Geosynthetics, J. Kuwano & J. Koseki (eds)

The stepped isothermal method for lifetime prediction of PET geogrids sheathed in PP

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Keywords: SIM, lifetime prediction, factor of safety against creep, failure mechanism, reliability analysis

ABSTRACT: The creep behavior of newly developed geogrids which consist of PET yarns sheathed in PP was evaluated using SIM. For the SIM procedure, three test parameters, the applied loads, temperature steps and number of ribs were investigated. The study confirmed that temperature steps of 10 and 14°C up to 80°C are applicable for the newly developed geogrids due to the low T_g and T_m of PP. At applied loads of 40 and 50%, only primary creep state was measured, while secondary creep state appeared at the applied loads of 60%. The lifetime prediction results show that the creep strain reaches to 5.8% after using 212 years when a 2 factor of safety against creep is applied. This gives guidelines for users to select the appropriate factor of safety against creep considering the field condition within shorter test times. In addition, the creep mechanism at the applied load of 60% might be different than those at the applied loads of 40 and 50% based on the different shape parameters of Weibull distribution. This means that the applied load of 60% is not appropriate for lifetime prediction of these composite geogrids.

1 INTRODUCTION

Creep refers to a time-dependent deformation process at stress less than tensile strength of the material. The creep property varies with the type of polymer and service temperature with respect to the glass transition temperature (T_g) and melting temperature (T_m) of the polymer. Geogrids are commonly made from four types of polymers; high density polyethylene (HDPE), polypropylene (PP), polyester (PET), and polyvinyl alcohol (PVA). The manufacturing process varies with polymer type, resulting in large difference in the creep behavior among the geogrids. Therefore, the creep property of each geogrid product should be evaluated so that the appropriate reduction factor can be applied in the design calculation.

In the last ten years, the stepped isothermal method (SIM) was developed to evaluate the creep of geogrids with shortening test times. In SIM, the sequence of creep responses is generated using a series of temperature steps under a constant load. Thornton et al. (1998) and Koo et al. (2004) have performed tests on PET geogrids using SIM. Based on the results, ASTM D 6992 recommends the appropriate temperature steps and dwell time. However, there is no comprehensive assessment method of SIM on composite geogrids composed of various materials. In this study, we have used the newly developed geogrids made from 35% of PET yarns sheathed in 65% of PP by volume fraction. This construction was developed to have low creep deformation and excellent resistance to installation damage. When performing SIM on the geogrids, the test temperature steps may be different than that of PET geogrids because of the low T_g and T_m of PP.

In this paper, the creep properties of PET geogrids sheathed in PP were evaluated using SIM procedure. The study investigates the effects of SIM testing parameters on the lifetime prediction of the newly developed geogrids.

2 EXPERIMENTS

The tests were performed basically according to ASTM D 6992, the standard SIM procedures, except for those parameters that are investigated in this paper. The three prime test parameters were investigated to assess their effects on the SIM as shown in Table 1.

Table 1. Test conditions for SIM tests.

Applied Stress (% of UTS)	Dwell Time (sec)	Temperature Steps (°C)	Number of Ribs
40	10,000	10, 14	3
50	10,000	10, 14	2, 3, 5
60	10,000	10, 14	3

3 RESULTS AND DISCUSSION

The procedures of obtaining master curve from SIM are well described and explained in the ASTM D 6992 as well as in the previous paper by Koo and Kim (2005). In this paper, the effects of temperature steps, applied loads and number of ribs were investigated on the SIM data and on the accuracy of lifetime prediction.

The SIM data are summarized and given in Table 2. The time-dependent creep strains at 100 years (creep strain after 1 hour) were analyzed. The averages of time-dependent creep strains are 0.64%, 1.05% and 2.50% at 40, 50 and 60% of ultimate tensile strength (UTS), respectively. The shifting factors ranged from 0.09 to 0.107/°C.

Table 2. Statistical significance for SIM data.

Applied Stress (% of UTS)	Temp. Range/ Steps (°C)	Shifting Factors $(°C)^{-1}$	Average Strain (%) at 100 yrs	CV% of Strain at 100 yrs
40	25~75/10	0.123	0.56	7.93
40	25~95/14	0.099	0.71	6.06
50	25~75/10	0.105	1.05	8.08
50	25~81/14	0.103	1.09	5.81
60	25~85/10	0.107	2.34	10.49
60	25~81/14	0.095	2.65	18.92

The repeatability was investigated and shown in Figure 1. The master curves are very similar up to 1,000 hours at all loading levels but shows variability at the later times at the applied loads of 50 and 60% of UTS. This might be due to the test temperature of SIM performed up to 75~95°C which is excessive for PP. The CVs% of time-dependent creep strain (coefficient of variation) at 100 years are 5.81~18.92%.

3.1 *Effects of applied loads*

At applied loads of 40 and 50%, only the primary creep state was observed, while secondary creep state after 10,000 hours and rupture occurred at applied load of 60% for both temperature steps of 10°C and 14°C even though the SIM master curves are shown only at 10°C of temperature steps in Figure 1. The CVs% of time-dependent creep stains at the applied load of 60% are much greater than those at the applied load of 40 and 50%. This is due to the secondary creep state of master curves at the applied load of 60%.

3.2 *Effects of temperature steps*

At most loading levels, the master curves for both temperature steps of 10°C and 14°C overlap one and other as shown in Figure 2. However, the creep rupture appeared above 80°C at the applied loads of 50 and 60%. The time-dependent creep strains at 100 years were analyzed using T-test. The temperature steps do not affect the creep strains at 100 years except those at the applied load of 40%. This might be due to the test temperature of 95°C at the 14°C of temperature step. This means that the temperature step imposes no effect on the creep behavior while the highest temperature of SIM might affect the long-term creep results.

In order to analyze the effects of temperature steps on shifting factors, T-tests were run with 95% statistical confidence. Temperature steps affect them except for the applied load of 50%. The shifting factor of temperature steps of 10°C is higher than that of 14°C with 95% statistical confidence.

Based on the results, the dwell times at temperature steps of 14°C should be longer than 10,000 seconds in order to avoid the test temperature higher than 80°C.

3.3 *Effects of number of ribs*

The effect of number of ribs on the creep behavior was evaluated using applied load of 50%. Figure 3 shows the master curves for the specimens with 2 ribs and 5 ribs. The master curves for 2 ribs and 5 ribs of specimens overlap one and other; the number of ribs imposes no effect on the creep behavior.

3.4 *Lifetime prediction*

The lifetimes of geogrids are predicted through analyzing the distribution of failure times. A failure distribution represents an attempt to describe

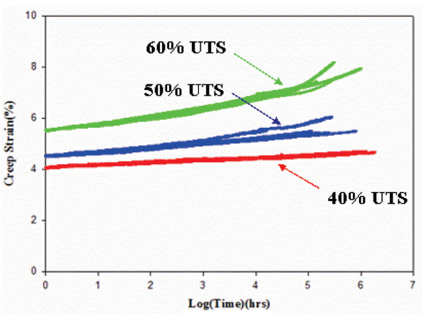

Figure 1. Creep master curves with 10°C of temperature step.

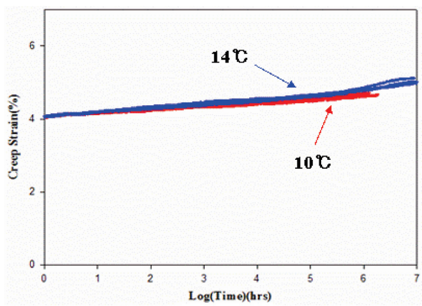

Figure 2. Comparison of creep master curves using two different temperature steps at 40% of UTS.

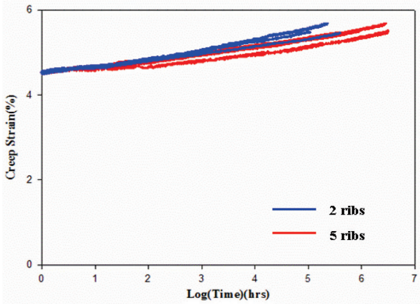

Figure 3. Effect of number of ribs under 50% UTS.

mathematically the length of the life of geogrids. Distinguishing different distribution functions is based on the failure rate known as hazard rate in reliability. Assuming that the geogrids follow an increasing failure rate (IFR) because the failure mode of geogrids is associated with the increase in creep strain due to applied stresses.

The lifetime prediction was performed at each loading level. The regression analyses were run using log time as a predictor variable and strain as a response variable in order to estimate the failure times for the master curves. The failure times at 125% of initial creep strains were extrapolated using the regression equations. And then, we predicted the B_{10} lifetimes of geogrids by applying Weibull distribution and estimating the reliability statistics. The detailed lifetime prediction technique using statistical reliability analysis is given in the previous work by Koo and Kim (2005).

The failure times are collapsed for all test conditions at 50% UTS in order to obtain enough data points for Weibull distribution. The lifetime prediction results are shown in Figures 4 and 5. The upper two graphs show failure probability density function and distribution, respectively. The lower left graph shows the reliability function and the right one shows the failure rate.

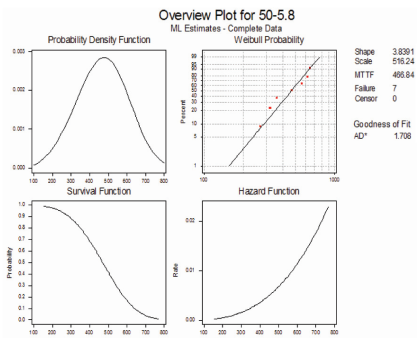

Figure 4. Reliability statistics for PET geogrids sheathed in PP at 50% of UTS.

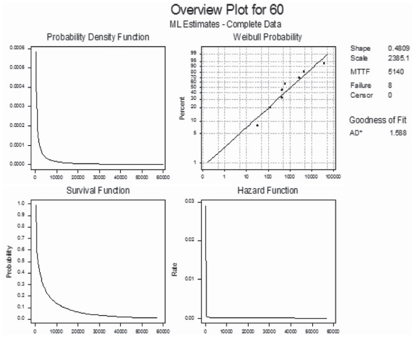

Figure 5. Reliability statistics for PET geogrids sheathed in PP at 60% of UTS.

The shape parameters of Weibull distribution for 40 and 50% of UTS are 3.84 and 1.87, respectively, which are greater than 1 while that for 60% of UTS is 0.48. In Figures 4 and 5, the failure rate increases as time increases at the applied load of 50% and vice versa at the applied load of 60% imposing that the failure rate changes according to the loading levels. Namely, the applied load of 60% is too high to predict the long-term creep behavior. It means that the creep mechanism might be different than the field condition, which is assuming the increase in creep strain due to accumulation of stresses as time goes by.

The lifetime prediction results at the applied load of 50% show that the B_{10} lifetime is 212 years at 5.8% of creep strains(1.3% of time-dependent creep strain) with 90% statistical confidence. It means that the creep strain reaches to 5.8% after using 212 years when a 2 factor of safety against creep is applied.

In addition, the SIM master curve agrees well with creep data upto 1,000 hours as shown in Figure 6.

3.5 *Comparison of SIM master curves for PET and PET georids sheathed in PP*

The master curves of PET geogrids were obtained from the previous work by Koo et al. (2004). Figure

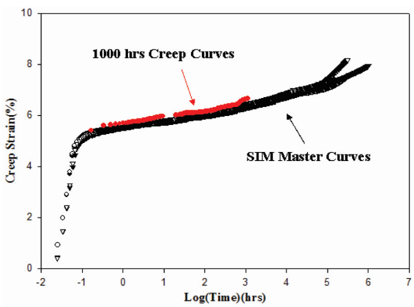

Figure 6. Comparison between results of long-term creep data and SIM test at the applied load of 60% UTS.

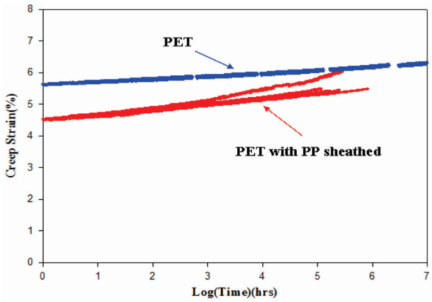

Figure 7. Comparison between results of long-term creep data and SIM test at the applied load of 60% UTS.

7 shows the SIM master curves for PET and PET geogrids sheathed in PP.

The 100% PET geogrids show the high initial creep strains but low time-dependent creep strains and vice versa for PET geogrids sheathed in PP. This study confirmed that Koerner (1997) explained the different creep mechanisms of PET and PP. For PET, the creep occurs when the chains break at the interface of the crystalline and amorphous regions while the creep occurs due to chain slippage within crystalline regions for PP.

4 CONCLUSIONS

For the SIM test procedure, at applied stress of 40, 50% UTS, only primary creep was observed while secondary creep stage were obtained at 60% UTS.

The temperature steps of 10 and 14°C were found to be applicable for PET geogrids sheathed in PP. However, both temperature steps and the highest temperature at the last step should be considered carefully according to the materials for SIM tests.

The creep mechanism of the applied load of 60% is different than those of the applied load of 40 and 50%. This means that the applied load of 60% is not appropriate for the lifetime prediction.

The long-term creep data for 1000 hours shows good agreement with SIM master curves.

Based on the results, caution must be carried out when the SIM procedure applied to new geosynthetics with various materials that do not have long-term creep data to be compared.

ACKNOWLEDGEMENTS

The authors acknowledge the financial contribution from Korean Ministry of Commerce, Industry and Energy towards this research granted by Korea Materials and Components Industry Agency.

The authors wish to extend special thanks to: Dr. Cho, Seong-Ho and Mr. Cha, Dong-Hwan, Sam Yang Corp. for their samples and advices; Dr. J. S. Thornton, TRI, USA, for helpful discussion.

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