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A comparison of different techniques for determining the tensile and creep strength and creep reduction factor of a geogrid

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ABSTRACT: Over the past 25 years extensive efforts of researchers and manufacturers have been devoted to developing and applying techniques for the determination of the Creep Limited Strength (T_B) of geosynthetic reinforcement materials, including geogrids. The major difficulty in this determination is the extension forwards by a factor of 10 to 100 times of the results of tests that can be carried out in realistic time-frames. Standard methods for Creep Testing, e.g. ISO 13431, have existed for some time, but there is still no international consensus on how to determine T_B.

In Western countries the techniques developed rely on time-temperature superposition (TTS): the use of temperatures above the design temperature to accelerate the creep process. Typically, creep tests are carried out at 3 or more temperatures using conventional or stepped isothermal (SIM) test methods. Then plots of limiting loads vs log(time) are produced, with the higher temperature data points "shifted" to produce a single plot that illustrates the performance at extended times at the design temperature. From this, a mean T_B at an appropriate design life can be taken.

In Japan, testing facilities at elevated temperature are not widely available and a novel technique for determining the T_B of HDPE Geogrids has been developed. This relies on the discovery that if the slope of conventional creep plots of strain vs. Log(time) in the region of 500-10,000hrs is plotted against the test load it is found that there is a specific load at which the gradient of the resulting plot changes abruptly. The load at this change point is considered to be the mean T_B for the product.

For design purposes, the mean T_B then may or may not be reduced by various factors to allow for variability. Then, for some design methods, the final T_B is compared to the short-term index strength, T_{max}, of the material to produce a Creep Reduction Factor, f_{cr}, which is the ratio between the two. The value of f_{cr} will depend on whether or not reduction factors have been applied to the mean T_B and the methods used for determining T_{max} and T_B.

In work done to produce data needed for different world markets for a single product it has been found that the Western and Japanese methods of determining T_B give similar results. Also that the range of different test methods and adjustments used in different markets in determining f_{cr} gives a wide range of values for this factor for the same product from a single set of creep data.

1 BACKGROUND

During the introduction of a new range of integral geogrids into world markets it was found that for similar products very different values for f_{cr} are given by different manufacturers. These values ranged from 1.67, PWRC 1997, to 2.80, Tensar International undated. One manufacturer, Tensar Corporation 2004, gives a range of 2.21 to 2.65 for a single product. There was no obvious reason for these differences as the products were all made by the same technology from similar polymers. Therefore a testing and analysis programme was started to identify the reasons and enable the economic marketing of the new products in all markets. This paper reports the results of that programme.

2 TESTING

To isolate the reasons for the differences in f_{cr} it was necessary to test a single product by the various test methods used in the different markets. This involved Tensile Testing and Creep Testing.

The product selected for the testing programme was a uniaxial high density polyeyhylene (HDPE) geogrid, manufactured by the punching and stretching method. Its specified short-term index strength properties declared for CE Marking purposes, BTTG 2005, are a mean of 99.9 kN/m and a lower 95% confidence level of 95.2 kN/m when tested in accordance with EN ISO 10319, ISO 1993.

2.1 *Tensile testing*

From studying the sources of values for f_{cr} It was found that there were three different index test methods used for the measurement of T_{max}:

- ISO 10319 (ISO 1993)
- ASTM D 6637 (ASTM 2001)
- "Standard Strength" (PWRC 1997)

ISO 10319 and the "Standard Strength" tests are "wide-width" test methods, with samples of approximately 200 mm in width being tested. With ASTM D 6637 there is an option to test either wide-width or single-rib samples. For this exercise the wide-width option was selected for commonality with the other test methods. The difference then between the test methods was in the speed at which samples were strained: see Table 1.

Table 1. Comparison of tensile test methods.

Test Method	Strain Rate
ISO 10319	20%/min
ASTM D 6637	10%/min
"Standard Strength"	1%/min

A number of product samples were tested at these three strain rates. The shape of typical load/strain plots is illustrated in Figure 1. All samples at all strain rates passed through a peak load at about 11% strain. Then the samples at 20%/min and 10%/min failed between 13% and 18% strain. The samples at 1%/min failed between 20% and 28% strain and some had a higher failure load than the initial peak. As this was not consistent, T_{max} for all test methods has been taken at the initial peak for analysis purposes.

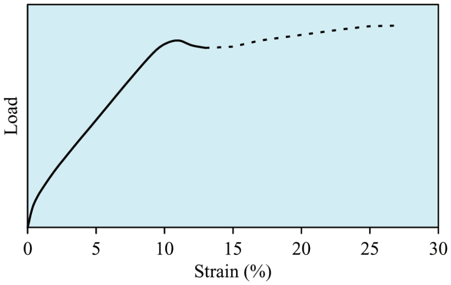

Figure 1. Typical tensile index test results.

As would be expected, the tests at lower strain rates gave lower values for T_{max} than the faster tests. From these results, typical values for T_{max} at the different test rates were calculated to be as shown in Table 2. Also shown are values for the Lower 95% Confidence Limit, T_{C95}.

Table 2. Comparison of tensile test method results.

Test Method	T_{max}	T_{C95}
	kN/m	
ISO 10319	99.9	95.2
ASTM D 6637	94.6	90.2
"Standard Strength"	77.4	73.8

2.2 *Creep testing*

A range of samples of the product and other members of the same family were creep tested using the methodology and equipment described in Wrigley et al. (2004), Tests were carried out at temperatures of 20°C, 40°C and 50°C with some test durations in excess of 5000 hours. Strain-time plots for the product at 20°C are shown in Figure 2. Similar plots were obtained from testing at the higher temperatures. Similar sets of data were obtained for each member of the product family.

3 ANALYSIS

3.1 *Determination of T_{Blot} (GRI 1991, BSI 1995, WSDOT 2005)*

Several similar protocols are available for the main method of analysis of creep data used internationally: GRI 1991, BSI 1995, WSDOT 2005, and an international standard is currently under development within ISO. These are based on analysing time to rupture or a strain limit at different loads. The concepts in Wrigley et al. 2004 are applied here to give an analysis based on failure being defined as rupture or 20% strain, whichever occurred first for each test.

From the plots of Figure 2 and similar data for other products in the family failure data was determined, time-shifted and normalized following the methodology of Wrigley et al. 2004, using the interpolated failure load at 1000hours as the normalising factor. This gave the plot of time to failure against normalized load shown in Figure 3.

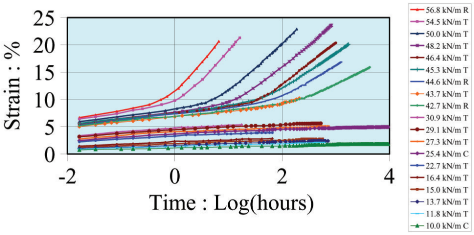

Figure 2. Creep tests at 20°C.

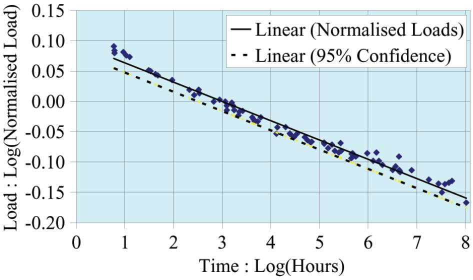

Figure 3. Failure load vs time.

From Figure 3, mean Creep Limited Strengths for a lot (or batch) of product with a strength of T_{max} = 99.9 kN/m for lives of 75 years (T_{Blot75}) and 120 years ($T_{Blot120}$) were calculated by using the slope of the mean trend line of Figure 5 to adjust the interpolated failure load at 1000 hrs.:

$$T_{Blot75} = 41.20\text{kN/m} \quad (1)$$

$$T_{Blot120} = 40.60\text{kN/m} \quad (2)$$

3.2 *Determination of T_{Blot} (PWRC 1997)*

When HDPE geogrids were being examined for approval for use in public projects in Japan the principles of Time-Temperature-Superposition could not be applied. Elevated temperature test results were not available for the products made in Japan. However, in studying 20°C test results researchers discovered an interesting phenomenon that is applied in PWRC 1997. Their study focused on the slope of Strain-Log(Time) plots such as Figure 2. This slope, which we will call "Strain Rate" for convenience, was plotted against applied load and it was found that there were two clear-cut regions of performance: below a critical load the slope of the plot was low and above that load the slope was significantly higher.

To examine this hypothesis the results of Figure 2 were analysed and plotted. Figure 4 was the result.

Figure 4 suggests that the performance-change hypothesis applies at about 55% Load, but the lack of data in the region 40% to 60% Load leaves a degree of uncertainty. However, as the Load is normalized by the Index Strength it was possible to then examine the creep data obtained for the other members of the product family and add the results to the plot as shown in Figure 5.

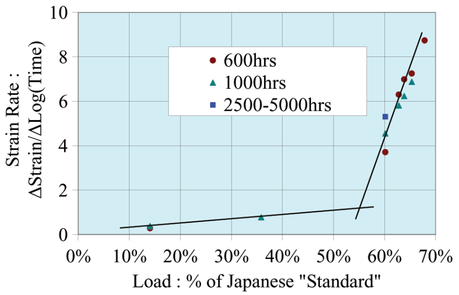

Figure 4. Strain rate vs load for the data at 20°C of Figure 2.

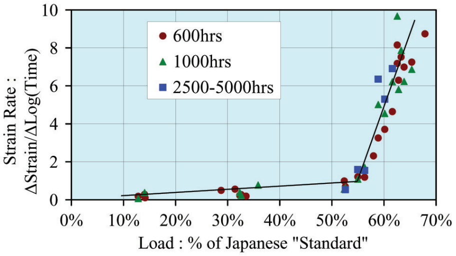

Figure 5. Strain rate vs load for the 20°C product family data.

It can be seen that there is now a clear change in performance as the load increases above 55% of "Standard". Below that level the Strain Rate gradually increases to 1% per log. decade of time. Above that level the rate very rapidly increases. This can therefore be considered to be a load at which there is a critical change in creep performance of the product family. If this change is representative of the Creep Limited Strength of the product then:

$$T_{BlotJ} = 42.6 \text{ kN/m} \quad (3)$$

This value for the Creep Limited Strength is not time-dependant.

3.3 *Determination of a representative T_B for the product*

Depending on the protocol followed there are various reduction factors that may or may not be applied to T_{Blot}. Particular examples are:

3.3.1 *GRI-GG4 or PWRC 1997*

No corrections are called for. It is assumed that the batch of product tested is typical of the product.

3.3.2 *BS 8006 or WSDOT T925*

T_{Blot} is reduced proportionately by the difference between the strength of the lot of product tested and the manufacturer's minimum strength specification or MARV. For the product tested for this analysis the manufacturer's minimum strength specification is T_{C95} from Table 2, therefore in this case, for a lot with the mean strength of 99.9 kN/m, the Reduction Factor, called here R_{lot}, is given by:

$$R_{lot} = T_{maxlot}/T_{specification} = 1.049 \quad (4)$$

3.3.3 *Wrigley et al. 2004*

A particularly cautious approach applied by some manufacturers and researchers is to apply 2 further Reduction Factors. One, R_{95}, is based on the lower 95% Confidence Limit for the mean line of Figure 5.

Table 3. Comparison of creep limited strengths and reduction factors.

Protocol	R_{lot}	R_{95}	R_{Batch}	T_{C95}	T_{B120}	T_{B75}	f_{cr120}	f_{cr75}
PWRC				73.8	42.6	42.6	1.73	1.73
GRI-GG4				90.2	40.6	41.2	2.22	2.19
WSDOT T95	x			90.2	38.7	39.3	2.33	2.30
BS8006	x			95.2	38.7	39.3	2.46	2.42
Wrigley et al.	x	x	x	95.2	36.4	36.9	2.62	2.58

The other, $R_{batch,}$ allows for the variation found in f_{cr} from batch to batch after applying R_{lot} and R_{95}.

From the data used to generate Figure 5 it was calculated that for the batch tested:

$$R_{95} = 1.037 \qquad (5)$$

$$R_{Batch} = 1.026 \qquad (6)$$

3.3.4 *Application of the reduction factors*

Table 3 shows which of the Reduction factors are applied in the above protocols, the resulting values for 120 and 75 year values of T_B and the Creep Reduction Factor, f_{cr}, to get to these values of T_B from the appropriate T_{C95} of Table 2.

4 CONCLUSIONS

4.1 *Japanese determination of creep limited strength*

The very close correlation between the Japanese and Western approaches to determining the Creep Limited Strength of an HDPE geogrid is most interesting. The concept that these products have a critical load below which long-term creep is limited should be studied further. It is possible that this phenomenon explains why there have been no reported successes in using the SIM protocol to predict the long-term failure of HDPE geogrids

4.2 *Variation in creep limited strength*

The range seen in Table 4 for the values of T_B derived by the four western protocols studied is confusing and inappropriate. As these are engineering materials we recommend that an adjustment, $R_{lot,}$ should be made to correct experimental values to Minimum Specification or MARV values as in BS 8006 and WSDOT T925, but that no further adjustment is needed.

4.3 *The use of creep reduction factors*

The Index Strength and Creep-Limited Strength of a product are independent properties of that product. Each varies only with the terms of a single test protocol.

In contrast, a Creep Reduction Factor depends on the terms of two independent test protocols and it cannot be considered to be an independent property of a product.

Therefore, we believe that the concept of a "Creep Reduction Factor" is flawed and misleading. The wide range of values we have shown for this factor can lead to mistakes in design that could have very serious consequences.

We would recommend that the Creep-Limited Strength of a product should be used as the independent property in specification and design.

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