THE SHORT- AND LONG-TERM COMPRESSIVE BEHAVIOR OF HIGH DENSITY POLYETHYLENE GEONET AT DIFFERENT INCLINED CONDITIONS

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ABSTRACT

The short- and long-term compressive behavior of high density polyethylene (HDPE) geonet were evaluated at four inclined conditions: the horizontal (0°), 1(V)-to-5(H), 1(V)-to-4(H), and 1(V)-to-3(H), to investigate the effect of the combined stresses (i.e., normal and shear) on the side slope of the landfill. The results of short-term compressive tests indicated that the compressive strength was largely unchanged at different inclined conditions; whereas the compressive strain increased with degree of inclination.

The long-term compressive behavior (i.e., creep) was evaluated using the stepped isothermal method (SIM). Applied stresses at 20% and 60% of normal compressive strength were used at four inclined conditions. The results indicated that the creep compressive strain increased with degree of inclination at both applied stresses. The primary creep stage was observed at all inclined conditions under the applied stress of 20% and at the horizontal and 1-to-5 under the applied stress of 60%, while the onset of secondary creep stage was obtained at inclined conditions of 1-to-4 and 1-to-3 under the applied stress of 60%. In addition, the creep reduction factors were calculated using the strain at 10⁴ hours. The reduction factor increased with degree of inclination, particularly at inclined conditions that exhibited secondary creep stage.

INTRODUCTION

HDPE geonets have been widely used as the drainage component in the leachate removal and leak detection systems of the landfills. In such applications, the geonet is subjected to a static compressive stress throughout the service duration; the thickness of the geonet subsequently decreases and so does the flow capacity. The decrease in the thickness and flow capacity continues with time due to the viscoelastic property of HDPE. Thus, the creep deformation is one of the critical reduction factors in the design of the geonet.

Limited tests have been performed to investigate the creep behavior of HDPE geonets using the conventional creep test method (Lawrence, 1987). The method requires the test to be performed at laboratory ambient condition for the duration of 1,000 to 10,000 hours according to GRI GS 4. Recently, an accelerated creep test, SIM, has been used to evaluate the creep
behavior of HDPE geonets (Thornton et al., 2000; Narejo and Allen, 2004; Allen, 2005). SIM was developed using the time-temperature superposition (TTS) principle by utilizing temperatures to accelerate the creep deformation and therefore, to shorten the long testing time. Furthermore, a single test specimen is exposed to a series of temperature steps instead of multiple specimens, as in TTS, eliminating the influence of material variability.

The majority of the creep studies focused only on the normal compressive behavior of geonets. However, on the side slopes of the landfill, the geonet is subjected to both normal and shear stresses. It is anticipated that different compressive behavior would be obtained at different inclined conditions. Jarousseau and Gallo (2004) studied the compressive creep behavior of various geocomposites under the combined normal and shear stresses using the conventional creep test method for 504 hours. They found a 15% to 30% greater reduction in thickness under the combined stresses than under only normal stress for some of the tested geocomposites.

In this paper, both short- and long-term compressive behavior of a bi-planar HDPE geonet were evaluated on four inclined conditions; the horizontal (0°), 1(V)-to-5(H) (11.3°), 1(V)-to-4(H) (14.0°), and 1(V)-to-3(H) (18.4°). For the long-term compressive behavior, SIM was employed to predict the creep properties of the geonet at applied stresses of 20% and 60% of the compressive strength. Based on the creep results, reduction factors associated with the allowable flow rate at four inclined conditions were determined for design applications.

TEST MATERIAL AND APPARATUS

A bi-planar HDPE geonet was used in this study. The physical properties of the geonet are given in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Standard</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>ASTM D 1505</td>
<td>0.947</td>
</tr>
<tr>
<td>Mass per unit area (kg/m²)</td>
<td>ASTM D 5261</td>
<td>0.98 (± 0.02)</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>ASTM D 5199</td>
<td>5.89 (± 0.02)</td>
</tr>
</tbody>
</table>

The short-term compressive test and the SIM test were performed using an Instron® 5583 with Merlin® software for the stress level control and the strain measurement. The deformation of the specimen was determined using the cross-head movement, which was then divided by the initial gauge length to obtain the strain value. The test temperature was controlled by an environmental chamber. The accuracy of temperatures in the chamber was ±0.5°C.

A special device was manufactured to evaluate the compressive behavior at various inclined conditions, as shown in Figure 1. The device consisted of two half circular blocks which can be set to four inclined conditions; the horizontal, 1-to-5, 1-to-4, and 1-to-3. The lower block of the device was placed on four rollers to avoid damage to the testing apparatus due to the
excessive lateral loading. The surface of the metal blocks contacting the test specimen was smooth. Sandpaper was attached onto the surface of the upper and lower blocks to keep specimen from sliding down. Prior to the tests, the upper and lower blocks were marked to check the slippage during the test.

**SHORT-TERM COMPRRESSIVE BEHAVIOR**

The short-term compressive behavior of the geonet was evaluated using test procedure described in ASTM D 6364. However, the dimensions of the test specimen were changed from 120mm x 120mm in ASTM to 101.6mm x 101.6mm in this study. The inclined conditions of the horizontal, 1-to-5, 1-to-4, and 1-to-3 were tested.

**Surface Roughness** Two types of sandpaper, grit 100 (fine) and grit 35 (coarse), were used to investigate the effect of surface roughness on the compressive behavior. Tests were conducted on the inclined condition of 1-to-4. Results of the tests are shown in Figure 2. The short-term compressive properties on these two types of sandpaper are relatively similar. In this study, the sandpaper of grit 100 was used for the short-term compressive tests.

**Short-Term Compressive Behavior and Repeatability** The short-term compressive tests were performed at four inclined conditions. Five replicates were tested on each inclined condition. The stress/strain curves at four inclined conditions are shown in Figure 3, and the compressive strength and strain with their corresponding standard deviation values are listed in Table 2. The compressive strength and strain are determined at the point where there is a significant change in the slope of the stress/strain curve, as shown in Figure 3. The repeatability of the test is consistent; the coefficient of variation for strength and strain are 1% and 4%, respectively. Data in Table 2 indicates that the short-term compressive strength does not change significantly among different inclined conditions. On the other hand, the compressive strain increases linearly with the inclined condition, as can be seen in Figure 4.

**Table 2 - Average compressive strengths and strains**

<table>
<thead>
<tr>
<th>Inclined ratio (angle)</th>
<th>Compressive strength (kPa)</th>
<th>Standard deviation (kPa)</th>
<th>Compressive Strain (%)</th>
<th>Standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (0.0°)</td>
<td>161.3</td>
<td>1.8</td>
<td>9.3</td>
<td>0.4</td>
</tr>
<tr>
<td>1-to-5 (11.3°)</td>
<td>160</td>
<td>1.3</td>
<td>10.3</td>
<td>0.4</td>
</tr>
<tr>
<td>1-to-4 (14.0°)</td>
<td>158.4</td>
<td>2.1</td>
<td>11.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1-to-3 (18.4°)</td>
<td>158.7</td>
<td>2.1</td>
<td>12.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>
LONG-TERM COMPRESSIVE BEHAVIOR USING SIM

The creep property of the geonet was evaluated using SIM. The test procedure conformed to ASTM D 6992. The test specimen was brought to equilibrium at 23.0±0.5°C for overnight. Prior to starting the test, a pre-stress of three percent of the short-term compressive strength was applied on the specimen in order to ensure the intimate surface contact. The test was then started by applying the stress at a strain rate of 10% of the gauge length per minute. Seven temperature steps were used with increments of 7°C and dwell time (i.e., isothermal time per each step) of 10^4 seconds. The short-term compressive strength at the horizontal condition was utilized to calculate the applied stress for the SIM tests, and 20% (32.3 kPa) and 60% (96.8 kPa) of compressive strength were tested at four inclined conditions. The SIM test result is presented in a creep master curve that was generated by shifting the individual creep curve at each of the seven test temperatures along the time axis.

**Surface Roughness** The effect of roughness of the block surfaces was again examined for the SIM test since the testing time and temperature were different from the short-term compressive test. The same two types of sandpaper (i.e., grit 100 and grit 36) were used on the inclined condition of 1-to-4 under 20% of compressive strength. As shown in Figure 5, the resulting creep master curves from the two sandpapers are very similar. In this paper, the sandpaper of grit 100 was used for the SIM tests.
**Repeatability**  The repeatability of the SIM test was investigated by performing three tests at the inclined condition of 1-to-4 under 20% of compressive strength. The creep master curves of three specimens are shown in Figure 6. The quantitative comparison is achieved by using the percentage of retained thickness at creep times of $10^1$, $10^3$, and $10^5$ hours. The average values and the standard deviations are summarized in Table 3.

![Figure 5 - Creep master curves with two sandpapers at inclined condition of 1-to-4 under 20% (32.3 kPa) of compressive strength](image)

![Figure 6 - Repeatability of the SIM test at inclined condition of 1-to-4 under 20% (32.3 kPa) of compressive strength](image)

**Table 3 - Statistical significance of the SIM test on the geonet**

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Percentage of retained thickness</th>
<th>Average (%)</th>
<th>Standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test 1</td>
<td>Test 2</td>
<td>Test 3</td>
</tr>
<tr>
<td>$10^1$</td>
<td>93.9</td>
<td>93.5</td>
<td>93.5</td>
</tr>
<tr>
<td>$10^3$</td>
<td>92.7</td>
<td>92.3</td>
<td>92.2</td>
</tr>
<tr>
<td>$10^5$</td>
<td>91.3</td>
<td>90.9</td>
<td>90.8</td>
</tr>
</tbody>
</table>

**SIM Test Result and Data Analysis**  Figures 7 and 8 show the creep master curves at four inclined conditions under 20% and 60% of the compressive strength, respectively. As expected, the percentage of retained thickness decreases with increasing time. At the same applied stress, the creep deformation increases with the degree of inclination. At 20% of compressive strength in Figure 7, the percentage of retained thickness is linearly correlated to the log-time. The same linear correlation can also be observed for inclined conditions of the horizontal and 1-to-5 at 60% of compressive strength, as shown in Figure 8. However, at the inclined conditions of 1-to-4 and 1-to-3, the linearity ceases at $10^{1.5}$ hours.
The different creep stages at 60% of compressive strength are evaluated by presenting the creep data in Sherby-Dorn plots, as shown in Figure 9. At the inclined conditions of the horizontal and 1-to-5, the strain rate decreases linearly with the percentage of retained thickness (i.e., primary creep stage). In contrast, at the inclined conditions of 1-to-4 and 1-to-3, the strain rate gradually decreases, and is probably entering the “plateau” region, i.e., the onset of the secondary creep stage.

The early termination of the creep master curve at the inclined condition of 1-to-3 under 60% of compressive strength is due to the horizontal movement of the lower block of the test device at the test temperature of 44°C. The movement was probably caused by the combination of the high shear stress and elevated temperature which led to the laydown of ribs in the geonet, as illustrated in Figure 10. The shear stress was then transferred to lower block, causing the rollers beneath the block to move from position P to P’.
Creep Reduction Factors

The creep reduction factor for design calculation can be obtained according to GRI GC 8, as expressed in Eq. 1:

\[
RF_{CR} = \left[ \left( \frac{t_{CO}}{t_{original}} \right) - (1 - n_{original}) \right]^{3} = \left( \frac{t_{CR}}{t_{original}} - (1 - n_{original}) \right)^{3}
\]  

(1)

where, \(RF_{CR}\) = reduction factor for creep, \(t_{original}\) = original thickness, \(t_{CO}\) = thickness at 100-hours, \(t_{CR}\) = thickness at >> 100-hours, e.g., at 10^4 hours, \(n_{original}\) = original porosity which is calculated according to Eq. 2

\[
n_{original} = 1 - \frac{\mu}{\rho \cdot t_{original}}
\]  

(2)

where, \(\mu\) = mass per unit area and \(\rho\) = density of the formulation.

In this paper, the creep reduction factors at 10^4 hours were determined, and the values are shown in Table 4. Overall, the reduction factor increases with degree of inclination and applied stress. A significant increase in the reduction factor is obtained under 60% of compressive strength at inclined conditions of 1-to-4 and 1-to-3, when the onset of the secondary creep stage took place. Note that the 10^4-hour data of the inclined condition of 1-to-3 at 60% of compressive strength was obtained by extrapolating the creep master curve from 10^3 hours.

**Table 4** - Creep reduction factors at 10^4 hours

<table>
<thead>
<tr>
<th>Inclined ratio (angle)</th>
<th>20% Stress</th>
<th>60% Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (0.0°)</td>
<td>1.02</td>
<td>1.05</td>
</tr>
<tr>
<td>1-to-5 (11.3°)</td>
<td>1.05</td>
<td>1.05</td>
</tr>
<tr>
<td>1-to-4 (14.0°)</td>
<td>1.06</td>
<td>1.23</td>
</tr>
<tr>
<td>1-to-3 (18.4°)</td>
<td>1.07</td>
<td>1.37</td>
</tr>
</tbody>
</table>
SUMMARY

The short- and long-term compressive creep behavior of the bi-planar HDPE geonet were evaluated. The results of short-term compressive tests showed that the compressive strength was not significantly affected by the different inclined conditions, while the compressive strain increased with degree of inclination. For the long-term compressive behavior, SIM was employed as the accelerated creep test method. The creep deformation increased with degree of inclination. Under 60% of compressive strength at inclined conditions of 1-to-4 and 1-to-3, the onset of secondary creep stage was observed. The creep reduction factor increased with degree of inclination. In particular, a significant increase in the reduction factor was found when the secondary creep stage began to occur.

ACKNOWLEDGMENTS

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