MEASURING CREEP OF DRAINAGE MATERIALS BY MEANS OF THE STEPPED ISOTHERMAL METHOD IN COMPRESSION

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Abstract: Measurement of the creep of reinforcing geotextiles in tension by means of the stepped isothermal method is now an established technique. Predictions can be made of the strain to be expected over a lifetime of typically 100 years. The measurement of creep of drainage materials in compression is equally important in practice, as a reduction in thickness due to creep can significantly reduce their drainage capability. The stepped isothermal method is more difficult to apply in compression because of the small strains and the greater thermal mass of the specimen and the loading platens.

This paper describes the method of testing and the results of tests on cuspated drainage geosynthetics. It indicates the improvements that were made in the course of testing and highlights which of the changes proved the most significant, particularly direct strain measurement and the use of heated platens. Surprisingly, some of the modifications changed the thermal shift factors and with them the predicted strains at long lifetimes.

Following publication of ASTM D7361-07 interlaboratory trials are recommended to establish the level of reproducibility between laboratories and to identify any further reasons for differences between them.

Keywords: cuspated drainage sheet, compressive creep, drainage, flow capacity, lifetime prediction, durability

INTRODUCTION

Geosynthetics for drainage purposes consist of two parallel sheets of nonwoven geotextile separated by an openwork structure. Water from the soil that penetrates the nonwoven sheets can then flow laterally along the openwork structure until it is removed by a pipe or drain. The soil is generally subject to pressure which will in turn compress the drainage geosynthetic. If this leads to a permanent reduction in thickness the drainage effectiveness of the geosynthetic will be reduced.

The openwork structure of these drainage composites consists predominantly of an extruded thermoplastic sheet within which is a regular pattern of truncated cones projecting from one side, otherwise known as a single cuspated core. Under load, thermoplastics deform first elastically and then slowly with time, a process known as creep. This can be measured by placing a square of drainage geosynthetic between two parallel steel plates, applying a static load to the plates and measuring the change in thickness, a method standardised as prEN ISO 25619-1. Tests last typically 1000 h or six weeks.

The lifetime of a drainage geosynthetic can be many years; if its location in a soil structure, such as a road embankment, prevents it from being replaced in service, then it must perform for as long as the road is in service, typically 100 years. Current practice is to extrapolate the results of creep tests by no more than ten times without supporting evidence, i.e. from six to sixty weeks. The additional supporting evidence consists of accelerated tests which are generally performed at higher temperature. The creep characteristic at the higher temperature is then matched to form a longer-term extension to the creep curve. This procedure, known as time-temperature shifting, is well established both for thermoplastics and geotextiles.

For geotextiles in tension problems can arise when accelerated creep curves measured on different specimens have to be shifted in this way, as the variability in initial strains can make the shifting process more difficult and lead to uncertainty in the prediction of strain. To avoid this problem the stepped isothermal method (SIM) was developed by Thornton and co-workers (1998a, 1998b). In SIM a single specimen is loaded in tension and the temperature is then raised in small steps. The sections of creep curve generated at each temperature are then shifted to form a single master curve, which forms a prediction of the creep behaviour at room temperature. This procedure has now been standardised as ASTM D6992-03.

The same procedure can in principle be applied to drainage geosynthetics in compression (Narejo and Allen 2004, Zanzinger 2008). In these materials the creep is almost entirely due to compression of the core. Obvious problems are that measurement of the change in thickness has to be more sensitive than in tension due to the small gauge length, and that the thermal mass is much greater. It is therefore more difficult to achieve a rapid change in temperature across the whole cross-section of the specimen. Less obvious is that time should elapse between the forming of the openwork structure and the measurement of creep, since newly formed thermoplastics undergo a process called physical ageing, a slow approach to a thermodynamically stable structure, which reduces the tendency to creep. These problems were addressed during tests on a range of drainage geosynthetics.

Since the work was completed ASTM D7361-07 has been published. This paper states the differences between the method used and this new standard, and points out the parameters which our experience has shown to be critical. All strains reported are total compressive strains taken from the point at which the preload was applied.

DRAINAGE MATERIALS TESTED

The drainage geosynthetics were of European origin and manufactured in HDPE. The nominal thicknesses were 4, 6 and 7 mm and all were single cuspates with the addition of one 7 mm thick double cuspate. All had been stored following manufacture. The range of pressures applied during the tests was compatible with the working compressive strength of the drainage geocomposites. It should be noted that the working compressive strength of any drainage geosynthetic is significantly lower than its ultimate short-term compressive strength.

COMPRESSIVE CREEP TESTS

The first series of SIM tests was performed on Material 4S250. The specimens were squares 100 × 100 mm corresponding to 225 nodes. In view of the small initial thickness of 4.7 mm, of which the core comprised 3.5 mm, two specimens were stacked together with a steel plate between them to improve the strain sensitivity. In some cases these specimens were deliberately matched such that the combined mass of each pair lay within a narrow band; heavy specimens were paired with light ones and vice versa. This should have reduced the variability in measurement. Extension was determined initially from the movement of the crosshead, after subtracting the machine characteristic measured in a control test with no specimen present.

The tests were performed in a servohydraulic machine that maintained a constant load by means of continuous feedback. This led to a fluctuation in load. Measured on the crosshead, there was a variation of approximately 0.5% strain, but the large number of measurement points meant that a mean curve could easily be obtained. A preload of typically 1-2% of the test load was applied at the start of each test and the strain was zeroed with this preload applied. The temperature of the environment surrounding the test was controlled to within ± 2 ºC, although regular monitoring showed that the temperature was generally within ± 1 ºC. The relative humidity of the surroundings was 50 ± 5 %.

The temperature was raised by 10 ºC every 3 h except overnight when the step duration was 16 h. This does not invalidate the procedure. At a temperature step the temperature generally changed to within ± 1 ºC of the new set point within 1 minute. The maximum temperature was 60 ºC, experience having shown that the creep of HDPE increases excessively above this temperature and is not representative of long-term performance. The method followed ASTM D6992 as far as possible, with necessary variations to allow for the compressive load.

The test method complied with ASTM D7361-07, which was published later, with the following exceptions:

- The specimen size was 100 × 100 instead of the minimum of 120 × 120 mm. In view of the small scale of the cusps, this is not regarded as significant.
- The fluctuation in load exceeded ± 0.5%. Since this was a fluctuation about a mean that was maintained to well within this tolerance, this is not believed to have had a significant effect.
- A temperature step of 10 ºC was agreed – this is permissible.
- The rate of initial loading was not monitored with the required precision. The creep response of cuspated cores should be considerably less sensitive to the method of loading than, for example, polyester fibres, so that this requirement should not be critical.
- Strain was measured every 60 s following loading instead of every 30 s. The resulting data file is quite sufficient for analysis.

The results are shown in the Table 1 and in Figure 1. The y-axis in Figure1 shows the compressive strain as a percentage reduction in thickness, such that 100% reduction would indicate total collapse of the structure. Time is shown in hours on a logarithmic scale. 100000 h (10^5 h) is 11.4 years and 1000000 h (10^6 h) is 114 years. Note that for clarity only a selection of points is shown.

Table 1. Compressive creep tests performed on 4S250

Pressure	Total compressive strain after 1 h	Predicted total compressive strain after 10^6 h (114 years)
50 kPa	6 %	11.2 %
100 kPa	9.3 %	16.1 %
175 kPa	11.8 %	23.5 %
250 kPa	13 %	29 %

The thermal shift used in the analysis was approximately 1.3/10ºC. The vertical shift to allow for normal thermal expansion of material and equipment was approximately 0.6% strain for each 10ºC step, and 0.8% at 250 kPa. It was noted that although the temperature in the surrounding chamber adjusted to the new temperature within one minute, the specimen took up to 30 min to adopt a plausible new creep characteristic. In addition it was noted that the preload had to be increased to ensure that all the nodes engaged with the pressure plates. This was due to the original curvature of the sheet. Otherwise no particular problems were identified and it is believed that the results provide a credible prediction of the reduction in thickness of the drainage geosynthetic over 1000000 h or 114 years.

It must be emphasized that this method only predicts the reduction in thickness. The end-of-life criterion is likely to be a minimum flow capacity. It is therefore necessary to make a separate determination of the relation between flow capacity and thickness, for example Böttcher (2006). The flow capacities of the materials tested are up to 2.5 l/s per metre width.

The second series of tests was performed on Material 6S250. The method used was the same. A 100 mm square represents 169 nodes. The results are shown in Table 2 and in Figure 2. The thermal and vertical shifts were the same as for the 4S250 material except at 175 kPa load. All were measured on a second batch of material except the test at 250 kPa that was measured on material from the first batch.

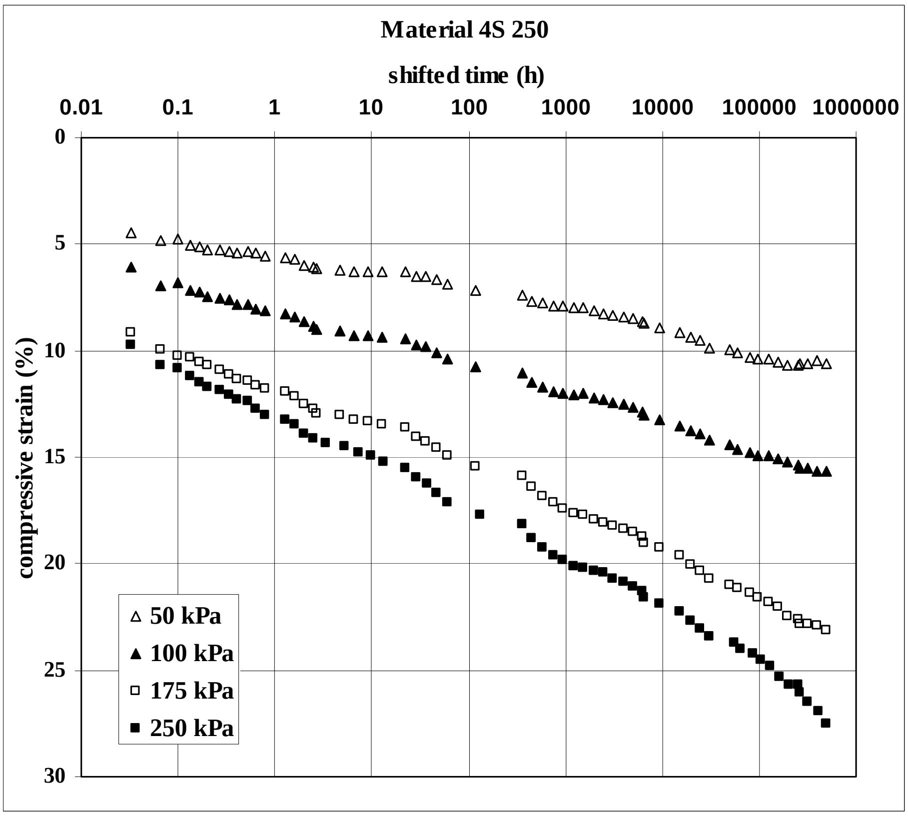

Figure 1. Compressive strain of Material 4S250

Table 2. Compressive creep tests performed on 6S250

Pressure	Total compressive strain after 1 h	Predicted total compressive strain after 10^6 h (114 years)
50 kPa	4.55 %	9 %
100 kPa	6.2 %	11.5 %
175 kPa	8.4 %	17.5 %
250 kPa	9 %	22 %

MODIFICATIONS

Following a review of the results the following improvements were introduced:

- The loading train was simplified to reduce movement.
- The method of strain measurement was changed to LVDT transducers attached directly to the loading plates.
- The loading plates (excluding the plate between the two specimens) were heated.

Table 3 indicates the results of these modifications. All tests were performed on one of two batches of Material 6S250. The batch number is given for information.

Table 3. Strains measured following changes to the method of measurement

Material batch	Pressure	Total strain after 1 h	Predicted strain after 10^6 h	Modifications to method
1	250 kPa	9 %	22 %	None
1	250 kPa	11.8 %	26.8 %	None
2	250 kPa	8.9 %	17 %	None
1	250 kPa	9.8 %	16.5 %	Conventional creep test
1	250 kPa	10 %	28 %	Simplified loading train
1	250 kPa	13.7 %	33 %	Simplified loading train
2	250 kPa	7.5 %	25 %	Direct LVDT strain measurement
2	150 kPa	5.9 %	11.3 %	Direct LVDT strain measurement and heated pressure plates

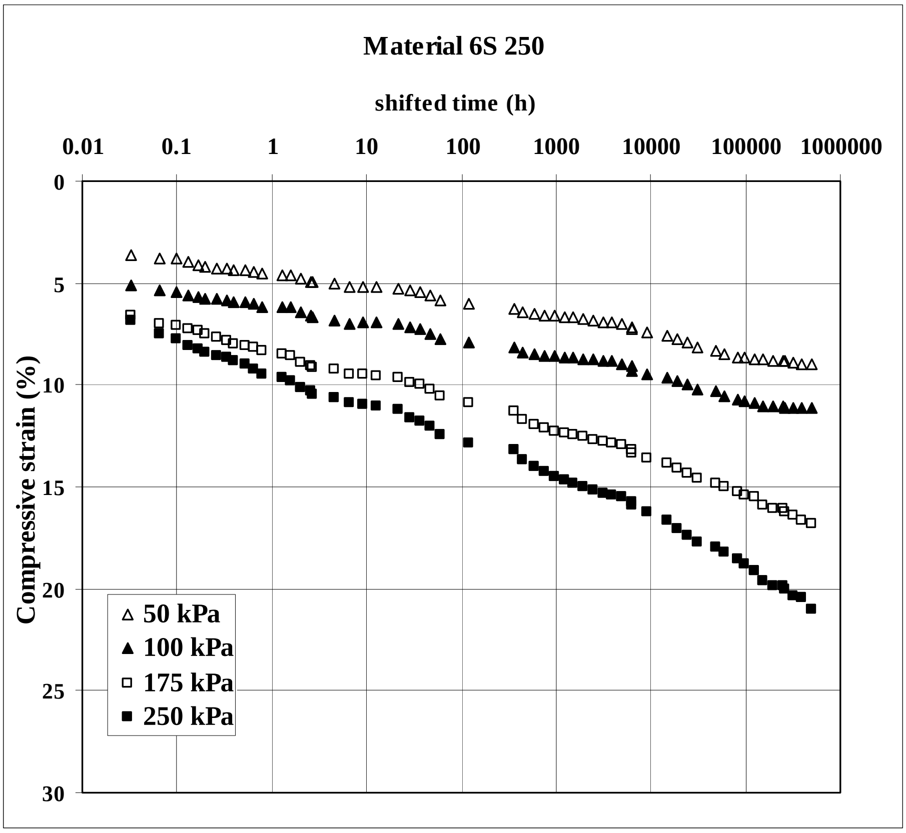

Figure 2. Compressive strain of Material 6S250

The top three results from control tests indicate the level of variability in the strain after 1 h and the considerably larger variation in the predicted strains after 114 years (10^6 h). No significant difference could be observed by eye between the two batches of material. The fourth line from a conventional test lasting only 137 h makes similar strain predictions, noting that extrapolation from 137 h directly to 1000000 h is not recommended.

Of the modifications made, the use of a simplified loading train made little difference to the prediction. However, the use of direct LVDT strain measurement yielded a much smoother curve in spite of the fluctuations in load caused by the servo mechanism. Removal of this fluctuation highlighted the long creep stabilisation time after each temperature increase and showed it to last for as long as 60 min. Analysis of these smoother curves had the surprising result that the optimal thermal shift reduced from 1.3/10ºC to 1.0/10ºC. This reduced the timescale or, more precisely, the duration at which a particular strain is predicted in the future. Conversely, the strain prediction at future durations increased, and the predicted strain at 114 years was at the upper limit of the range of the original tests.

The third modification turned out to be the most significant, as it all but eliminated the creep transition time at the temperature steps. First trials were made by adding aluminium fins – as are used to cool engines – to the pressure plates to aid thermal transfer, but without much success. With heated pressure plates, however, the creep transition time was all but eliminated. At the same time however the optimal thermal shift factor rose from 1.0/10ºC to 1.6/10ºC and the predicted strains at 114 years were correspondingly lower. The vertical shift reduced from 0.6% strain to 0.2% strain for each 10ºC step. Direct measurement of thermal expansion (0.014%/10ºC) indicated that the vertical shift was not due to direct thermal expansion of the specimen alone.

COMPARISON WITH SECOND LABORATORY

A comparison was made with a second laboratory on 6S250, as shown in Table 4.

Table 4. Interlaboratory trial on 6S250

Test laboratory	Method	Pressure	Total strain after 1 h	Predicted total strain after 10^6 h
External laboratory	SIM	150 kPa	8 %	13 %
ERA	SIM	150 kPa	5.9 %	11.3 %

The agreement was satisfactory, noting the general level of variability observed, in spite of the external laboratory using a thermal shift factor of 2.7/10ºC.

TESTS ON OTHER MATERIALS

Further tests were performed using 7S250, 6S500, 7D240, 4S500, 7S750 and 6SR250 materials, the results of which are shown in Table 5.

Table 5. Compressive creep tests on 7S250, 6S500, 7D240, 4S500, 7S750 and 6SR250

Product	Pressure	Strain after 1 h	Strain after 10^6 h (114 years)	Changes to method
7S250	50 kPa	4.1 %	8 %	
6S500	250 kPa	6.8 %	14.4 %	
7D240	50 kPa	6.2 %	10.9 %	
7D240	125 kPa	6.7 %	20.5 %	
4S500	250 kPa	5.8 %	11.7 %	Higher preload LVDTs strain measurement
7S750	375 kPa	6.5 %	13.6 %	
6SR250	50 kPa	2.6 %	5.5 %	
6SR250	100 kPa	3.5 %	9.0 %	
6SR250	175 kPa	6 %	15.5 %	
6SR250	250 kPa	7.8 %	18 %	As above plus heated plates
6SR250	175 kPa	6.3 %	13.4 %	

The thermal shift factors were 1.0/10ºC but with heated pressure plates the optimum rose to 1.3/10ºC and 1.6/10ºC at 175 kPa.

CONCLUSIONS

- It is demonstrated that SIM can be used as a method for the prediction of compressive creep strain of drainage geosynthetics. Conventional creep tests are required to validate the initial strains. A relation between flow rate and thickness is required to predict the progressive reduction in in-plane flow capacity.
- Direct measurement of creep strain across the pressure plates is recommended to improve the quality of data for analysis. The use of two specimens in tandem provides a means of increasing the sensitivity of strain measurement.
- The preload should be sufficient to ensure that the openwork structure engages with the pressure plates over the entire area. Strain is measured as total strain relative to a zero taken immediately after application of the preload.
- Heated platens were found necessary to ensure a rapid change in both temperature and creep behaviour.
- Variations in test method lead to unexpected changes in the optimum temperature shifts. These can lead to significant differences in the timescales at which particular strains are predicted.
- Interlaboratory trials to ASTM D7361-07 should be set up in order to establish the reproducibility of the method and to determine the contributions from the procedure, from the operator's interpretation of the results including the thermal shift factors, and from the product itself.
- Some of the levels of precision required by ASTM D7361-07 are regarded as unnecessarily stringent.

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