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Experimental Assessment of Mechanical Properties of Geo-grid Reinforced Material and Long-Term Performance of GT/HDPE Composite

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Abstract

This paper is concerned with the long-term performance of geo-textile (GT) composites in terms of creep deformation and frictional properties. Composites of PVA GT and HDPE GM were made to investigate the advanced properties of long-term performance related to waste landfill applications. The same experiments were also performed for typical polypropylene and polyester GT and compared to PVA GT/HDPE GM composites. We also develop high performance GT composites with GM by using PVA GT, which is capable of improving the frictional properties and thus enhances long-term performance of GT composites. Experimental study reveals that the friction coefficient of GT composites is relatively large compared with those of polyester and polypropylene non-woven GT as long as the friction media has similar size to the particles of domestic standard earth. In addition, the geo-composites bonded with geo-grid by a chemical process were investigated experimentally in terms of strain evaluation and creep response values. Geo-grid plays an important role as a reinforcing material. Three kinds of geo-grid were prepared as strong yarn polyester and they were woven type, non-woven type, and wrap knitted type. The sample geo-grids were then coated with PVC. The rib tensile strength tests were conducted to evaluate geo-grid products in terms of tensile strength with regard to single rib. The test was performed according to GRI-GGI. It was concluded again from the experiments that the tensile and creep strains of the geo-grid showed such stable values that the geo-grid prepared in this study could protect geo-textile partially in practical structures.

Keywords

Geo-composite, geo-textile, PVA GT/HDPE, creep deformation

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1. Introduction

Products involving geo-textiles have been mainly applied for reinforcement of ground and slope plane, reclamation, dam and tunnel construction, reinforcements for coastal embankment and soil retaining wall, railway and road construction, and waste landfill construction, etc. Among those applications, geo-textiles (GTs) are used for the purposes of protection and/or reinforcement, filtration, drainage, and even separation. Since GTs, in particular, are generally adopted as the covering material of geo-membrane (GM) for waste landfills, it is very significant to consider the long-term performance of GTs against sunlight and various chemical conditions encountered until a landfill is complete. In addition, the environmental temperature to which the interior of the landfill is exposed rises to about 80 degrees in summer due to degradable organic wastes; furthermore, a landfill becomes more seriously exposed to ultraviolet radiation and leachate solution as the period for reclamation increases. Therefore, it is necessary to use GTs that have been proven invulnerable to such exposure in waste landfills [1–4].

The needle punched non-woven GTs of staple fibers mainly applied to flooring material in waste landfills contain polypropylene and polyester as one of the raw materials and they help to maintain stability against acid and alkali materials. However, GTs tend to decompose when exposed to ultraviolet light, i.e. sunlight. While polyester is superior to polypropylene in terms of dynamic performance, it may cause degradation of the tensile properties by hydrolysis occurring when it is exposed to acid or alkali at relatively high temperature. Even though polypropylene non-woven GTs are more efficient generally in terms of long-term performance, they show some problems in durability when they are exposed to alkali or ultraviolet light at higher temperature. In addition, when additives such as carbon black and anti-oxidant are mixed with polypropylene to improve stability against ultraviolet radiation, this may increase the manufacturing cost and thereby become more difficult to produce textiles than with polyester. Besides all of these, polypropylene or polyester GTs are used for installation over the HDPE GM in waste landfills and frictional properties between these materials is known to be the cause of decrease in the long-term performance of geo-synthetics [5, 6].

Controlled or ecological landfills are supposed to use complex systems in order to protect the soil. Lately these systems have frequently used geo-synthetics, which offer many advantages such as homogeneity of their properties for the whole surface, ease of installation, superior qualities compared to natural materials, speed of installation, etc. Landfills represent works that rapidly adopted the new geo-synthetic materials by their complex structure and technical requirements. Moreover, this kind of work contributed to the widening of the possible applications and made possible the research activities in this field. Geo-textiles are the most used geo-synthetics and they have a large place in landfills as separation layer, filtration, protection of the geo-membrane against puncture, erosion protection in capping systems, etc. Geo-grids are used for reinforcing the soft ground, for increasing the bearing capacity, for steep slopes or veneer cover soils reinforcement. One of the newest solutions of reinforcing soft soils is represented by geo-cells [7–9]. Usually, the geo-grid itself shows very high tensile strength and it is used as a reinforcing material in places where loads are applied in a concentrated manner. However, geo-grid features a lattice form so it cannot control the materials such as soils passing through.

In this study, PVA geo-textile/HDPE geo-membrane composites were made to examine the waste landfill related properties, such as frictional properties and long-term performance. Thermally bonded GT composites such as PVA GT/HDPE GM, PVA GT, and HDPE GM are used as model materials for experiments. Polyester and polypropylene non-woven GT have also been prepared by a needle punching process for experimental purposes. Also, a geo-grid, which is a good reinforcing material because of its unique mechanical properties, is tested for application. Three kinds of geo-grid (GG 1, GG 2 and GG 3) functioning as reinforcing material were tested. The manufacturing methods of the three kinds of geo-grid were a woven type, non-woven type and warp knitted type, respectively. After they were manufactured as high strong yarn polyester, they were coated with PVC. The geo-grids prepared for this study have been tested in terms of mono-rib tensile strength, wide-width strip tensile strength, contact point strength, and creep characteristics, respectively. Geometries including specific dimensions and other physical properties are summarized in Table 1. Figure 1 shows the schematic for the mechanism of separation and/or reinforcement geo-composites using geo-grid and geo-textile. Figure 2 shows the typical shape and dimension of the geo-grid. Figure 3 shows real features of each geo-grid, i.e. GG 1, GG 2 and GG 3, respectively. Note that specimens GG 1 and GG 2 have been manufactured in woven type process and GG 3 in knitted type process, respectively.

2. Experiments and Methods of Evaluation

Geo-textile composites of PVA GT/HDPE GM, PVA GT of 600, 1000, 1500, 2000 g/m^2 and HDPE GM (thickness; 1.5 mm) were produced by a thermal bonding process. Table 2 shows the specifications of these composites and the specification was prepared for comparisons of their long-term performances between polyester and polypropylene non-woven GT which are similar to each other in terms of thickness and weight. Figure 4 shows the schematic diagram of geo-textile composite (left) and the typical installation of polypropylene or polyester GT upon HDPE GM (right), respectively. Note that polyester and polypropylene GT were manufactured in a needle punching process. Figure 5 shows general and detailed photographs of geo-textile composites.

Frictional characteristics of geo-textile composites are measured by using Compact Direct Shear Apparatus in accordance with ASTM D5321. The garnet paper with #36 grit having similar size to particle of domestic standard earth is attached to the surface of the upper part of a movable shear box and the friction coefficients are measured after adding vertical stresses of 25, 50, 100 psi (173, 345, 690 kPa),

Table 1.
Physical features of geo-grid for test

Item	Content	GG 1		GG 2		GG 3	
		A × B	C × D	A × B	C × D	A × B	C × D
Apparent dimensions of geo-grid	Size of grid lattice (A × B, C × D) (mm)	24.0 × 24.6	17.2 × 20.2	26.4 × 26.7	19.1 × 23.2	27.0 × 26.6	19.2 × 20.0
	Thickness (mm)	Main rib 0.8	Auxiliary rib 1.9	Main rib 1.8	Auxiliary rib 2.7	Main rib 1.9	Auxiliary rib 1.8
	Point of contact thickness (mm)	1.2		2.0		2.3	
Grid density	No. of ribs/m	Main rib 42 ± 1	Auxiliary rib 41 ± 1	Main rib 37 ± 1	Auxiliary rib 37 ± 1	Main rib 37 ± 1	Auxiliary rib 39 ± 1

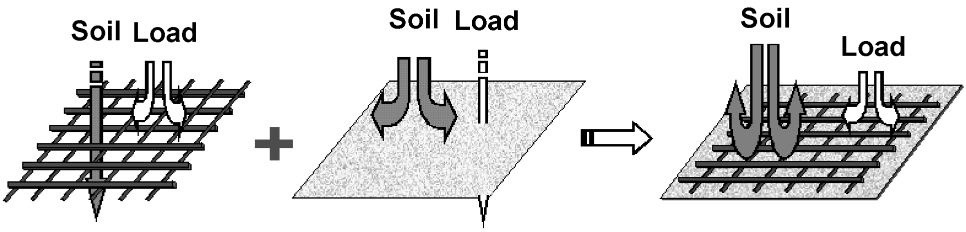


Figure 1. Complex mechanism of separation/reinforcement.

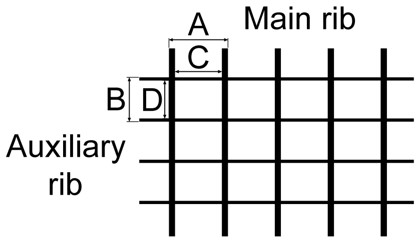
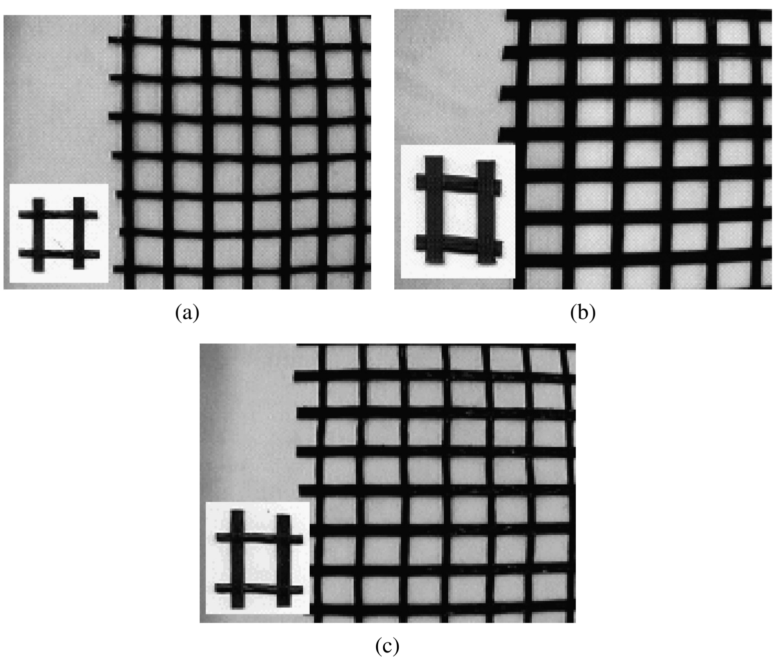


Figure 2. Typical shape and dimension of geo-grid.



(a) (b) (c)

Figure 3. Various appearances of geo-grid (a) GG 1, (b) GG 2 and (c) GG 3.

respectively, for the evaluation of their effects. The rate of creep deformation of geo-textile composites is measured and evaluated in accordance with ASTM D 5262. Values equivalent to 20, 40 and 60% of the maximum tensile strength of geo-textile

Table 2.
Specifications of geo-textile composite and nonwoven geo-textiles

Geosyntheics	Geotextile composite	Polyester GT	Polypropylene GT
Weight (g/m^2)	600, 1000, 1500, 2000, 2500	600, 1000, 1500, 2000, 2500	600, 1000, 1500, 2000, 2500
Fineness (d)	8 for PVA GT	10	12
Manufacturing	Thermal bonding	Needle punching	

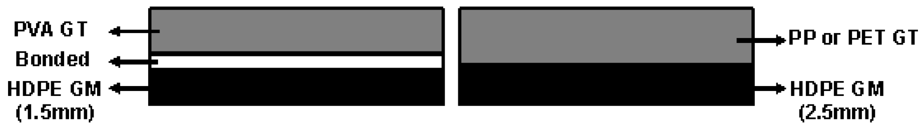


Figure 4. Schematic diagram of geo-textile composite (left) and its installation on HDPE GM (right).

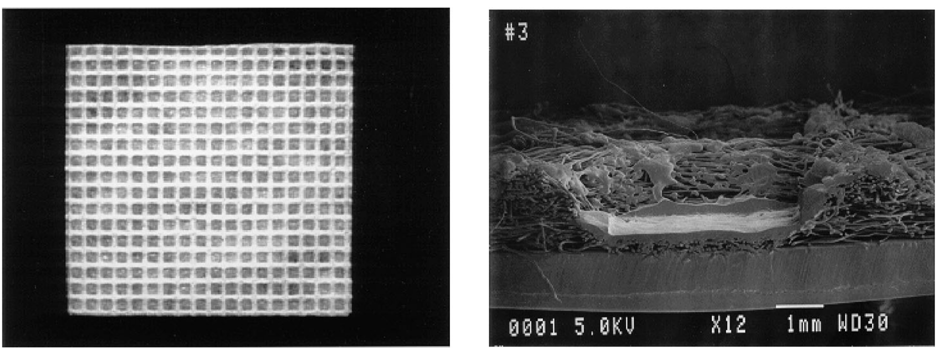


Figure 5. Photographs of geo-textile composites.

composites are added to the creep load. Then, the feasibility is given only when the rate of creep deformation is less than 10%.

3. Results and Discussion

3.1. Tensile Strength of Mono Rib

The rib tensile strength test is the test method to evaluate tensile strength with regard to one rib for quality evaluation of geo-grid products, and it was conducted according to the GRI-GGI [10]. As we can see in Fig. 6, in the case of three kinds of geo-grid (GG 1, GG 2 and GG 3), the tensile strains at the maximum tensile strength show very good tensile deformation characteristics in the range of 10.0–13.0%. Also, the ratios of tensile strength of GG 1, GG 2 and GG 3 in the latitude direction/longitude direction are 45.4, 30.6 and 32.68%, respectively. No specific trend between the tensile strength ratios of warp knitted type geo-grid (GG 3) and woven type geo-grid (GG 1 and GG 2) is shown. It is very interesting to note that

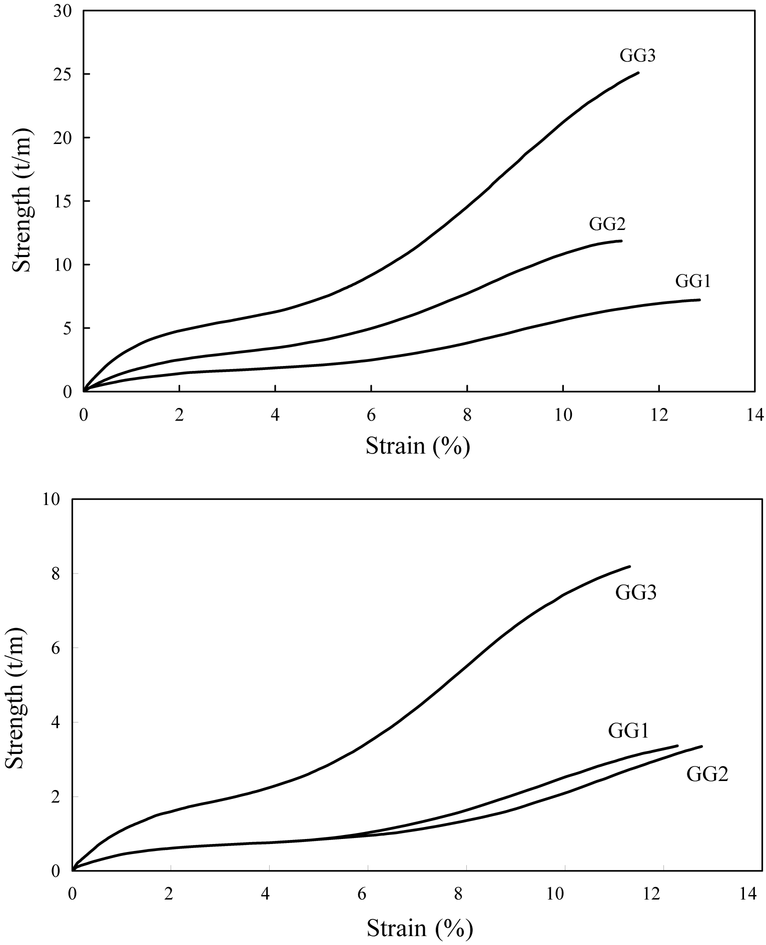


Figure 6. Mono rib tensile strength of geo-grid.

there is no specific trend observed through the experiments even though the design of product and the manufacturing method are different from each other.

3.2. Wide-Width Strip Tensile Strength

This tensile strength test was conducted according to the ASTM D 4595 test method [11] for the geo-grid. The wide-width strip tensile strength values of each geo-grid are shown in Fig. 7. It is easily seen from the figure that the wide-width strip tensile strength shown in the figure is quite similar to those of mono-rib, although there is slight difference, and also tensile strain obtained from experiments shows almost the same trend as that in mono-rib. Comparing the load–stretch action of the geo-grid with that of the geo-textile, a slight difference is shown; this is considered to be dynamic action that occurs due to the morphological structure difference between the geo-textile that was manufactured by pulling together the

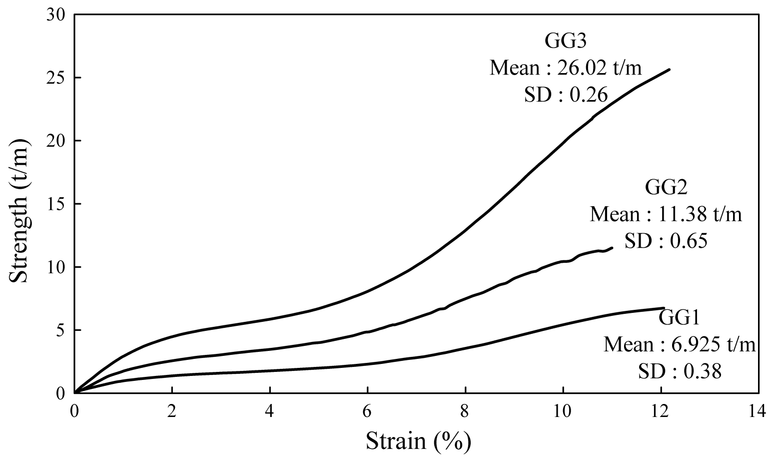


Figure 7. Wide-width strip tensile strength of geo-grid.

Table 3.
Contact point strength and efficiency of geo-grid

Contact point feature	GG 1 (Woven type)	GG 2 (Woven type)	GG 3 (Knitted type)
Contact point strength (kgf)	21.94	27.18	45.01
Contact point efficiency (%)	12.68	8.79	5.69

mono filament and the geo-grid that was manufactured from yarn in the form of textile.

3.3. Contact Point Strength

This is the test method to decide ultimate strength at the contact point between the main rib and the auxiliary rib. The efficiency of the contact point effect is assessed by comparing it with rib tensile strength. The contact point strength test was carried out under the GRI-GG2 [12]. The contact point strength of the geo-grid should be sufficiently large that the geo-grid can move in the reinforced structure. In Table 3, the contact point strength and efficiency of geo-grid (contact point strength/rib tensile strength) is indicated. As we may see here, the efficiency at the contact point shows a relatively smaller value, as the tensile strength becomes larger. This is due to dimension or design of products.

3.4. Creep Feature

GRI-GS 10 is the test method for the creep feature evaluation of geo-synthetics. After measuring each creep strain in the five temperature ranges, the long-term creep action is predicted by using the superposing principle of time-temperature. In this study, for the creep feature evaluation, the outcomes in the real time test

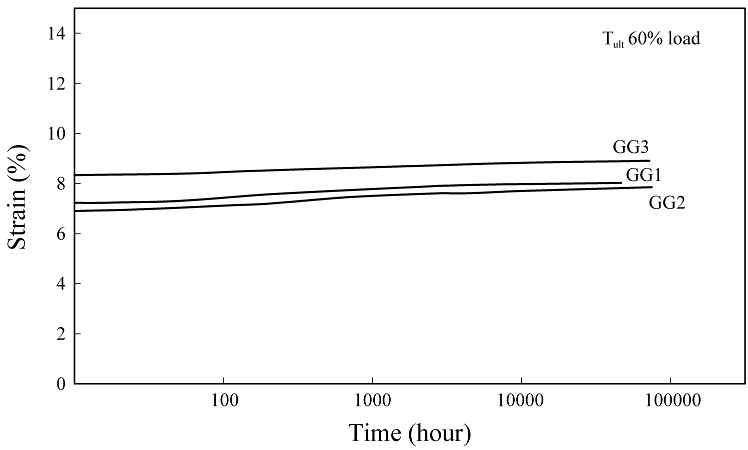


Figure 8. Time-creep strain curve of geo-grid.

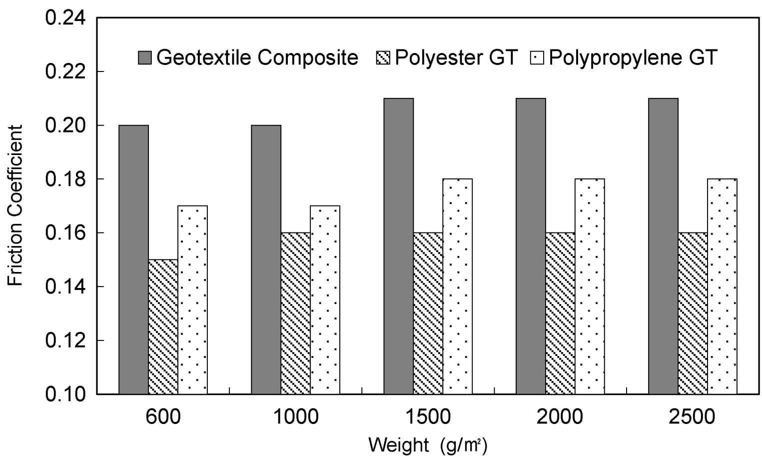


Figure 9. Friction coefficients of goetextile composites.

by applying the above mentioned time and temperature superposing principle are extrapolated to the time axis; in this manner, the creep feature change of the geo-grid after an extended time was forecast. The overlapping curve was drawn up, after experiments were conducted in each temperature (20, 35, 50°C) by adding 60% load of the maximum tensile strength with regard to three kinds of geo-grid (GG 1, GG 2 and GG 3). The result is indicated in Fig. 8. As may be seen in the figure, the excellent creep feature that was maintained with less than 10% of strain value was shown, after 10 000 h.

Figure 9 shows the friction coefficients of geo-textile composites for different weights and GTs. It is seen from the figure that the friction coefficient does not vary with different weight of materials. However, it is very dependent on material such that the friction coefficient is greatest for geo-textile composite and least for polyester GT. It is interesting to note from the figure that the greater frictional coefficients are observed for the weight over 1500 g/m^2 regardless of type of materials. It is understood from the experimental results that the reason why geo-textile composites have the largest friction coefficient is that PVA GT has more compacted textile density than other GTs. However, polyester and polypropylene GT have lower values of friction coefficients because their textile density is relatively smaller than PVA GT. Frictional features of geo-textile composites are seen to be better than those of polyester and polypropylene GT, but actual proof would be different in different application sites.

Long-term performances of geo-synthetics contain ranges of factor of safety (FS) for the purpose of stabilizing construction. The factor of safety means an evaluation function indicating the proportion of engineering property to application property of geo-synthetics as [5]:

$$\mathrm{FS} = \frac{\text{application property value}}{\text{engineering property value}}. \tag{1}$$

If general GTs are used for reinforcement and protection, the rate of deformation exceeds 10%. Consequently, the actual FS will become larger than the maximum 2.5 recommended by AASHTO M 288-96 as for geo-synthetic products for reinforcement and protection. Therefore, it should be remembered that performances will decrease in long-term applications.

The reduction factor for creep deformation follows the equation given by

$$RF_{\mathrm{CR}} = \frac{T_{\mathrm{ST}}}{T_{\mathrm{LT}}}, \tag{2}$$

where RF_{CR} = creep reduction factor, T_{LT} = 10 year design life strength of the geo-grid in sustained ASTM D 4595 or sustained GRI GG-1, or ASTM D 5262 testing at which curve becomes asymptotic to a constant strain line, of 10% or less, and T_{ST} = short term strength of the geo-grid in ASTM D 4594, GRI GG-1 or GG-2 testing, whichever is comparable to the long term creep test [10–12].

Figure 10 shows creep-property of geo-textile composites. It is again seen in the figure that the weight of material is not a major parameter for reduction coefficient due to creep deformation. The relationship between reduction coefficient due to creep deformation and weight is quite similar to that of friction coefficient as shown in Fig. 9, except that the dependency of material is different. It is known again from the figure that the reduction coefficient is greatest for polyester GT and least for geo-textile composites, which is a very good indication for the purpose of waste landfill installations. In the case that 20% of the maximum tensile strength is added to polypropylene and polyester GT, creep deformation would happen to be 10% or more, making the reduction coefficient to creep deformation meaningless. On the other hand, as for geo-textile composites, even if up to 40% of the maximum tensile strength is added to them, creep deformation would remain within 10% and thus creep FS would have a value less than 2.5, which is recommended by AASHTO M 288-96 as maximum value for reinforcement and protection.

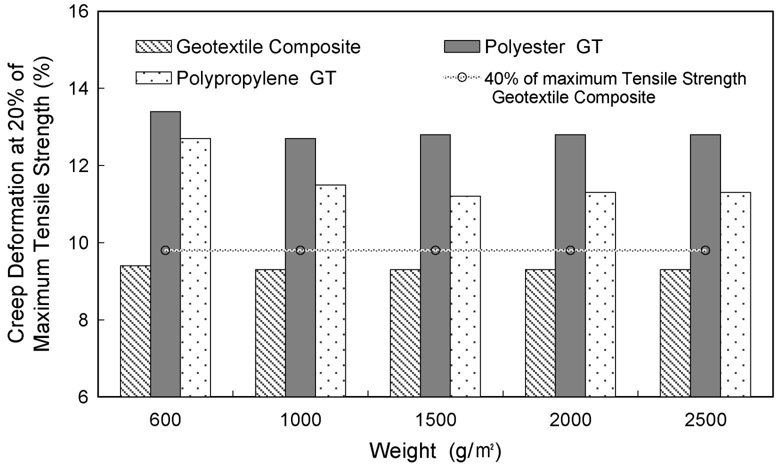


Figure 10. Reduction coefficient due to creep deformation of geo-textile composites.

4. Summary

In the present study, PVA geo-textile/HDPE geo-membrane composites were made to examine the waste landfill related properties such as frictional property and long-term performance. Thermally bonded GT composites such as PVA GT/HDPE GM, PVA GT and HDPE GM were used as model materials for experiments. Polyester and polypropylene non-woven GT were also prepared by a needle punching process for experimental purposes. It is concluded from the present investigation that in the case of using friction media having similar size to particle of domestic standard earth, the friction coefficient of geo-textile composites is relatively large compared with those of polyester and polypropylene non-woven geo-textiles. In the event that 20% of the maximum tensile strength is added to polypropylene and polyester non-woven geo-textiles, creep deformation becomes 10% or more, making it impossible to find reduction factors causing creep deformation. For geo-textile composites, even if up to 40% of the maximum tensile strength is added to them, creep deformation would remain within 10% and creep FS have the value less than 2.5, demonstrating that they are suitable for reinforcement works. It is also concluded from the experimental results that the weight of the material is not a major parameter for either friction or reduction coefficients as they are very much dependent on the construction material itself. The study also experimentally reveals the mechanical properties of geo-grids for applications. It can be concluded from the experiments about the mechanical properties of geo-grids that their strain was lower than 13%, and creep response values were below 10% during 10 000 h (ASTM D 4594, GRI GS 10). It was also revealed from the present study that its tensile strain and creep strain showed such stable values that it not only can carry out its role adequately, but also it is expected to induce an effect to protect geo-textile partially in the structure.

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