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THE MEMORY OF GEOSYNTHETICS DURING CREEP

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Abstract: Creep and creep rupture behaviour have to be considered when choosing appropriate geosynthetics for long-term applications. The tBU therefore performs both kinds of testing according to the different international standards to provide the needed data for the use of geosynthetics.

Geosynthetic reinforcements are not under a constant static stress during their utilisation. Therefore the influence of a lower stress level was examined on the complete creep and creep rupture behaviour and to see the influence of a relaxation phase on the creep behaviour under a reloaded stress was evaluated.

The creep tests were performed on a woven PET geogrid with a PVC coating at 20°C according to DIN EN ISO 13431. The load levels were 40 and 60 % of the Nominal Tensile Strength (NTS). The load was applied with the help of lever arms and the strain was optically determined by measurement marks that were attached to the specimen. During the relaxation phase the specimen with the measurement marks and the clamping system were stored horizontal at 20°C to keep the specimen as stress-free as possible. At the beginning of the relaxation phase of the specimen the strain was furthermore measured over duration of 200 hours as well as before the reloaded stress. The different time phases are divided as followed:

- 1st phase: constant stress level for approx. 5 years
- 2nd phase: relaxation for approx. 3 years
- 3rd phase: reloaded stress for approx. 6.5 years

Right now the tests have reached test duration of approximately 14.5 years total. They were not stopped and will be continued. The essential question of these tests is: Do geosynthetics have some kind of memory and therefore will they return to the same strain as it would be expected theoretically or will the outcome of this be a different progression.

Keywords: creep, geogrid, long-term creep test, long-term behaviour, polyester, tensile strain

INTRODUCTION

In many application fields of geosynthetics, long-term behaviour plays an important role since the residual strength and the strain can help to choose the suitable geosynthetic for the individual application (Müller-Rochholz, 2005). These properties of materials are determined through standardised tests. One of these tests determines the creep behaviour. If geosynthetics are subjected to a constant mechanical load, a time-dependant increase in deformation at a given stress (creep) and a time-dependant stress relief after successful deformation (relaxation) will be observed. This behaviour is called visco-elasticity. The best way to show the visco-elastic property of a geosynthetic is the Burger-Kelvin model as shown in Figure 1 (Oberbach, 2001 / Müller-Rochholz, 1990).

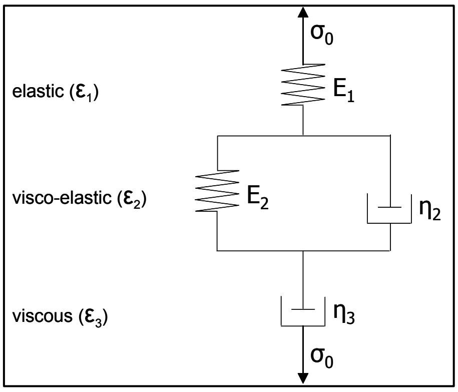

Figure 1. Burger-Kelvin model

The Burger-Kelvin model describes three different types of deformations which occur in the creep process. The model uses springs (Hook elements) and dampers (Newton elements).

- The initial deformation ε_1 is the spontaneous elastic deformation of a Hook element (represented by a single spring) which spontaneously returns to a defined fraction of its original size and shape after the load is removed.
- The time-dependant deformation ε_2 is a reversible visco-elastic deformation, represented by the parallel circuit of a spring and damper.

- The 3rd deformation ε_3 is a time-dependant irreversible viscous deformation (i.e. a permanent set), represented by a single damper.

From these three types of deformation, a theoretical graph of strain versus time can be derived for a creep test, see Figure 2 (Müller-Rochholz, 1990). This figure already includes the theoretical strain-time curve for a new load application .

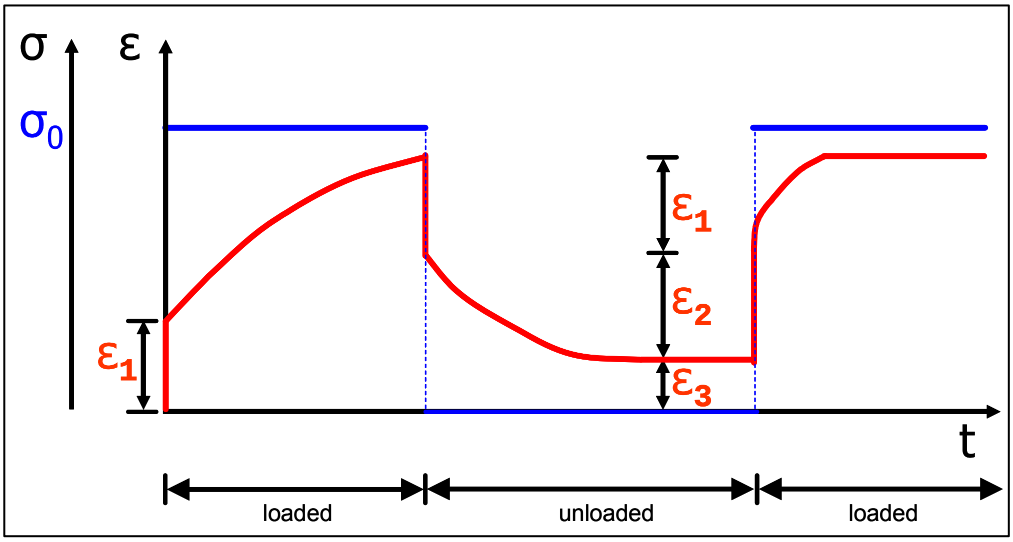

Figure 2. Theoretical graph of strain versus time in a creep test

After the specimen experiences a spontaneous initial deformation, total deformation increases depending on the raw material and the geosynthetic product while a constant load is applied. After the load is removed in the creep test, the specimen experiences a permanent set; starting from this permanent set, a new identical load is applied which again produces a defined initial deformation and an increasing total deformation. In an ideal case, the amount of total deformation after and before the load is removed should be identical providing that the geosynthetic has not yet reached the damage area where the geosynthetic experiences a non-linear increase in deformation. (Staubermann, 2003 / Koslowski, 1996).

PARAMETERS

Material and test parameters

In this test, which is still going on, a PVC coated woven PET geogrid has been used. The material characteristics and test parameters can be seen from Table 1.

Table 1. Material characteristics and test parameters

Material	PET-GGR
Specimen width	7 strands
Test direction	MD (machine direction)
Nominal strength	60 kN/m
Load levels	40 % and 60 % of the nominal strength
Pre load	1 % of nominal strength
Test temperature	20 °C
Test standard	DIN EN ISO 13431 (11.1999)

Test apparatus and procedure

The specimens are subjected to a static force distributed uniformly over the specimen width, at constant ambient conditions. After the specimens are integrated into the test apparatus and after the pre-load is applied, the zero measurement of the deformation is carried out (Figure 3). Subsequently the specimens are subjected to an external load in a jerk-free and continuous process where the load is increased to the test force within 60 seconds. From this point on, the test load will be kept constant. At defined intervals, the deformation of the specimens is measured optically and the strain is determined. The load apparatus consists of an upright steel frame. The test loads are applied to the specimens using articulated lever arms. The loads are applied by steel plates of measured weight. With the help of an electro-mechanical force measurement system, the predefined test force is checked and, if required, corrected. The deviation of force is less than 1 %.

The load apparatus is located in a room equipped with a 10 cm thick isolation, which is kept at a temperature of 20 °C ± 1 °C using a heater with close-loop temperature control. Deformation is measured with the help of a video camera mounted on an electronic height calliper gauge, between two measurement marks fixed on the specimen. The strain values determined from the measurements are evaluated in a diagram with a time axis having a logarithmic scale against the material strength expressed in percent of the nominal strength. After 45.888 h, the tests had to be stopped for these two geogrid specimens, due to external and local conditions. After the load was removed during a period of 22,392 hours, the tests were restarted. From this moment on, both tests have been going on for approx. 58,720 h (March 2008). This results in a total runtime of approx. 127,000 hours. This corresponds with a total test period of 14.5 years, including those periods where the load was removed.

Figure 3. Specimens with deformation measurement system

RESULTS

From the deformation values measured, the following strain values were determined. Table 2 and Figures 4 to 8 indicate only the relevant results.

Table 2. Results of the determination of strain

Total time [h]	Test phase	Strain under 40 % load [%]	Strain under 60 % load [%]
0.017	Load applied for the 1st time	10.2	11.3
0.067		10.4	11.4
0.25		10.5	11.5
0.50		10.6	11.6
1		10.8	11.7
96		11.1	12.1
8736		11.7	12.4
45672		11.7	12.4
45672.15	Load removed	8.0	7.9
45672.53		7.8	7.7
45673.22		7.6	7.5
45888		6.7	6.8
68064		6.3	6.0
68064.017	Load applied for the 2nd time	11.4	12.4
68065		11.5	12.5
68088		11.6	12.6
69576		11.7	12.7
126851		11.7	12.7

The strain-time curves determined from the strain results are shown in the following diagrams.

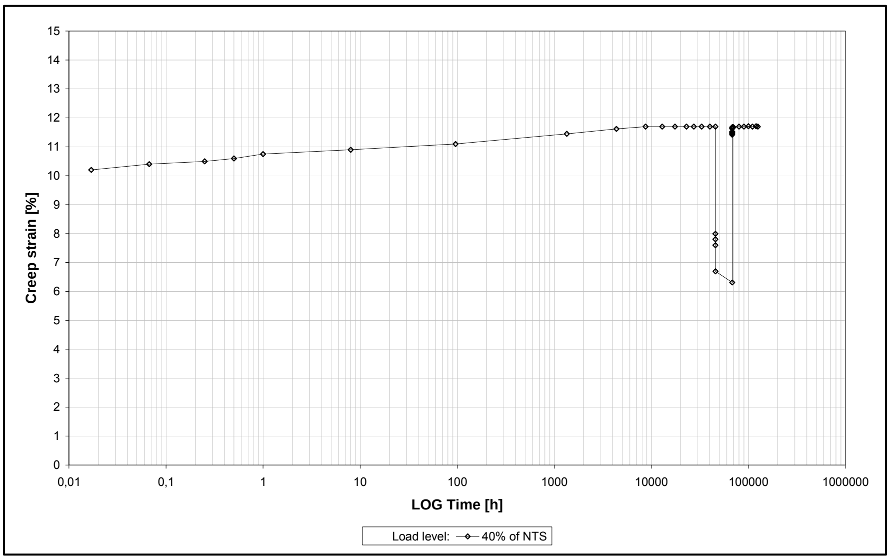

Figure 4. Graph of creep versus time under 40 % of NTS load

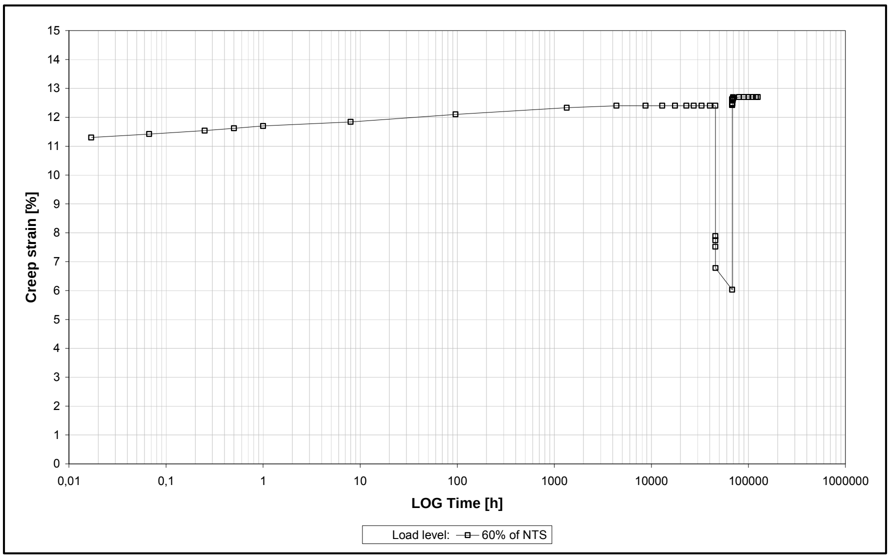

Figure 5. Graph of creep versus time under 60 % of NTS load

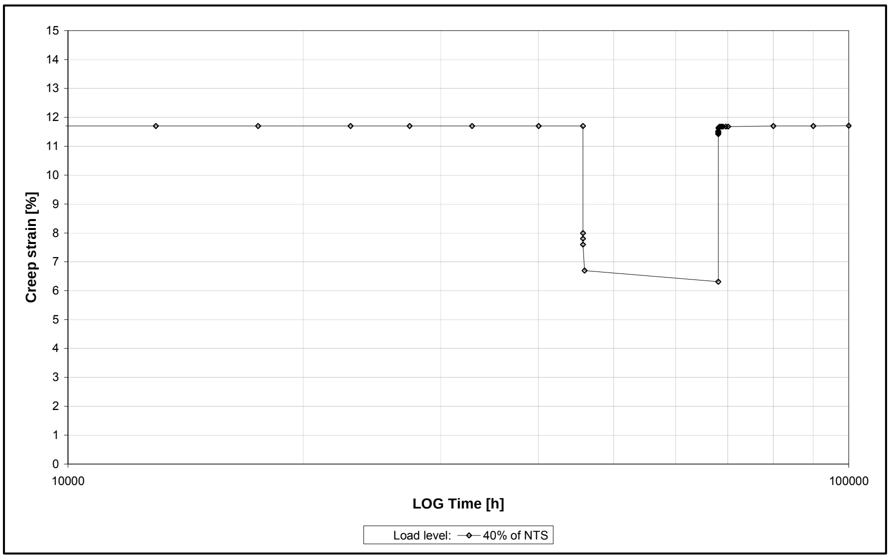

Figure 6. Increase in the load removal time period with restart under 40 % of NTS load

The results after restarting the tests show that the strain experienced at the end of the 1st load application phase is reached a short time after the tests are restarted with the same specimens or even slightly exceeded in the test under 60 % NTS load. The strain remains constant, and there is no change in the pitch of the curve compared to the last phase before the load is removed. To illustrate the results in a more clear-cut way, the graph of Figure 7 shows the strain against a time axis with a linear scale.

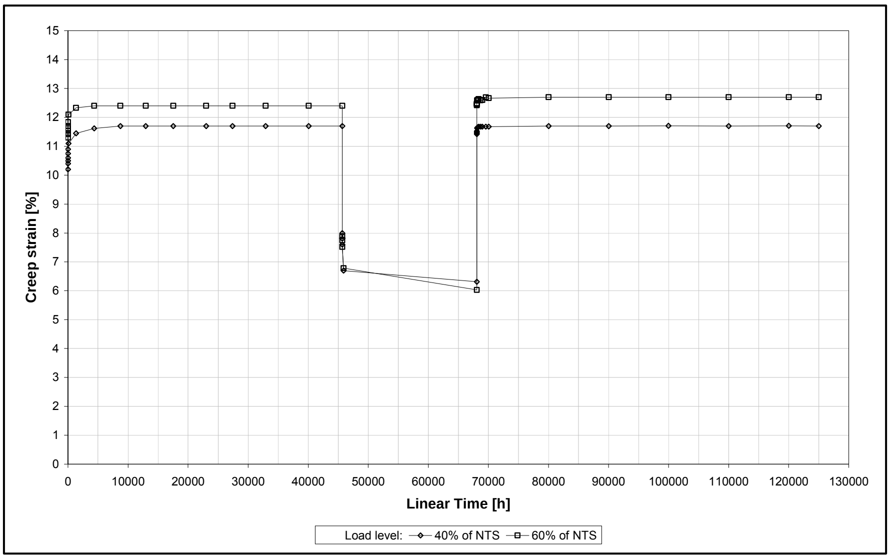

Figure 7. Linear time scale, for both 40 and 60% of NTS, (Zoom of the creep curves)

In a further evaluation process, the creep modulus E_c is determined. The creep modulus is defined as the ratio of stress over the strain experienced as a function of time. It is given by the following equation:

$$E_c(t) = \frac{\sigma}{\varepsilon_c(t)}$$

E_c (t) is the time-dependant modulus of creep, σ is the constant stress and ε_c (t) is the time-dependant strain.

In this test, the calculation was performed using a constant force instead of stress because the specimens consist of woven geogrids, and hence calculation of the cross-sectional area is very complex. The creep modulus was expressed in N/m, the value of which was determined from the specimen width. For the comparison of the two load application phases, the restart of the tests was chosen as a zero point in time on the basis of which the creep modulus was calculated.

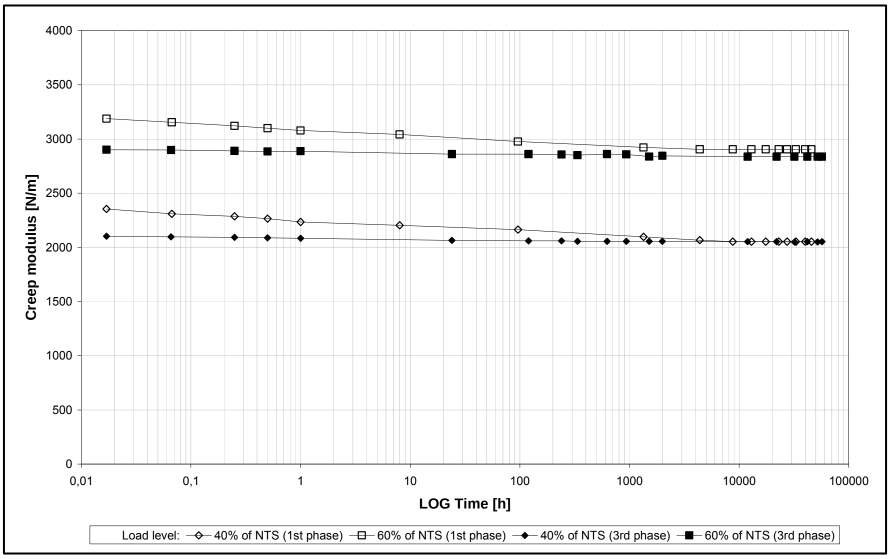

Figure 8. Comparison of the creep moduli of both load application phases (40 and 60 % of NTS load)

The difference between the creep moduli in the 1st phase and 3rd phase can be explained by the fact that the spontaneous deformation is not as large when the load is applied again, because of an irreversible deformation already occurred. After the same or a similar strain level is reached, the curves coincide (under 40 % NTS load) or are parallel (under 60 % NTS load). The offset for the specimen under 60 % NTS load results from the strain difference between end of the 1st load application phase and the instantaneous end of the 2nd load application phase. The tests are not yet complete and shall be continued for as long as possible.

CONCLUSION

The theoretical assumptions made at the beginning on the strain-time curve after a creep load is applied a second time are confirmed by this series of tests. Basically two differences in the values can be found. The creep modulus deviates significantly at the beginning of the second load application phase and then approaches that of the 1st load application phase. The other difference is caused by the time period required to reach a constant strain level. In the 2nd load application phase, the strain level is reached more quickly since the specimens have already experienced a permanent set ("irreversible deformation") and the molecule chains have aligned depending on the material, and hence they can reach the constant strain level faster. Therefore, geosynthetics have turned out to have a sort of "memory" in the creep test.

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