Lifetime Prediction of Geocomposites Through Assessment of Long-term Compressive Creep Using SIM

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ABSTRACT
The short- and long-term compressive behaviors of geocomposite were evaluated at three inclined conditions: the horizontal (0^o), 1-to-6(9.5^o) and 1-to-4(14^o) to investigate the effects of the combined stresses(normal and shear) on the side of the landfill. The long-term creep behaviour was evaluated with various stresses at 200kPa, 400kPa and 568kPa(50% of the compressive strength) using the stepped isothermal method (SIM). The effects of applied stresses and inclined conditions were investigated on short- and long-term compressive behaviour using statistical analysis. Using the relationship between transmissivity and thickness reduction(Giroud et al., 2000), the creep reduction factors were estimated at 114 years of lifetime. These results provide the useful information and caution for designing drainage materials for long-term applications, particularly in inclined conditions.

1. INTRODUCTION

Geocomposite and geonet have been widely used as the drainage materials in the leachate collection and removal system, and leak detection system of the landfill. The geonet is typically applied to the base of landfill while the geocomposite, which consists of two layers of needle-punched nonwoven geotextile thermally bonded onto both sides of the HDPE geonet, is widely employed on the side slopes of landfills. In such applications, the geocomposite is subject to the static compressive stress throughout the service duration. The decrease in the thickness and flow capacity continues with time due to the viscoelastic property of HDPE geonet. With increased awareness of the need for long-term, equilibrium flow measurements, the standardized approach leads to use of time-dependent reduction factors for geosynthetic flow data.

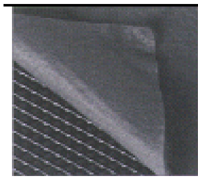
This paper focuses on the creep reduction factor resulting from a reduction in geocomposite thickness while many studies have been performed to investigate the compressive creep behaviour of HDPE geonets alone(Thrornton et al., 2000, Allen, 2005, Yeo, 2005). Geocomposites are designed and employed to perform under load. Their performance is not only load dependent, but time dependent as their cross sectional area, porosity and related flow capacity under load. The long term compressive creep reduction factor of geocomposite is determined by thickness reduction in geotextiles as well as geonet associated with the allowable flow equation using the confounded porosity of them.

The experimental approaches used stepped isothermal method(SIM) to determine the long-term reduction in thickness with various loads and inclined conditions since the cross sectional area and porosity change with the interaction between loads and inclined conditions. The effects of loads and inclined conditions were analyzed on compressive creep reduction factors using statistical analysis at the required service lifetimes in the fields.

2. TEST MATERIALS AND APPARATUS

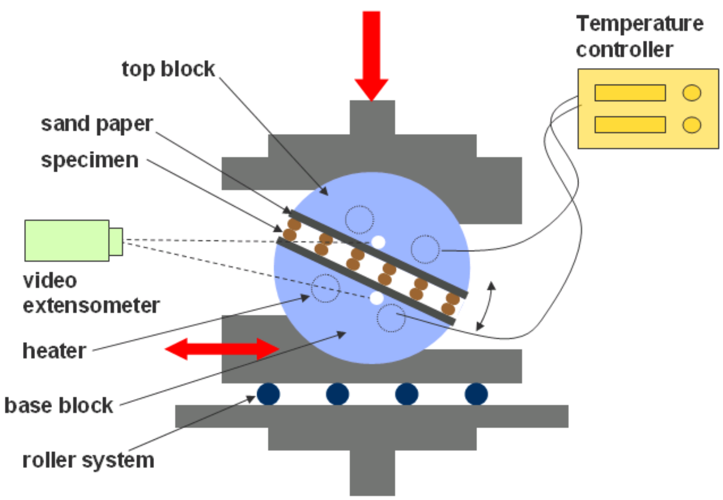
The geocomposite used in this study consists of two layers of needle-punched nonwoven geotextile thermally bonded onto both sides of the HDPE geonet. The physical properties of nonwoven geotextile and geonet are listed in Table 1.

Table 1. Physical properties of geocomposite.

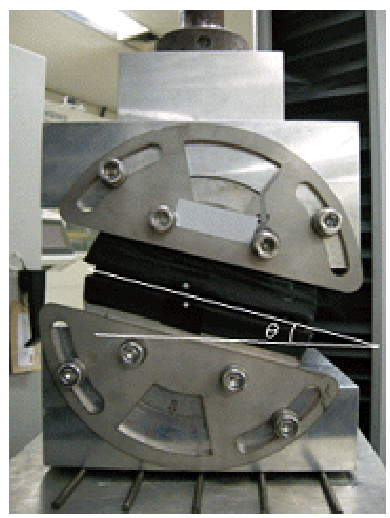
Sample	Property	Nonwoven geotextile	Geonet	Geocomposite
	Raw material	PET	HDPE	-
	Density (g/cm^3)	1.380	0.956	-
	Mass per unit area (g/m^2)	656.0	1501.2	2202.7
	Thickness (mm)	3.69	5.58	6.56

The compressive device is designed to evaluate the compressive behaviour of a geocomposite at different inclined conditions. Figure 1 shows the schematic layout and photograph of apparatus. The compressive device consists of two half circular blocks, and a specimen is placed between blocks. These blocks (top & down block) can be rotate arbitrarily to set desired inclined position. And the lower block has a roller system to allow lateral movement of the block during the test. Using this roller system, the load cell can avoid the damage due to the excessive lateral loading occurred in inclined test condition. Sandpapers are attached onto the surface of top and base blocks contacted with specimen to keep specimen from sliding down the block during the test.

The temperature is controlled by the heater, which is located nearby the surface of top and base blocks, and an environmental chamber to perform the SIM test. The creep deformation of the specimen is detected by the video extensometer.



a) Schematic layout



b) Photograph of apparatus

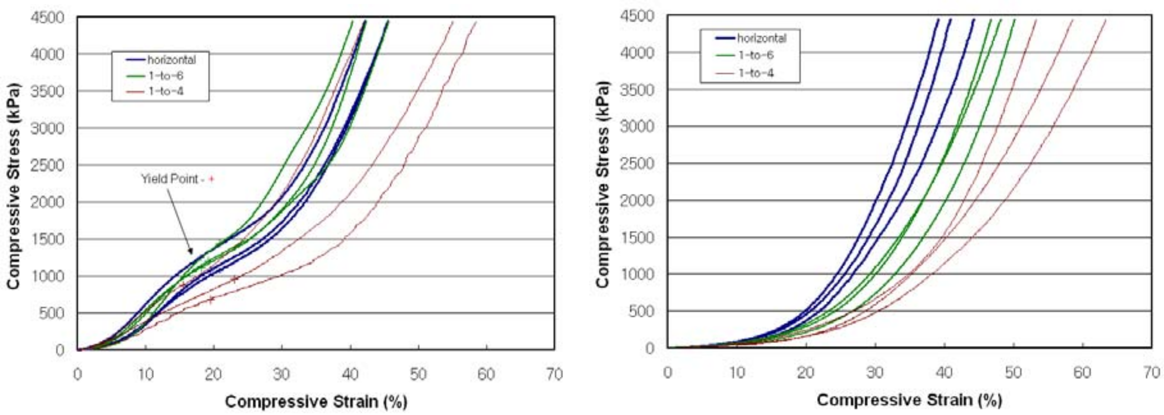
Figure 1. Apparatus for the compressive test.

3. CREEP TESTING

In this paper, both short- and long-term compressive behaviours of a geocomposite were evaluated on three inclined conditions; the horizontal (0^o), 1-to-6(9.5^o) and 1-to-4(14^o). For the long-term compressive creep behaviour, SIM was employed to predict the long-term creep properties of the geocomposite at applied loads of 200, 400 and 568kPa(50% of the compressive strength).

3.1 Short-term Compressive Behaviour

The short-term compressive behaviours of geonet and geocomposite were tested according to the ASTM D 6364 test method, and the results are shown in Figure 2. The dimensions of a test specimen were 150 mm x 150 mm. The loading was applied at a constant speed of (1±0.1)mm per minute. To estimate the effect of inclined condition, the test was performed at three different inclined conditions. The compressive strength and strain for geonet are determined at the point where there is a significant change in the slope of the stress/strain curve, as shown in Figure 2. Unlike the geonet which exhibits pronounced peaks, the compressive strength of the geocomposite increases continuously with strain. There is no apparent way to define the compressive strength and strain.



a) Geonet b) Geocomposite

Figure 2. Short-term compressive behaviour at different inclined conditions.

The effects of thickness and inclined conditions are investigated on compressive strength/strain of geonet. Table 2 shows the thickness and compressive strengths at the inclined conditions of geonet. The repeatability of the test becomes inconsistent; the coefficient of variation for strength and stress increase with the degree of inclined condition. The reason for the variability is probably due to the variance of combined stress(normal/shear) becoming larger in inclined condition. Data in Table 2 indicates that the short-term compressive strain does not change significantly among different inclined conditions. On the other hand, the compressive strength does not change upto 1-to-6 of the inclined condition and decreases significantly at 1-to-4 of the inclined condition. This is probably due to the confounded effects of thickness and inclined condition on the compressive strength. In order to remove the thickness variation, the regression analysis was performed using inclined condition, thickness as predictor variables and compressive strength as a response variable. The predicted compressive strengths are shown with actual compressive strength with regression equation in Figure 3. The compressive strength shows the negative correlation with inclined condition due to the shear stress enhancing the deformation higher and the positive correlation with thickness as expected.

Table 2. Compressive strength of geonet.

Inclined condition	Specimens	Initial thickness (mm)	Compressive Strain (%)	Compressive Strength (kPa)
horizontal	1	5.75	18.1	1254.3
	2	5.49	20.8	1077.5
	3	5.59	19.5	1074.7
	average	5.61	19.5	1135.5
	CV(%)	2.33	6.9	9.1
1-to-6 (9.5°)	1	5.79	20.8	1432.6
	2	5.89	19.2	1195.5
	3	5.79	18.1	1113.3
	average	5.82	19.4	1247.1
	CV(%)	1.00	7.0	13.3
1-to-4 (14.0°)	1	5.66	23.0	954.2
	2	5.41	15.4	873.7
	3	5.59	19.6	673.6
	average	5.55	19.4	833.8
	CV(%)	2.32	19.6	17.0

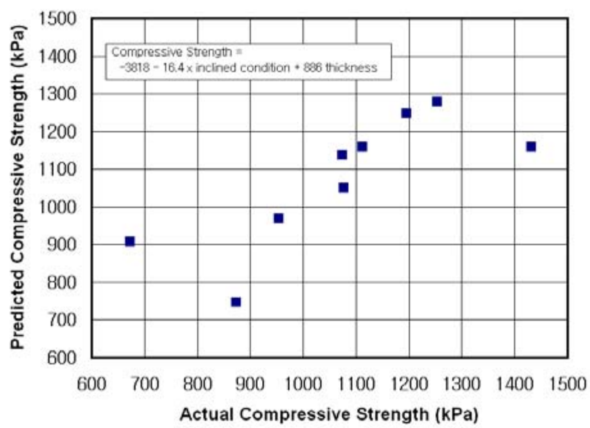
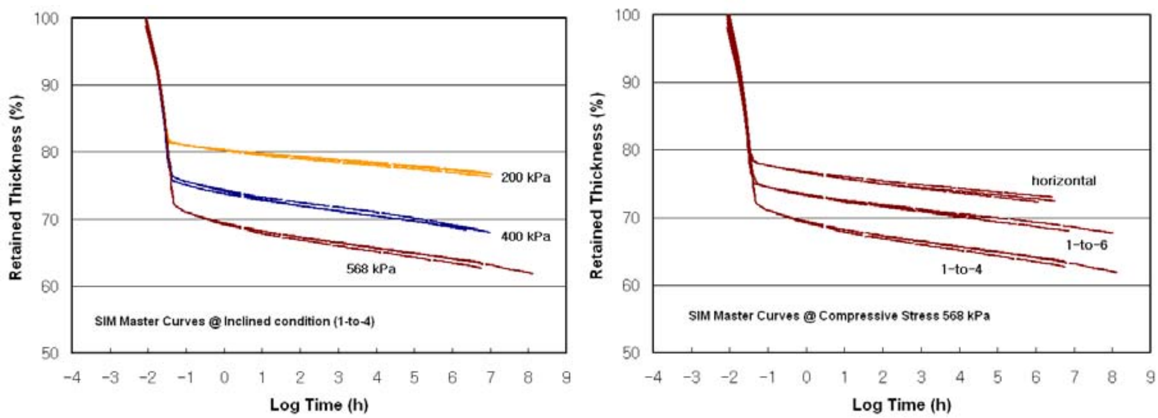


Figure 3. Actual and predicted compressive strengths using regression analysis.

3.2 Long-term Compressive Creep Behaviour Using SIM

The long-term creep property of geocomposite was evaluated using SIM according to ASTM D 6992 and RS K 0029. The SIM was performed at 7°C of temperature step with 10,000 sec of dwell time and 60,000 sec of total test times in order to estimate changes in hydraulic transmissivities due to the thickness reduction of HDPE geonet bonded with PET nonwoven geotextiles. The short-term compressive strength of geonet at horizontal condition was utilized to calculated the applied stress for the SIM tests, and 200, 400 and 568 kPa(50% of compressive strength)were tested at three 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 six test temperatures along the log time axis. The repeatability of the SIM test was investigated by performing three tests at all test conditions as shown in Figure 4. The repeatability of the SIM test was consistent; the creep master curves are overlap with each other.

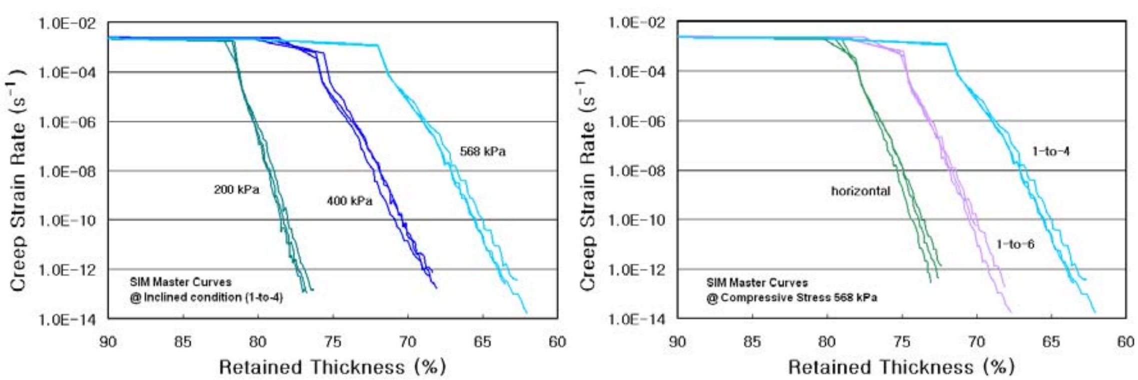
Figure 4 shows the effects of applied stresses and inclined conditions on creep master curves, respectively. For all test conditions, the geocomposite exhibits a much greater initial reduction of retained thickness due to the high compressibility of the geotextile. As expected, the percentage of retained thickness decreases with increasing time. At the same applied stress, the creep deformation increases with the degree of inclination. The same linear correlation can also be observed for loads on creep deformation



a) at different compressive stress b) at different inclined condition

Figure 4. Long-term compressive creep master curves of geocomposite.

The creep stages are evaluated by presenting the creep data from Figure 4 in Sherby-Dorn plots, as shown in Figure 5. The strain rate decreases linearly with the percentage of retained thickness at all test conditions showing only primary creep stages. The strain rates decrease slightly lower at the inclined condition of 1-to-4 under applied stress greater than 400kPa. The onset point of secondary creep stages might be near to the inclined condition of 1-to-4 under the higher than 50% of stress.



a) at different compressive stress b) at different inclined condition

Figure 5. Sherby-Dorn plots for creep results.

4. ESTIMATION OF CREEP REDUCTION FACTOR

4.1 Creep Reduction Factors(RFcr)

The creep reduction factor for design calculation can be obtained using the relationship between transmissivity and thickness reduction(Giroud et al., 2000):

$$RF_{CR} = \frac{\theta_{CO}}{\theta_{CR}} = \left[\frac{(t_{CO}/t_0) - (1-n_0)}{(t_{CR}/t_0) - (1-n_0)} \right]^3 \tag{1}$$

where *RFcr* is reduction factor for creep, t_0 is original thickness (m), t_{CO} is thickness at 100 h (m), t_{CR} is thickness at over 100 h(e.g. at 10,000 h or 100 years) (m), and n_0 is original porosity.
The porosity of the geocomposite was calculation by combination of porosities of geotextile and geonet as expressed in Eq. 2:

$$n_0 = 1 - \frac{\mu_{GC}}{(\rho_{GN} \cdot t_{GN} + \rho_{nonwoven} \cdot t_{nonwoven})} \tag{2}$$

where μ_{GC} is mass per unit area of geocomposite (kg/m^2), ρ_{GN} is density of geonet (kg/m^3), $\rho_{nonwoven}$ is density of nonwoven geotextile (kg/m^3), t_{CN} is initial thickness of geonet (m), and $t_{nonwoven}$ is initial thickness of nonwoven geotextile (m).

In this paper, the creep reduction factors at 10^6 hours(114 years) were determined, and the values shown in Table 3. Overall, the reduction factor increases with degree of inclination and applied stress. The range of creep reduction factors are provided 1.4 to 2.0 for both primary and secondary leachat collection systems in landfills regardless of applied stress, slope angle, and service time(Koerner, 2005). This range of values may seem high for geocomposites used on the slope under high applied load.

The creep reduction factors show significant increase at 1-to-4 of the inclined condition under 400kPa and higher applied stress than 200kPa. The creep reduction factor increases by 0.07~0.22 with increasing applied stress and by 0.01~0.16 with the degree of inclination. This means that the inclined angle and stress have a synergy effect on creep reduction factor.

Table 3. Creep reduction factors of geocomposites at 10^6 hours (114 years).

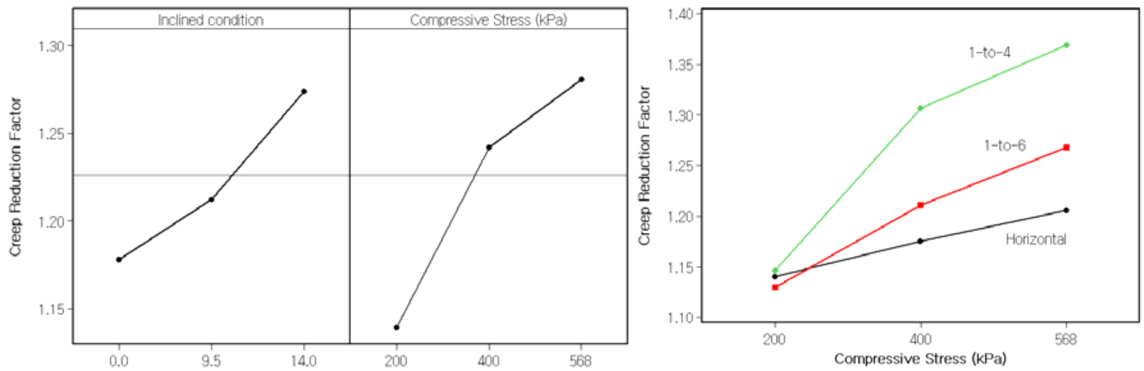
Inclined condition	Compressive Stress(kPa)		
	200(17% stress)	400(35% stress)	568(50% stress)
Horizontal(0^o)	1.14	1.18	1.21
1-to-6(9.5^o)	1.13	1.21	1.27
1-to-4(14^o)	1.15	1.31	1.37

4.2 Statistical Data Analysis

In order to quantify the effects of inclined angle and applied stress on creep reduction factor, the analysis of variance was performed as shown in Table 4. The effects of both factors show the significant relationships on creep reduction factor with 99% of statistical confidence. As we expected the synergy effect of inclined angle and applied stress, the interaction between two factors are significant with 99% of statistical confidence. Figure 6 shows the main effects(inclined condition and applied stress) and interaction effect on creep reduction factors and the increase in creep reduction factor with the applied stress twice is equivalent to those of horizontal condition to the 15^o of inclined angle. The interaction between the inclined angle and applied stress becomes more significant at 1-to-4 of the inclined condition under 400kPa and higher applied stress.

Table 4. Analysis of variance for creep reduction factors of the geocomposite.

Source of variation	DF	SS	MS	F	P
Inclined condition	2	0.0428	0.0214	73.18	< 0.01
Applied stress	2	0.0790	0.0395	135.28	< 0.01
Inclined condition x Compressive stress	4	0.0184	0.0046	15.77	< 0.01
Error	14	0.0041	0.0003		
Total	22				



a) main effect plot b) interaction effect plot

Figure 6. Effects of applied stresses and inclined conditions on creep reduction factors.

5. CONCLUSION

The short- and long-term compressive behaviours of geocomposite were evaluated at three inclined conditions: the horizontal, 1-to-6(9.5^o) and 1-to-4(14^o). In the short term test, the compressive strength decreased as inclined angle increases while the compressive strain does not change significantly.

The long-term creep strain varied greatly with the inclined angles and the applied stresses. The only primary creep stage was obtained at all test conditions. The absence of the secondary creep was due to the localized interface friction between the geotextile and the geonet. The friction prevented the abrupt roll-over phenomenon in the geonet. However, the gradual decrease in strain rate is observed and creep reduction factor increases substantially at the inclined condition of 1-to-4 under the higher applied stress than 400kPa even though only primary creep stages were observed for all test conditions. The onset point of secondary creep stages might be near to the inclined condition of 1-to-4 under the higher than 400 kPa.

Overall, the creep behaviour of geocomposite should be evaluated with combination of geotextile and geonet since geonet alone would yield different creep properties from geocomposite. In addition, the interaction effects of inclined angles and the applied stress are significant and caution should be applied when designing and applying drainage materials for long-term applications, particularly in the slope under high applied load.

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