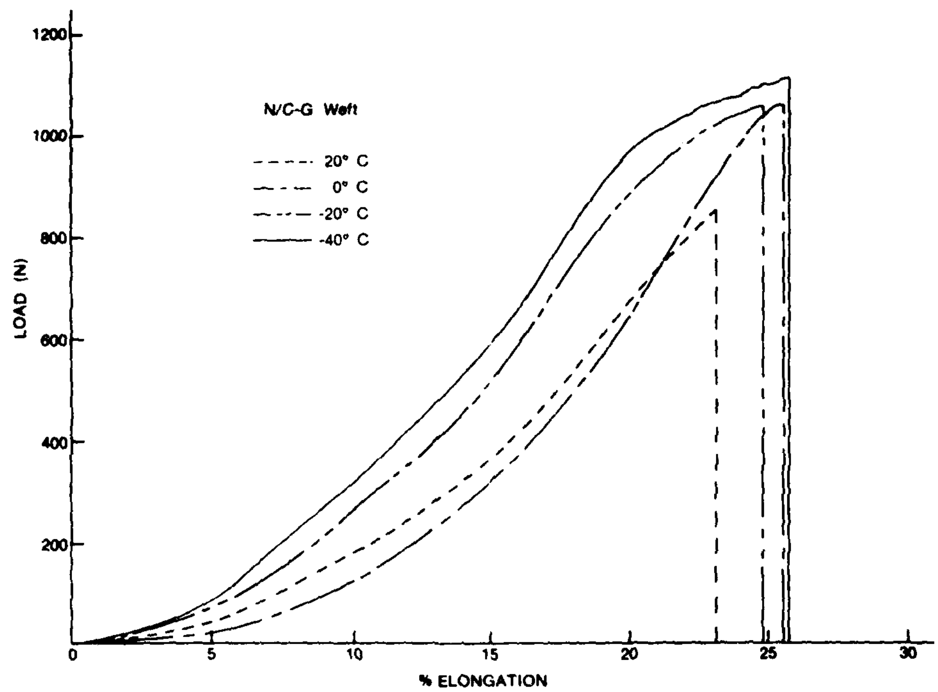

Figure A-2: Load-Elongation Curves of N/C-G Weft at the Four Temperatures.

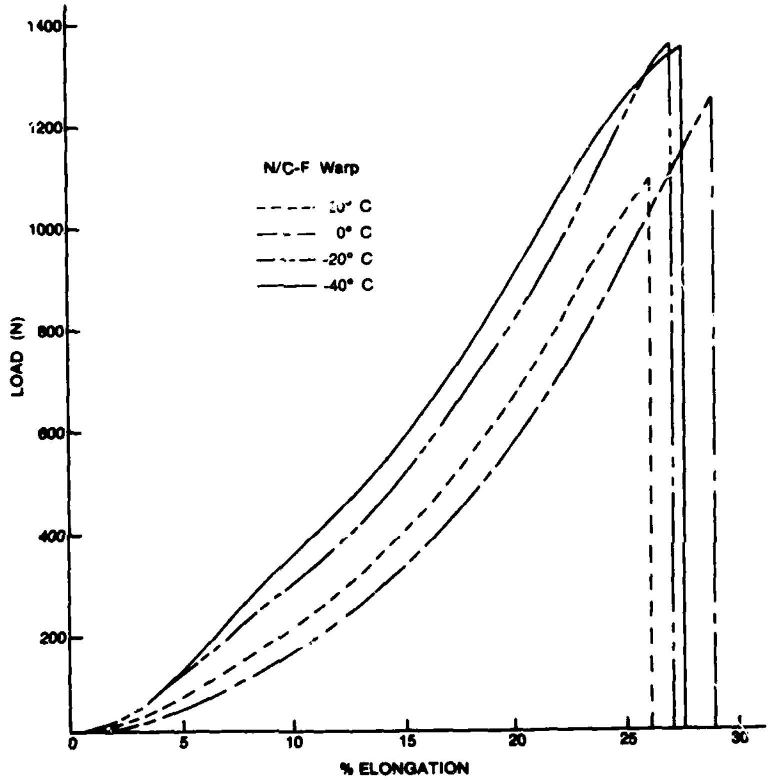

Figure A-3: Load-Elongation Curves of N/C-F Warp at the Four Temperatures.

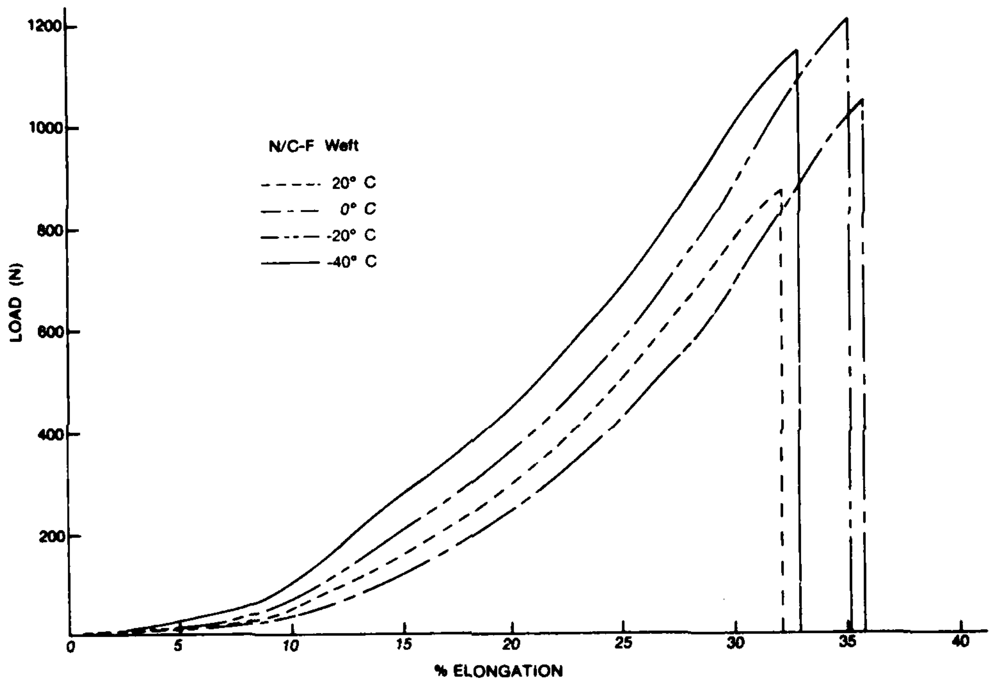

Figure A-4: Load-Elongation Curves of N/C-F Weft at the Four Temperatures.

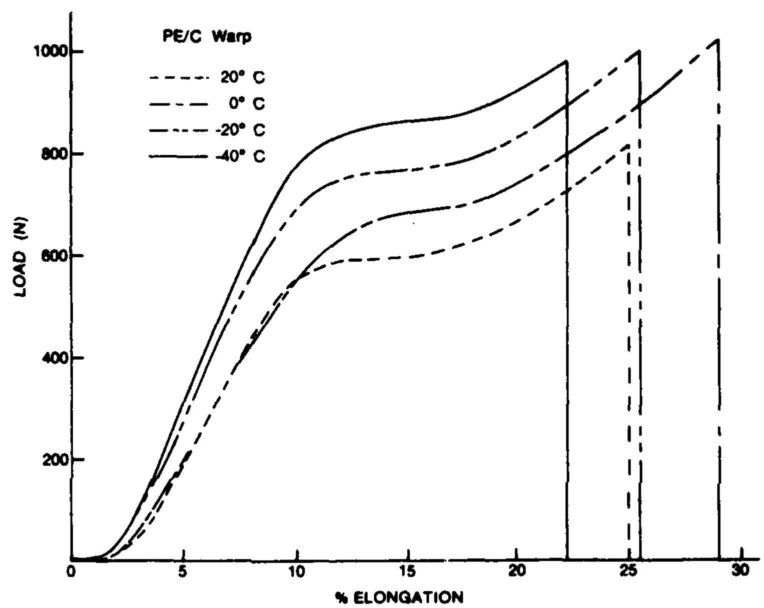

Figure A-5: Load-Elongation Curves of PE/C Warp at the Four Temperatures.

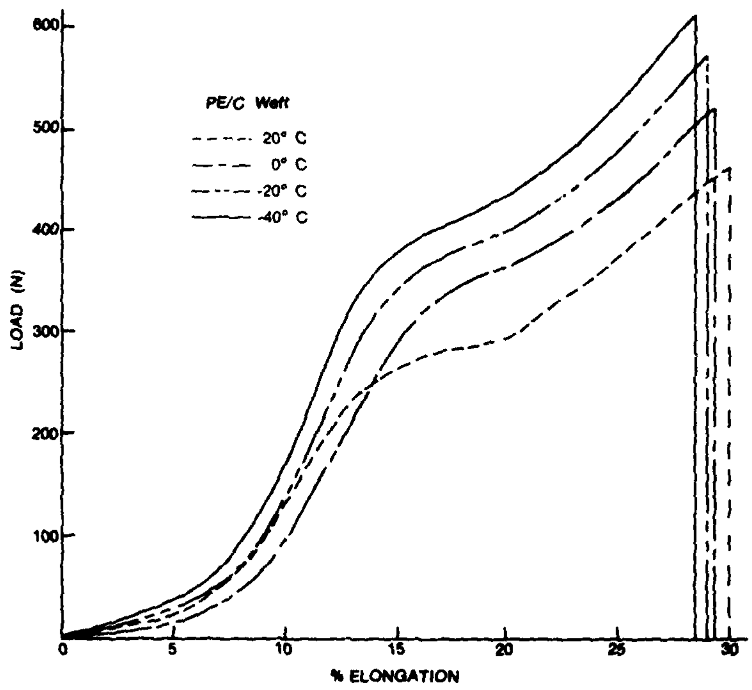

Figure A-6: Load-Elongation Curves of PE/C Weft at the Four Temperatures.

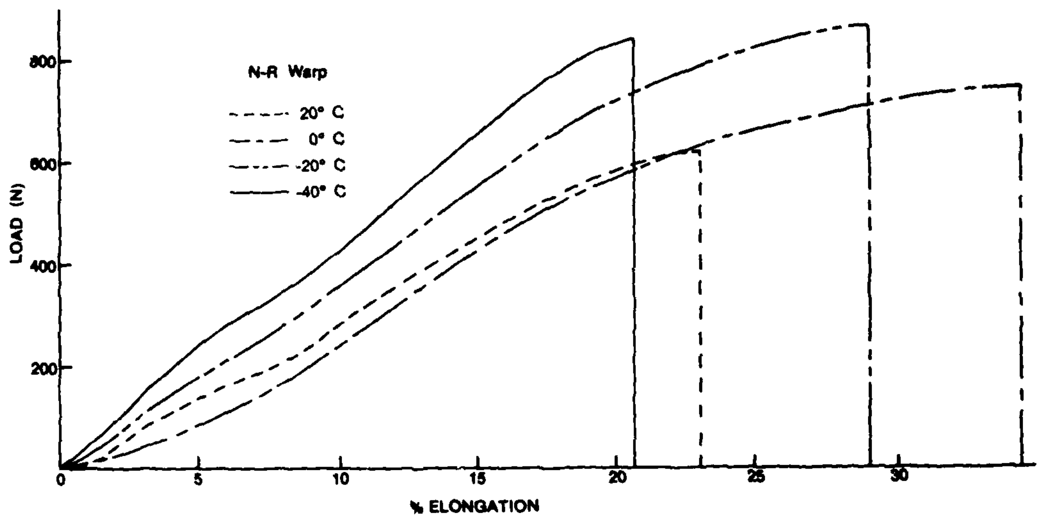

Figure A-7: Load-Elongation Curves of N-R Warp at the Four Temperatures.

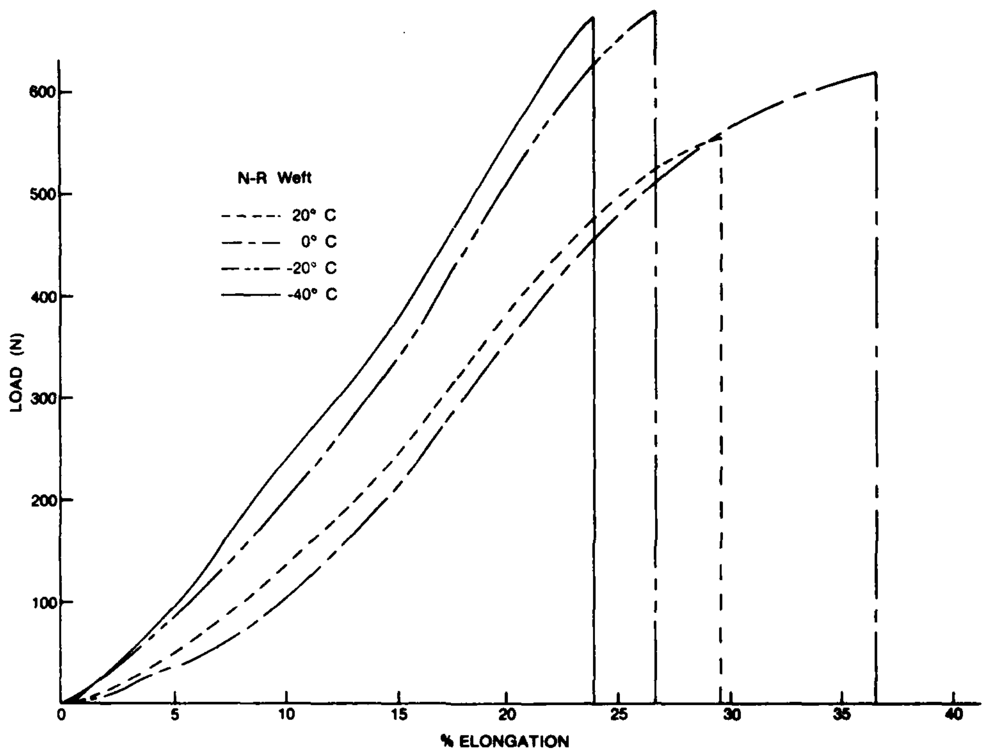

Figure A-8: Load-Elongation Curves of N-R Weft at the Four Temperatures.

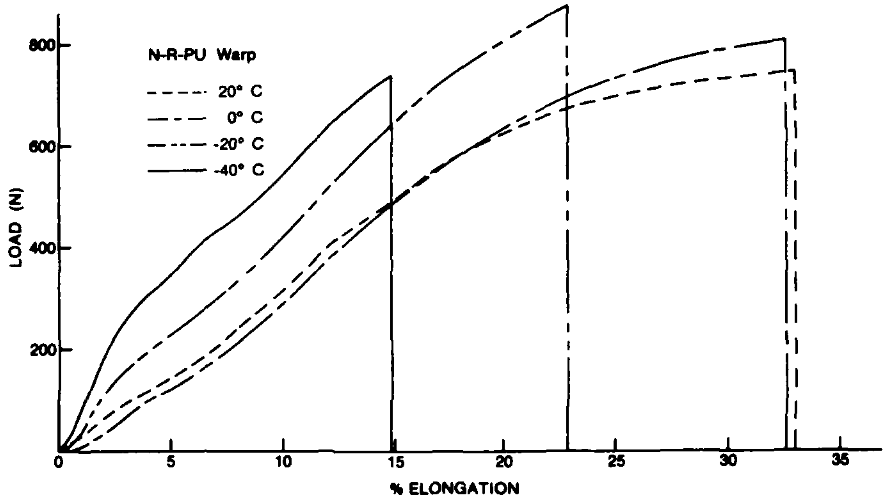

Figure A-9: Load-Elongation Curves of N-R-PU Warp at the Four Temperatures.

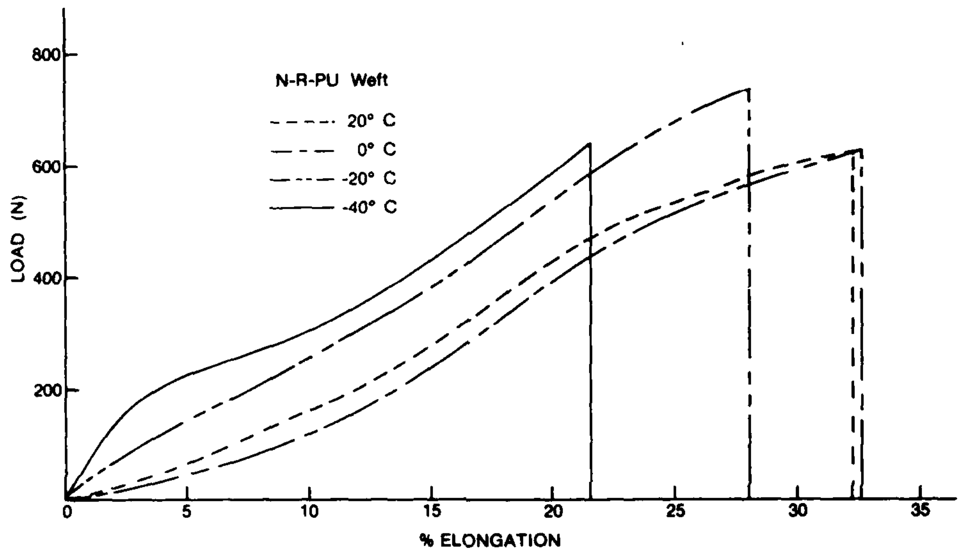

Figure A-10: Load-Elongation Curves of N-R-PU Weft at the Four Temperatures.

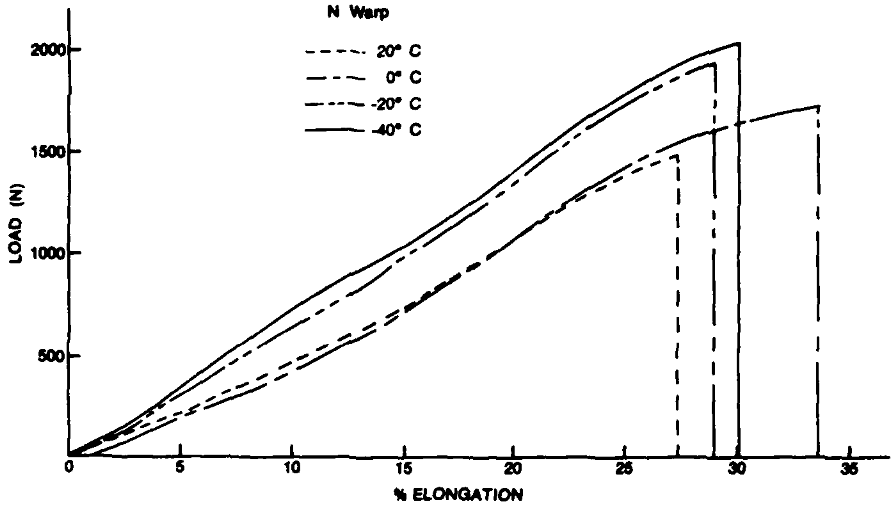

Figure A-11: Load-Elongation Curves of N Warp at the Four Temperatures.

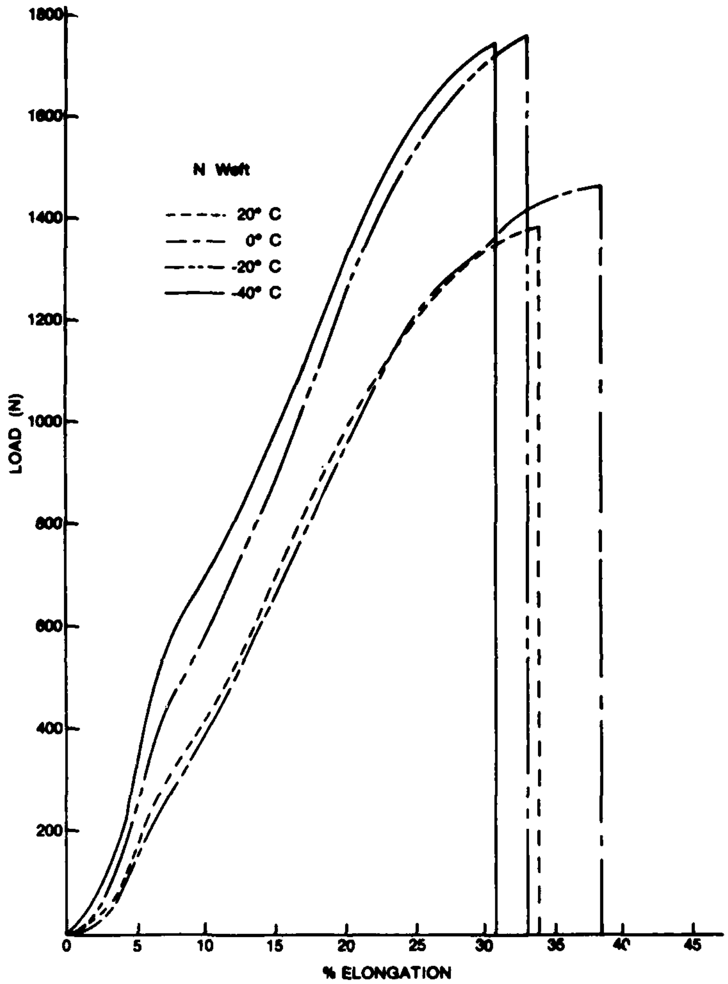

Figure A-12: Load-Elongation Curves of N Weft at the Four Temperatures.

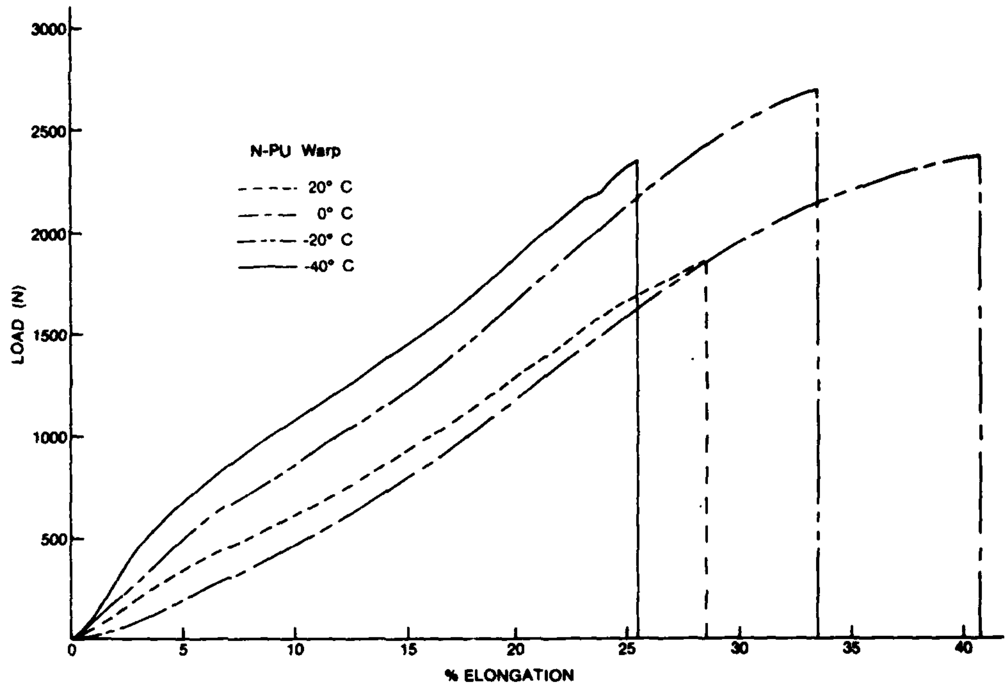

Figure A-13: Load-Elongation Curves of N-PU Warp at the Four Temperatures.

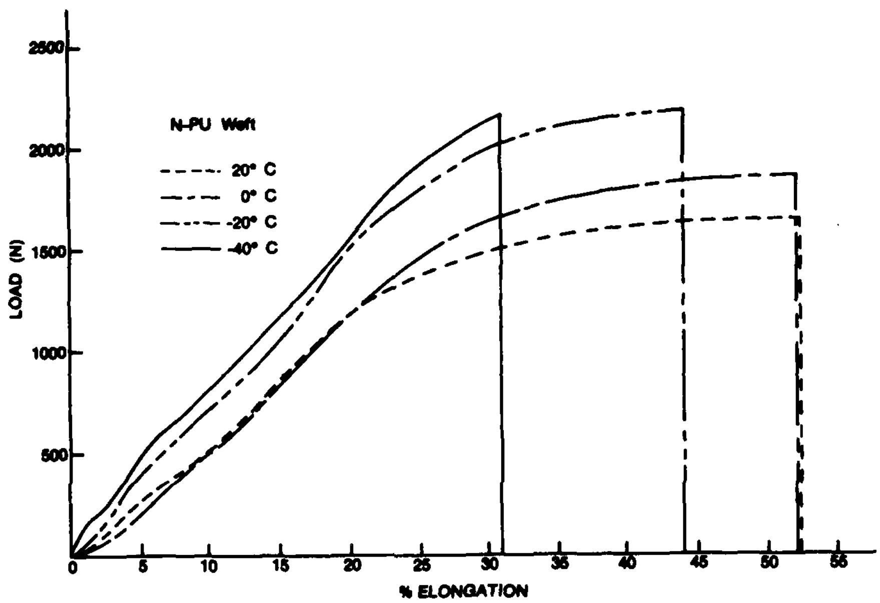

Figure A-14: Load-Elongation Curves of N-PU Weft at the Four Temperatures.

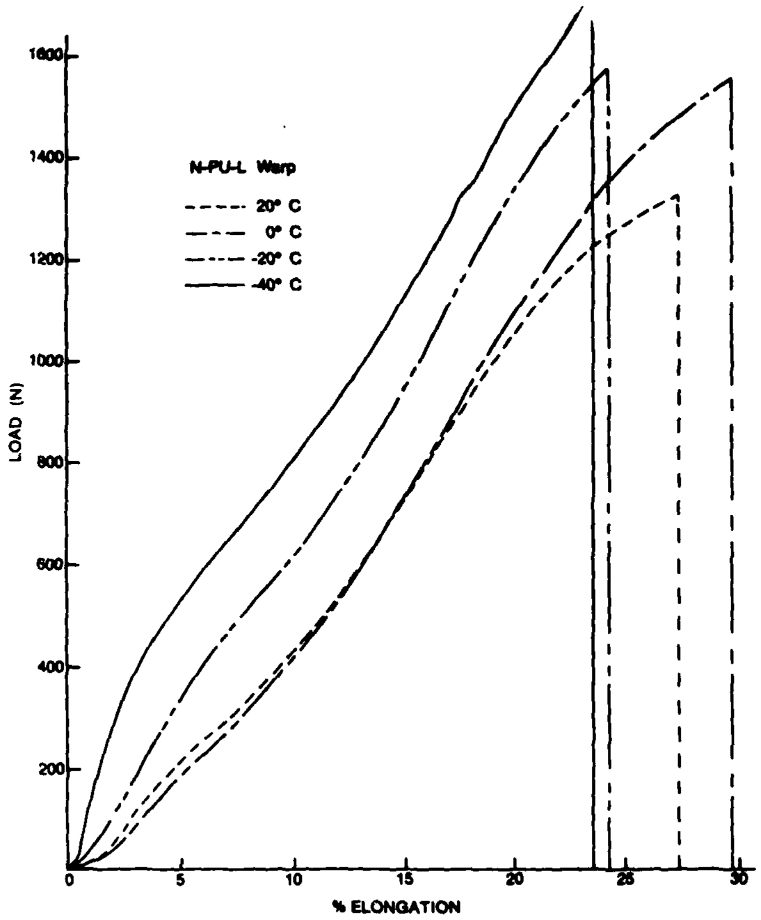

Figure A-15: Load-Elongation Curves of N-PU-L Warp at the Four Temperatures.

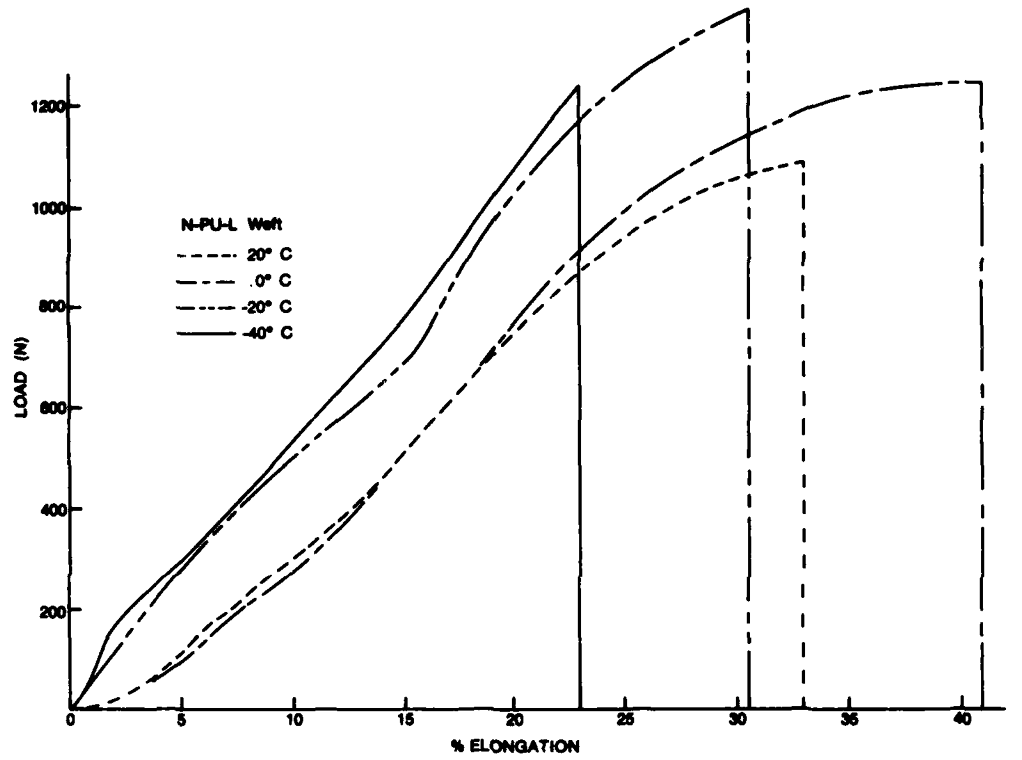

Figure A-16: Load-Elongation Curves of N-PU-L Weft at the Four Temperatures.

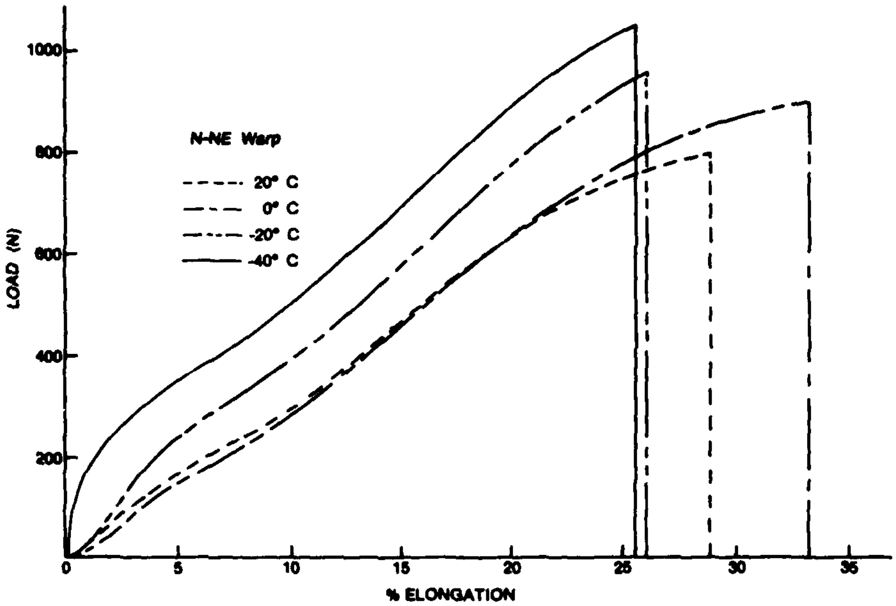

Figure A-17: Load-Elongation Curves of N-NE Warp at the Four Temperatures.

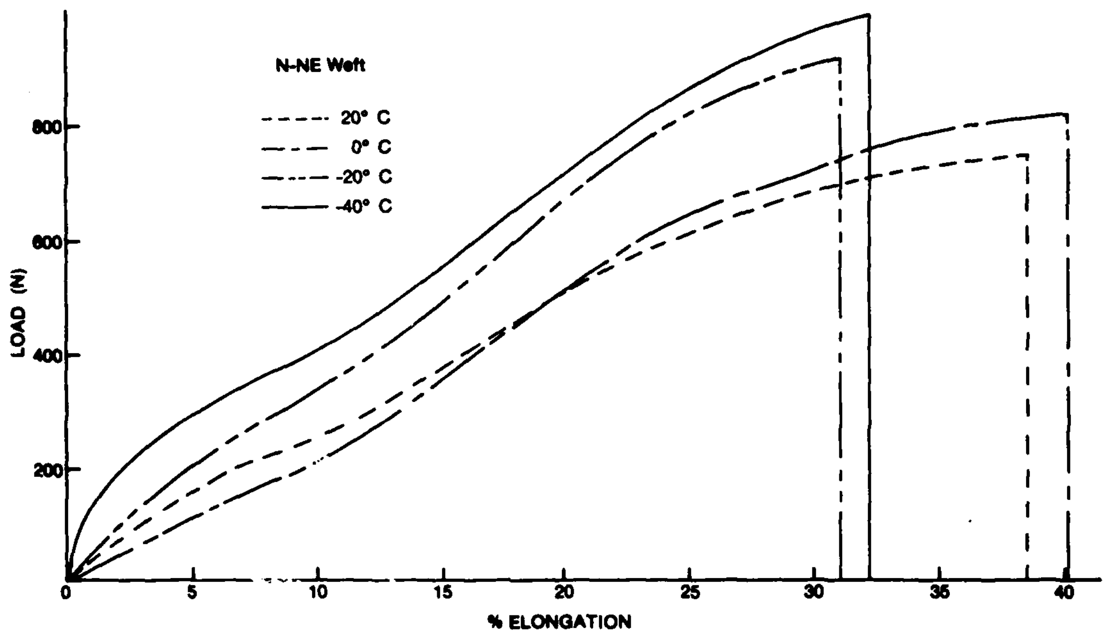

Figure A-18: Load-Elongation Curves of N-NE Weft at the Four Temperatures.

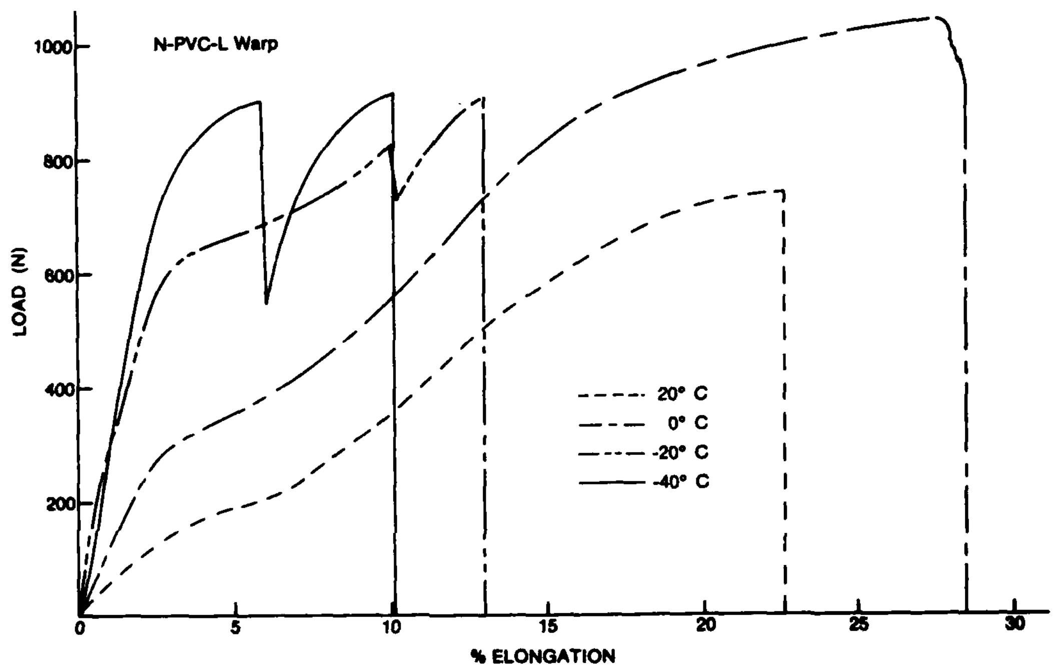

Figure A-19: Load-Elongation Curves of N-PVC-L Warp at the Four Temperatures.

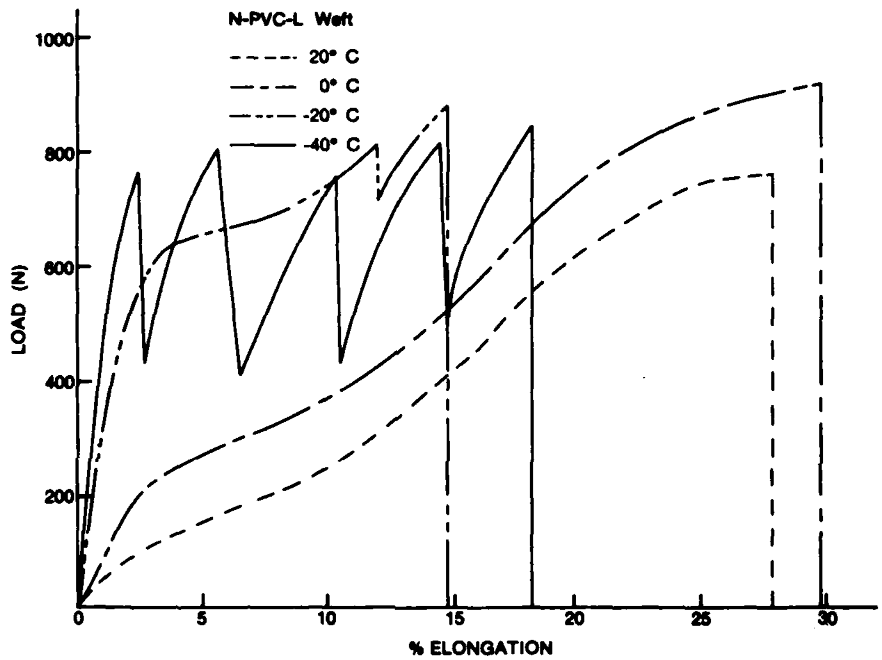

Figure A-20: Load-Elongation Curves of N-PVC-L Weft at the Four Temperatures.

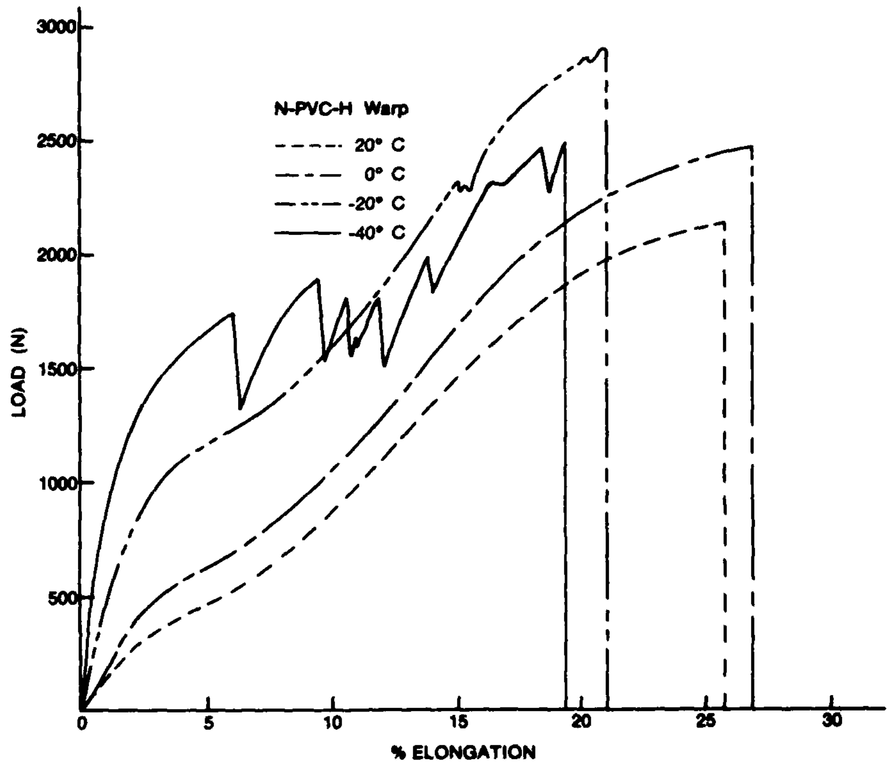

Figure A-21: Load-Elongation Curves of N-PVC-H Warp at the Four Temperatures.

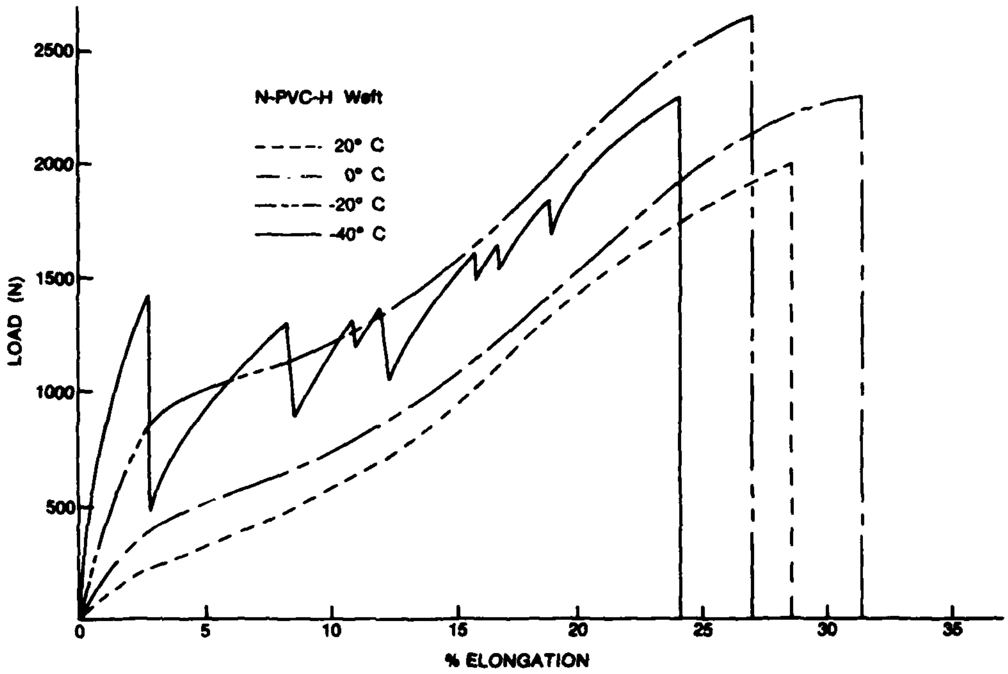

Figure A-22: Load-Elongation Curves of N-PVC-H Weft at the Four Temperatures.

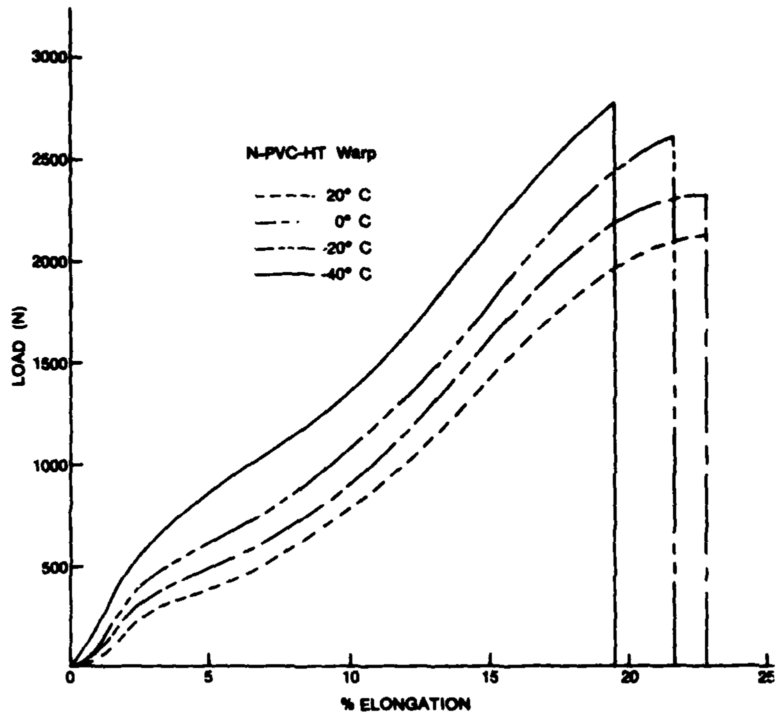

Figure A-23: Load-Elongation Curves of N-PVC-HT Warp at the Four Temperatures.

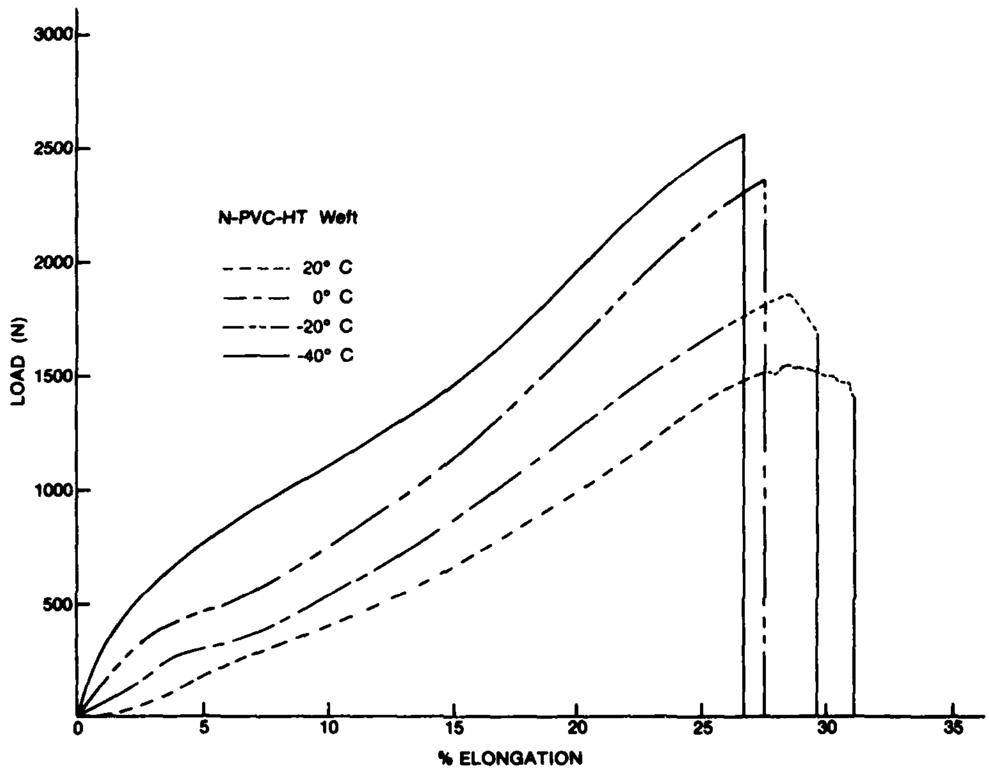

Figure A-24: Load-Elongation Curves of N-PVC-HT Weft at the Four Temperatures.

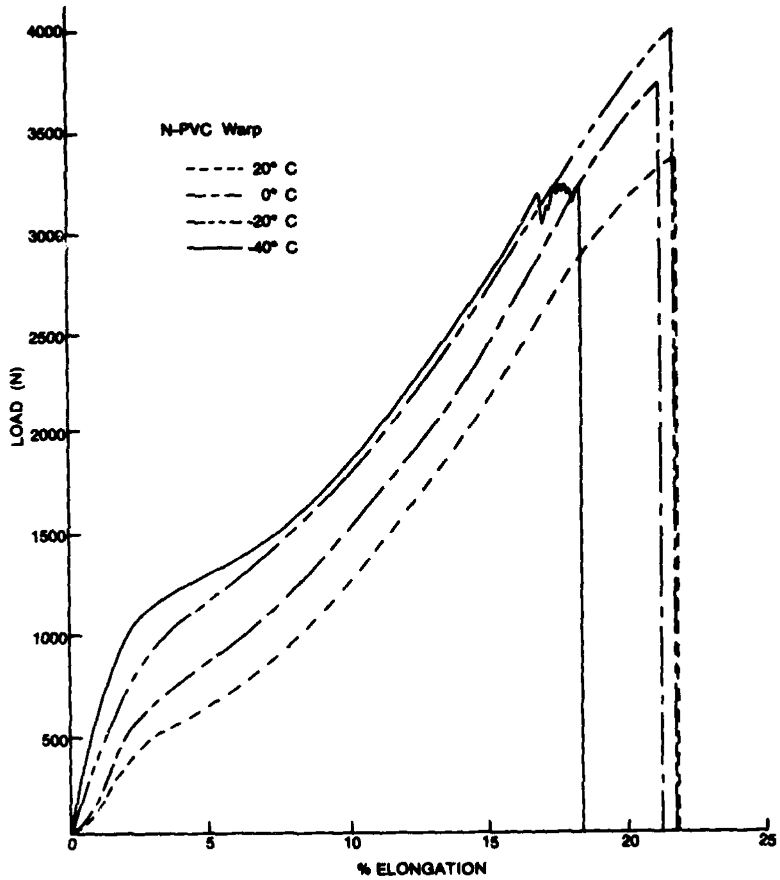

Figure A-25: Load-Elongation Curves of N-PVC Warp at the Four Temperatures.

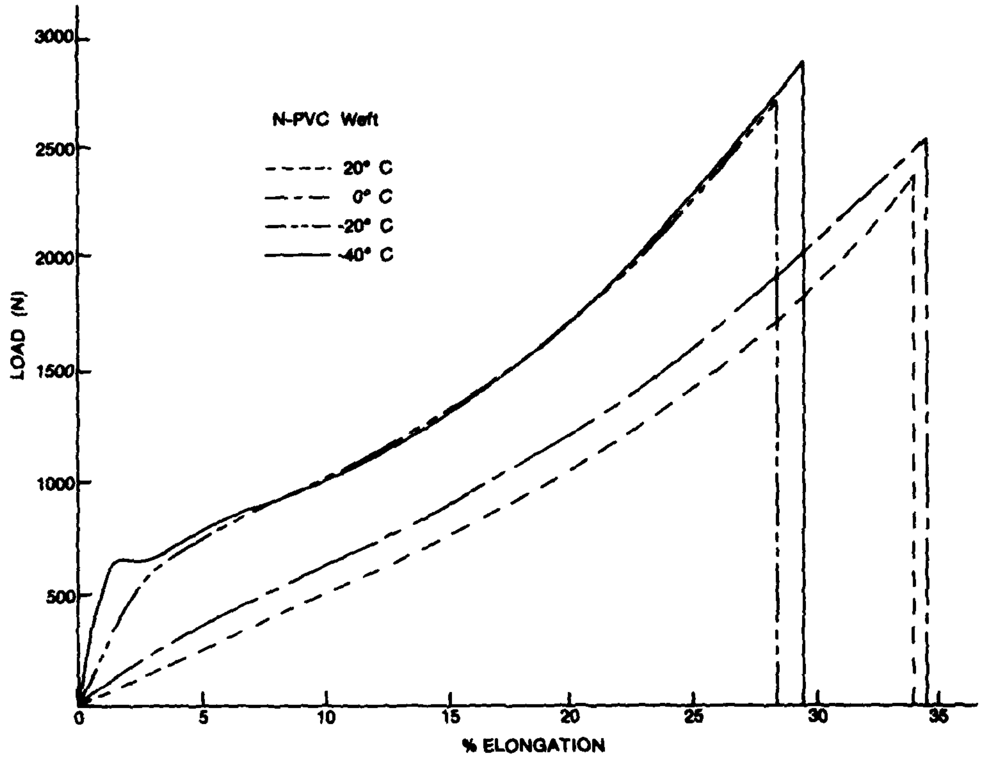

Figure A-26: Load-Elongation Curves of N-PVC Weft at the Four Temperatures.

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The effect of low temperatures on the shape of the load-elongation curve, the initial modulus, breaking load, percent elongation and work to rupture of 13 coated and uncoated fabrics was examined. It was found that the cotton/synthetic blends were least sensitive to low temperatures, the nylon fabrics, be they coated with polyurethane or neoprene, or uncoated, were more sensitive, and the PVC-coated nylon scrims, the most sensitive, and for all practical purposes, completely inappropriate for use at temperatures below 0°C.

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KEY WORDS

LOW TEMPERATURE TESTS

COATED FABRICS

WOVEN FABRICS

BREAKING LOAD

ELONGATION

YIELD POINT

INITIAL TANGENT MODULUS

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