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# Application of Stepped Isothermal Methods to Lifetime Prediction of Geogrids

## SIM을 적용한 성토보강용 지오그리드의 수명예측

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## Abstract

The failure of geogrids can be defined as an excessive creep strain which causes the collapse of slopes and embankments. In this study, the lifetime of knitted polyester geogrids was predicted by using SIM(Stepped Isothermal Methods using TTS principal) and statistical data analysis techniques. The results indicate that the creep strain was 8.74, 8.79, 8.80% with 2.16～2.20% of CV% at 75, 100, 114 years, respectively and the creep strain reaches 9.3% after 100 years of usage at 27℃ which meets the required lifetime(creep strain less than 10% after 100 years of usage) in the fields. The SIM method is shown to be effective in reduction of uncertainty associated with inherent variability of multi-specimen tests and shorter test times than conventional TTS(Time-Temperature Superposition).

## 요 지

사면 또는 옹벽 등 토목구조물에 보강용으로 적용되는 지오그리드의 고장은 토목구조물의 형태변형을 유발할 수 있는 과도한 크리프 변형으로 정의할 수 있다. 본 연구에서는 지오그리드의 크리프 변형을 단시간에 시험할 수 있는 SIM(Stepped Isothermal Methods)과 통계적 수명평가기법을 적용하여, Polyester 편포형 지오그리드의 수명을 예측하였다. 그 결과 예측한 75, 100, 114년에서의 크리프 변형율은 각각, 8.74, 8.79, 8.80%이고, CV%는 2.16~2.20%로 매우 반복성 있는 결과를 보여준다. 수명 예측 결과는 27°C에서 100년 사용 후 지오그리드의 크리프 변형율이 9.3%로 추정되었고, 현장에서 요구되는 수명(100년 사용 후 크리프 변형율 10% 미만)을 만족하는 것을 확인할 수 있었다. 이 연구를 통하여, SIM을 적용할 경우 기존의 시간-온도 중첩원리(Conventional Time-Temperature Superposition)를 적용한 수명평가 방법에 비하여 시료간의 편차를 최소화 시킬 수 있고 또한 99.5%의 시험시간을 단축시킬 수 있어서 매우 효과적인 것으로 판단된다.

**Keywords** : Creep, Lifetime Prediction, Stepped Isothermal Method, Time-Temperature Superposition, Geogrid

## 1. Introduction

Creep properties are important parameters in the design of goesynthetic-reinforced soil structures. Traditional approaches for the determination of creep behavior comprise the application to a sustained load and the measurement of the strain of geosynthetics as a function of time with elevated temperature steps.

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The conventional creep test uses multi specimens/ multi-temperature steps with test duration longer than 1,000 hrs[1] or 10,000 hrs[2]. For this reason, conventional creep tests are time consuming, expensive and contain uncertainty associated with inherent variability among specimens. To overcome this difficulties, it has been suggested to run stepped isothermal method (SIM)[3～5] which uses a single specimen per test and employs multi-temperture steps through the test duration. While the creep data is shifted using time-temper-ature superposition(TTS) principles, the single speci-men/multi-temperature steps approaches allows the reduction of uncertainty associated with inherent variability of multi-specimen tests and tremendously short testing time(16～32 hrs).

The objective of this study is to introduce the SIM to the lifetime prediction of knitted polyester geogrids.

## 2. SIM Procedures and Design

Accelerated creep tests were performed on knitted polyester geogrids using the accelerated creep test equipment[6]. The load level of 50% ultimate tensile strengths(UTS) were applied to 100kN/m knitted geogrids. The SIM testing was conducted using five specimens of single ribs of geogrids. Each specimen was allowed to reach equilibrium at 27°C prior to test initiation. Temperature was stepped 14°C every 10,000 seconds starting 27°C and ending at 90°C. Creep strains for the geogrids are plotted versus log time at each level of temper-atures as shown in Fig. 1.

## 3. Results and Discussion

### 3.1 SIM Shifting

The creep strain curves obtained from SIM testing were prepared for joining to make up the master curve by adjusting the starting times for each of the elevated stepped isothermal exposures. The first segment, which is done at the reference temperature, needs no adjustment. Subsequent segments do, to account for the effect of the creep history created by the prior exposures. This is accomplished by subtracting rescaling times, t' from the test times for each elevated temperature step as shown Fig. 2. The rescaling process, when completed properly, will match the initial slope of each elevated temperature segment to the ending slope of the prior segment. Then, when connected end to end after small vertical shifts to account for thermal expansion, the creep-strain segments become a master creep curve as shown in Fig. 3. The master curves obtained from

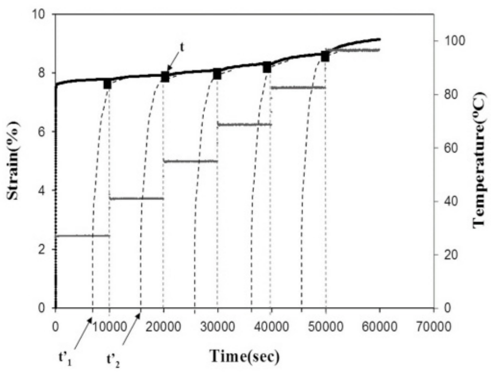


Fig. 1. Stepped Isothermal methods with rescaling

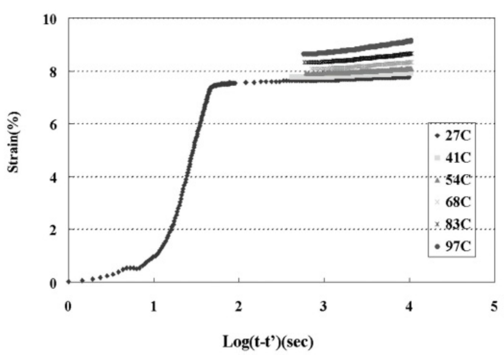


Fig. 2. Creep strain vs. log(time) after rescaling

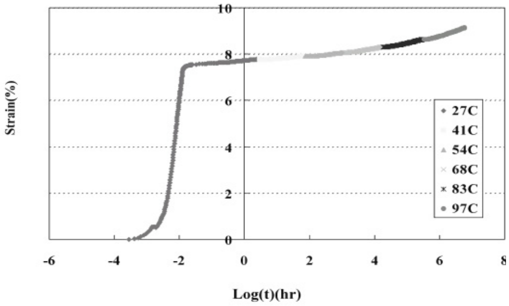

Fig. 3. SIM shifting at the step one reference temperature

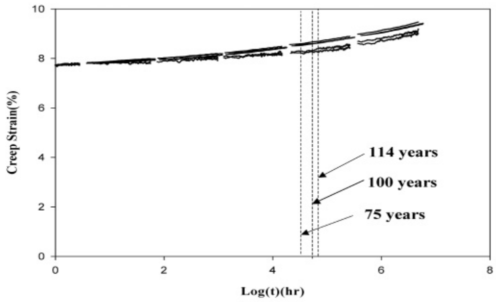

Fig. 4. SIM master curves

the SIM shifting are shown in Fig. 4. Most significant is that the test time to generate one master curve is 16 hours for SIM shifting and 3,000 hours for the conventional TTS shifting.

## 3.2 Lifetime Prediction using Statistical Data Analysis Technique

The results obtained from SIM shifting methods were analyzed using statistical data analysis technique. For the geosynthetics community, long term generally means 75, 100 years or sometimes 1,000,000 hours, which is 114 years. Therefore, the creep strains were estimated at 75, 100 and 114 years and the average and the CV% are summarized in Table 1. The estimated creep strains obtained from SIM are 8.74～8.80% with 1% less CV% than conventional TTS[6] at 75, 100 and 114 years, respectively.

The regression analyses were run using log time as a predictor variable and the log strain as a response variable in order to estimate the failure times for the master curves obtained from the SIM shifting. The failure times and long-term 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[6].

The reliability analyses were run and the results are shown in Fig. 5. The estimated creep strains are 9.3% for the SIM shifting at 100 years of $B_{10}$ lifetime at 27°C with 90% statistical confidence. It means that the predicted lifetimes satisfy the required lifetimes(creep strain less than 10% after 100 years of usage) in the fields.

## 4. Conclusions

We have validated the use of the stepped isothermal method(SIM) for lifetime prediction of a knitted geogrid. The estimated creep strains and predicted lifetimes show that the estimated creep strains reach 9.3% after 100 years of usage with 90% statistical

Table 1. Estimated Failure Times with Statistical Significance

| Failure time(Yrs.) | N | Creep Strain(%) | CV(%) of Creep Strain(%) | 95% C.I. for Creep Strain |
|---|---|---|---|---|
| 75 | 5 | 8.744 | 2.162 | (8.482, 9.007) |
| 100 | 5 | 8.785 | 2.230 | (8.519, 9.051) |
| 114 | 5 | 8.803 | 2.191 | (8.534, 9.072) |

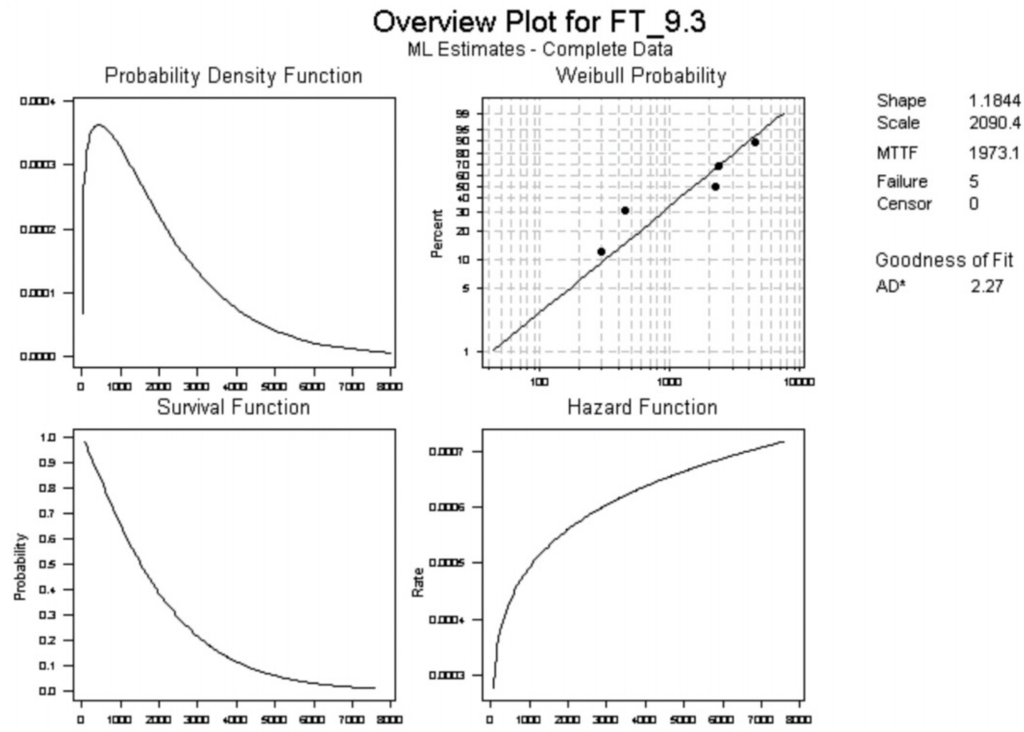


Fig. 5. Reliability analysis results for SIM methods

confidence.

The SIM, which allows the reduction of test time by 99.5%, is recommended for predicting lifetimes of polyester geogrids without the uncertainty associated with the inherent variability among specimens.

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