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Creep strains of high strength polyester geogrids measured by conventional and accelerated test methods

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ABSTRACT: The objectives of this study were to investigate the creep behavior and associated reduction factors for high strength Polyester geogrids. Four different types of polyester geogrids whose nominal tensile strengths varied from 100 to 400 kN/m were investigated. These geogrids were fabricated using knitting and woven techniques. Series of conventional long-term and Stepped Isothermal Method (SIM) tests were performed to evaluate the long-term creep strain of these geogrids. ASTM D5262 and ASTM D6992 test standards were used in the study. The results of the conventional creep tests were used to evaluate the repeatability of the SIM test method. The results obtained from Ramp and Hold tests indicated that the elastic moduli varied from 3993 to 6571 kN/m for these geogrids. The conventional long-term creep strains for 10,000 hours were varied from 1.32% and 0.53%. Knitted geogrids showed higher creep strains than that associated with woven geogrids. The long-term creep strains for the test geogrids were within primary and secondary creep regions. The results of SIM tests showed that a minimum of 6 to 8 steps should be used in order to predict the creep behavior beyond 75-year design life. The results obtained from SIM tests showed match good with the results obtained from long-term creep tests for woven geogrids. Based upon SIM test results obtained from the test geogrids, the creep rupture reduction factors were found to vary from 1.35 to 1.43 for 75-year design life.

1 INTRODUCTION

The main design concern for the long-term stability of geosynthetic reinforced soil structures is prediction of the creep behavior of the geosynthetics under design loads. The long term stresses and strains in the reinforcement should not exceed their corresponding allowable design values during the life of the structure. The current state-of-practice design methods and standards usually incorporate a factor of safety for creep, along with safety factors for other degradation mechanisms, to obtain the allowable long-term strength of. geosynthetics (FHWA 1993; Task Force 27 1989). The factor of safety for creep load is determined from unconfined creep tests with a minimum duration of 10,000 hours (Allen 1991; GRI-GG4 1991). It is general practice that geosynthetics creep data from these tests can only be extrapolated up to one order of time magnitude (i.e., up to 10 years) (FHWA 1993; Jewell and Greenwood 1988). However, creep performance for a longer duration can be predicted in accelerated creep tests. In these tests, creep load are applied on geosynthetics at elevated temperatures. The results of these tests can be shifted to extrapolate creep behavior, at the same loading levels, to longer time intervals using time-temperature superposition principles.

Task Force 27 guidelines (1989) reinforced an accelerated testing procedure on plastic pipes [ASTM Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials – D2837] (ASTM 1990), as a guideline for running accelerated creep tests. However, this procedure is related to failure modes associated with plastic pipes that are not applicable to geosynthetics.

Various researches have been done to evaluate the time-temperature-creep relationship on various geotextiles and geogrids (Yeo 1995; Farrag and Shirazi 1998; Farrag 1998; Thornton et al. 1998 & 1999; Greenwood et al. 2004; Wrigley et al. 2004; Zormberg et al. 2004). Bush (1990) evaluated temperature shifts on geogrids at temperatures from 10°C to 40°C. These studies showed the applicability of predicting creep strains from elevated-temperature creep tests.

2 OBJECTIVES

This paper presents the creep behavior of four different types of polyester geogrids tested using the conventional long-term creep tests and accelerated stepped isothermal test methods. The results obtained from these two test methods are provided for comparison purposes between the two test methods. The results of the conventional creep tests were used to evaluate the repeatability of the SIM test method. The results obtained from SIM tests can be used to evaluate the creep rupture reduction factors of the test geogrids for 75-year design life.

3 MATERIALS AND TEST PROGRAMS

Four different PVC coated polyester geogrids provided from local (Taiwan) manufacturers were used in this study. The nominal wide width strengths of these geogrids varied from 100 to 400 kN/m. Geogrids B and C were manufactured by the weft insertion weaving process and geogrids A and D were manufactured by a knitting process. All products were made from high tenacity, high molecular weight (>25,000 g/mole), alkali tolerant (max. 30 carboxyl end group) fibers. The glass transition temperatures of these fibers were around 75°C. Typical engineering properties of these products are summarized in Table 1. Typical polyester fiber double hump stress versus strain response was observed for the test products. The initial modulus of Product A is higher than that of Product D due to different process procedure (knitting vs. weaving). Both products exhibit gradual peak in secant modulus at strains corresponding to about 75% of the ultimate tensile strength (UTS).

Table 1. Summary of the engineering properties of the test materials.

Item	Type of Geogrid			
	A	B	C	D
Nominal Strength (kN/m)	400 × 50	400 × 100	100 × 40	100 × 30
Junction weaving Method	Woven	Knitting	Woven	Knitting
M.D. Tensile strength (kN/m)	525.67	463.18	126.13	127.31
M.D. elongation at break (%)	11.06	12.19	11.16	13.70

4 CONVENTIONAL & SIM CREEP TESTS

The testing program conducted in this study involved conventional creep tests (ASTM D5262) conducted at 21°C and 60% RH test conditions and accelerated (SIM) creep tests (ASTM D6992) conducted to characterize creep strains and define creep failure and rupture.

Two single-station and one multi-station rigid double-lever action creep frames providing a 20:1 and 10:1 mechanical advantage in the loading train were employed, respectively. Temperature control of 20 ± 1°C was achieved through the use of environmental chamber and temperature-controlled room. Grips used in the wide width creep tests were a custom two-roll design fabricated in-house. The wide width tensile tests were conducted in the temperature controlled geosynthetics testing laboratory using a Model GT-7000 Go-Tech testing machine equipped with capstan roller grips. Extension measurements for the creep test were made using a LVDT clamped to the specimens.

A series of stepped isothermal creep and creep rupture tests were performed for the Products A and B. A multiple-purposes environmental chamber with insulated walls was constructed to enclose the grips and test specimens. The environmental chamber houses two 10 kW electrical heaters used to achieve temperature jumps of 10 to 20°C within 3-6 minutes as well as to maintain a constant temperature during creep loading. The multiple-purpose environmental chamber was relative large (90 × 90 × 150 cm), and it is able to hold the 200-mm wide width specimens and grips. Temperature was controlled using a custom made digital temperature controller with fuzzy logic capabilities equipped with an electronic thermocouple. Thermocouples for temperature control and data acquisition were positioned close to the specimen. Two 1/4 HP motors and two 7.5 by 3 inches fans were used within the environmental chamber to enhance air circulation and promote uniform temperature. The environmental chamber and temperature control system was able to maintain constant temperature ±1°C. Because of the comparatively large thermal mass (90 × 90 × 150 cm) of this system, temperature jumps were achieved in approximately 3-6 minutes.

Displacements between reference points in the specimen were measured using an external LVDT (Gefran Model PA1-F-100-S01M). The LVDT was directly mounted to the specimen with a gauge length of 100 mm. Since the LVDT measurements are temperature sensitive, temperature corrections were applied to the displacement data. Temperature, displacements, and tensile load were recorded using an automatic data acquisition system. Data were collected every second to adequately capture the stress-strain response until rupture.

All tests were conducted using specimens from the same roll, and were performed using the same load frame, instrumentation, specimen preparation procedures, and initial loading procedures. Testing was conducted in the machine direction of the geogrid specimens. Since wide specimens (100 mm or 200 mm in width as required) were used through-out the testing program, sampling and conditioning procedures of the tests were always conducted in general agreement with wide-width (method B) tensile testing

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standard ASTM D6637 (ASTM 2003). A preload of 222 N or 1.25% of UTS (whichever lower) was applied prior to each test to condition the specimen and minimizing the initial "setting in" of the stress-strain curve. The LVDT was mounted directly to the specimen upon completion of the preloading.

5 CREEP STRAIN

Greenwood (2004) had noted that there can be quite a wide variability in the measurements of the initial strain for geogrids in creep tests. Therefore, several series of ramp and hold (R & H) short term creep tests were performed to determine the average short term elastic modulus of the test geogrids. Typical R & H test results for product A corresponding 40% to 80% of UTS is shown in Figure 1. The short term initial elastic (creep) strains versus corresponding percentage of UTS for products A and B were plotted in Figure 2. The average initial elastic modulus can be analyzed based upon linear regression of the test data shown in the figure. The initial elastic moduli were 6571 and 3993 kN/m for products A and B, respectively. These initial elastic moduli were used

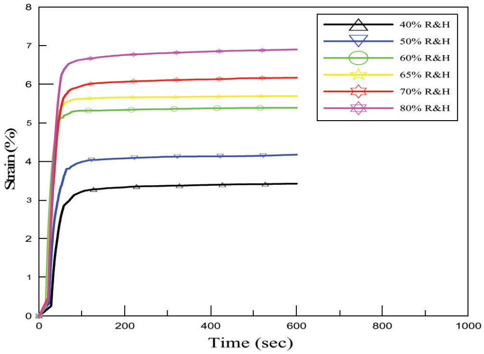

Figure 1. Creep strain vs. percentage of UTS for short term creep tests of product A.

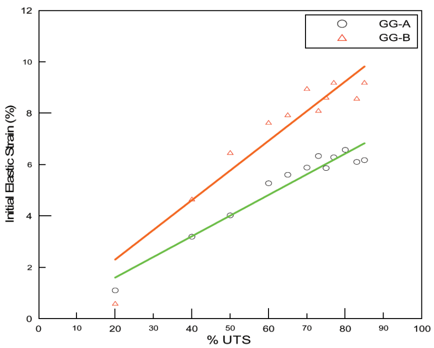

Figure 2. Creep modulus vs. percentage of UTS for products A & B.

to adjust the long term and SIM creep curves for the test results.

Figure 3 shows the creep curves derived from the results of the conventional long-term creep tests for the test geogrids under standard test conditions. The creep loads were 60% and 65% of corresponding ultimate tensile strength (UTS) of 10,000 and 1,000 hour duration. Replicate creep (R & H) tests of shorter duration were used to adjust the vertical location of the long term tests. The long-term creep data were shifted vertically to align with the median of the strain range exhibited by the R & H branches and all creep curves were rescaled to account for ramp time. Generally, consistent linear creep strain showed in log time scale. Please also note that geogrids containing knitted joints (Types A and D) show higher creep strain response than that associated with the geogrids containing woven joints. The conventional long-term creep strains for 10,000 hours for products A, B, and D were 1.32%, 0.53%, and 1.22, respectively. As shown in the figure, linear creep strain rate was observed for all test conditions. However, the creep strain rates for products A and D are clearly higher than that associated with products B and C. It is believed that the production procedure and the engineering properties of the raw materials have major influence on the creep behavior of the products.

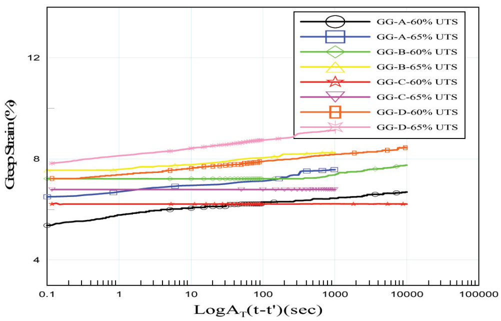

Figure 3. Long-term creep test (10,000 & 1,000 hrs) results for the test products.

Eleven and eighteen tests represent replicate specimens tested ranging from 20% to 85% of UTS were conducted on Products A and B for 10°C and 11°C dwell temperature, respectively. Note that typical test was performed at step temperature of 10°C ranged from 20° to 90°C, which is slightly above the glass transition temperature (often quoted as 82°C) of PET (Thornton et al. 1998). The isothermal steps are each about 10,800 seconds long. Typical 6 to 8 isothermal steps were used in the tests.

Typical creep response under the influence of the constant applied load (60% UTS) and the temperature profile for the test products is presented in Figure 4. The load and strain data can be converted to creep modulus. In addition, the creep modulus responses

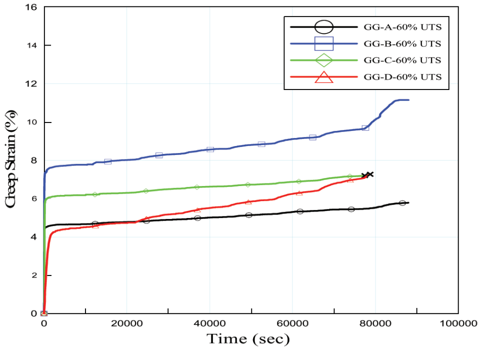

Figure 4. Typical creep strain vs. linear time for SIM test at 60% UTS of the test products.

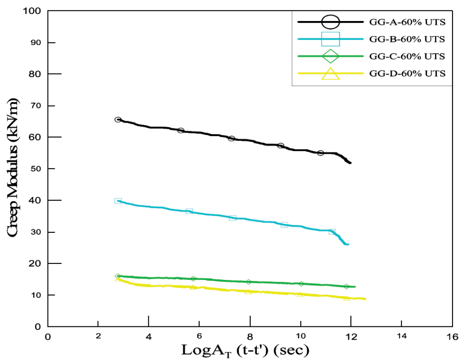

Figure 5. Typical creep modulus master curves for SIM test at 60% UTS of the test products.

for the second through the eighth temperature steps are rescaled to new starting times between 100 and 300 seconds, increasing 2 to 2.5 on the log scale. Vertical shifts were performed to remove the thermal contractions from the creep data. Finally, the master creep modulus curve is obtained by horizontal shifts of the segments to achieve the result shown in Figure 5 for the reference temperature given by the first step, 20°C. The duration depicted by this master curve is 9.15 log seconds which converted to over 75 years. The master creep strain curves can be computed from the master creep modulus curves shown in Figure 6. A series of cumulative shift factors used in the SIM time-temperature superposition procedures to create the master curves. The SIM shift factors were approximately linear distributed extending to 90°C and not to depend on load level.

Figures 7 and 8 presented a series of master creep curves for replicate specimens SIM tests ranging from 20% to 85% of UTS on Product A and B for 10°C and 11°C step temperature, respectively. The master curves (solid lines) obtained from the conventional creep tests were also shown in the Figures. The creep

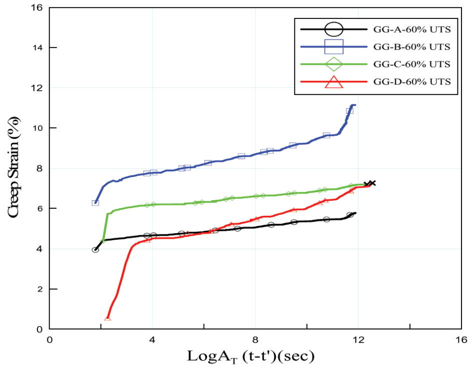

Figure 6. Typical refined master creep strain curves for SIM test at 60% UTS of the test products.

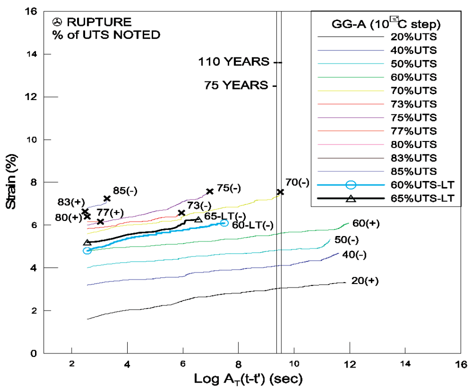

Figure 7. Creep strain vs. log time curves for the product A.

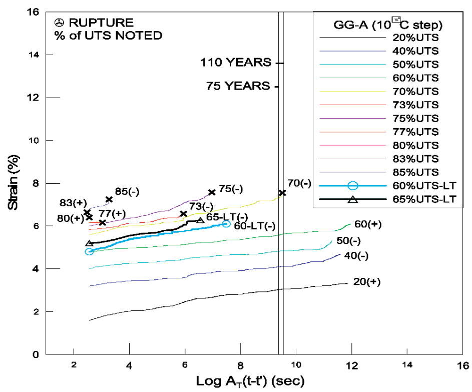

Figure 8. Creep strain vs. log time curves for the product B.

strain rates for the tests less and equal to 60% UTS conducted by SIM are quite agreed with each other. The separation between the 60% UTS conventional and SIM curves were the combination effects of specimen to specimen variation and the selections of the factors for the time-temperature shifts. The

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predicted strain rate and total creep strain observed from SIM tests are slightly less than those obtained from the conventional tests.

6 CREEP RUPTURE

Figures 9 and 10 presents the linear regress plots of rupture load as percentage of UTS versus log time to rupture for the conventional and SIM creep tests performed for Products A and B, respectively. These data points are located scatter around the regress lines for both products. The dash lines represent the boundaries for one standard deviation away from the average regression line. The 75 year rupture loads at a reference temperature of 20°C are 70% and 74% of UTS for products A and B, respectively. The corresponding reduction factors are 1.43 and 1.35.

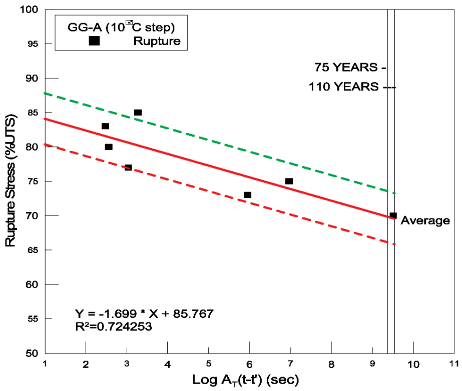

Figure 9. Creep rupture data and regression line for the product A.

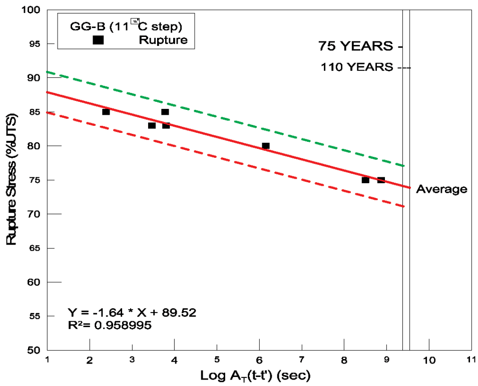

Figure 10. Creep rupture data and regression line for the product B.

7 CONCLUSIONS

The initial strain in creep tests can be quite a wide variability. Therefore, a series of ramp and hold (R & H) short term creep tests at different percentage of UTS should be performed to determine the average short term elastic modulus of the test products. The elastic modulus obtained should be used to adjust the vertical location of the long term and accelerated creep tests. The initial elastic moduli are 6571 and 3993 kN/m for the test products A and B, respectively.

Linear creep strain rates were observed from a series conventional long-term creep tests of the test products. The creep strain rates for products with knitting junctions were higher than that associated with the products with weaving joints. 10,000-hour long-term creep strains for products A, B, and D were 1.32%, 0.53%, and 1.22, respectively.

The use of SIM test as a special application of TTS for polyester geogrids appears to be validated by the results presented herein. Typical test was performed at step temperature of 10°C ranging from 20° to 90°C, which is slightly above the glass transition temperature of PET. The isothermal steps were about 10,800 seconds long. Typical 6 to 8 isothermal steps were used in these tests. A series of cumulative shift factors used in the SIM time-temperature superposition procedures to create the master creep curves. The duration depicted by these master curves was 9.15 log seconds which can be converted to over 75 years. The predicted strain rate and total creep strain observed from SIM tests were slightly less than those obtained from the conventional tests. The slope of SIM test generated creep strain curves increased with increase in applied loads greater than 60% UTS. Linear regress analysis for creep test data of rupture load versus rupture time can be used to predict the long term rupture loads at a reference temperature. The 75 year rupture loads at a reference temperature of 20°C are 70% and 74% of UTS for products A and B, respectively. The corresponding reduction factors are 1.43 and 1.35.

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REFERENCES

Allen, T.M. (1991). "Determination of the Long Term Tensile Strength of Geosynthetics; A State of-the-art Review." *Proceedings*, Geosynthetics' 91 Conference, Atlanta, pp. 351-379.

ASTM D2837, (1990). "Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials." *American Society for Testing and Materials,* West Conshohocken, PA.

ASTM D6637, (2003). "Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method," *American Society for Testing and Materials*, West Conshohocken, PA.
ASTM D5262, (2002). "Standard Test Method for Evaluating the Unconfined Tension Creep Behavior of Geosynthetics," *American Society for Testing and Materials,* West Conshohocken, PA.
ASTM D6992, (2003). "Standard Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method," *American Society for Testing and Materials*, West Conshohocken, PA.
Bush, D.I. (1990). "Variation of Long-term Design Strength of Geosynthetics in Temperatures up to 40°C," *Proceedings, 4th International Conference on Geotextiles, Geomembranes, and Related Products*, pp. 673-676.
FHWA, 1993. "Guidelines for Design, Specifications, and Contracting of Geosynthetic Mechanically Stabilized Earth Slopes on Firm Foundations," FHWA-SA-93-025.
Farrag, K. and Shirazi, H. (1997). "Development of an Accelerated Creep Testing Procedure for Geosynthetics – Part I: Testing," *ASTM Geotechnical Testing Journal*, Vol. 20, No. 4, pp. 414-422.
Farrag, K., (1998). "Development of an Accelerated Creep Testing Procedure for Geosynthetics – Part II: Analysis," *ASTM Geotechnical Testing Journal*, Vol. 21, No. 1, pp. 38-44.
Greenwood, J.H., Kempton G.T., Brady, K.C. and Watts, G.R. (2004). "Comparison between Stepped Isothermal Method and Long-term Creep Tests on Geosynthetics," *Proceeding, 3rd European Geosynthetics Conference,* Munich, Germany, pp. 527-532.
GRI-GG4 Standard Practice, (1991). "Determination of the Long Term Design Strength of Stiff Geogrids," *Geosynthetics Research Institute,* Drexel University.
Jewell, R.A. and Greenwood, J.H. (1988). "Long Term Strength and Safety in Steep Soil Slopes Reinforced by Polymer Materials," *Geotextiles and Geomembranes*, No. 7, pp. 8-118.
Task Force No. 27, (1989). "Design Guidelines for Use of Extensible Reinforcements (Geosynthetic) for the Mechanically Stabilized Earth Walls in Permanent Applications" Joint Committee of AASHTO-AGC-ARBTA on Materials.
Thornton, J.S., Paulson, J.N. and Sandi, D. (1998). "Conventional and Stepped Isothermal Methods for Charactering Long Term Creep Strength of Polyester Geogrids," *Proceedings, 6th International Conference on Geosynthetics*, Atlanta, pp. 691-698.
Thornton, J.S., Sprague, C.J., Klompmaker, J. and Weeding, D.B. (1999). "The Relationship of Creep Curves to Rapid Loading Stress-Strain Curves for Polyester Geogrids," *Proceedings, Geosynthetics' 99*, pp. 735-744.
Wrigley, N.E., Wei, L. and Junyi, P. (2004). "Accelerated Creep Testing and Quality Assurance," Proceeding, 3rd European Geosynthetics Conference, Munich, Germany, pp. 551-556.
Yoe, K.C. (1985). "The Behavior of Polymeric Grids used for Reinforcement," Ph.D. Thesis, University of Stathelyde, Glasgow, U.K.
Zornberg, G.G., Byler, B.R. and Knudsen, J.W. (2004). "Creep of Geotextiles Using Time-Temperature Superposition Methods," *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, Vol. 130, No. 11, pp. 1158-1168.

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