ALLEN, T., VINSON, T. S. and BELL, J. R.
Oregon State University, Corvallis, Oregon, U.S.A.

Tensile Strength and Creep Behavior of Geotextiles in Cold Regions Applications

Résistance à la traction et comportement au fluage des géotextiles dans les régions froides

In recognition of the need to determine mechanical properties of geotextiles used in cold region applications, a research program was conducted to 1) investigate the influence of freeze-thaw cycles in a freshwater and saline water environment on the load-strain-strength characteristics of geotextiles, and 2) evaluate the load-strain-strength and creep characteristics of geotextiles at subfreezing temperatures. Five geotextiles, each with different construction and/or material characteristics were employed in the program. A wide strip tensile test was used to characterize the load-strain-strength behavior of the geotextiles. Creep characteristics were evaluated at various percentages of ultimate tensile strength. Based on the results presented it is concluded that the load-strain-strength and creep characteristics are not adversely affected by subfreezing temperatures in a temperature range associated with many cold region engineering applications. Freeze/thaw cycling in a dry, distilled water, or saline water environment has no appreciable influence on the load-strain-strength characteristics of the geotextiles tested.

Afin de déterminer les propriétés méchaniques des géotextilés utilisés dans les régions froides, on a établi un programme de recherche pour 1) étudier dans un milieu d'eau douce et d'eau saline, l'influence des cycles gel-dégel sur les caractéristiques charge-déformation-résistance des géotextiles, et 2) évaluer les caractéristiques charge-déformation-résistance et le comportement au fluage des géotextiles à des températures sous 0°=C. Cinq géotextiles ont été étudiés au cours du programme. Un essai de traction sur éprouvette large a été utilisé pour caracteriser le comportement charge-déformation-résistance. Le fluage a été évalué pour differents pourcentages de la résistance limite à la traction. Sur l'observation de ces resultats on peut conclure que les caractéristiques charge-déformation-résistance et le comportement au fluage sont peu affectés par des températures sous 0°=C. Les cycles gel-dégel dans un milieu sec, d'eau distilleé ou d'eau de mer ont peu d'influence sur les caractéristiques charge-déformation-résistance des géotextiles utilisés.

INTRODUCTION

In the past decade considerable attention has been focused on the cold regions of the world owing to the abundance of natural resources which exist there, in particular oil and gas reserves. Engineering/construction practices for building foundations, roadways, and embankments in cold regions of the world are intimately associated with freezing related phenomena of initially unfrozen ground, and thawing related phenomena of initially frozen ground. Freezing of initially unfrozen frost-susceptible soil can result in heave at the ground surface and disruptions of embankments or foundations placed on or wholly within the zone of freezing. Thawing of ice-rich soils results in loss of bearing strength and settlement (termed thaw instability).

Recently, engineers concerned with arctic and subarctic problems have incorporated geotextiles in their design/construction recommendations for embankments and foundations (1). The geotextiles have been used primarily as filter and separation and/or reinforcing layers. Further, it has been suggested by engineers that the geotextiles might act as a capillary transmission barrier when placed in frost-susceptible soils (2,3).

While successful applications of geotextiles in cold regions have been made, many questions remain unanswered relative to the performance of geotextiles in a cold environment. For example, the influence of freeze-thaw cycles or subfreezing temperature on load-strain-strength and creep characteristics of geotextiles is largely unknown. Also little is known about the ability of geotextiles to prevent thaw instability.

In recognition of the need to determine mechanical properties of geotextiles used in cold regions, a research program was conducted to investigate the influence of freeze-thaw cycles in a freshwater and saline water environment on the load-strain-strength characteristics of geotextiles, and evaluate the load-strain-strength and creep characteristics of geotextiles at subfreezing temperatures. The results from the research program are presented herein.

GEOTEXTILES TESTED

Five geotextiles, each with different construction and/or material characteristics, were employed in the research program. These geotextiles are described in Table 1.

Table 1. Geotextiles Selected for Research Program

Geotextile	Filament	Geotextile Construction	Nominal Weight gm/m^2 (oz/yd^2)
Bidim C-34	Polyester Continuous	Nonwoven Needlepunched	272 (8)
Stabilenka T-100	Polyester Continuous	Nonwoven Resin Bonded	100 (3)
Typar 3401	Polypropylene Continuous	Nonwoven Heat Bonded	136 (4)
Fibretex 300	Polypropylene Continuous	Nonwoven Needlepunched	300 (8.8)
Propex 2002	Polypropylene Slit Film	Woven	150 (4.4)

The geotextile types were selected to insure that the load-strain-strength characteristics associated with several geotextile constructions and fiber polymer compositions could be compared in a meaningful way.

TEST PROCEDURES AND EQUIPMENT

Tensile Tests

A strip tensile test was used to characterize the load-strain-strength behavior of the geotextiles. A 200 mm (8.0 in.) sample width was employed to insure the results obtained would simulate, to as great a degree as practical, the plane-strain loading conditions which exist in the field (4). Five test specimens of a given geotextile type for a given test condition were trimmed to 200 mm (8.0 in.) in width by 220 mm (8.5 in.) in length with an accuracy of ± 4 mm (± 0.15 in.) The weight of each test specimen was recorded. The specimens were secured in 230 mm (9.0 in.) wide tensile test grips at a grip spacing of 100 mm (4.0 in.). The grips were placed in the load frame and a tensile test was conducted at a rate of strain of 10%/min. A pretension strain of 0.5 to 1.0% was applied to the specimen prior to the conduct of the test.

Both MTS and Instron test systems were employed in the program. The Instron was used for specimens which exhibited high elongation at failure. MTS test systems were used to test all the other geotextiles. Load and displacement were measured with linear variable differential transformers and load cells during the conduct of the test.

Each geotextile type was tested under the following conditions:

(1) room temperature [22°C (71°F)] in a dry state

(2) subfreezing temperature [-12°C (10°F)] in a dry state

(3) room temperature in a saturated surface dry (wet) state

(4) room temperature [22°C (71°F)] in a saturated surface dry (wet) state following 50 freeze/thaw cycles in a dry state

(5) room temperature [22°C (71°F)] in a saturated surface dry (wet) state following 50 freeze/thaw cycles in distilled water

(6) room temperature [22°C (71°F)] in a saturated surface dry (wet) state following 50 freeze/thaw cycles in saline water

The freezing temperature condition was achieved by placing the geotextiles in a walk-in cold room for 24 hours, and testing in the cold room. The saturated surface dry (wet) condition was achieved by soaking the geotextiles in water for 24 hours and toweling the specimens just prior to testing. Freeze/thaw cycling for either distilled or saline water was achieved by placing a specimen in a sealed plastic bag filled with either distilled or saline water and placing the bag on a rack in a freeze/thaw chamber. Thermistors were placed inside select specimen bags to monitor actual bag temperatures and insure complete freezing and thawing.

The tensile strength of each specimen was normalized to a nominal mass per unit area to account for sample variability. The normalized strength, S_N, is given by:

$$S_N = (M_n/M)S \tag{1}$$

in which, M_n = nominal mass per unit area of all specimens of a specific geotextile type
M = mass per unit area of the specimen
S = ultimate geotextile specimen strength

The normalized strengths of five specimens of a given geotextile type for a given test condition were averaged. The significance of the average values when compared with the average normalized strength of other test cases was determined using a student's T-distribution assuming a 90% confidence level.

Creep Tests

The creep characteristics of the geotextiles considered were evaluated at room temperature [22°C (71°F)] and subfreezing temperature [-12°C (10°F)] when loaded to various percentages of ultimate wide strip tensile strength. Three test specimens of a given geotextile type for a given test condition were trimmed to dimensions of 152 mm (6.0 in.) by 305 mm (12.0 in.). The samples were secured in grips with a grip spacing of 76 mm (3.0 in.). The loads were applied over a 152 mm (6.0 in.) specimen width. The three test specimens, secured in their grips, were connected in series for dead weight loading. Staples were spaced vertically at 64 mm (2.5 in.) in the center of the specimen to serve as an initial length for the measurement of deformation with time.

Tensile tests were conducted for each geotextile type to determine an average ultimate strength. The procedures described in the preceding section were employed except that the specimen size was 190 mm (7.5 in.) by 150 mm (6.0 in.) and a 76 mm (3.0 in.) grip spacing was used. Five specimens of each geotextile type were tested (for dry strength only). After the specimens were tested, the ulitmate strength obtained for each specimen was normalized to a nominal weight per unit area (Eq. (1)). The normalized strengths of the specimens for a geotextile type were averaged. The average normalized strength was used to determine the load required for each set of three creep samples, as shown below:

$$\text{Load} = P_u (M_a/M_n) N_{ave} \tag{2}$$

in which, P_u = percent of ultimate strength
M_a = average mass per unit area of the three specimens hung in series
M_n = nominal mass per unit area of all specimens of a specific geotextile type
N_{ave} = average normalized ultimate strength for a geotextile type

Each geotextile type was tested at four different load levels, specifically, 20, 35, 50, and 65% of ultimate 152 mm (6.0 in.) wide strip tensile strength. The loads associated with a given test condition were applied instantaneously to the three test specimens in series and deformation readings were taken at 1, 2, 5, 10, 30, 60, 120, 240, 1440, and 2880 min. Thereafter, readings were taken every week up to approximately 15 weeks or until failure occurred. A test was also terminated when no measurable deformation occurred over a period of one week. The subfreezing temperature condition was achieved by conducting the creep tests in a walk-in cold room.

TEST PROGRAM RESULTS

Tensile Load-Strain-Strength

Tensile axial load versus strain relationships for the geotextiles tested at temperatures of 22 and -12°C (71 and 10°F) are shown in Figure 1. The results indicate that for the geotextiles tested the needlepunched geotextiles have high elongation and intermediate strengths. The woven geotextile has the highest strength but the lowest elongation. The heat bonded geotextiles have strength and elongation characteristics intermediate to those of the needlepunched and woven geotextiles. The modulus and strength of the heat bonded geotextiles increased with decreasing temperature. The elongation at

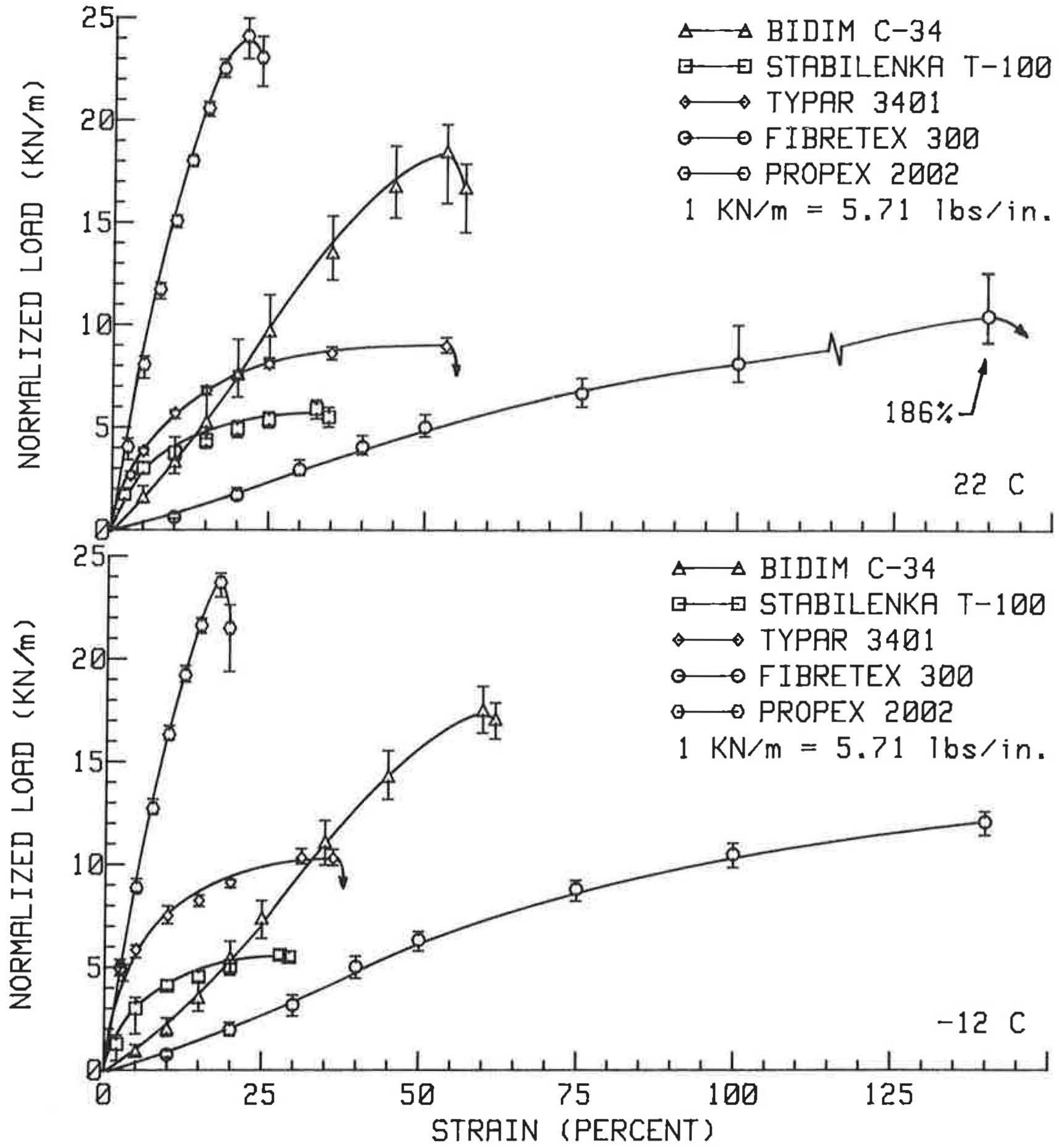

FIGURE 1: AXIAL LOAD VERSUS STRAIN (DRY CONDITION).

failure decreased significantly for the heat bonded geotextiles and all polypropylene geotextiles. No other statistically significant (90% probability) deviations in load-strain-strength characteristics were observed. The effects of geotextile construction appears to be much greater than the effect of temperature on the geotextile for small strains.

A summary of all the tensile load-strain characteristics of the geotextiles tested is given in Table 2. The elongation at failure for the heat bonded polyester geotextile increased upon wetting. The reasons for this are not clear. All other results indicate that normalized strength, percent elongation at peak strength, and normalized secant modulus at 10% strain do not change appreciably when the geotextiles considered were tested in a dry or wet condition at room temperature or following 50 freeze/thaw cycles in a dry, distilled water, or saline water environment.

Creep Strain

Typical creep strain versus time relationships for the geotextiles tested at 22° and -12°C (71° and 10°F) at a

Table 2. Load-Strain Characteristics of Geotextiles

Geotextile	Property	I	II	III	IV	V	VI
Bidim C-34	Normalized Strength (kN/m)*	18.6	17.5	16.0	16.1	15.3	16.7
	% Elongation at Peak Strength	53.2	60.0	59.9	54.8	59.0	54.5
	Normalized Secant Modulus at 10% strain (kN/m)	33.5	20.3	25.2	28.4	21.9	33.6
Stabilenka T-100	Normalized Strength (kN/m)	5.9	5.6	5.3	5.7	5.8	5.4
	% Elongation at Peak Strength	32.6	27.9	44.0	43.8	44.0	43.9
	Normalized Secant Modulus at 10% strain (kN/m)	37.7	41.0	30.8	33.8	33.1	31.2
Typar 3401	Normalized Strength (kN/m)	8.9	10.3	8.8	9.1	8.9	8.5
	% Elongation at Peak Strength	53.3	31.3	43.8	48.2	47.8	36.7
	Normalized Secant Modulus at 10% strain (kN/m)	56.9	75.2	61.9	62.2	60.4	59.2
Fibretex 300	Normalized Strength (kN/m)	10.3	-	9.9	9.9	9.7	9.6
	% Elongation at Peak Strength	186	-	166	187	187	181
	Normalized Secant Modulus at 10% strain (kN/m)	6.1	7.5	7.5	5.8	4.9	6.1
Propex 2002	Normalized Strength (kN/m)	24.2	23.7	24.4	25.4	24.7	24.2
	% Elongation at Peak Strength	21.2	18.0	19.8	20.4	21.1	21.1
	Normalized Secant Modulus at 10% strain (kN/m)	151	163	162	162	151	148

I = Control, Dry Condition, 22°C (71°F)
II = Control, Dry Condition, -12°C (10°F)
III = Control, Wet Condition, 22°C (71°F)
IV = 50 Cycles Freeze/Thaw, Dry Environment, Wet Condition
V = 50 Cycles, Freeze/Thaw, Distilled Water Environment, Wet Condition
VI = 50 Cycles, Freeze/Thaw, Saline Water Environment, Wet Condition

Note: Samples which were subjected to freezing and thawing were cycled between -15 and +15°C (5 and 58°F)

*1 lbs/in. = 0.175 kN/m

load level of 50% of the 152 mm (6.0 in.) wide strip tensile strength are shown in Figure 2. Sixty minute creep strain versus load level relationships are shown in Figure 3. As shown in Figure 2 a reduction in temperature resulted in a decrease in creep strains for geotextiles with polypropylene fibers. At this load level creep strains for geotextiles with polyester fibers were not significantly influenced by temperature. At load levels of 20% ultimate strength or below, however, the decrease in creep strain with temperature was not statistically significant for any geotextile. The influence of temperature on creep strains is apparently related to filaments and not to the geotextile construction. The results shown in Figure 3 indicate creep strains were greatest for geotextiles with polypropylene fibers. All of the polypropylene materials experienced tertiary creep and failed at load levels of 50% or 65% of wide strip tensile strength at 22°C (71°F). The geotextiles with polyester fibers did not fail until the load level was taken to 80% of wide strip tensile strength at 22°C (71°F). Significantly, however, none of the geotextiles failed at load levels as great as 65% at -12°C (10°F).

The geotextile construction process appears to dominate the magnitude of the short-term creep strain at any time. Needlepunched geotextiles have the greatest short-term creep strains at a given load level. Heat bonded and woven geotextiles have the lowest short-term creep strains.

CONCLUSIONS

Based upon the test results presented for the five geotextiles considered in the research program, the following conclusions have been reached: 1) the mechanical properties of geotextiles, in terms of load-strain-strength and creep characteristics, are not adversely affected by subfreezing temperatures in a temperature range associated with many cold regions engineering applications; 2) Freeze/thaw cycling in a dry, distilled water, or saline water environment has no appreciable influence on the load-strain-strength characteristics of geotextiles; 3) the geotextile construction dominates the short-term creep strain; 4) other factors being equal polyester geotextiles have the lowest creep rates and highest thresholds of tertiary creep; and 5) a reduction in temperature results in decreased creep rates for polypropylene geotextiles.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support for the research program provided by the Crown Zellerbach Corporation. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Crown Zellerbach Corporation.

REFERENCES

(1). Tart, R.G., and Luscher, U., "Construction and Performance of Frozen Gravel Fills," Proceedings, Specialty Conference on The Northern Community: A Search for a Quality Environment, American Society of Civil Engineers, Seattle, WA, April 1981, pp. 693-704.

(2). Roth, W.H., "Fabric Filter for Improving Frost Susceptible Soils," Proceedings, International Conference on the Use of Fabrics in Geotechnics, Vol. 1, Ecole Nationale Des Pontes et Chausses, Paris, April 1977, pp. 23-28.

(3). Hoover, J.M., Pitt, J.M., Handfelt, L.D., and Stanley, R.L., "Performance of Soil-Aggregate-Fabric Systems in Frost-Susceptible Roads, Linn County, Iowa," Report 15U-ERI-AMES-80211 Project 1269, Dept. of Civil Engineering, Engineering Research Institute, Iowa State University, Ames, Iowa, May 1980.

(4). Shrestha, S.C. and Bell, J.R., "A Wide Strip Tensile Test of Geotextiles," Proceedings, Second International Conference on Geotextiles, Las Vegas, Industrial Fabrics Association International, St. Paul, August 1982.

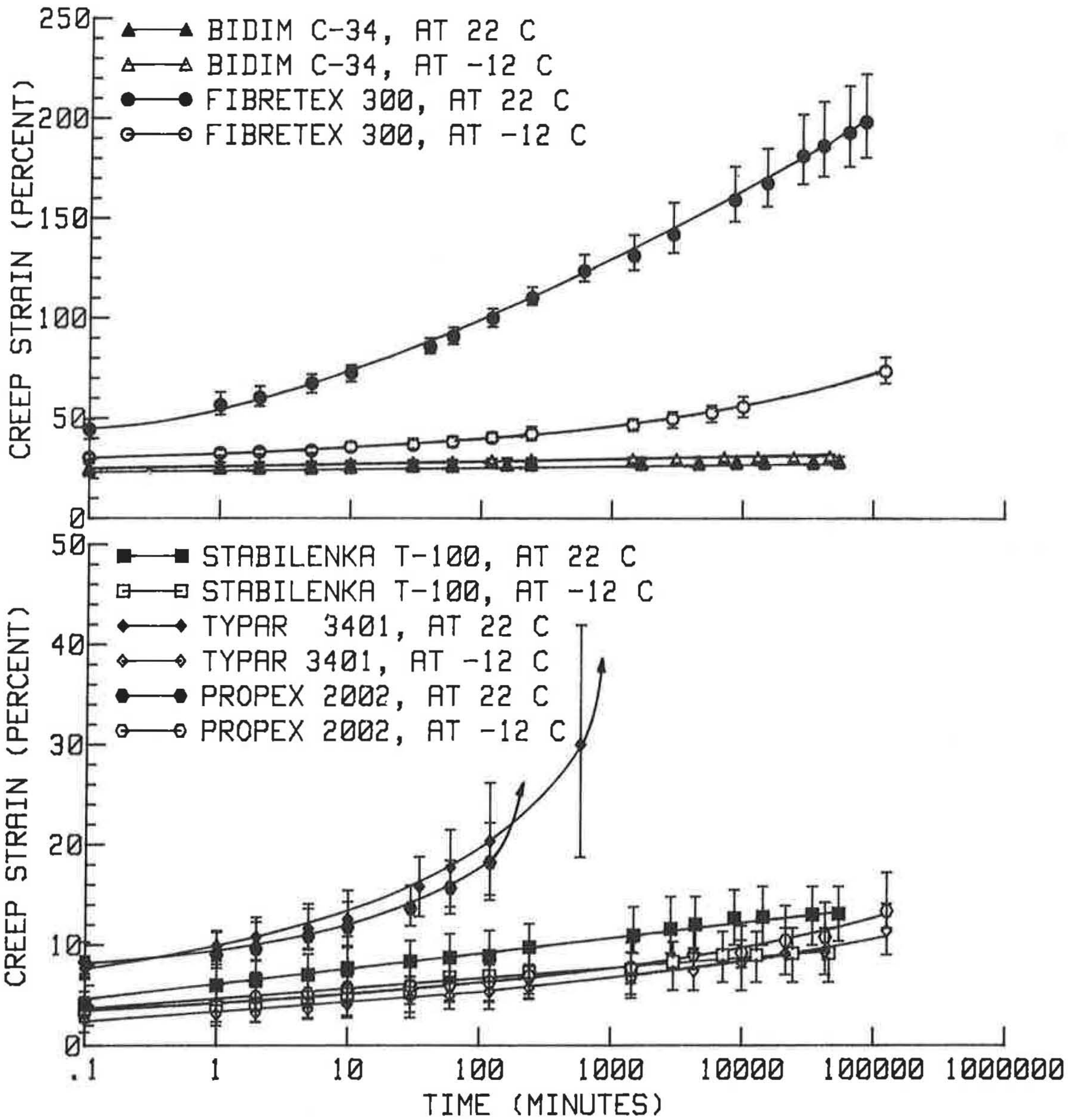

FIGURE 2: CREEP STRAIN VERSUS TIME AT 50% WIDE STRIP TENSILE STRENGTH.

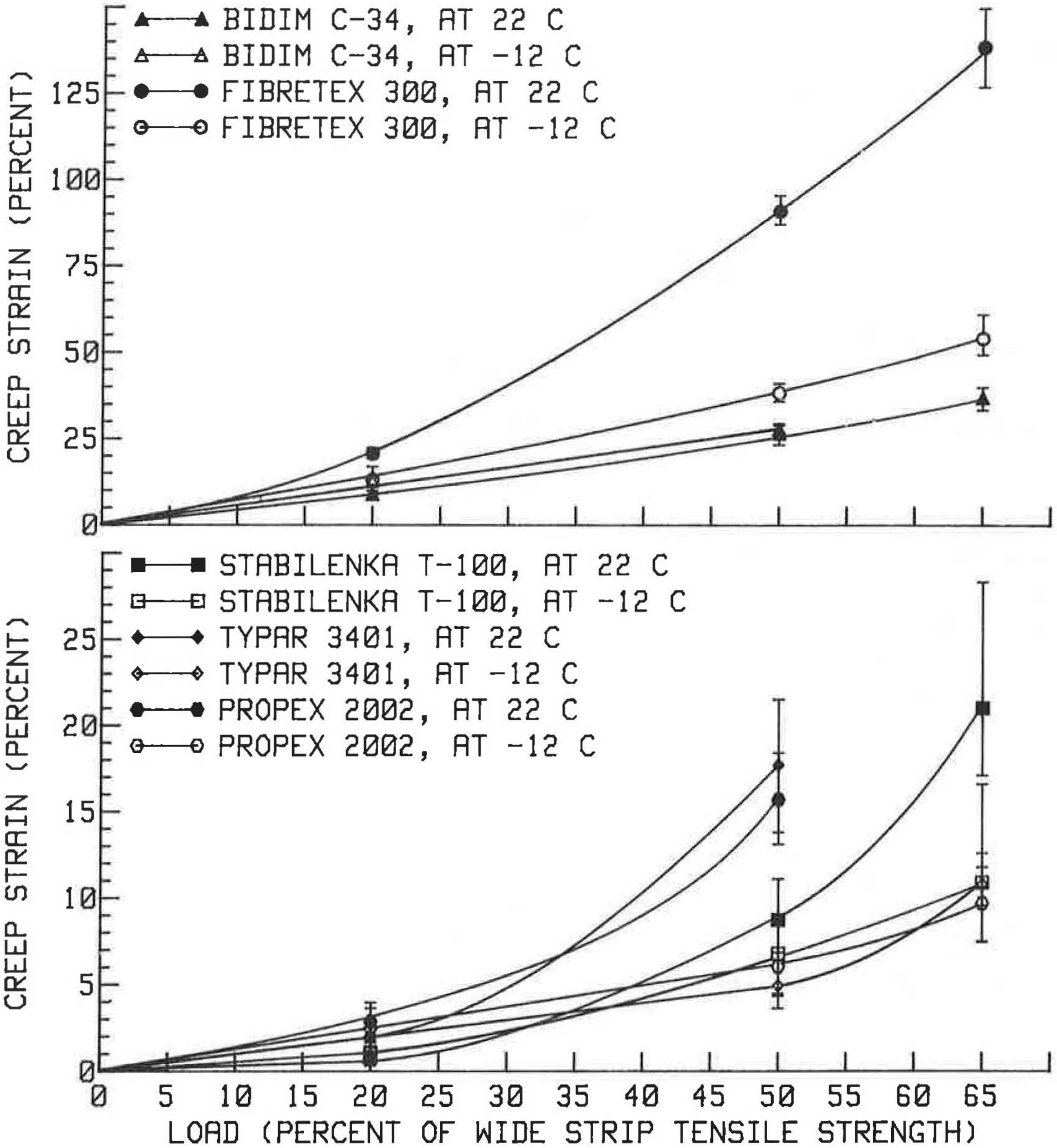

FIGURE 3: SIXTY MINUTE CREEP STRAIN VERSUS LOAD LEVEL.