Creep Lifetime Prediction of Composite Geogrids using Stepped Isothermal Method

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Abstract

The creep behavior of newly developed composite geogrids which consists of PET yarns sheathed in PP were 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 composite geogrids due to the different transition temperatures between two materials. 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 lifetimes of composite geogrids were estimated at each of loading level using statistical reliability analysis technique. The results show that the lifetimes longer than 100 years can be predicted within 16 hours. Therefore, SIM is very effective and economical accelerated creep test methods, especially for lifetime prediction. This gives guidelines for users to select the appropriate factor of safety against creep considering the field condition within shorter test times.

Key words : Creep reduction factor, Lifetime prediction, Stepped isothermal method, Composite geogrid

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 composite geogrids were evaluated using SIM procedure. In addition, the reduction factor against creep were evaluated at the using temperature in order to meet the required design life in the field.

2. Experiments

The tests were performed basically according to ASTM D 6992 and RS K 0023, 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. In this paper, the effects of temperature steps, applied loads and number of ribs were investigated on the creep behaviors of composite geogrids.

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.

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%.

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

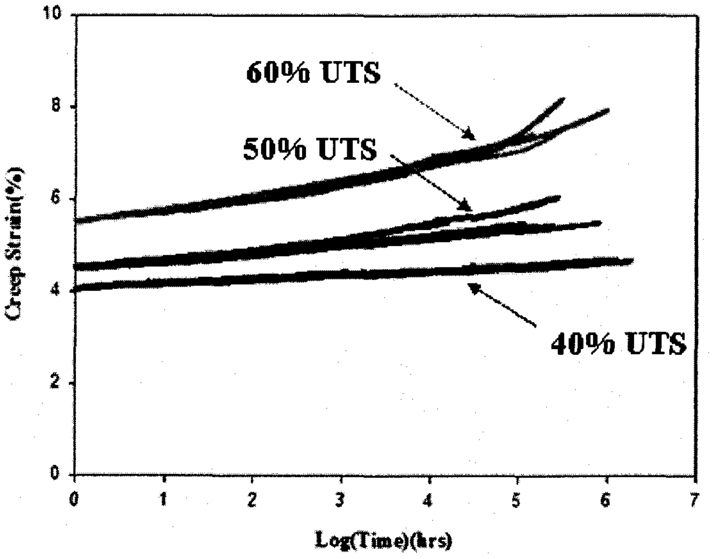

Figure 1. Creep master curves with 10°C of temperature step

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 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.

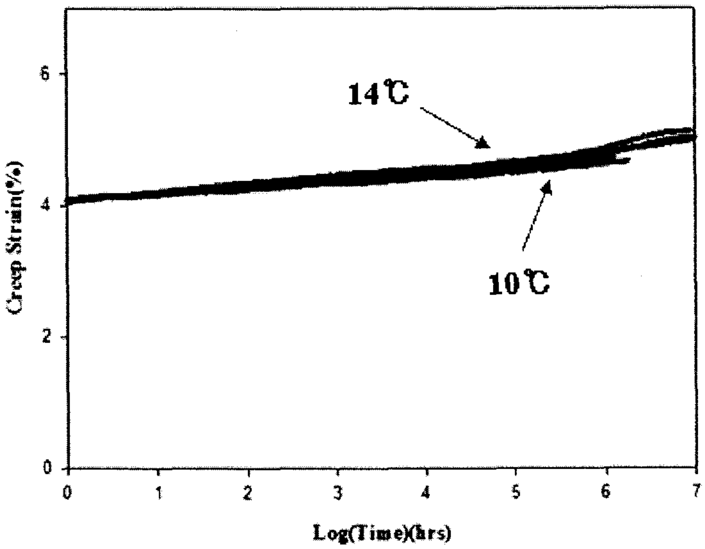

Figure 2. Comparison of creep master curves using two different temperature steps at 40% of UTS

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.

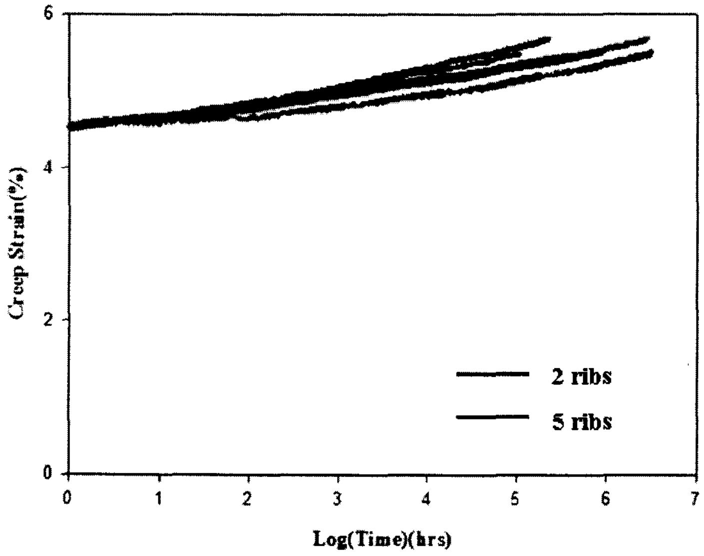

Figure 3. Effect of number of ribs under 50% UTS

3.4 Comparison between long-Term Creep Data and SIM Master Curves

The long-term creep data were obtained upto 1,000 hours and compared with SIM master curves at each loading level. The SIM master curve agrees well with long-term creep data upto 1,000 hours as shown in Figure 4. It means that the SIM is very powerful to obtain the creep master curves within shorter test times.

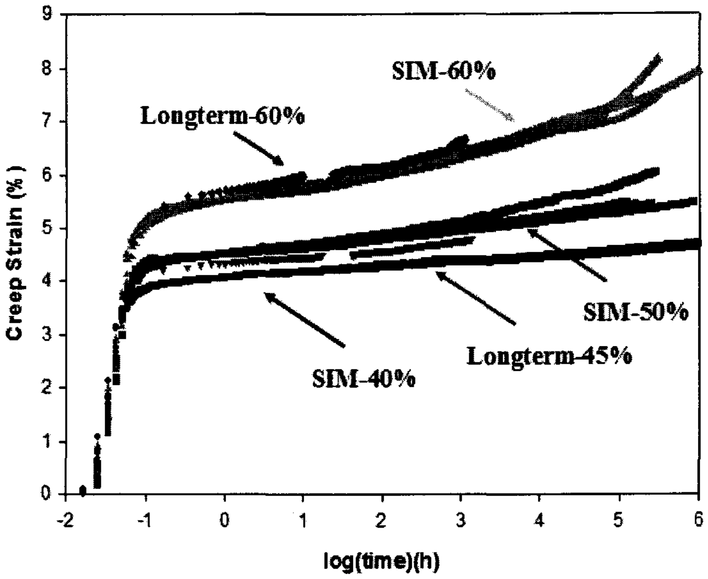

Figure 4. Long-Term Creep Data vs. SIM Master Curves

3.5 Prediction of Lifetimes

The lifetimes of geogrids are predicted through analyzing the distribution of failure times. A failure distribution represents an attempt to describe mathematically the length of the life of geogrids. The creep failure times from the SIM master curves were estimated at 1, 1.25 and 1.5% of time-dependent creep strains at reference temperatures of 25°C. The detailed methods for predicting lifetimes and creep reduction factors are well described and explained in RS K 0023 as well as in the previous paper by Koo and Kim (2005). Figure 5 shows the creep failure time distribution at 1% of time-dependent creep strain by applying Weibull distribution.

Using the creep failure time distribution, three creep failure times of B_{10}, B_{50} and mean time to failure(MTTF) were estimated at 5.06(40% of UTS), 5.77(50% of UTS), 8.52%(60% of UTS) of creep strains by applying Weibull distribution as shown in Table 3. The lifetime prediction results are satisfied with the specification of RS K 0009 at all loading levels in which the geogrids should reach less than 10% of creep strain at 50 years of B_{10} life with 90% statistical confidence. Through the lifetime prediction at each loading level, the user can select an appropriate geogrids considering the field condition.

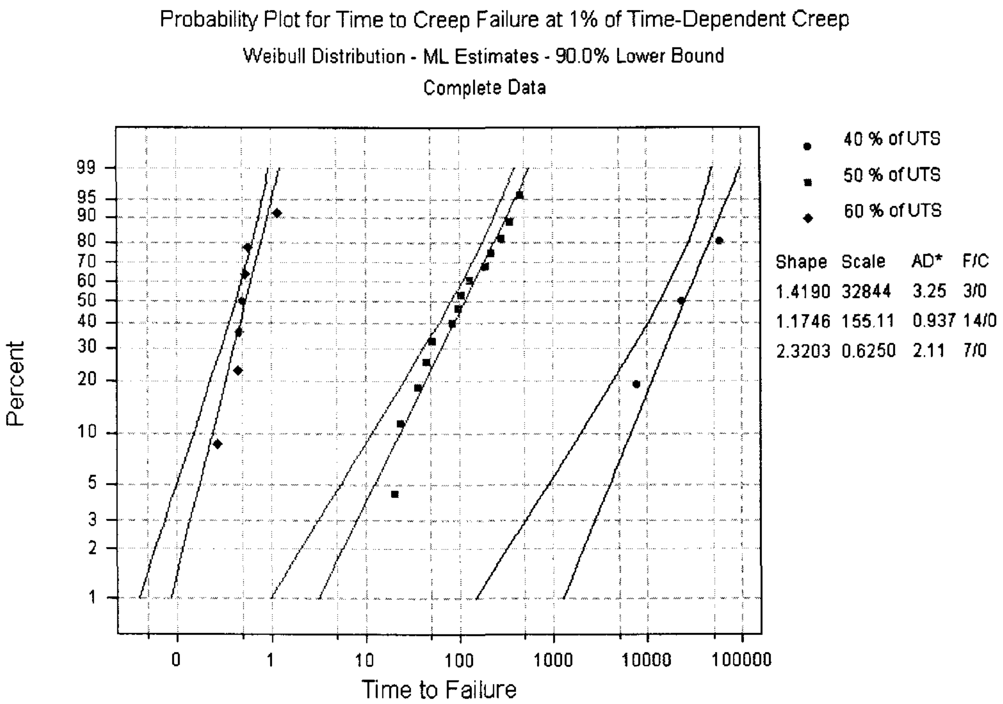

Figure 5. Failure Time Distributions at Each Loading Level - 25°C

Table 3. Results of Lifetime Prediction at 25°C

% of UTS	Creep Strain(%)	Lifetimes(yrs)	Percentile	90% C. I.
40%	5.06	B_{10}	6,725	1,955
		B_{50}	25,367	13,672
		MTTF	29,873	17,599
50%	5.77	B_{10}	198	90
		B_{50}	1,252	841
		MTTF	1,776	1,270
60%	8.52	B_{10}	252	88
		B_{50}	1,195	683
		MTTF	1,518	941

4. Conclusion

For the SIM test procedure, the temperature steps of 10 and 14°C were found to be applicable for composite geogrids with a caution of the temperature at the last step according to the transition temperature of materials. At applied stress of 40, 50% UTS, only primary creep was observed while secondary creep stage were obtained at 60% UTS. The creep mechanism might be different than the field condition at the applied load of 60%. The long-term creep data for 1,000 hours shows good agreement with SIM master curves at each loading level. 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.

Using SIM, the lifetimes of geosynthetics could be predicted longer than 100 years within 16 hours. Moreover, the predicted lifetimes at each loading level provide useful information for users to select an appropriate geogrid in the field.

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