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On the Effect of Thermal Cycles on the Tensile Behavior of Rigid Fiberglass Geogrid

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Abstract: Studying the effect of temperature cycles on the mechanical behavior of geosynthetic material is essential for the analysis and design of reinforced soil structures in cold climate. High-strength fiberglass geogrids are relatively new soil reinforcement materials that have improved properties with a potential for a wide range of applications. This research involves a preliminary experimental investigation that has been performed to examine the effect of temperature cycles on the response of high strength biaxial geogrid material, namely stiff fiberglass geogrids. Single ribs of geogrid were subjected to different thermal cycles and a series of tensile tests were performed to measure the ultimate strength and strain at failure for each sample. The experimental results are compared and the differences in mechanical properties in each thermal cycle are highlighted. Results indicated that, for the temperature range used in this study, thermal cycles have minimal effects on the mechanical properties of stiff fiberglass geogrids. The results also showed that fiberglass geogrid presents superior mechanical properties with significantly lower strains at failure.

1. INTRODUCTION

Polymers are important supplement to conventional materials used in civil engineering applications due to excellent mechanical properties, especially in harsh environments. In the past two decades, a large number of studies have focused on studying the mechanical properties of polymers subjected to extreme environmental conditions (e.g., Hsieh and Tseng 2008; Kongkitkul et al., 2012; Koda et al., 2018). For instance, Al-Kawi (2012) reported that tensile and fatigue stresses decreased by 46% with increasing temperature from 40°C to 60°C after investigating the behavior of woven strand mats E-GF- reinforced polyester composites at temperatures of 40°C, 50°C and 60°C. Similar findings were reported by Torabizadeh (2013) who investigated the tensile behavior of unidirectional glass fiber (GF) reinforced epoxy matrix composites at room temperature (25°C) as well as at -20°C and -60°C. The tensile test results showed that the stress-strain curve is affected by the increase in temperature. Recently, Zhao and Wang (2018) investigated experimentally the tensile fatigue properties of glass fiber reinforced polymers (GFRP) used in civil engineering applications under high temperature. They tested a total of 105 bars in six different temperatures, namely, 100°C, 150°C, 200°C, 250°C, 300°C and 350°C, for a period of 0, 1 or 2 hours. The GFRP bars were tested under different durations of cyclic loads and temperature exposures. The results showed that tensile strength decreases with the increase in holding time and temperature.

This brief literature review shows a number of experimental investigations that have been performed to measure the tensile strength of different types of polymeric material under different temperature conditions. However, there is a need to expand these studies to cover the effect of thermal cycles on fiberglass geogrids.

2. EXPERIMENTAL PROGRAM

2.1 Material and sample preparation

The material tested is fiberglass biaxial geogrid manufactured by Titan Environmental Containment Ltd. The geogrid has a thickness of 2.5 mm and contains high modulus fiberglass with durable polymeric coating manufactured using precision weaving process. To prepare the material for testing, single rib samples measuring 250 mm were cut from a large sheet of geogrid (50 cm × 50 cm). Figure 1 shows a portion of the fiberglass geogrid sheets and a sample that has been prepared for testing.

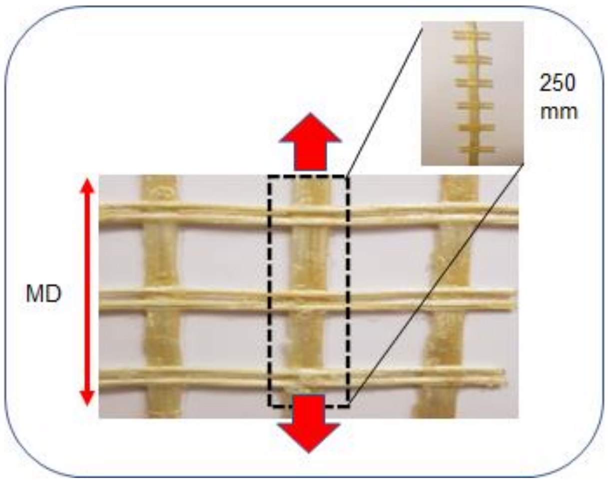

Figure 1 Fiberglass (ConForce) geogrid

2.2 Experimental setup

A series of laboratory experiments was preformed to investigate the effect of freeze-thaw cycles on the tensile strength of the fiberglass geogrid as well as the maximum strain at failure. The prepared samples were subjected to a thermal cycle consisting of exposing the specimens to a temperature of -28 °C for 30 minutes and then room temperature for 10 minutes. The said cycle was repeated 4, 8, 12, 16, and 20 times to reach the number of cycles required. All testing took place using the MTS machine shown in Figure 2. The machine has a load cell capacity of 300 kN. To record the strains resulting from the tensile loading, an axial extensometer with 50 mm gage length was fixed to the specimen during the test.

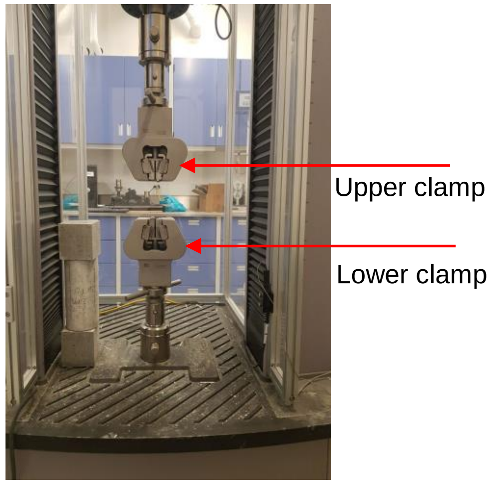

Figure 2 The MTS loading machine used in the experiments

2.3 Test procedure

Single rib geogrid strength tests are performed following ASTM D 6637 test method. It involves applying an increasing load to the tested samples up to failure. The objective of the test is to determine the maximum tensile stress that can be carried by the geogrid sample before failure. This can be determined by measuring the maximum load divided by the original cross section of the sample. Moreover, the sample elongation is also recorded for each load increment up to failure. The sample is tightly held by the lower and upper grips attached to the MTS machine. During the tensile test, the top grip is moved upward at a constant rate of 17 mm/min to pull and stretch the sample. The force and the corresponding elongation are continuously monitored to allow for a stress-strain relationship to be obtained. The machine stops as soon as the sample fails. Figure 3 shows the details of the tensile test setup as well as the extensometer attached to the tested sample.

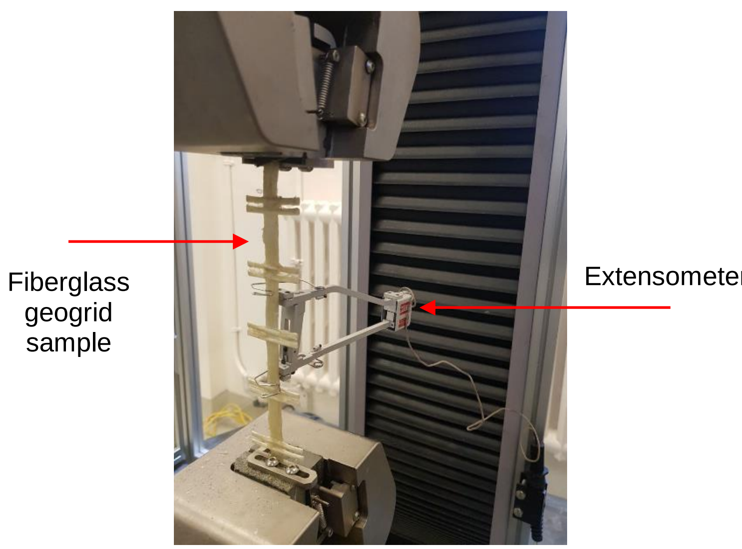

Figure 3 Details of the tensile test setup

3. RESULT AND DISCUSSION

3.1.1 Control tests

Six fiberglass geogrid samples were tested at room temperature without exposure to thermal cycles. Table 1 summarizes the ultimate strength in kN and the ultimate strain for each sample. The average values for the ultimate strength and the corresponding strain were found to be about 5.1 kN and 1.1%, respectively.

Table 1 Result under room temperature (control test)

Sample number	Ultimate strength (kN)	Ultimate strain (%)
1	5.1	1.1
2	5.1	1.0
3	5.3	1.2
4	5.2	1.1
5	5.2	1.1
6	4.9	1.0
Average	5.1	1.1

3.1.2 Effect of thermal cycles on the stress-strain response

Thirty fiberglass geogrid samples were tested after exposure to thermal cycles that range from four to twenty. Table 2 shows the average ultimate strength and ultimate strain for each thermal cycle. Moreover, the table shows the total duration for each tested thermal cycle. The highest ultimate strength of 5.2 kN was obtained by sixteen thermal cycles and the lowest ultimate strength of 5.1 kN was obtained by eight thermal cycles with corresponding ultimate strain of 1.1 % and 1.0%, respectively.

Table 2 Recorded properties under different thermal cycles

	Number of thermal cycles				
	4	8	12	16	20
Total duration (min)	160	320	480	640	800
Ultimate strength (kN)	5.1	5.1	5.1	5.2	5.2
Ultimate strain (%)	1	1	1.1	1.1	1.1

3.1.3 Effect of thermal cycles on the ultimate strength

The ultimate strength of the tested samples at zero cycles is found to be about 5.1 kN. The ultimate strength is found to slightly change with the increase in the number of cycles. The maximum difference in strength compared to the control tests is found to be insignificant (2%). Therefore, the material seems to be capable of maintaining its ultimate strength after multiple freeze-thaw cycles. Figure 4 shows the recorded ultimate strength in measured in each thermal cycles.

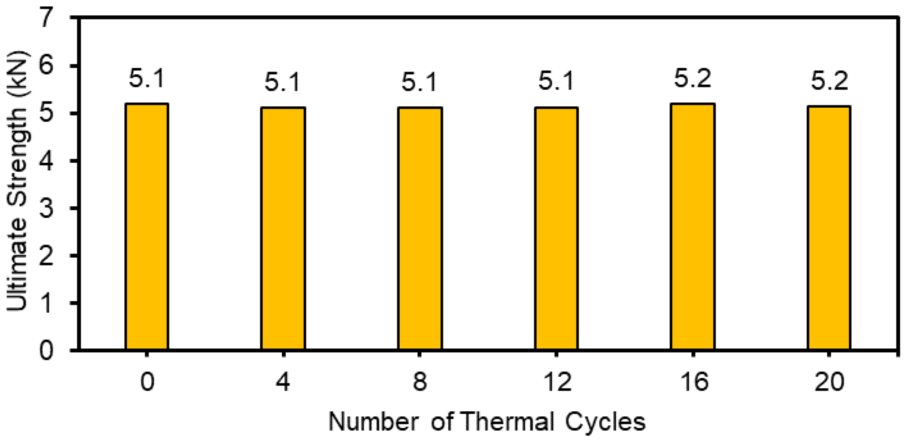

Figure 4 Fiberglass geogrid ultimate strength for each tested thermal cycle

3.1.4 Effect of thermal cycles on strains

During testing, an extensometer is used to record the strains induced in the geogrid samples. As shown in figure 5, the recorded strain values fall between 1% and 1.1% with an average of 1.07%, which indicates a stable strain with increasing the number of thermal cycles. In other words, the effect of thermal cycles on the material's strain is negligible. Figure 5 shows the ultimate strain per single rib in each thermal cycle

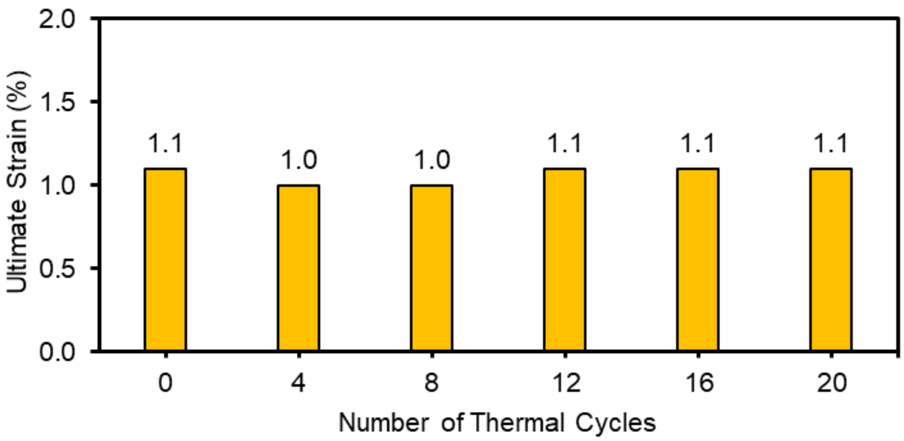

Figure 5 Fiberglass geogrid ultimate strain for each tested thermal cycle

3.1.5 Effect of thermal cycles on the modulus of elasticity

The material's elastic modulus is taken as the slope of the linear portion of the stress-strain relationship in the elastic deformation range. All samples are found to reach failure within the elastic range. The control test provided a modulus of elasticity of 204 MPa. The modulus slightly changed with the increase in the number of thermal cycles with a maximum value of 209 MPa at 20 cycles. Figure 6 shows the change in the modulus of elasticity the change in thermal cycles. The thermal cycles generally have a slightly positive effect on the material modulus.

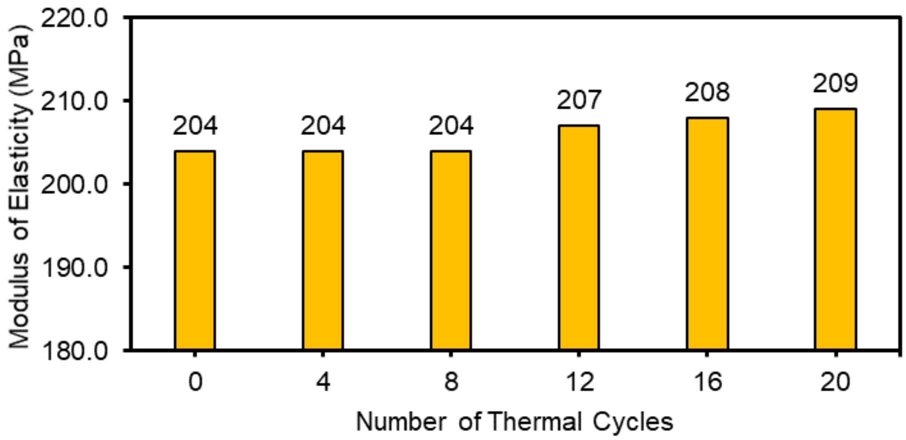

Figure 6 Value of the fiberglass geogrid modulus of elasticity for each tested thermal cycle

4. CONCLUSION

The tensile behavior of a stiff fiberglass geogrid exposed to a different number of thermal cycles ranging from -28 °C to 21 °C was investigated using the single rib method presented by ASTM D 6637. The following conclusions are derived from the experimental results:

- For the control tests (at room temperature), the ultimate strength, ultimate strain, and modulus of elasticity of the tested fiberglass geogrid were found to be 5.1 kN, 1.1% and 204 MPa, respectively.
- The strength and strain of the tested fiberglass geogrid remained constant regardless of the number of thermal cycles.
- Fiberglass showed a slight increase in modulus of elasticity with the increase in the number of thermal cycles.

5. ACKNOWLEDGEMENT

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