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The effect of strain rate and various stress-strain histories on the tensile strength of geosynthetics

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ABSTRACT: The results of tensile tests of five different geosynthetics are presented. The influence of strain rate on their stress-strain characteristics was investigated. The specimens of geosynthetics were stretched with different strain rate which varied from 0.2 x 10^{-3} 1/s (1.2%/min) to 200 x 10^{-3} 1/s (1200%/min). The different loading histories were applied before particular specimens' failures – special attention was put on the influence of short periods of creep and stress relaxation on the tensile strength of geosynthetics.

1 INTRODUCTION

Tensile strength is one of the most important mechanical parameter of geosynthetics. The value of this parameter should be determined before the use of the materials in practice. Several technical standards describe conditions in which the tensile strength tests should be performed. The tests are executed in laboratory condition i.e. in stabile, normalised level of temperature and humidity, with constant strain rate.

Geosynthetics, used in practice, work in variable, natural conditions and sometimes are exposed to unexpected stress-strain histories, which are neglected by authors of the standards. Designers and constructors which use geosynthetics have to estimate the influence of these unexpected effects on their strength. Some of them assume very high safety coefficients in their calculations. It is an easy way to avoid answering the difficult technical questions but seems not to be a very economical way. Therefore, factors influencing of the geosynthetics stress-strain behaviour should be recognised by the use of experimental investigation and theoretical works, prior to their practical use.

Results of experimental works (Ingold (1994); Van Santvoort (1994)) suggested that standard laboratory tests of geosynthetics may lead to different tesults if these tests are performed at different strain rate.

In this article the experimental results of the influence of strain rate, various stress and strain histories on strength of geosynthetics are described. Special attention was put on experiments (tensile tests) performed at constant strain rate, followed by the creep or stress relaxation stages. After these stages the specimens of materials were subsequently loaded with the same strain.The method of theoretical analysis of the experimental results was described by Sawicki and Kazimierowicz-Frankowska (2001).

2 EXPERIMENTAL PROGRAMME

2.1 Materials

There were five geosynthetics selected for the experiments. They are produced different manufacturing processes and with the use of different polymers, so they have different mechanical properties.

– ”Lentex” nr 48214/210/26/0 (generic symbol: L) - it is PP needle-punched geotextile reinforced with PE geonet (mass per unit area = 608g/m^2);
– ”Watina” nr 7/14/310 (generic symbol: W) - it is nonwoven needle-punched PP&PET geotextile (mass per unit area = 220g/m^2) :
– ”Instytut Wlókiennictwa” nr I-V/400 (generic symbol: IW) - it is nonwoven stitched PP&PET geotextile (mass per unit area = 400g/m^2);
– ”Pabianice” nr 41-100/1 (generic symbol: P) - it is woven PA geotextile (mass per unit area = 445g/m^2);
– ”Zloty Stok” nr 231/200 (generic symbol: ZS) - it is PE geogrid (mass per unit area = 570g/m^2),.

All specimens of geosynthetics, used to experiments, were 10cm wide and 5cm long.

2.2 Initial experiments

During the initial experiments the uniaxial tensile rupture strength, in the plane of the geosynthetics, was measured. The specimens of materials (their ends) were fixed to the clamps. The clamps were moved apart at a constant rate. Five different strain rates were applied to each type of geosynthetic ranging from 1.2%/min (0.2 x 10^{-3} 1/s) to 1200%/min (200 x 10^{-3} 1/s). The following quantities were measured: strain rate, elongation and applied force. The stress-strain characteristics of investigated materials, obtained for different strain rate, were compared.

2.3 Basic series of experiments

During the basic series of experiments different stress-strain histories were applied before the ultimate tensile rupture. The specimens of geosynthetics were stretched with constant strain rate (19.2%/min). From one to four short (each for one hour duration) creep or stress relaxation stages were introduced during the tensile tests. Different values of the tensile stress were applied to specimens, in the range from 20% to 80% of the tensile strength (R).

3 TEST RESULTS

3.1 Effect of strain rate on strength of geosynthetics

For all investigated geosynthetics the measured rupture load was a function of the rate of strain at which the samples were tested. The typical effect of different rate of strain is indicated in Figure 1 (for geosynthetic IW) and in Figure 2 (for geosynthetic ZS).

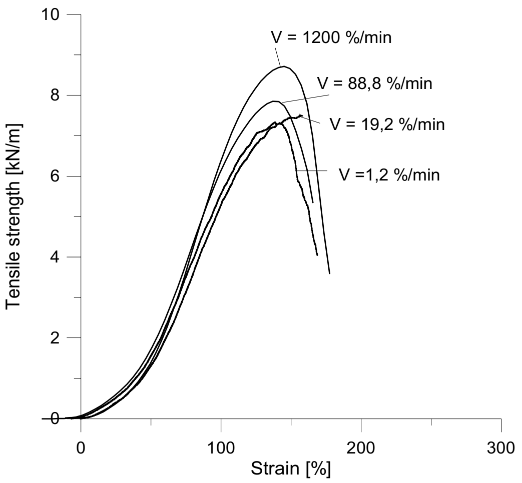

Figure 1. Load-strain curves for geosynthetic IW.

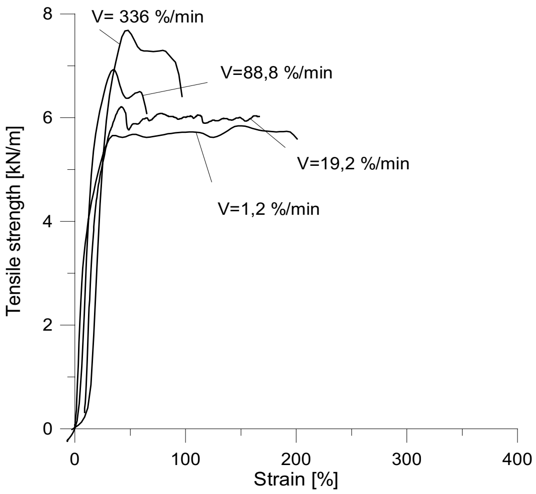

Figure 2. Load-strain curves for geosynthetic ZS.

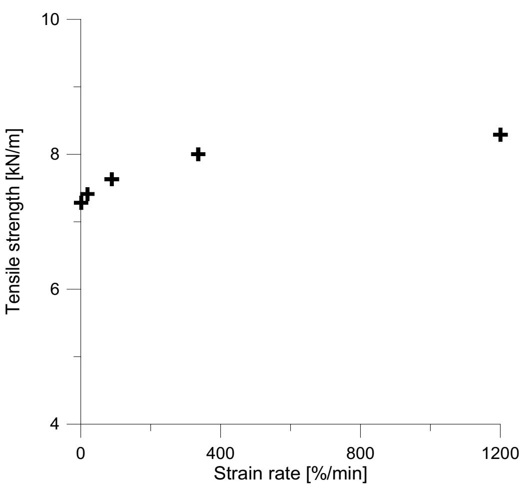

Figure 3. Increase of strength of the geosynthetic IW with the strain rate.

Figures 3 and 4 show the relationships between the strength and the strain rate for geosynthetics IW and ZS.

For the other types of geosynthetics (L and W) the influence of strain rate on their strength had similar character (to material IW and ZS). The strength of these materials increased with increasing of the strain rate.

The difference in values of the strength obtained from tensile tests performed with minimum (1.2%/min) and maximum (1200%/min) strain rate were:

– for geosynthetic ZS: 27.9%;
– for geosynthetic L: 19.3%;
– for geosynthetic W: 13.1%;
– for geosynthetic IW: 12.2%.

The stress-strain characteristics of five geosynthetics tested at various strain rate, do not differ too much for stresses lover than 60-70% of their strength. So on they can be approximated by the one common curve.

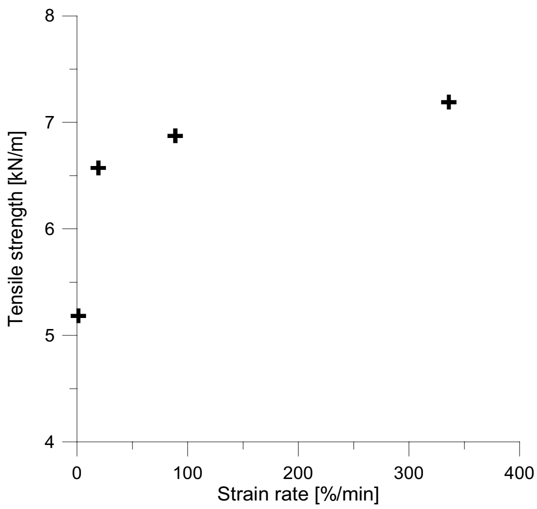

Figure 4. Increase of strength of the geosynthetic ZS with the strain rate.

3.2 Effect of various stress-strain histories on strength of geosynthetics - influence of intermediate stress relaxation stages.

The influence of five stress relaxation histories on strength of geosynthetics was investigated:

– one stage of intermediate relaxation (σ = 0.7R; where σ - stress level at which the stress relaxation stage beginning);
– two stages of relaxation (σ_1 = 0.35R; σ_2 = 0.7R) - Figures 5-6;
– three stages of relaxation (σ_1 = 0.6R; σ_2 = 0.7R; σ_3 = 0.8R) - Figure 7;
– four stages of relaxation (σ_1 = 0.2R; σ_2 = 0.3R; σ_3 = 0.4R; σ_4 = 0.5R) - Figure 8;
– four stages of relaxation (σ_1 = 0.4R; σ_2 = 0.5R; σ_3 = 0.6R; σ_4 = 0.7R) - Figure 9.

The results, obtained from this kind of experiments, were compared with standard stress-strain curves (without the stress relaxation stages).

It can be seen that after an intermediate stress relaxation a rapid return to the standard (universal) stress-strain curve take place. The short time of relaxation has no influence on strength of investigated geosynthetics.

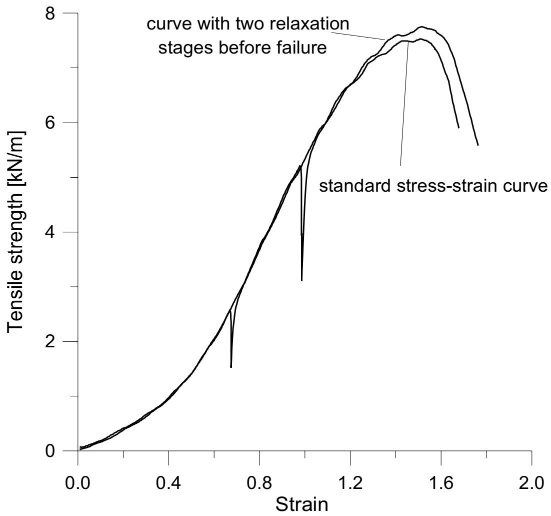

Figure 5. Load-strain curves for geosynthetic IW.

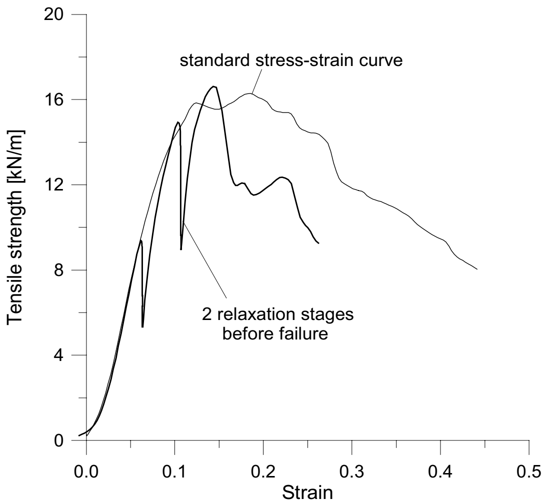

Figure 6. Load-strain curves for geosynthetic L.

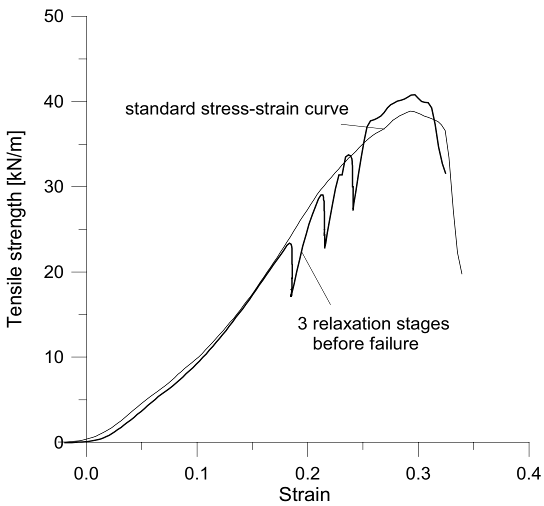

Figure 7. Load-strain curves for geosynthetic P.

It is interesting to note that the decreasing of stresses (D) during relaxation stage can be represented by empirical formula:

$$D = A \cdot \sigma , \qquad (1)$$

where:

σ - stress level at which the stress relaxation stage is beginning;

A - empirical coefficient; we can find two values of this parameter:

A_1 - related to the first step of relaxation stage;

A_f - related to the second and further steps of relaxation.

The values of these coefficients are presented in Table 1.

Table 1. Coefficients A_1 and A_f for some geosynthetics.

Geosynthetic	Value of A_1	Value of A_f
P	0.32	0.24
W	0.28	0.25
IW	0.40	0.37
L	0.40	0.36
ZS	0.47	0.45

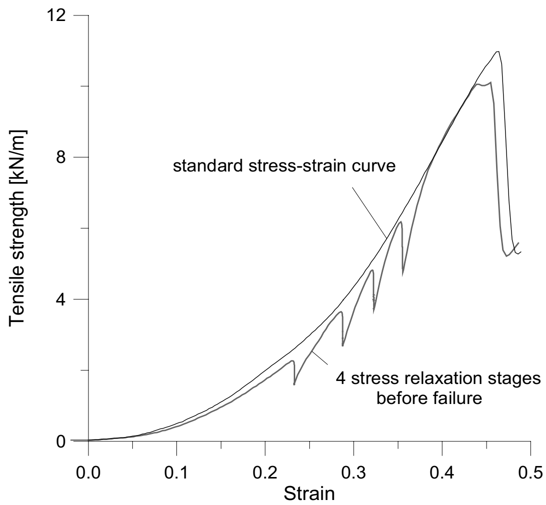

Figure 8. Load-strain curves - geosynthetic W.

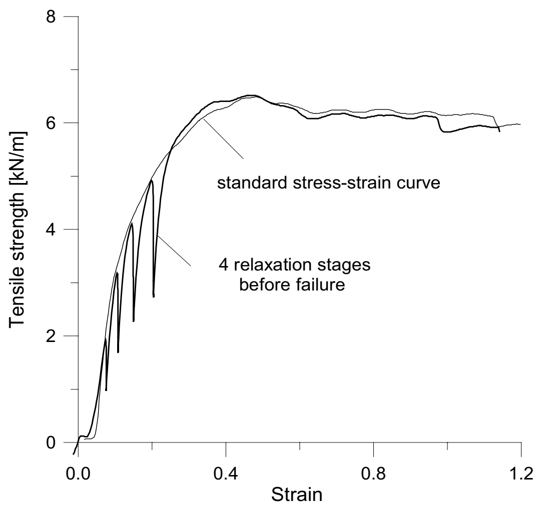

Figure 9. Load-strain curves for geosynthetic ZS.

3.3 Effect of various stress-strain histories on strength of geosynthetics - influence of intermediate creep stages.

The influence of two intermediate creep histories on strength of geosynthtics was investigated:

– one stage of creep ($\sigma = 0.7R$);
– two stages of creep ($\sigma_1 = 0.35R$; $\sigma_2 = 0.7R$); see: Figures 10-12.

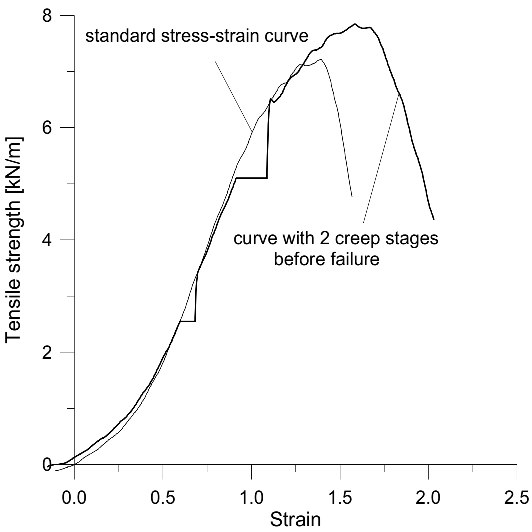

Figure 10. Load-strain curves for geosynthetic IW.

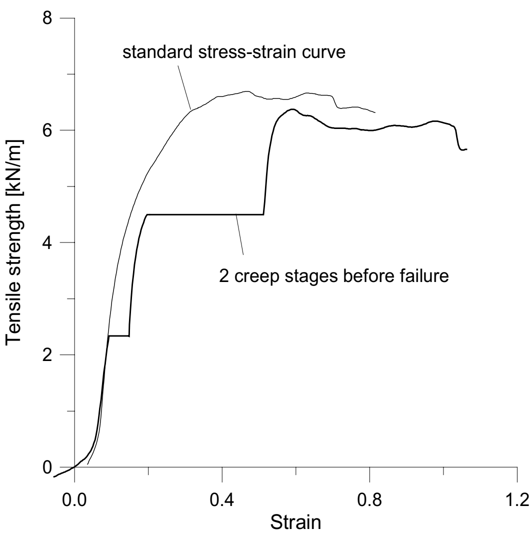

Figure 11. Load-strain curves for geosynthetic ZS.

Table 2. Deformation during second stage of creep (ε_2)

Geosynthetic	Value of ε_2
P	1.1 ε_1
W	1.1 ε_1
IW	2 ε_1
L	2 ε_1
ZS	6 ε_1

For all investigated geosynthetics, after intermediate periods of creep, a rapid return to the standard stress-strain curves is visible.

The values of deformation during first (ε_1) and second (ε_2) stage of creep were compared in Table 2. It can be seen that for two geosynthetics (IW, L) the deformation is proportional to the stress level. For materials P and W the value, of deformation, during intermediate creep stages, is nearly independent from the stress.

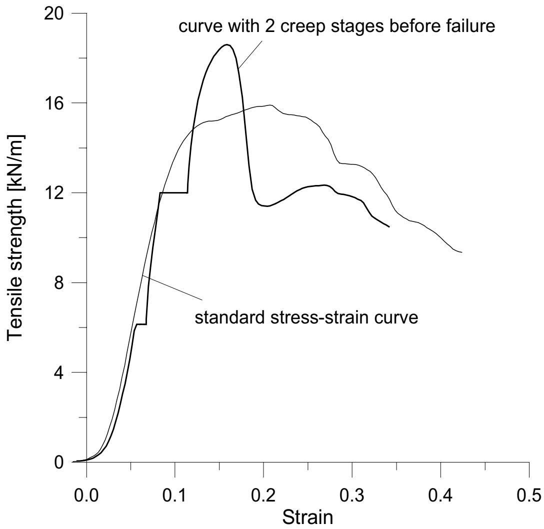

Figure 12. Load-strain curves for geosynthetic L.

The strength of some sampes of geosynthetics subjected to intermediate creep or stress relaxation is greater than the original (without the stages). Perhaps, the reason of this phenomena is difference between samples of the same material, which were tested.

4 CONCLUSIONS

The main results presented in this paper and conclusions which arise from these can be summarised as follows:

– The tensile strength decreases with decreasing rate of extension for geosynthetics. The influence in the range considered (from 1.2%/min to 1200%/min) is from 12.2% (for non-woven stitched PP&PET geotextile IW) to 27.9% (for PE geogrid ZS).
– The stress-strain characteristics of the five geosynthetics tested at various strain rate don't differ much for stresses lover than approximately 70% of their strength.
– The short intermediate periods of creep and stress relaxation do not influence the standard, universally stress-strain curves for a given strain rate. After a short period of creep or stress relaxation a rapid return to the original stress-strain curve is visible.

5 REFERENCES

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