Predicting the long-term strength of a geogrid using the stepped isothermal method

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ABSTRACT: This paper describes a procedure for performing the stepped isothermal method, adapted to correspond with EN ISO 13431. Creep-rupture results are presented for a new form of polyester geogrid and a regression line is drawn, yielding a 114 year design load of 61.7 kN/m. it is proposed that the method should be standardised, and recommendations are made on how and to which materials it should be applied.

1 CONVENTIONAL CREEP-RUPTURE TESTING OF SOIL REINFORCEMENTS

Current codes of practice for soil reinforcements require a prediction of the maximum load which the material will sustain over the design life of the structure. If this load were applied over the entire lifetime of the structure, the reinforcement would be expected to fail when the lifetime had expired. For a design life of 120 years the load for a polyester reinforcement to be used at 20ºC will be typically 60% of its tensile strength.

The conventional means of estimating this load is to perform creep-rupture (also known as stress-rupture) tests at higher loads and short times and to establish a relation between load and time to failure, generally plotted as load or the logarithm of load against the logarithm of time (ISO 13431). This is then extrapolated to longer lifetimes at lower loads. If, however, the duration of testing is less than 10% of the service life, the design codes impose a penalty reduction factor on the design load, thus reducing the competitiveness of the material (BS 8006: 1995, AASHTO 1997). For a 120 year design life it is therefore be necessary to test for 12 years, as described in a separate paper at this conference (Greenwood, Kempton, Watts and Bush 2000).

Further acceleration can be achieved by performing parallel series of tests at elevated temperatures. A stress-rupture line is derived at each temperature. These lines are shifted along the log (time) axis until they superimpose, a procedure known as time-temperature superposition, effectively extending the room temperature line to longer times. A similar procedure is used to extend the creep strain characteristic, in which the strain generated by the load is plotted against log (time). A particular problem in applying the method to the creep strain of polyester reinforcements is that there is great variability between nominally identical specimens in their initial strains on loading, even though they have similar behaviour afterwards. This means that the separation between creep strain characteristic at the same temperature can be as large as the separation due to a difference in temperature. Time-temperature superposition therefore becomes very inaccurate.

2 THE STEPPED ISOTHERMAL METHOD

The stepped isothermal method (SIM) has beed described in detail by Thornton and co-workers (1998a, 1998 b). Its purpose is to obtain a rapid prediction of creep and creep-rupture behaviour. It achieves this by measuring the creep and time to rupture of a single specimen under load while the temperature is increased in a series of steps. The procedure avoids the problems of specimen-to-specimen variation that limit the accuracy of conventional time-temperature superposition.

One unexpected feature of SIM is that the temperature can be raised as high as 90ºC without invalidating the results. The creep behaviour would be expected to change above 70ºC, where a glass-to-rubber transition occurs in the amorphous regions of the semicrystalline polyester fibres. Thornton et al demonstrated however that no such transition occurs, and explain this absence by pointing out that the creep properties of the polyester fibres are governed by the crystalline fraction and by the tie molecules which run from one crystal to another. These tie molecules carry the load and are unaffected of the state of the amorphous material around them.

To generate a creep-rupture curve still requires upwards of 12 separate specimens all of which rupture, but the ability to raise the temperature as high as 90ºC mean that the individual tests can be performed within 24 h. It is thus possible to generate a simulated creep-rupture curve representing a hundred years of lifetime in two to three weeks.

The method used is as described by Thornton but is adapted to be similar to EN ISO 13431. It has been set out in an Internal Procedure at ERA. ERA's recommended improvements are as follows.

1. The specimen dimensions, grips, extensometry and initial loading procedure should be as for EN ISO 13431. Single ribs are, however, acceptable for geogrids. The specimens should be conditioned in the reference environment for >16 h.
2. The cabinet temperature control should be designed to change rapidly and stabilise to within ± 1ºC within 2 min.
3. The data logger should monitor strain and temperature at preset times. It is important that sufficient readings are taken directly following a step change of temperature, but too many readings can prove intractable and add little to the accuracy of the result. As a guide, there should be a minimum of ten readings within the first ten minutes and ten more within the remaining duration of the temperature step.
4. Load should also be measured if it is applied hydraulically and not by means of dead weights. The load should be constant to within ± 1% or, preferably, ± 0.5%.
5. The minimum duration of a temperature step should be 2½ hours. No maximum limit is necessary: an overnight temperature step is less efficient but no less accurate.
6. The mean measured temperatures and, where appropriate, mean measured load should be used in the analysis rather than the set values.
7. The temperature increments should not exceed 15^{o}C for polyester geosynthetics.
8. The horizontal and vertical shift factors and the time additions should be chosen such that the creep modulus/shifted time graph is smooth and continuous, with no overlapping of the curve sections, no steps at the temperature changes, and no abrupt changes of gradient. All the shift factors and time additions should be reported and the horizontal shift factors should be plotted against temperature (e.g. Table 1) to ensure that they lie on a straight line or continuous curve (Fig. 1).
9. If the load is expressed as a percentage of tensile strength, then it shall be stated whether that strength is an independent measured strength or a nominal, characteristic or MARV (minimum average roll value) quoted by the manufacturer.
10. The creep strain or curves should be plotted showing the measurements made at each temperature step (Fig. 2). Report the shifted time to rupture and nature of failure.

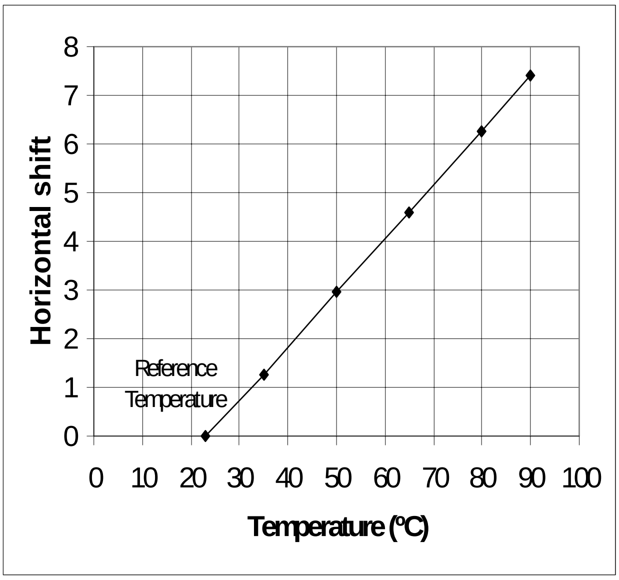

Figure 1. Horizontal shift factors used for specimen VDY 007

Table 1. Shift factors for specimen VDY 007

Temperature (ºC)	Time addition (h)	Total vertical shift (% strain)	Temperature shift (decades of time on logarithmic time scale)
23	0	0	0
35	0.2	0.025	1.25
50	0.05	0.05	2.95
65	0.5	0.1	4.6
80	0.05	0.15	6.25
90	0.22	0.22	7.4

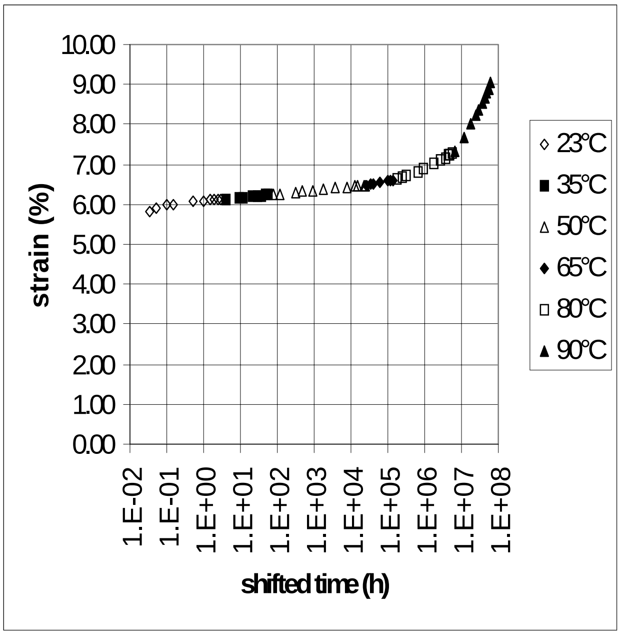

Figure 2. Creep curve for specimen VDY 007

3 THE NEW GEOGRID

Colbond Geosynthetics have developed a new geogrid based of straps/bars of black extruded PET in the longitudinal direction. Transparent straps of otherwise similar material are laid in the transverse direction and welded using infrared laser light onto both sides of the black straps to form a rectangular grid.

4 TENSILE STRENGTH

Single straps were taken from a sample of the new geogrid (coded VDT, VDY) in the direction of reinforcement. The tensile strength of the batch was measured in general accordance with EN 10319 using flat plate grips. The results are shown in Table 2.

Table 2. Tensile strength

Specimen	Tensile load (kN)	Elongation at break (%)	Failure location
VDY 008	5.085	6.75	Near grip, not at intersection
VDY 009	5.109	7.16	Near grip, not at intersection
VDY 010	5.015	8.6	At intersection
VDY 011	5.262	7.9	Near grip, not at intersection
VDY 013	5.769	8.75	At intersection
mean	5.248	7.83	
s.d.	0.304	0.87	

The tensile strength of the batch in kN/m, which is calculated from that for single straps by multiplying by 20 straps/m, equals 104.9 kN/m. With the strip measured as 10.17 mm wide and 0.75 mm thick the tensile strength of the material of the strap is 6876 MPa (N/mm²). The characteristic strength of the material is 90 kN/m.

5 SIM RESULTS

Twelve SIM tests were performed using loads of between 56% and 80% of batch tensile strength. Both roller grips and plate grips were used. Since no significant differences were noted, all tests are included in the results.

The creep curves are given in Fig. 3. The stress-rupture results are given in Table 3 and Fig.4.

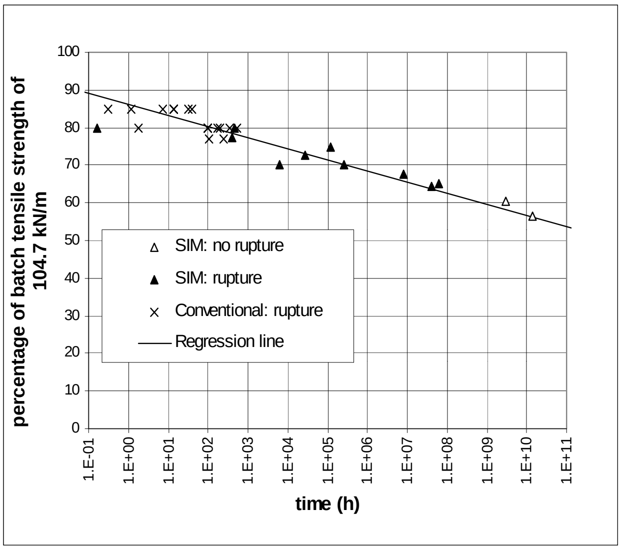

Figure 3. SIM creep curves for all specimens

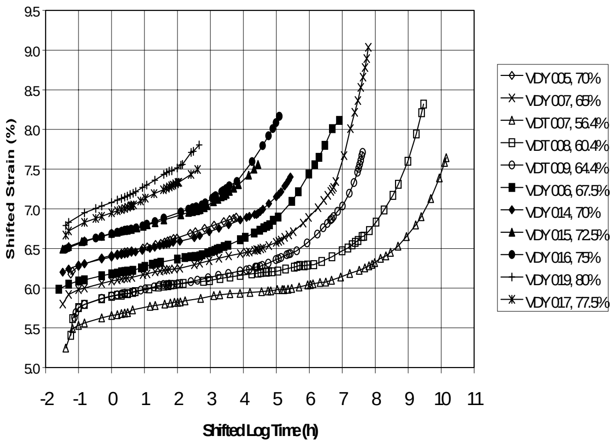

Figure 4. SIM Creep-rupture curve

Table 3. Creep-rupture results

Specimen No.	% tensile strength	Shifted log [time (h)]	Failure mode
VDY 002	80	-0.78	Rupture between grip and extensometer bar
VDY 019	80	2.65	Ruptured inside gauge length
VDY 017	77.5	2.61	Rupture between grip and extensometer bar
VDY 016	75	5.09	Rupture between grip and extensometer bar
VDY 015	72.5	4.44	Rupture close to grip
VDY 005	70	3.78	Rupture between grip and extensometer bar
VDY 014	70	5.42	Ruptured inside gauge length at node
VDY 006	67.5	6.91	Rupture between grip and extensometer bar
VDY 007	65	7.79	Ruptured inside gauge length at node
VDT 009	64.4	7.62	Rupture between grip and extensometer bar
VDT 008	60.4	9.47	Test terminated: no rupture
VDT 007	56.4	10.15	Test terminated: no rupture

6 ANALYSIS OF THE CREEP-RUPTURE RESULTS

Following temperature shifting, and plotted as load against log time, the times to rupture lay on a straight line. This line coincided with the extrapolation from conventional stress-rupture tests performed by the manufacturer. Analysis of all the results together gave a regression line of

$$\sigma = 86.05 - 2.931 \log t$$

where σ is the applied load expressed as a percentage of the tensile strength and t is time in hours, the load corresponding to a lifetime of 10^6 h (114 years) is 68.5% of the tested batch tensile strength of 104.9 kN/m or 71.9 kN/m. The design load corresponding to a lifetime of 10^6 h (114 years) is therefore to be taken as 68.5% of the characteristic strength in accordance with the standards in force.

ERA has found on other products that the long-term strength derived by SIM can be somewhat higher than that derived by conventional creep testing or time-temperature superposition. This will be explained in a separate publication.

7 CONCLUSION AND RECOMMENDATIONS

By means of 12 stepped isothermal tests, each one lasting about 24 h, a long-term design strength of 71.9 kN/m has been derived for a polyester geogrid, prior to the application of reduction and safety factors.

In addition to ERA's detailed comments above it is recommended that:

- the procedure for SIM is standardised, particularly since the analysis of the data includes correction factors which allow scope for choice.
- SIM data should only be accepted for properties and materials where there is a published validation of the method by comparison with conventional methods. So far this applies only to the creep strain of polyester geogrids.
- All creep and creep-rupture data derived using SIM should be stated as such.

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