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Creep properties of geosynthetics during increasing loading and after partial unloading

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ABSTRACT: The aim of this paper is to present the results of the experimental investigations of geotextiles creep properties under increasing loading and partial unloading. Tests were performed on four selected geosynthetics. Creep of the specimens under tensile load in the range 10-50% of the tensile strength was measured. In the last part of the article the results of approximation of the experimental data by using three selected rheological models are discussed.

1 INTRODUCTION

The time-dependent properties of geosynthetics influenced the behaviour of engineering structures in which they are used as reinforcement (Kazimierowicz-Frankowska 2003). Generally, creep is treated as a degradation phenomenon, although it is possible to find an interesting opposite approach to this problem (Bernardi and Paulson 1997, Greenwood et al. 2001, Hirakawa et al. 2002).

Standard creep tests are performed under constant stress level (Ingold 1994). In practice, geosynthetics are sometimes exposed on various stress-strain histories. Further, it is also important to investigate their rheological properties for variable load levels. The paper describes results of creep tests, which were conducted on record geotextiles creep properties under increasing load and creep after partial unloading. The results presented here are part of a wider research programme dealing with the time-dependent properties of geosynthetics (Kazimierowicz-Frankowska 2005).

2 EXPERIMENTAL SETUP AND TESTING PROGRAMME

2.1 *Materials*

The experimental programme involved four different geotextiles. All of them were manufactured in Poland and their basic properties were as follows:

- “Pabianice” No. 41-100/1 (generic symbol: PT) – woven PA geotextile (mass per unit of area = 445 g/m^2; tensile strength: 123 kN/m; elongation at failure: 35%);
- “Pabianice” No. 156-164 (generic symbol: PpT) – woven PP geotextile (mass per unit of area = 320 g/m^2; tensile strength: 143 kN/m; elongation at failure: 27%);
- “Lentex” No. 48214/210/26/0 (generic symbol: L) – PP needle-punched geotextile reinforced with PE geonet (mass per unit of area = 608 g/m^2; tensile strength: 15 kN/m; elongation at failure: 14%);
- “Watina” No. 7/14/310 (generic symbol: W) – non-woven needle-punched PP & PET geotextile (mass per unit of area = 220 g/m^2; tensile strength: 8.5 kN/m; elongation at failure: 39%).

The geotextile specimens used in experimental tests were 10 cm wide and 10 cm long. Their creep parameters were investigated in the machine direction (the direction in which the geosynthetics are produced).

2.2 *Testing programme*

During the initial experiments the standard tensile tests were performed (with the constant strain rate 10%/min). Their results enabled to indicate the basic mechanical properties of geotextiles (i.e. average ultimate tensile strength and elongation at maximum tensile strength). Then the specimens of materials (their ends) were fixed to the clamps. The top clamps were fixed to the creep test rigs while the dead loads were hung on the bottom clamps. Some different initial values of the tensile load were applied to specimens during the creep tests, in the range 10%-50% of the tensile strength (indicated as R in the figures). The elongation of specimens under the loads was measured over a period of 100-500 hours by using electronical displacement gauges, fixed independently to the frame. In the case of the first series of specimens, after this time, they were additionally loaded. In the case of the second one, specimens were partially unloaded down to half of the initially applied load. The influence of the following different load histories on creep properties of geosynthetics was investigated:

- increasing loading: two ($\sigma_1 = 0.2R$, $\sigma_2 = 0.4R$) or four ($\sigma_1 = 0.1R$, $\sigma_2 = 0.2R$, $\sigma_3 = 0.3R$, $\sigma_4 = 0.4R$) different stress levels were applied during creep tests;
- partial unloading: the initial stress level (in the range between 0.1-0.5R) was reduced to half of the initially applied stress;
- two different stress histories involved both: increasing loading and partial unloading:
  - $\sigma_1 = 0.1R$, $\sigma_2 = 0.2R$, $\sigma_3 = 0.3R$, $\sigma_4 = 0.4R$, $\sigma_5 = 0.3R$, $\sigma_6 = 0.2R$, $\sigma_7 = 0.1R$;
  - $\sigma_1 = 0.1R$, $\sigma_2 = 0.3R$, $\sigma_3 = 0.5R$, $\sigma_4 = 0.3R$, $\sigma_5 = 0.1R$. The tests were performed at the Technical University of Koszalin (Filipkowski et al. 1998).

All the experiments were performed under the same laboratory conditions. (the average temperature was 20°C (±2°C) and the average humidity was 57% (± 8%).

3 TEST RESULTS AND DISCUSSION

3.1 *Creep curves for increasing loads*

Typical creep curves obtained for the increasing load are shown in Figure 1 (two steps of loading) and Figure 2 (four steps of loading).

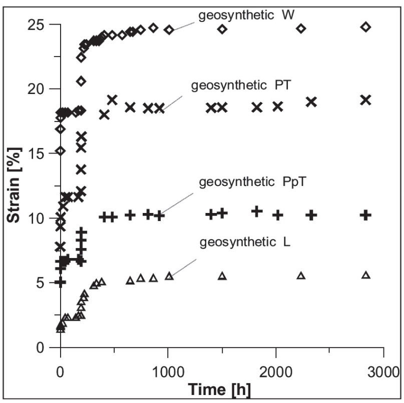

Figure 1. Creep curves for increasing load. Two steps of loading: $\sigma_1 = 0.2R$, $\sigma_2 = 0.4R$.

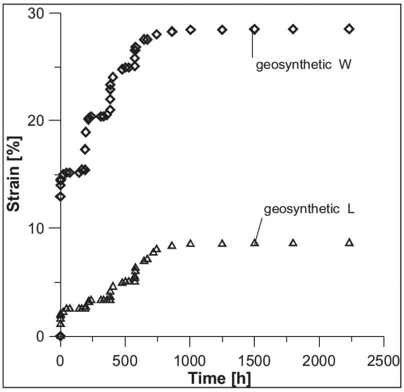

Figure 2. Creep curves for increasing load. Four steps of loading: $\sigma_1 = 0.1R$, $\sigma_2 = 0.2R$, $\sigma_3 = 0.3R$, $\sigma_4 = 0.4R$.

The qualitative character of all creep curves is similar. The same phases at every step of loading can be determined. The instantaneous strain (after applying the load), the primary creep (characterized by large, decreasing in time, strain rates) and the secondary creep (the strain rate tends to zero and creep curves tend to horizontal asymptotes).

3.2 *Creep under partial unloading*

Figure 3 shows experimental results from the creep tests followed by partial unloading down to half of the initially applied load. The qualitative character of the creep curves after partial unloading strongly depends on the initial stress level. In the case of the initially low stress level (in the range: 0.1-0.3R) the partial unloading caused instantaneous decrease of strain in specimens to the constant level. When the samples are subjected to higher stresses (0.4-0.5R) - two different stages can be defined after partial unloading. The first stage, when the strain recovery was observed and second stage when strains of the specimens stabilized at constant level (Figure 3) were noted.

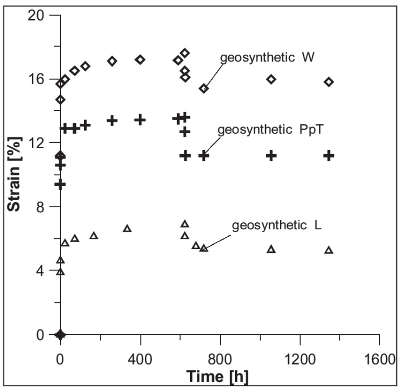

Figure 3. Creep curves for partial unloading. Two steps of load: $\sigma_1 = 0.4R$, $\sigma_2 = 0.2R$.

3.3 *Creep under history involved increasing loading and partial unloading*

Figures 4-5 show the creep curves obtained during tests involved both: increasing loading and partial unloading. The values of deformation during first (ε_1), second (ε_2), third (ε_3) and fourth (ε_4) stages of increasing stress levels are compared in Table 1 (data from Fig. 4) and Table 2 (data from Fig. 5). It can be observed that while ε_1 is different for particular kind of material, ε_2, ε_3, ε_4 related to ε_1 are quite similar.

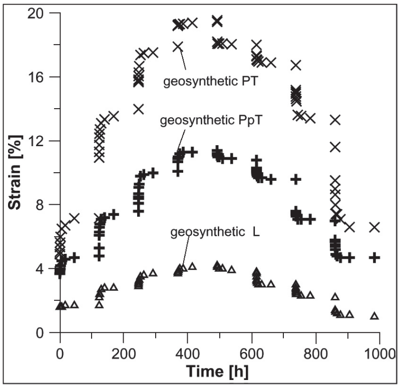

Figure 4. Creep curves for stress history involved increasing loading and partial unloading: $\sigma_1 = 0.1R$, $\sigma_2 = 0.2R$, $\sigma_3 = 0.3R$, $\sigma_4 = 0.4R$, $\sigma_5 = 0.3R$, $\sigma_6 = 0.2R$, $\sigma_7 = 0.1R$;

Table 1. Strains during following stages of increasing loading.

Geosynthetic	ε_2	ε_3	ε_4
L	$0.7\varepsilon_1$	$0.5\varepsilon_1$	$0.2\varepsilon_1$
PT	$0.8\varepsilon_1$	$0.5\varepsilon_1$	$0.2\varepsilon_1$
PpT	$0.6\varepsilon_1$	$0.5\varepsilon_1$	$0.2\varepsilon_1$

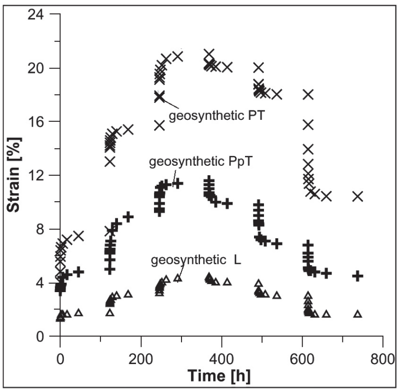

Figure 5. Creep curves for stress history involved increasing loading and partial unloading: $\sigma_1 = 0.1R$, $\sigma_2 = 0.3R$, $\sigma_3 = 0.5R$, $\sigma_4 = 0.3R$, $\sigma_5 = 0.1R$.

Table 2. Strains during following stages of increasing loading.

Geosynthetic	ε_2	ε_3
L	$0.9\varepsilon_1$	$0.7\varepsilon_1$
PT	$1.0\varepsilon_1$	$0.7\varepsilon_1$
PpT	$0.9\varepsilon_1$	$0.5\varepsilon_1$

4 RHEOLOGICAL MODELS

4.1 *Selected models*

Three different models, presented in Figure 6, were used to approximation of the experimental data. Their properties, constitutive equations and methods of determining the models' parameters as well as the linear and non-linear ranges of the load-strain behaviour of geosynthetics during loading and unloading are described by Sawicki & Kazimierowicz-Frankowska 1998.

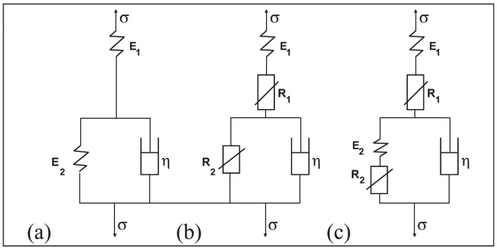

Figure 6. Models used to approximations of the data.

4.2 *Increasing loading (model a)*

The rheological properties of geosynthetics during the first stage of the creep program ($\sigma = \sigma_1$) were successfully described by the standard linear solid model (Figure 6a, Williams 1980). During the second, third and fourth stages of load the Boltzmann principle was used to predict the material strains. The geosynthetics parameters are presented in Table 3. The typical results of approximation the experimental data are shown in Figure 7.

Table 3. Average rheological parameters of model used in approximation of creep data under increasing loading (Fig. 6a).

Geosynthetic	$E_1 \times 10^6$ N/m	$E_2 \times 10^6$ N/m	$\eta \times 10^6$ Nh/m
L	0.285	0.202	12.783
W	0.013	0.030	2.822
PT	0.164	0.236	20.691
PpT	0.296	0.475	22.017

4.3 *Partial unloading (models b and c)*

Two different models were selected to describe geosynthetics rheological properties after partial unloading (Figure 6b and Figure 6c). The first was

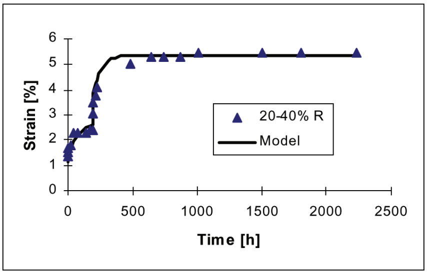

Figure 7. Approximation of experimental data. Geosynthetic L. $\sigma_1 = 0.2R$, $\sigma_2 = 0.4R$.

successfully used in the cases for low applied stress levels (Figure 8). The second one (fifth parameters' model) was applied to describe geosynthetics behaviour under higher load levels: 0.4-0.5R (Figure 9).

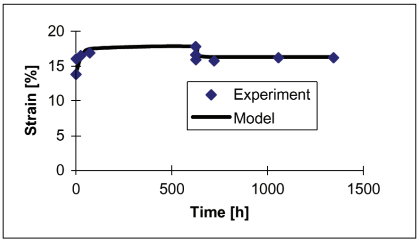

Figure 8. Approximation of experimental data. Geosynthetic W. $\sigma_1 = 0.3R$, $\sigma_2 = 0.1R$.

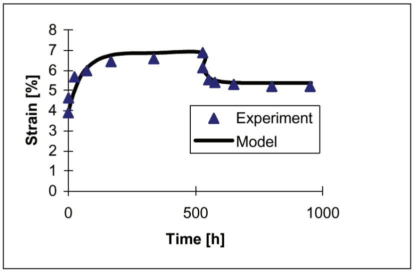

Figure 9. Approximation of experimental data. Geosynthetic L. $\sigma_1 = 0.5R$, $\sigma_2 = 0.25R$.

The additionally spring element in this model (the second plastic element in previous model was replaced by the elasto-plastic one) enables to describe the observed strain recovery after partial unloading. Table 4 shows average model parameters for investigated geosynthetics.

5 SUMMARY

The following conclusions can be drawn from the present study:

Table 4. Average rheological parameters of fifth parameters' model used to approximate the experimental data after partial unloading (Figure 6c).

Geo-synthetic	$E_1 \times 10^6$ N/m	$E_2 \times 10^6$ N/m	$R_1 \times 10^6$ N/m	$R_2 \times 10^6$ N/m	$\eta \times 10^6$ Nh/m
L	0.402	0.404	0.252	0.404	10.64
W	0.082	0.154	0.020	0.034	1.00
PT	1.168	4.805	0.246	0.819	20.00
PpT	1.770	1.135	0.419	2.282	5.00

- The qualitative character of the creep curves obtained for increasing loading is similar in all cases. Two phases of creep can be determined for every investigated load level (in the range 10-40% of the tensile strength). The primary creep and secondary creep.
- The qualitative character of the creep curves after partial unloading strongly depends on the initial stress level.
- The quantitative character of creep behaviour (during increasing loading and after partial unloading) is the individual properties of the investigated geosynthetics.
- Three different rheological models were successfully used to approximation of the experimental data. They also may be applied to the lifetime prediction of geosynthetics.

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