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Report

The Creep-Limited Strength

of

E'GRID 50-170R

Based on 10,000+hr. Testing

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For: **BOSTD (Qingdao) Geosynthetics Company Ltd.**

1: Background:

During 2005/6, creep testing of the product range known as E'GRID xxxR extended beyond 10,000 hours. With the extended test duration data the creep performance of these products has been re-examined and appropriate revisions made to their Ultimate Creep Limit Strengths (UCLS) to meet market needs and appropriate Quality Control Limit Strengths (QCLS) have been set.

The tests were carried out in accordance with the methodology of ISO13431. A total of 281 individual samples were tested. Of these, 75 were at loads that produced data useable determining the UCLS's. The remainder were used to analyse the Isochronous Performance of the products. 9 tests had durations of 10,000hours or more.

The objectives of this testing were to:

- determine the Ultimate Creep Limited Strengths (UCLS) of the individual products at temperatures of 10-30^{O}C and lives of 75-120 years.

- determine the Isochronous performance of these products

2: Definition of "Ultimate Limit":

Initially, the plan was to take all samples to rupture. However, this proved to not be feasible. As with previous testing of E'GRID products, it was found that most of the samples of this range strained to beyond 20% with just 17 samples failing below 20%. Therefore, the remaining tests were terminated after passing 20% strain and it was decided that for this testing the definition of "Ultimate Limit" for a sample would be defined as the time to 20% strain, or the time to rupture or termination, whichever was the shorter. The performance of any reinforcing product at strains greater than this is of no interest to a geotechnical engineer.

This definition forms the basis of this report and the determination of the UCLS and QCLS for each of the products.

3: Testing:

The tests were carried out in 3 separate temperature-controlled laboratories at temperatures of 20^{0}C, 40^{0}C and 50^{0}C, all controlled within ±1degC. 5 of the test stations used are shown in Fig.1.

Fig. 1: Creep tests in progress at 20^{0}C

These test stations are designed for ease of use. The creep load is a dead weight hanging directly on the sample. The gauge-length of each sample is the centre 3 pitches of the grid. This gives initial gauge lengths of approximately 750mm.

4: Test Results:

The results of the tests plotted as Strain vs. Log(Time) are shown in Figures 2-6 (Attached after the text of this report). Five different products were tested: E'GRID 50R, 65R. 90R, 130R and 170R in order of increasing thickness. These products were all manufactured from the same polymer recipe and manufacturing process, including the shape, size and pitches of the holes punched prior to stretching. The only applied difference between individual products being the thickness of the starting sheet used.

5: Determination of Ultimate Creep-Limited Strengths

The analysis process from Creep Data to Ultimate Creep-Limited Strength (UCLS) and appropriate Quality Control Limit Strength (QCLS) for the new products consists of 5 stages:

1: Determination of Time-Shift Factors for each product:

In this stage each product is treated separately. Block-shift factors are applied to the individual test times at 40^0C and 50^0C to obtain equivalent 20^0C times for these tests.

The optimum shift factors are determined by obtaining a straight-line plot of Log(test load) vs. Log(test time) with a minimum deviation of the test points from the line of this plot.

2: Determination and application of mean shift factors.

During Stage 1 the shift factors determined will not be exactly the same for each product. This is one of the manifestations of differences between different batches of product. This difference is then taken account of by averaging the individual shift factors and then re-analysing and plotting the creep data using the mean shift factors.

3: Normalisation:

In order to integrate the data from the different products it must be normalised.

Previous testing of these products had shown that their UCLS is closely related to their index strength as measured in accordance with ISO 10319. The individual test loads can therefore be normalised by dividing them by this index strength. These normalised loads can then form the basis of an integrated plot of Log(Normalised Load) against Log(Time) with a best-fit straight-line drawn through them.

4: Determination of the UCLS's and appropriate QCLS's of the product range:

Based on the relationship established in Stage 3, appropriate values for 20^OC UCLS's at different design lives and QCLS's can be calculated.

5: Determination of the UCLS's at different design temperatures:

From a plot of the shift factors from Stage 2 appropriate shift factors relative to 20^0C for 10^OC and 30^OC can be determined. With these, plots of Normalised Load against Log(Time) for the different temperatures can be drawn and adjustment factors for UCLS's calculated.

These stages were applied to the data of this study as follows:

5.1: Determination of Time-Shift factors for Each Product:

First, the data for each sample was plotted as Log(load) vs. Log(Time to failure or 20%) as illustrated in Figure 7

Then, the data for 40^{0}C and 50^{0}C was shifted to the right until a best-fit straight line through all points may be plotted, as also illustrated in Figure 7.

In Figure 7 the best-fit straight trend line through the shifted points is shown for each product. The selection of optimum shift factors to give best-fit trend lines was based on two criteria:

A: To maximise the R^2 value for the trend line

B: To give a good fit of points where data from two different temperatures overlapped

The application of the "common-sense" process B is perhaps more important in such an exercise than the purely mathematical process A

5.2: Determination and Application of Mean Shift Factors:

From the analyses of Stage 1 the shift factors shown in Table 1 were determined.

Product	Shift Factors	
	20-40^{o}C	40-50^{o}C
E'GRID 170RB	820	22
E'GRID 130RB	820	25
E'GRID 90RB	820	17
E'GRID 65RB	500	17
E'GRID 50RB	820	30
Mean Shift Factors	756	22.2

Table 1: Temperature Shift Factors

At the foot of Table 1 is shown the mean of the individual shift factors. These means were then used to re-analyse and plot the creep data for each product as illustrated in Figure 8.

5.3: Normalisation and determination of 95% Confidence Limits:

From Tests carried out prior to the start of creep testing, the Index strength of each product sample used in these creep tests in accordance with ISO 10319 at 20^{O}C is shown in Table 2:

Product	Index Strength kN/m
E'GRID 170RB	181.7
E'GRID 130RB	140.9
E'GRID 90RB	90.8
E'GRID 65RB	79.4
E'GRID 50RB	69.4

Table 2: Individual Product Index Strengths

These figures were used as the basis of the normalisation of all the data for the different products.

The five individual plots of Figure 8 were brought together by dividing each individual test load by the appropriate Index Strength. Then this normalised data was plotted as Log(Normalised Load) against Log(Time) to give Figure 9. As with the individual plots, the best fit straight line was then plotted through the data.

5.4: Determination of the UCLS's and appropriate QCLS's of the product range:

It can be seen from Figure 9 that the relationship between Normalised Load (L_N) and Log(T) is given by:

$$\mathrm{Log}(L_N) = -0.2027 - 0.0321\ \mathrm{Log}(T) \qquad (1)$$

Now: $$L_N = \mathrm{UCLS/QCLS} \qquad (2)$$

From equations (1) and (2) the relationships between the UCLS and QCLS for a product at 20^{O}C and different design lives were calculated as shown in Table 3

Design Life	75 Years	100 Years	120 Years
	$10^{5.817}$ Hours	$10^{5.943}$ Hours	$10^{6.022}$ Hours
UCLS/QCLS	0.4079	0.4041	0.4018

Table 3: Relationship between UCLS and QCLS at 20^{O}C

From the figures of Table 3 and marketing considerations the specification UCLS and QCLS figures for each product in the range were set as shown in Table 4:

Product	QCLS ISO 10319 @ $20^{O}C$ kN/m	UCLS @ $20^{O}C$		
		75 Years kN/m	100 Years kN/m	120 Years kN/m
E'GRID 170R	170.0	69.3	68.7	68.3
E'GRID 150R	162.0	66.1	65.5	65.0
E'GRID 130R	141.9	57.9	57.3	57.0
E'GRID 110R	112.0	45.7	45.3	45.0
E'GRID 90R	90.0	36.7	36.4	36.2
E'GRID 65R	68.7	28.0	27.8	27.6
E'GRID 50R	54.0	22.0	21.8	21.7

Table 4: Specification UCLS and QCLS for each product @ $20^{O}C$

In this table there are 7 products, compared to the 5 that were tested. This because products with a strength intermediate between E'GRID 90R and E'GRID 130R and E'GRID 130R and 170R are now required for the market. As these products lie within the range of the actual products tested it is safe to apply the relationship of UCLS to QCLS of Table 3 to the properties of these products.

5.5: Determination of the UCLS's at different design temperatures:

In Figure 10 the Logarithm of the Mean Shift Factors from Table 1, referred to $20^{O}C$, are plotted against Temperature. As can be seen these give a very close fit to a straight line plot. From the formula for this line:

$$\text{Log(Shift Factor)} = 0.1413\text{xTemperature} - 2.8122 \qquad (3)$$

From Equation (3):

$$\text{The Log(Shift Factor) for a change of } \pm 10\text{degC} = \pm 1.413 \qquad (4)$$

If this ± Shift Factor is applied to the mean plot of Figure 9 this generates mean plots for the performance of the products at $10^{O}C$ and $30^{O}C$ as shown in Figure 10 on either side of the plot for $20^{O}C$. These new plots are displaced vertically from the $20^{O}C$ plot by a factor of ±0.0454 on the Log(Normalised Load) scale. This means that at any given design life:

$$UCLS_{30degC} = UCLS_{20degC}/1.1102 \qquad (5)$$

and:

$$UCLS_{10degC} = UCLS_{20degC}*1.1102 \qquad (6)$$

From the relationships of equations (5) and (6) and the figures of Table 4, the figures in Table 5 for the 120-year UCLS's of the products at $10^{O}C$ and $30^{O}C$ were derived:

Product	UCLS @ 120 Years		
	$10^{O}C$ kN/m	$20^{O}C$ kN/m	$30^{O}C$ kN/m
E'GRID 170R	75.8	68.3	61.5
E'GRID 150R	72.2	65.0	58.5
E'GRID 130R	63.3	57.0	51.3
E'GRID 110R	49.9	45.0	40.5
E'GRID 90R	40.2	36.2	32.6
E'GRID 65R	30.6	27.6	24.8
E'GRID 50R	24.1	21.7	19.5

Table 5: 120-year UCLS at Different Temperatures

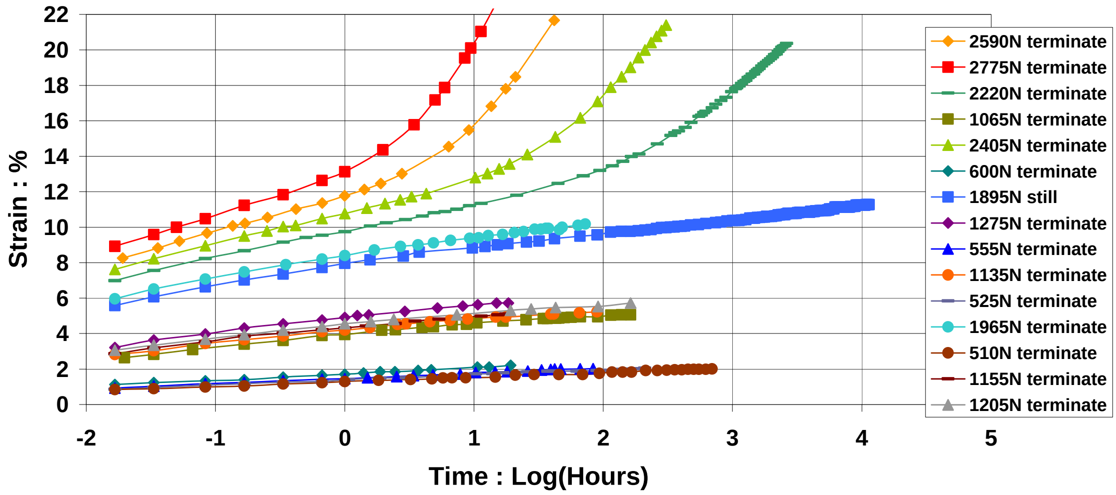
6: Isochronous Behaviour of the Products

The above determinations provide the data for product Ultimate Creep Limited Strength needed for Limit State design. However, in some circumstances it is necessary to understand the behaviour of the product under the lower load actual working conditions in a reinforced soil structure. For example: It can be desirable to limit the strain that will occur after construction is completed in critical structures such as bridge abutments.

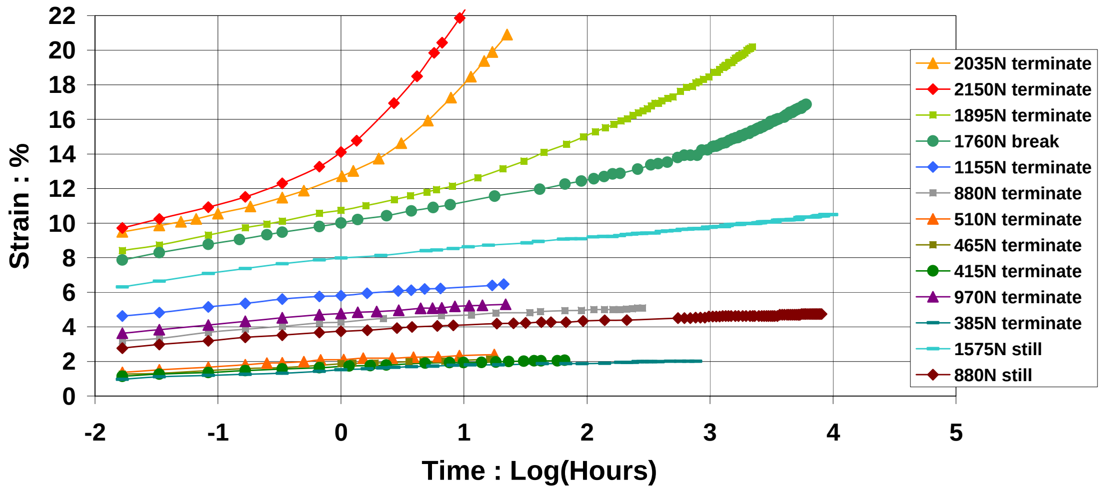
To provide the information needed for such understanding the isochronous behaviour of the products at various times of loading from a few weeks to 100 years or more must be determined.

This is achieved by considering the data from all the creep tests carried out on the products, including those that did not reach rupture or 20% strain during testing. This data is analysed to provide information on the time it takes to reach various strain levels at different load levels.

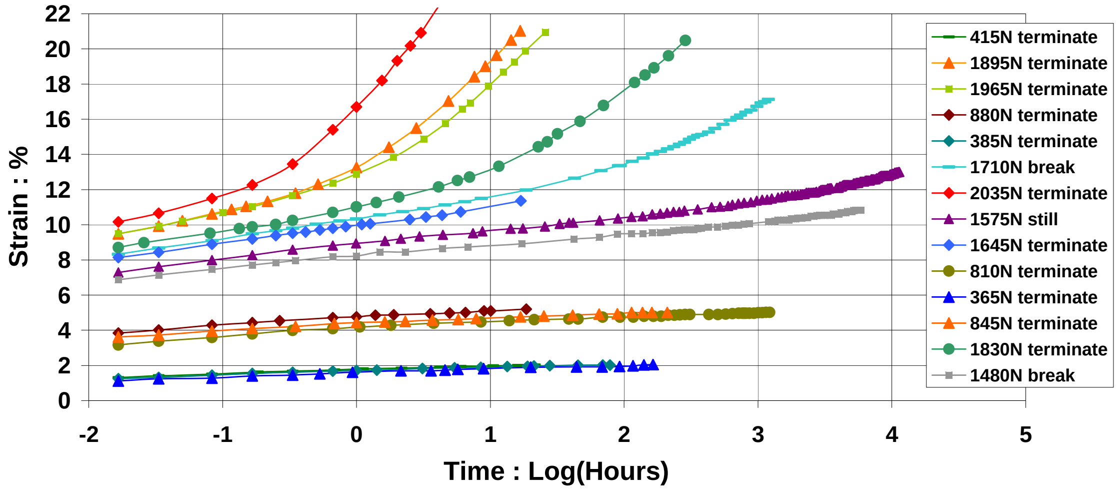
For the analysis of this report strain levels of 2%, 5%, 10% and 20%/rupture were considered. The creep data plotted in figures 2-6 were analysed for each strain level, as described in section 5 above. This resulted in the plots of Figure 12. From Figure 12 data was derived for the loads required to generate the various strain levels at times of 10, 100, 1,000, 10,000, 100,000 and 1,000,000 hours. This data was then used to generate the Isochronous plots of Figure 13. These plots can now be used to understand the behaviour of the products and reinforced soil structures during and after construction.



A: E'GRID 50R @ 20degC

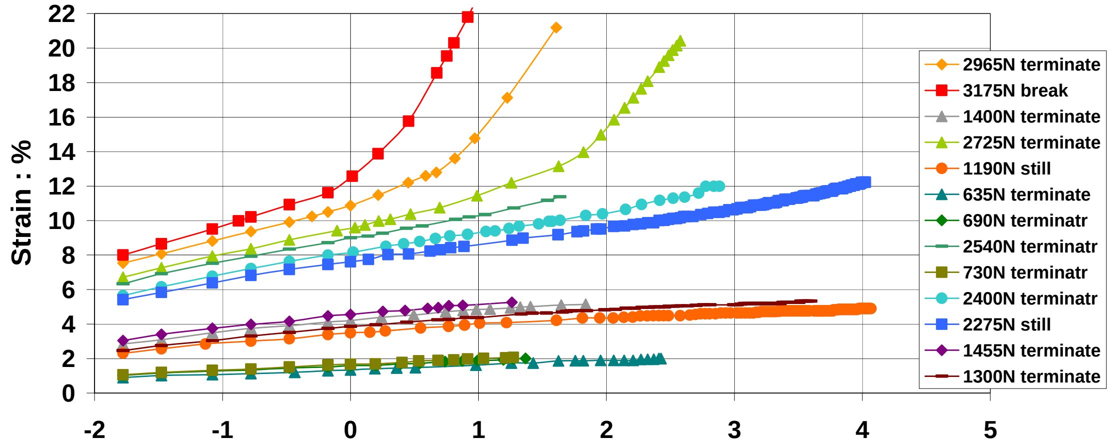


B: E'GRID 50R @ 40degC

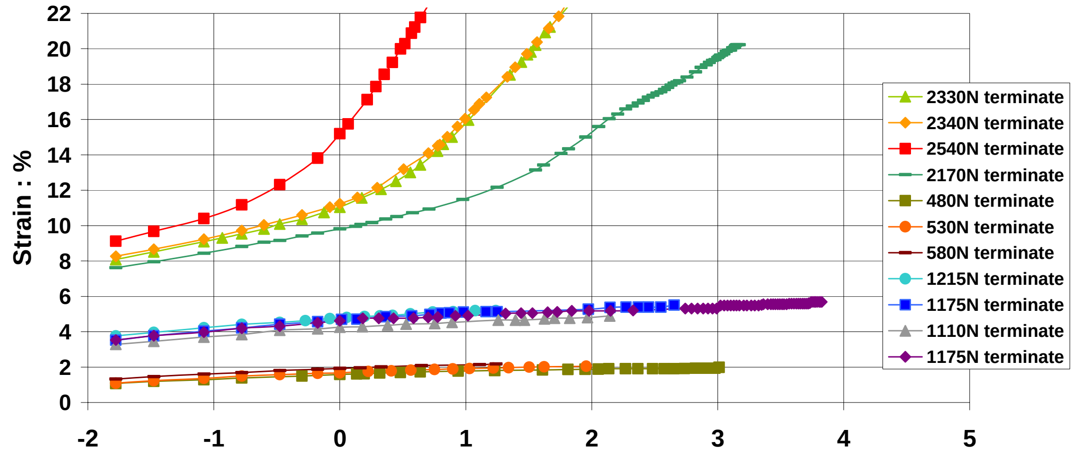


C: E'GRID 50R @ 50degC

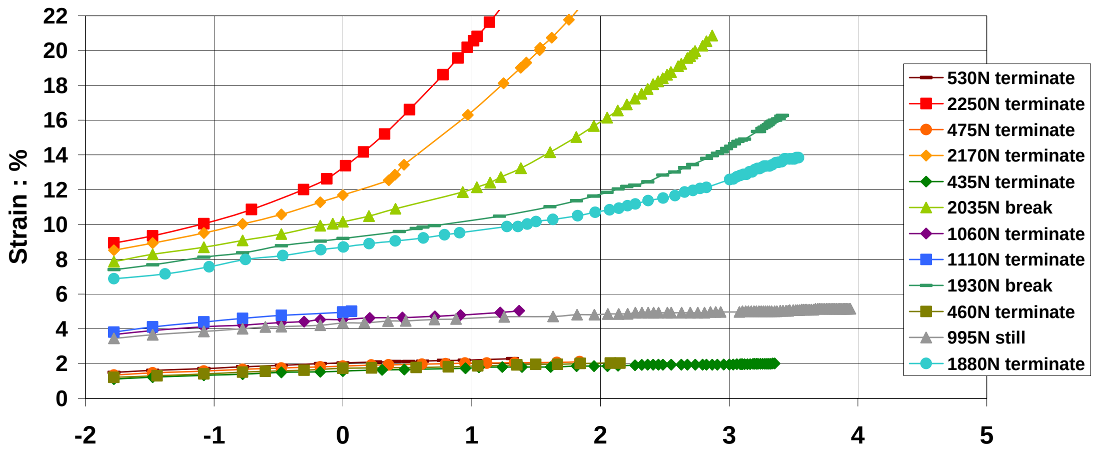
Figure 2 : E’GRID 50R Creep Test Results



A: E'GRID 65R @ 20degC

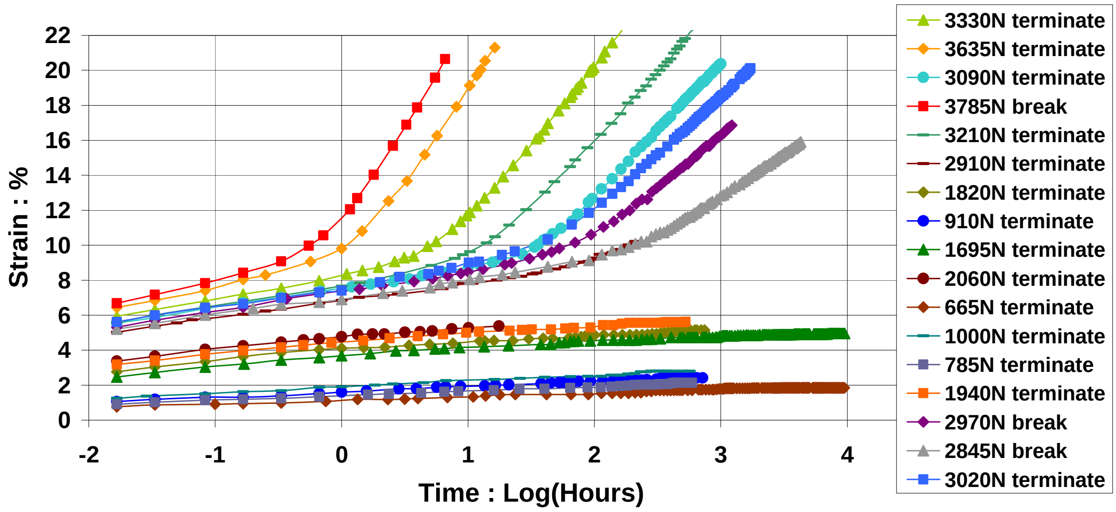


B: E'GRID 65R @ 40degC

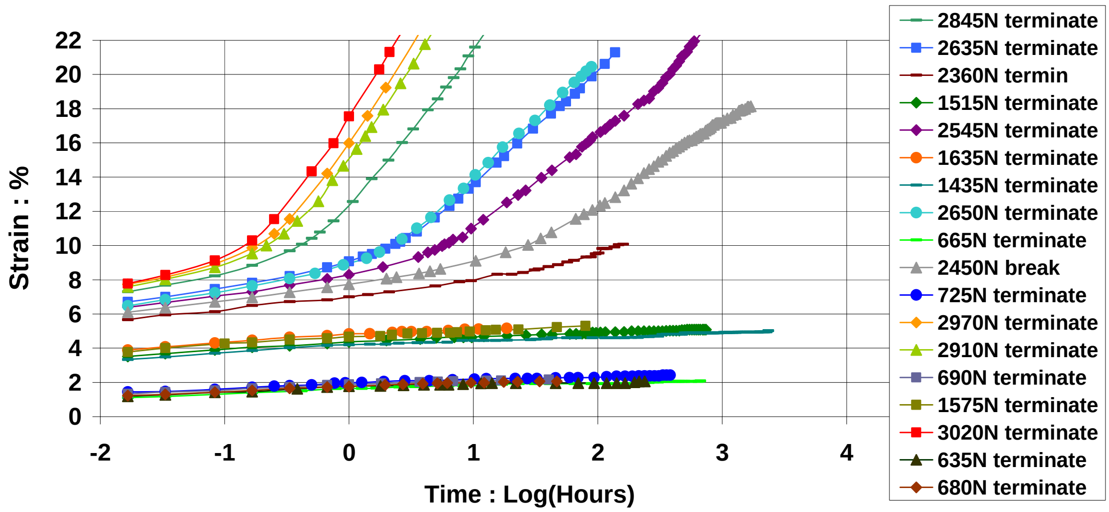


C: E'GRID 65R @ 50degC

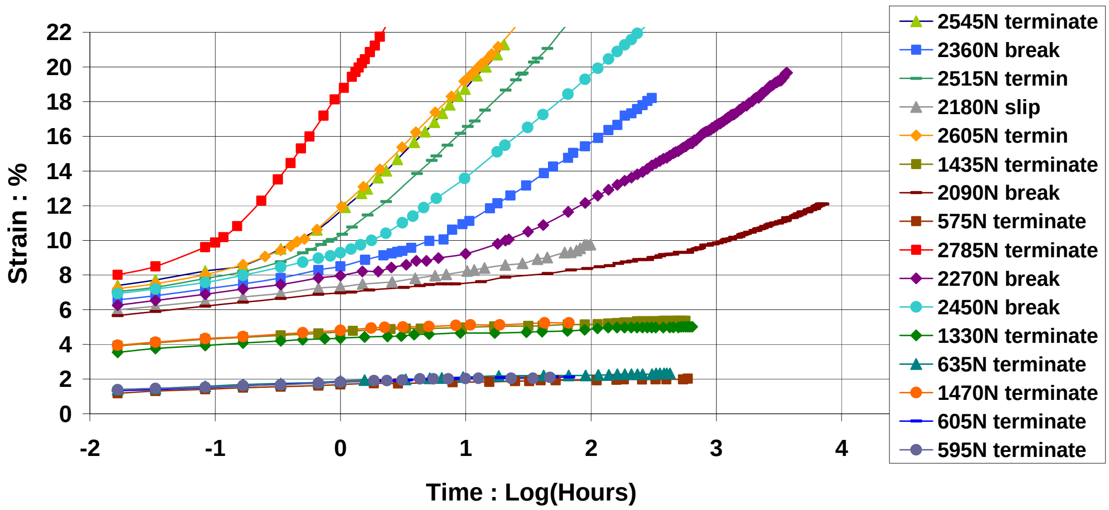
Figure 3 : E'GRID 65R Creep Test Results



A: E'GRID 90R @ 20degC

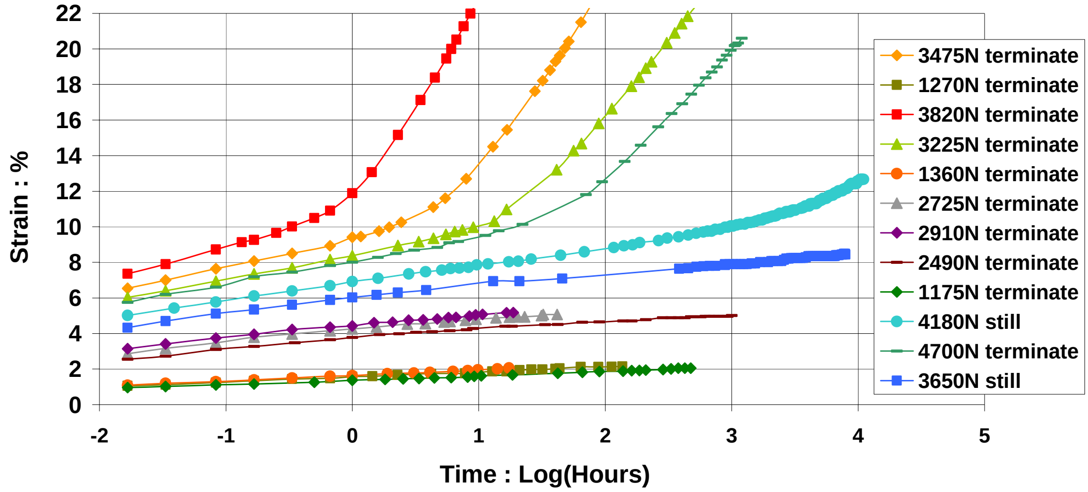


B: E'GRID 90R @ 40degC

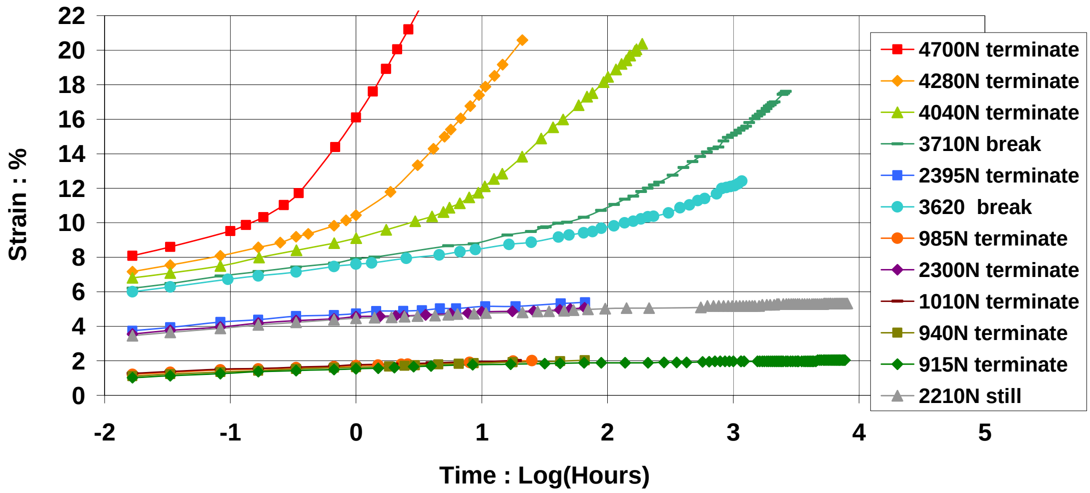


C: E'GRID 90R @ 50degC

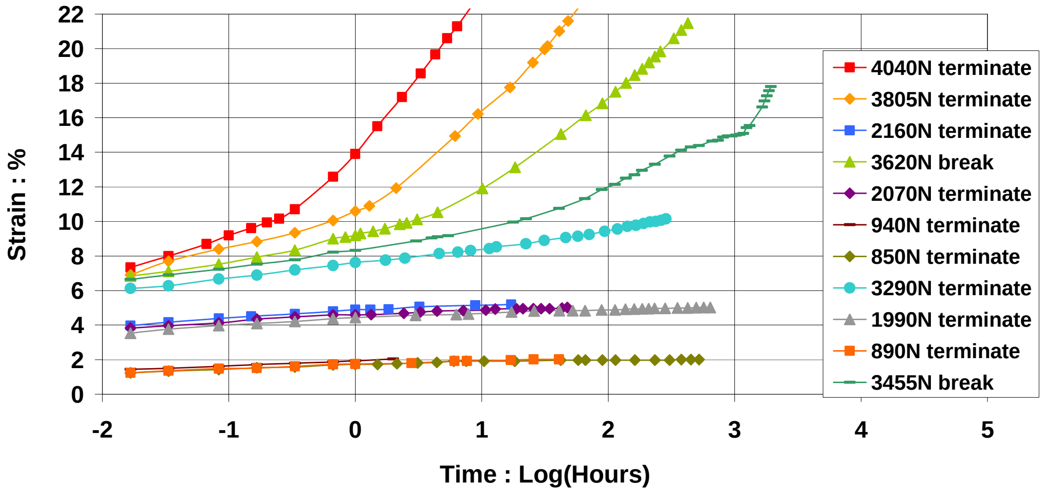
Figure 4 : E'GRID 90R Creep Test Results



A: E'GRID 130R @ 20degC

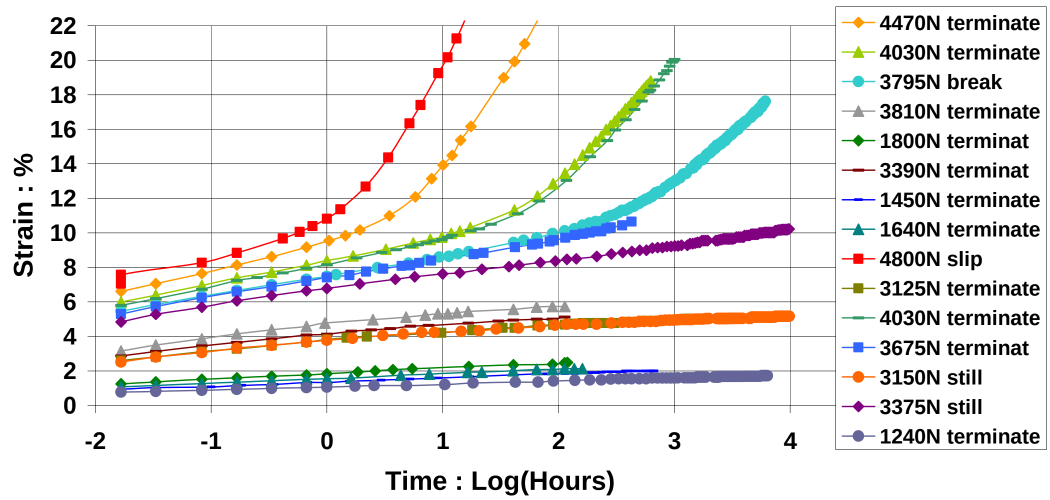


B: E'GRID 130R @ 40degC

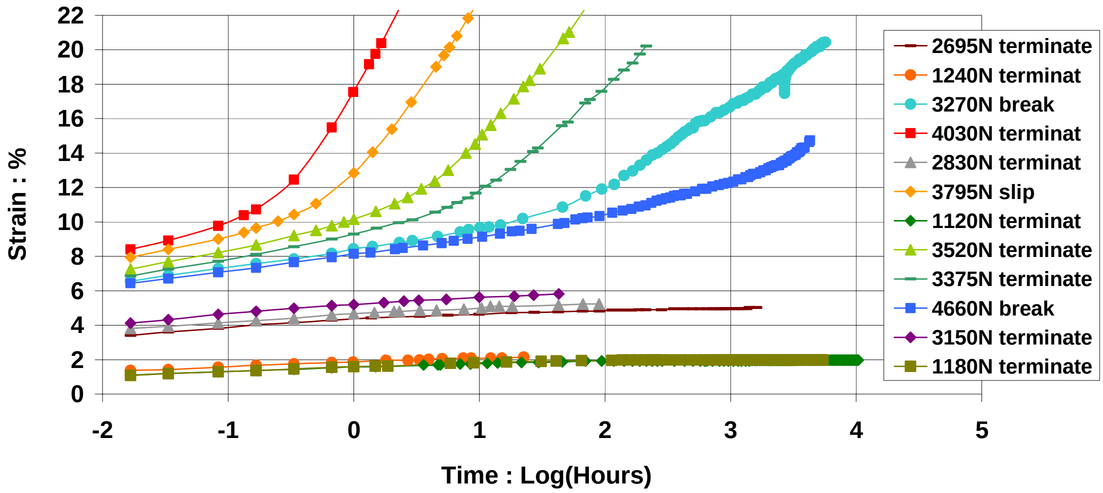


C: E'GRID 130R @ 50degC

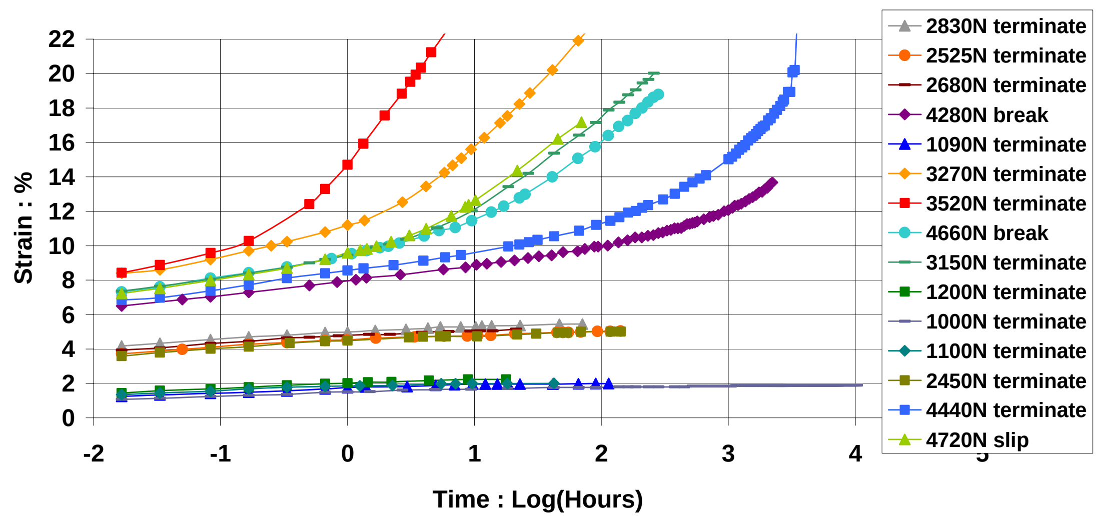
Figure 5 : E'GRID 130R : Creep Test Results



A: E'GRID 170R @ 20degC

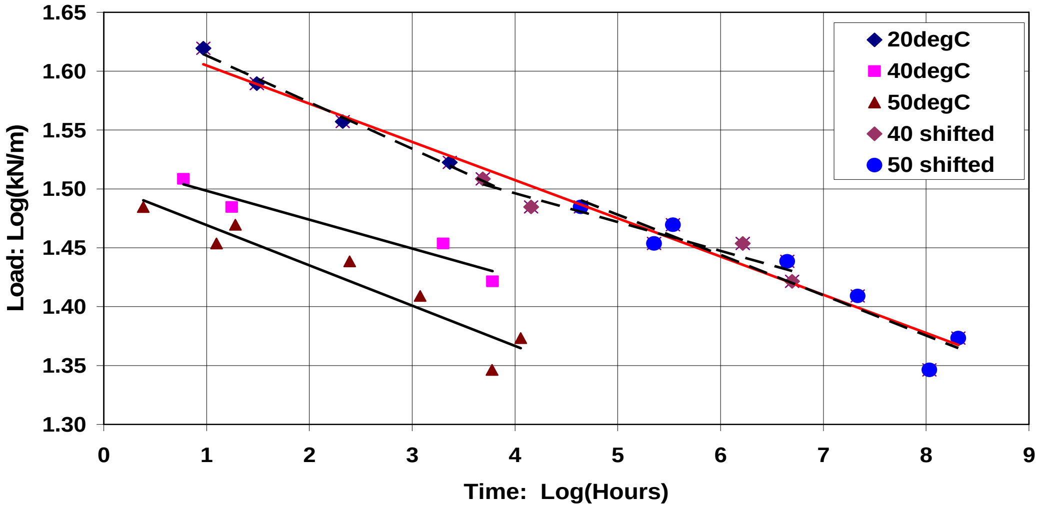


B: E'GRID 170R @ 40degC

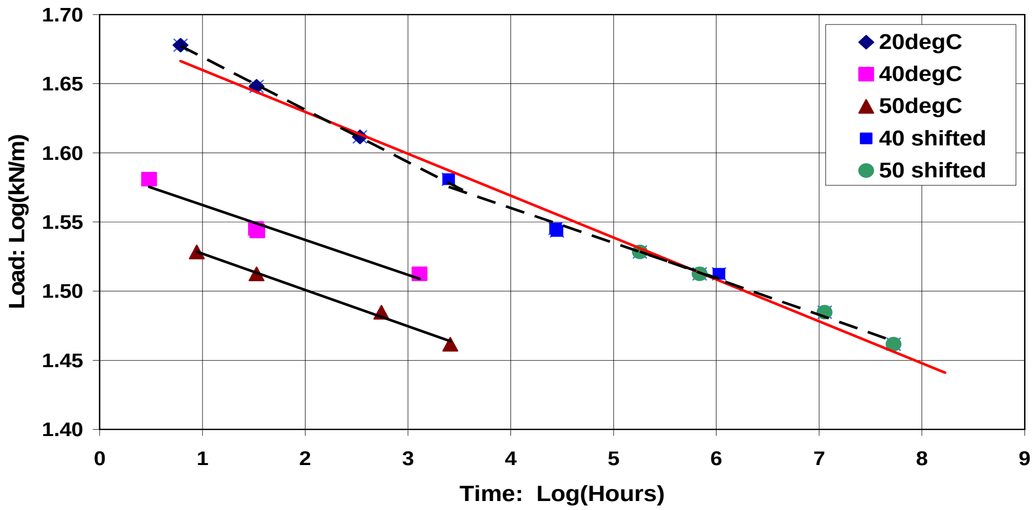


C: E'GRID 170R @ 50degC

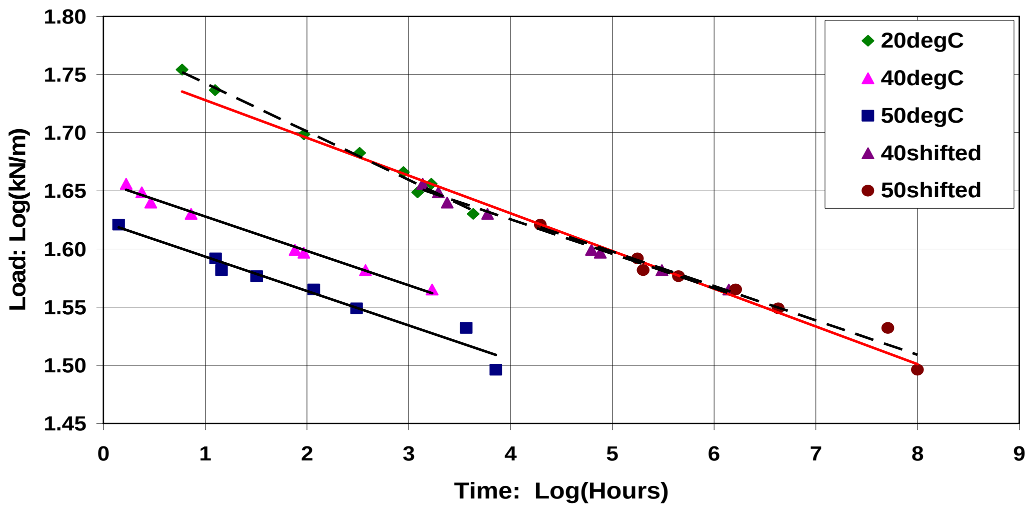
Figure 6 : E'GRID 170R : Creep Test Results



A: E'GRID 50R

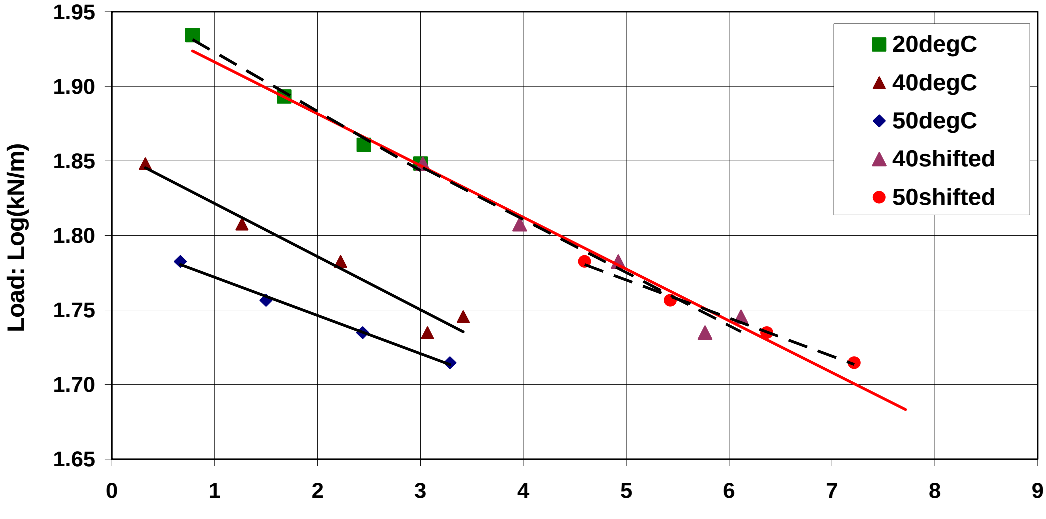


B: E'GRID 65R

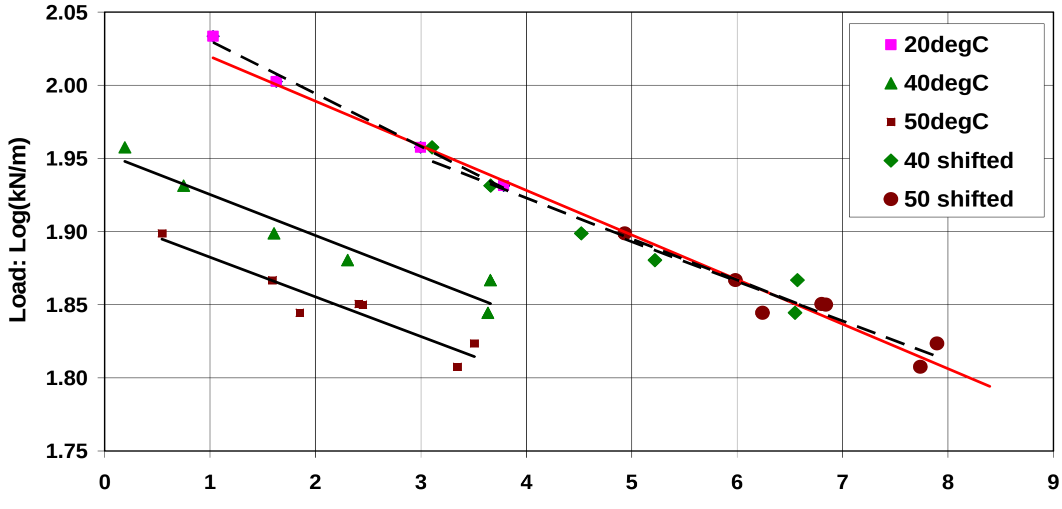


C: E'GRID 90R

Figure 7 : Time Shifting : Individual Products



D: E'GRID 130R



E: E'GRID 170R

Figure 7 cont : Time Shifting : Individual Products

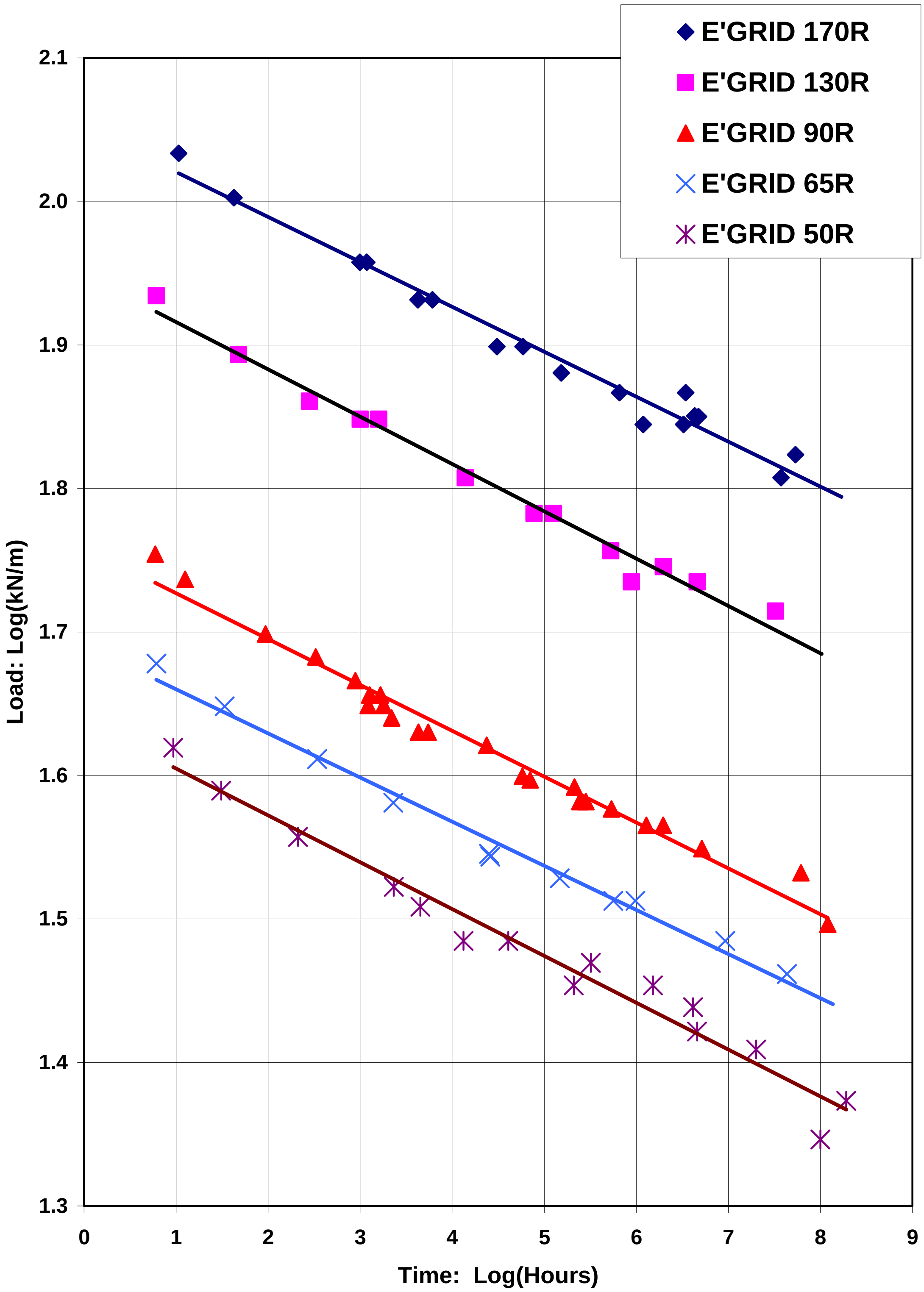


Figure 8 : **All Products : Time to Rupture/20% after Time-Shifting by Mean Time Shift Factors**

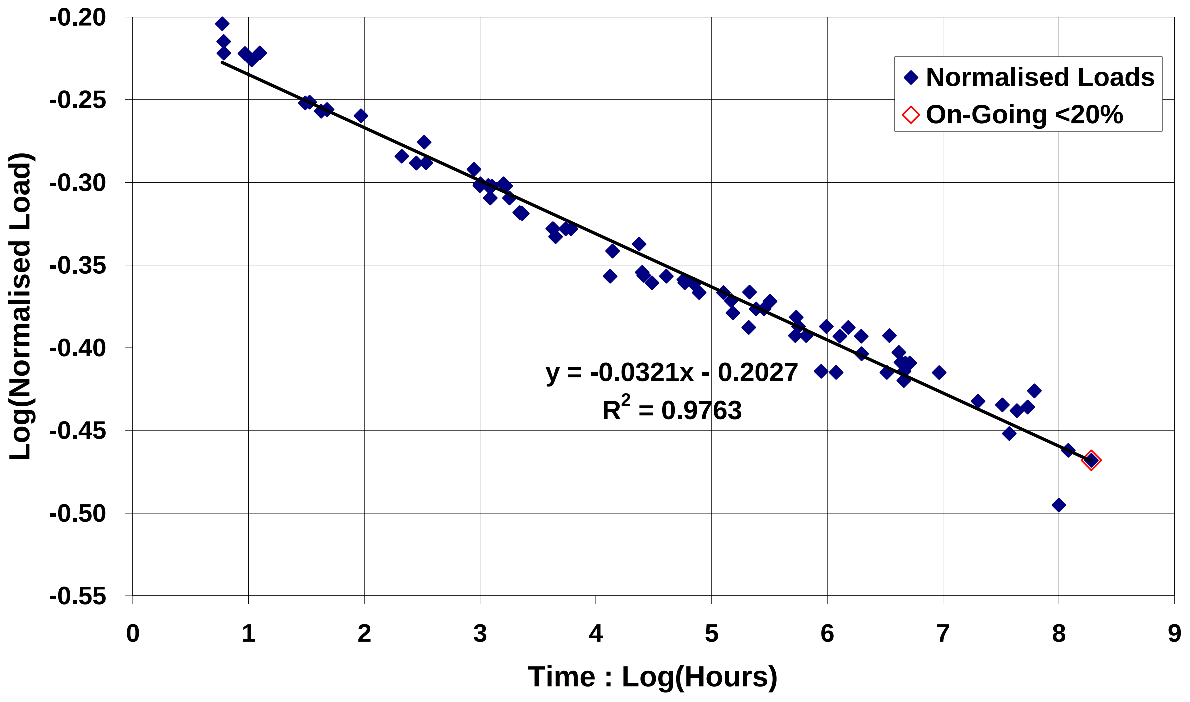


Figure 9 : All Products : Normalised Loads to Rupture/20% @ 20^{O}C

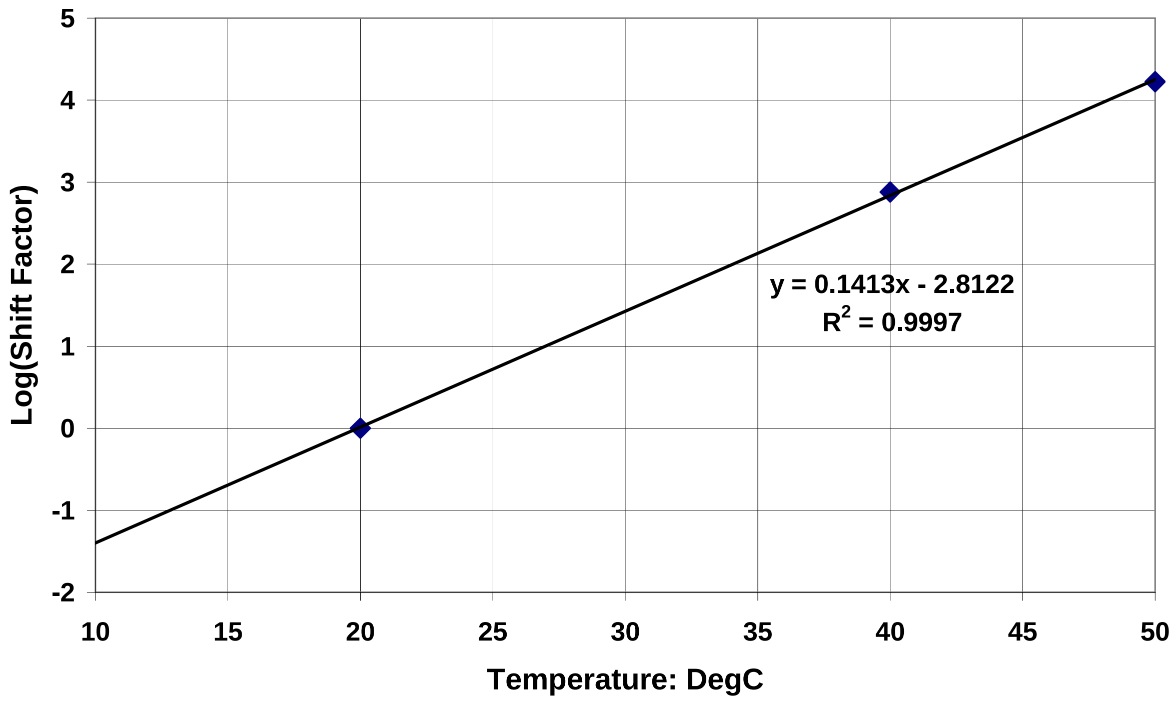


Figure 10: Shift Factors from 20^{O}C

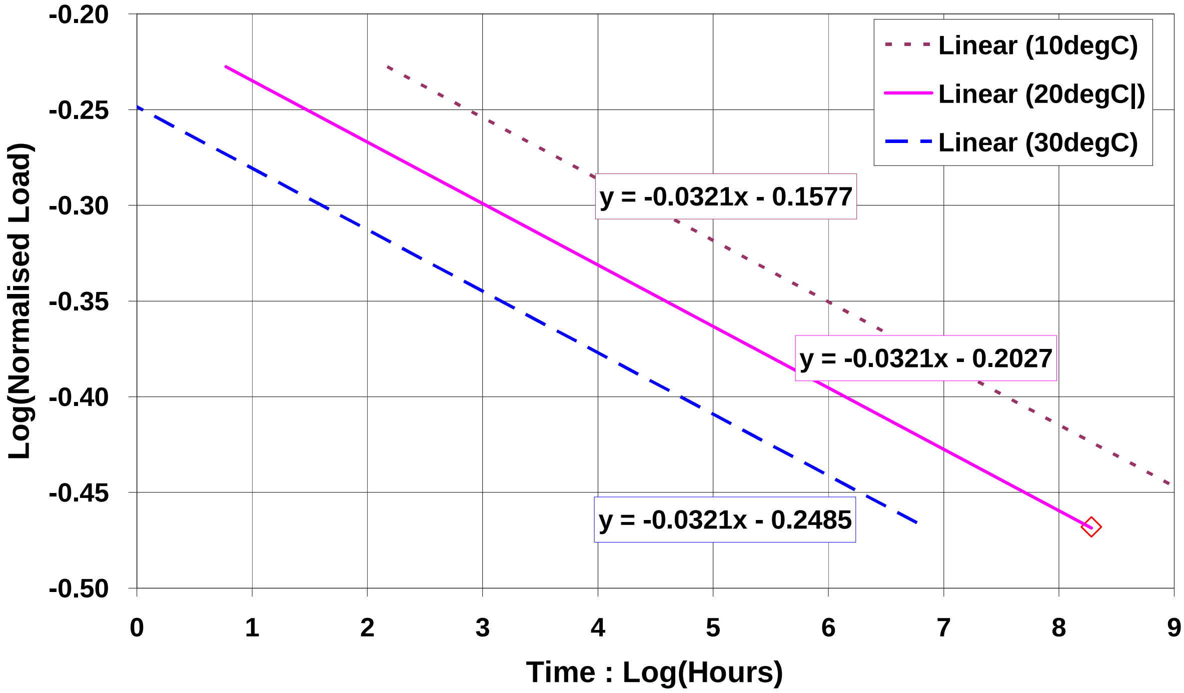


Figure 11 : All Products : Normalised Loads to Rupture/20% @ 10^{O}C, 20^{O}C, 30^{O}C

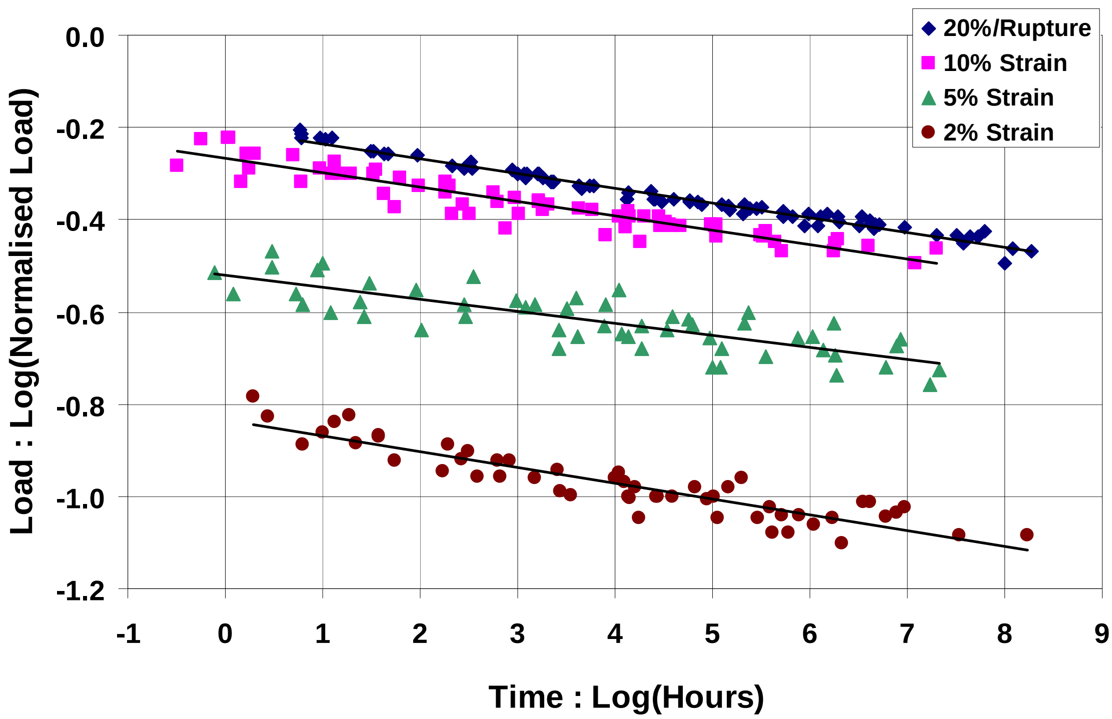


Figure 12: Loads Needed to generate Various Strain Levels

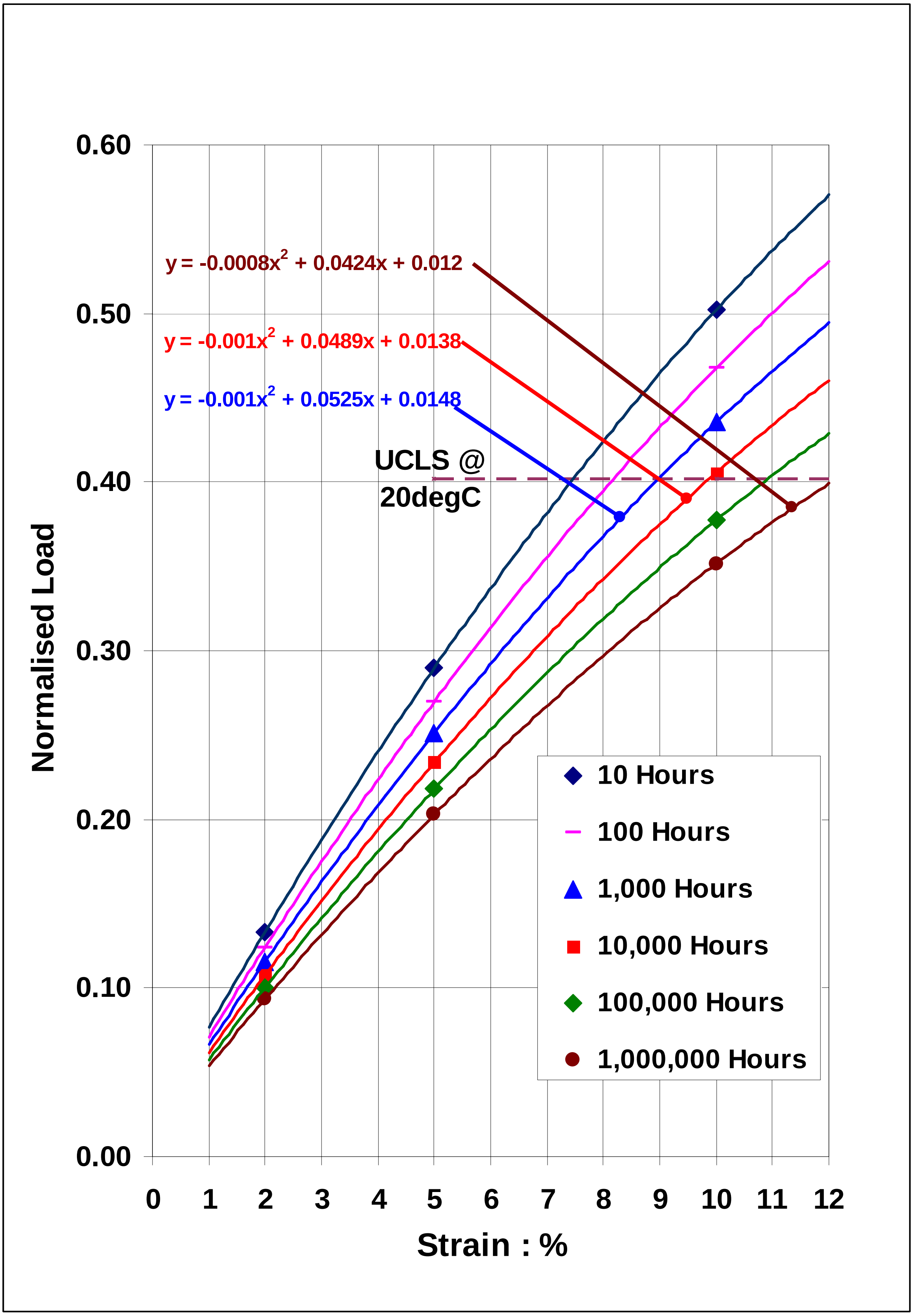


Figure 13: Isochronous Behaviour of the Products