RE-ANALYSIS OF REDUCTION FACTORS FOR GEOGRIDS BY INSTALLATION DAMAGE, CHEMICAL DEGRADATION AND CREEP DEFORMATION

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ABSTRACT

Usually, the tensile properties of geogrid are affected by the creep, installation damage, chemicals etc. So, the long-term design strength of the geogrid reinforcement is reduced by these reduction factors. GRI-GG4 presented that total reduction factor is simply multiplication of each factors. But in fact these reduction factors are complexly affected to long-term properties and one factor can affect to another. In this paper, installation damage test, creep test and chemical resistance test was carried out individually and combinedly and reduction factors were analyzed. Un-notched WBG-6 remained unchanged when it was exposed to pH=9 at 50℃ for 4 months, but notched WBG-6 slightly decreased. Chemical resistance decreased followed by installation damage, while the effect is very limited in real environment. Combined reduction factor of installation damage and creep is lower than that of calculated value. Total reduction factor of installation damage, chemical degradation and creep is lower than that of calculated value according to GRI GG-4.

Keywords: Total reduction factor, installation damage, chemical degradation, creep

INTRODUCTION

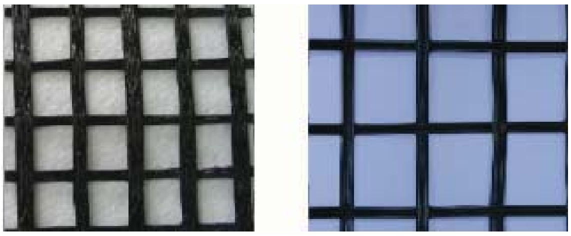
Geogrids made of high polymers are increasingly being used for reinforcement recent days in civil engineering. However, most geogrids show only 6-7% of tensile force of maximum tensile strength due to the conventional design while in practical application, which acts as a factor of a lowering of price competitiveness that is a unique advantage of geogrids. The cause of conventional design results from consideration of a safety factor in terms of civil engineering and uncertainty of long-term property of materials. Total reduction factor that is used when calculating allowable tensile strength of geogrids is made by multiplying the installation damage reduction factor, chemical degradation reduction factor, and creep reduction factor etc. In case of a model estimating allowable tensile strength considering reduction factor over the short-term tensile strength of geogrids, it has a limit not to consider interaction force between reduction factors.

Polyester geosynthetics, it was reported that they have excellent resistance to a wide range chemicals, but weak resistance to alkaline conditions (Koerner, R.M. 2005). PET filament may directly get exposed to environment cause of installation damage, rupture of junction and rupture of coating materials due to extension during its service life. This may accelerate chemical degradation and chemical resistance property can be changed. In order to observe the effect of coating materials on the chemical resistance, notch on the geogrid was made that the filaments are directly appeared. So, chemical resistance tests of both notched and un-notched specimen were performed and compared.

There are many previous studies on installation damage test combination with creep test (Billing, J.W. et al. 1990, Allen, T.M. and Bathurst, R.J. 1996, Hsieh, C. et al. 2000, Cho, S.D. et al. 2006). Up to now, the creep test by damaged specimens upon construction focused on only the variety of geosynthetics material or construction conditions and the studies on variation of reduction factor by characteristics of soil have never been implemented. Besides, the studies on the effect of chemical degradation on creep characteristics have not been conducted either. Therefore, in this study, accurate long-term allowable tensile strength was calculated considering interrelation between reduction factors. The purpose of this experiment is to reduce uncertainty of allowable tensile strength by suggesting precise reduction factor considering complex effects and to reflect this in the design properly.

EXPERIMENTAL

For the samples to be used for this experimental, woven and welded type of geogrids were used and the design strength was 6T, 8T respectively. The yarn of geogrids is polyethylene terephthalate (PET) and the coating material of woven geogrid is polyvinyl chloride (PVC). But the coating material of welded geogrid is polypropylene (PP). Figure 1 shows a picture of the geogrid used in this study. And the specification and physical properties of geogrids were represented in Table 1.



(a) woven geogrid (b) welded geogrid

Fig. 1 Photograph of geogrids used in this study.

Table 1 Specifications of geogrids

Geogrid	Raw Material /Coating polymer	Mechanical properties (ASTM D 4595)	
		Ultimate tensile strength (ton/m)	Elongation at Break (%)
WG-8	PET/PVC	10.1	10.7
WBG-6	PET/PP	7.9	11.1

Residual tensile strength of WBG-6 was tested in different deposition conditions. Chemical resistance tests were performed according to U.S. EPA 9090 standard. Figure 2 shows photograph of notched WBG-6. Coating material was removed by notch carefully that any filament was not cut. Appropriate notch was made on the surface of geogrid in cross machine direction using sharp blade and then it was bent that the ductile PP coating material was completely broken from the surface and the PET filaments got exposed. After making the notch, it was inspected carefully. If any PET filament was destroyed or any coating material on the surface remained unbroken, that specimen was rejected. Alkali solutions used in the experiments were a typical NaOH solution, corresponding to that produced by contact between the front wall of the revetment reinforcement or the concrete structure with rain or underground water.

Installation damage of geogrids was evaluated with compact condition in laboratory. Filling materials were divided by sieves and particle size of (0-0.5 mm, soil) and (4.75-37.5 mm, gravel) were selected for installation damage test individually. The experiment was conducted in accordance to ENV ISO 10722-1 and load cycle was taken 200.

Original and installation damaged geogrids were immersed in closed beakers in NaOH (pH 9 and pH 13) buffer solutions for test chemical resistance. The experiment was performed according to U.S. EPA 9090 standard.

Creep test were performed on the original geogrids, installation damaged geogrids and installation damaged with the chemical treated geogrids. Accelerated creep tests (ASTM D 6992) were performed on woven geogrids using the accelerated creep test equipment. The load level of 50-78% ultimate tensile strength was applied to woven geogrids.

Fig. 2 Photograph of notched WBG-6.

RESULTS AND DISCUSSION

Tensile Property of Destroyed Geogrids

Figure 3 and 4 illustrate the chemical resistance of notched and un-notched geogrids to the NaOH solution (pH=9, pH=13). WBG-6 shows that there was merely any decrease in weak alkaline condition but rapidly decreased in severe alkaline condition. Strength retention of WBG-6 at 50 ℃ decreased more rapidly than at room temperature, 23 ℃ .

Notched geogrid decreased in pH=13 more steeply than un-notched geogrd. This is cause of PET filament directly exposed to solutions and accelerated the chemical degradation. Notched geogrid showed no change in pH=9 at 23℃ but slightly decreased at 50℃ that can be explained as thermal effect. For un-notched WBG-6 reduction factor is negligible but notched WBG-6 showed 1.1. Reduction factor range of WBG-6 showed 1-1.1, which satisfied guidelines for the usual reduction factor values. The value was a bit over to the reduction factor (1.05) that was actually used in the design. Considering extreme condition of experiment (notched geogrid, pH=9 at 50℃), it may be predicted that chemical resistance of WBG-6 is excellent in actual environment.

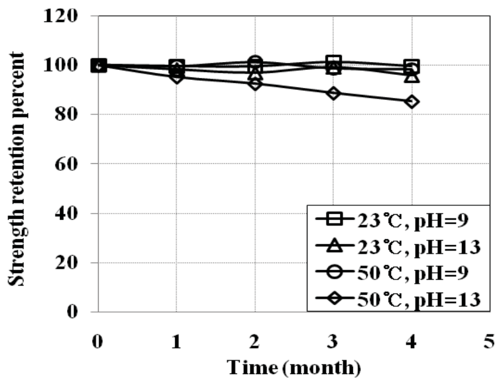


Fig. 3 Strength retention of un-notched WBG-6.

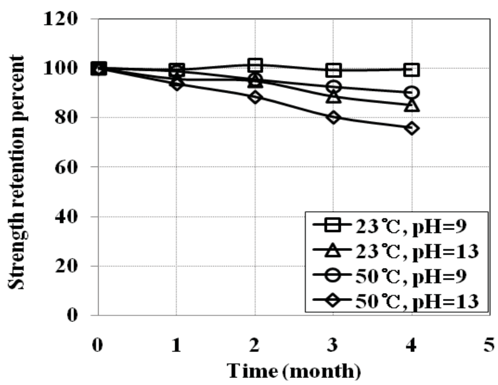


Fig. 4 Strength retention of notched WBG-6.

Figure 5 to 6 shows the percentage of tensile strength retention of WG-8 after different chemical exposure. There was merely small amount of decease in original and specimen of installation damage in filling soil (IDS) after exposure to pH 9. In contrast, there was decrease in specimen of installation damage in gravel (IDG) at pH 9. This is cause of PVC coating material destroyed during installation test and PET filament directly exposed to solutions and got the chemical degradation. It may be a problem if continuously chemical degradation occurs on geogrids as it is expected that service life of geogrid's is 50-100years. Since WG-8 showed less than 10% decrease in extreme condition (pH 9, 50℃, and installed in gravel), it can be predicted that in real environment chemical degradation followed by installation damage is very limited. Moreover, it hardly reaches to the activation energy for chemical degradation as temperature in reinforcement wall is usually lower than 20℃. But in some specific conditions, like slope of landfills, the temperature may over 50℃. It may require caution to use geogrids at high alkali condition and more time is needed to evaluate chemical degradation properly. The tensile strength decreased much in severe alkaline condition pH 13. Especially IDG showed tensile strength retention of 64.4%.

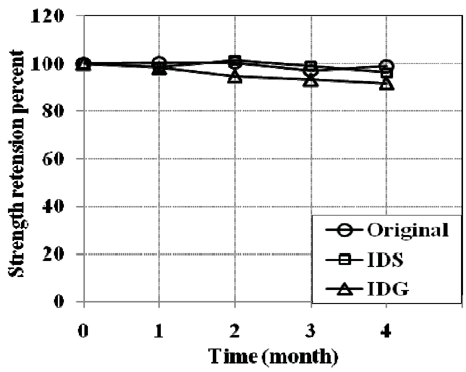


Fig. 5 Rib tensile strength retention percent of WG-8 with exposure conditions (pH 9, 50℃).

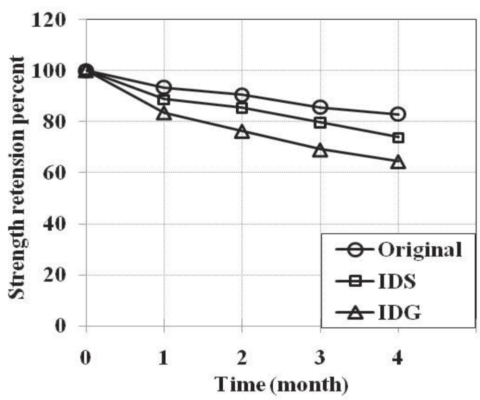


Fig. 6 Rib tensile strength retention percent of WG-8 with exposure conditions (pH 13, 50℃).

Creep Property of Destroyed Geogrids

Under the condition of pH 9, 50 ℃, creep characteristic of WG-8 that was exposed for 4 months was represented (Fig. 7). In case of 50% and 60% of ultimate tensile strength (UTS), they shows the stable behavior during test period, there was not a rupture in the case of 65%, but it showed strain exceeding 7.5% that is a limited strain. There was creep rupture in case of 68% and 75%. Compared with creep characteristic of original geogrid, it showed almost similar strain under the same load. Therefore, it could be known that there was little change of creep characteristic after chemical exposure.

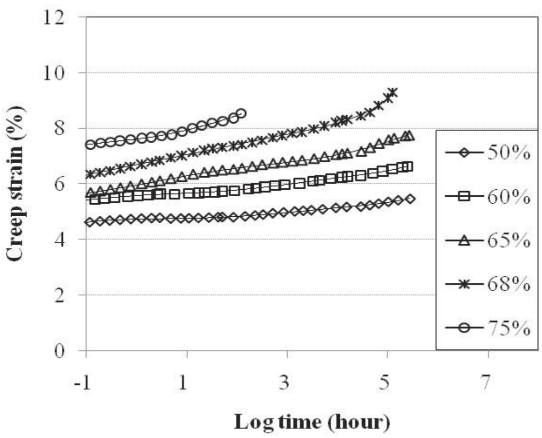


Fig. 7 Tensile creep master curve of WG-8 after chemical exposure (pH 9, 50℃, 4 months).

Figures 8 and 9 show the resulting creep properties of the WG-8 after installation damage. After installation damage, the value of creep strain is higher than that of without installation damage at the same load. This is because some of the filaments are greatly damaged or torn by the installation damage that the remaining filaments suffered higher load than usual. In case of IDS, it showed stable behavior during test period in case of 50% and 60% of UTS, and there was creep rupture under the load more than 65%. On the other hand, in case of IDG, it showed stable behavior only at 50% of UTS and there was creep rupture under the load more than 60%.

Figures 10 and 11 show the resulting creep properties of the WG-8 after installation damage and chemical degradation. The experiment result turned out to be similar with the case considering only installation damage. In case of IDS, it showed stable behavior during test period in case of 50% and 60% of UTS and there was creep rupture under a load more than 65%. On the other hand, in case of IDG, it showed stable behavior under only 50% of UTS and there was creep rupture at 58% of UTS as well. From this, it can be known that the effect of chemical exposure condition (4 months, 50℃) on creep characteristic was limited.

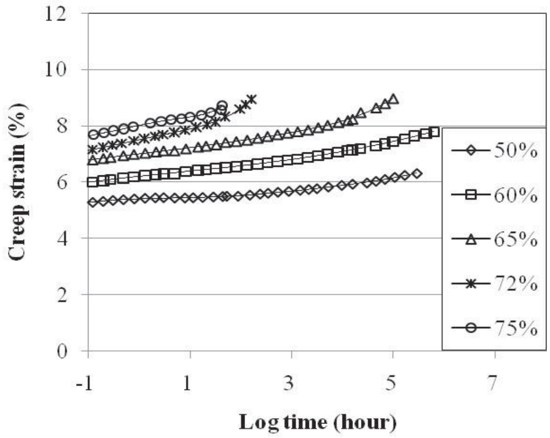


Fig. 8 Tensile creep master curve of WG-8 after installation damage by filling soil.

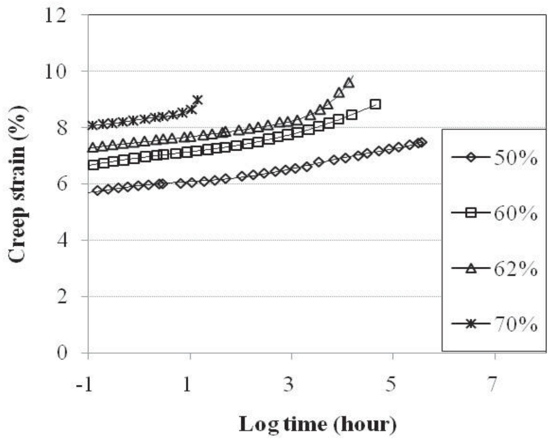


Fig. 9 Tensile creep master curve of WG-8 after installation damage by gravel.

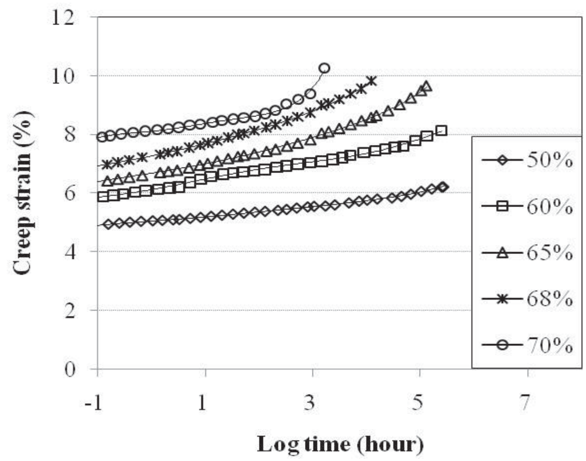


Fig. 10 Tensile creep master curve of WG-8 after installation damage and chemical exposure (pH=9, 50℃, soill).

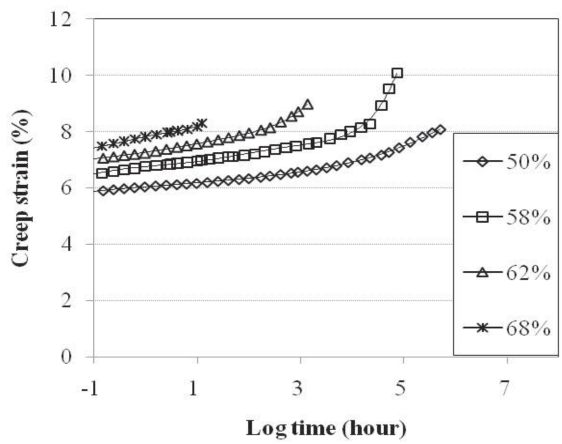


Fig. 11 Tensile creep master curve of WG-8 after installation damage and chemical exposure (pH=9, 50℃, gravel).

The calculated reduction factors were represented in Tables 2 to 3. There was no change in reduction factors i.e. combination of RF_D and RF_{CR}, this is cause of good chemical resistance in pH=9. Also, there was no change in combination of RF_{ID}(soil) and RF_D. But tested value is higher than calculated value in the combination of RF_{ID}(gravel) and RF_D. This is cause of gravel destroyed surface of coating materials and accelerated chemical degradation. However, the difference is not too much. The tested reduction factor is lower than the calculated value in the combination of RF_{ID} and RF_{CR}, especially at gravel, lower than 12%. This is cause of mutual effect of installation damage and creep test. The same is applicable for the total reduction factor.

Table 2 Reduction factor of geogrids at pH=9, 10^6 hours (soil)

Reduction factor	Calculated	Tested
RF_D, RF_{CR}	1.54	1.55
RF_{ID},RF_D	1.1	1.1
RF_{ID},RF_{CR}	1.69	1.61
RF_{ID},RF_{CR},RF_D	1.69	1.59

Table 3 Reduction factor of geogrids at pH=9, 10^6 hours (gravel)

Reduction factor	Calculated	Tested
RF_D, RF_{CR}	1.54	1.55
RF_{ID},RF_D	1.28	1.35
RF_{ID},RF_{CR}	1.97	1.76
RF_{ID},RF_{CR},RF_D	1.97	1.84

CONCLUSIONS

Notched WBG-6 has low resistance compared to un-notched WBG-6 at the severe conditions pH=13. Un-notched WBG-6 has no change in pH=9 at 50℃ after 4 months, but notched WBG-6 slightly decreased and showed chemical degradation reduction factor 1.1. It means that chemical resistance property may be changed when coating material destroyed. Caution must be taken, if the change of reduction factor is large, to calculate allowable tensile strength. While coating material was completely removed and pH=9 is very extreme condition considering the temperature in the field is lower than 20℃, it can be concluded that change of chemical degradation reduction factor is very low. Chemical resistance decreased followed by installation damage, while the effect is very limited in real environment. Combined reduction factor of installation damage and creep is lower than that of calculated value. Total reduction factor of installation damage, chemical degradation and creep is lower than that of calculated value according to GRI GG-4. In conclusion, GRI GG-4 is a conservative test method, includes sufficient reduction factors to be considered to predict long-term properties of geogrids. Therefore it is proposed that calculated allowable tensile strength from GRI GG-4 test method can be directly used to design geogrid-reinforced soil structures and it seems that addition safety factor is not needed.

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