

Effect of damage during installation of woven geotextile on their creep and creep rupture behavior – laboratory tests

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ABSTRACT: Damage during installation (DDI), creep and creep rupture behavior of geosynthetics have been subjected to extended studies. To contribute to the comprehension on the effect of damage during installation on the long-term mechanical behavior of geosynthetics, a research program was established. On this paper the results available for one of the geosynthetics studied are presented. This material has been subjected to field damage tests, using two different soils and two compaction energies. To characterize the effect of the damage induced in long-term mechanical behaviour, tensile creep tests and creep rupture tests were carried out, according with the procedures described in EN ISO 10319 and EN ISO 13431, respectively. The results obtained are compared and discussed. The main conclusions of the study are presented.

1 INTRODUCTION

To contribute to the evaluation of the effect of the installation damage of geosynthetics (GSY) on their mechanical behaviour, a research program was established. A woven geotextile was submitted to field damage tests and the short and long-term mechanical behaviour of this material was studied using laboratory tests. This paper will update and continue previous papers on these issues: Pinho-Lopes et al. (2000 and 2002) and Paula et al. (2008).

2 MATERIAL AND TEST PROGRAM

2.1 Geosynthetic

The research program implemented includes a larger number of geosynthetics (Pinho-Lopes et al., 2000 and 2002 and Pinho-Lopes, 2006). The results presented here refer only to one geosynthetic, a biaxial woven polypropylene geotextile (GTX-W) with 320g/m² unit mass area.

Table 1. Geosynthetic studied

Material	Nominal tensile strength (kN/m) MD/CMD
Woven polypropylene geotextile	65/65

MD – machine direction

CMD – cross machine direction

2.2 Test program

The test program established consists in: 1) inducing the effects of the installation damage in field, under real conditions, on samples of geosynthetics; and 2) characterising the effects of the damage induced on the mechanical behaviour of the geosynthetics in isolation.

To carry out field damage tests, experimental embankments were built, using adequate construction procedures. More details can be found in Pinho-Lopes et al. (2002) and Pinho-Lopes (2006). After installation, the geosynthetics were exhumed and recovered to be tested. They were installed in contact with two different soils: Soil 1 is an aggregate used in road construction, while Soil 2 is a residual soil from granite (Table 2). To study the effect of the compaction energy in the damage induced, two different compaction energies (CE) were considered. CE1 means soils have been compacted to only 90% of standard Proctor density (D_{pr}) and CE2 means a high compaction ($D_{pr} = 98\%$). Therefore, four different embankments were built.

Each geosynthetic was placed over the foundation layer. In any case the traffic of construction equipment was allowed over the geosynthetics before having at least a 150mm layer of soil over it. The soil was then spread in two 200mm layers, levelled and compacted to the defined compaction energy.

A description of the visual damage observed is presented in Pinho-Lopes et al. (2002), which includes electronic microscopy observations.

Table 2. Grain size distribution parameters of Soil 1 and Soil 2

Soil	%<0,074mm	d ₁₀ (mm)	d ₃₀ (mm)	d ₅₀ (mm)
Soil 1	5.18	0.22	2.68	11.78
Soil 2	21.53	0.07	0.17	0.38
	d ₆₀ (mm)	d _{max} (mm)	C _U	C _C
Soil 1	19.15	50.80	87.81	1.71
Soil 2	0.68	5.00	9.64	0.58

d_x: effective size diameter at which x% of the soil is finer; d_{max}: maximum soil particle size ; C_U: uniformity coefficient; C_C: coefficient of curvature.

The evaluation of the damage induced was carried out by submitting intact (reference) and damaged materials to the same index tests: wide-width tensile tests (EN ISO 10319), creep rupture tests and creep test (EN ISO 13431).

For the tensile tests, the procedures described in the standard were used, thus, 5 specimens of 200mm width were tested, using hydraulic clamps.

For the creep and creep rupture tests, 3 specimens for each load level were considered. The specimens were 10cm wide. Capstan clamps were used.

3 ANALYSES AND RESULTS

3.1 Tensile tests

The results obtained from the wide-width tensile tests are presented in Table 3 in terms of the tensile strength, strain for rupture and the corresponding values of the coefficient of variation.

The same results are presented in Table 3 in terms of residual tensile strength and residual strain for the tensile strength of the different types of specimens tested. These quantities are defined by the following equation 1:

$$X_{res} = \frac{X_{dam}}{X_{int}} \times 100 (\%) \quad (1)$$

Where X_{residual} is the residual value of the property after DDI (residual strength, T_{res}, or residual strain, ε_{Tmax res}), X_{dam} is the value of the property after DDI (tensile strength and the strain of the damaged material) and X_{int} is the same parameter corresponding to reference (intact) samples.

The lowest values of the residual strength refer to the samples obtained after DDI with Soil 1 and CE2.

From Tables 3 and 4 it is clear that the most aggressive soil is Soil 1, with values for the residual strength of GTX-W of 34% (91%, for Soil 2 CE2). In fact, these differences can be explained by the type of soil: Soil 1 (d₅₀=11.78 mm), with grains larger than Soil 2 (d₅₀=0.38 mm), is more “aggressive” to the geosynthetic inducing more severe consequences.

Table 3. Results obtained from the tensile tests – coefficient of variation of the tensile strength (CV_T), and coefficient of variation of the strain (CV_ε)

GSY	Quantity	Intact material	After DDI field tests		
			Soil 1		Soil 2
			CE1	CE2	CE2
GTX-W	T (kN/m)	77.5	43.7	26.4	70.4
	CV _T (%)	1.8	8.6	5.0	1.0
	ε (%)	13.0	8.9	7.1	11.7
	CV _ε (%)	4.8	13.1	7.9	5.6
	T _{res}	-	56.4	34.0	90.6
	ε _{Tmax res}	-	68.3	54.8	90.7

As expected, the compaction energy used in the field DDI tests influences the changes in the mechanical behavior of the geosynthetic. In fact, higher compaction energy (CE2) corresponds to lower values of the residual strength and strain.

After the DDI field tests it is possible to define values for the corresponding reduction factors (RF) to be used in the design of the geosynthetics (Table 4) from the following equation 2:

$$RF_{DDI} = \frac{T_{int}}{T_{dam}} \quad (2)$$

Where RF_{DDI} is the reduction factor for damage during installation, S_{intact} is the tensile strength of the undamaged material and the S_{damaged} is the tensile strength of the damaged material.

Table 4. Reduction for damage during installation

Geosynthetic	γ _{DDI}		
	Soil 1		Soil 2
	CE1	CE2	CE2
GTX	1.77	2.94	1.10

* It was not possible to obtain this result

The values obtained for the reduction factors for DDI reflect the influence of the factors referred before. These values range from 1.10 (after DDI with Soil 2 CE2) to 2.94 (after DDI with Soil 1 CE2).

More details can be found Pinho-Lopes et al. (2000 and 2002) and Paula et al. (2008).

3.2 Creep rupture tests

In Figure 1 the results obtained from the creep rupture tests are presented, as well as the creep rupture curves and the lower 95% confidence limit curves (LCL 95%) for the different types of samples considered. Such results allow the prediction of the design life of the material, using extrapolations. However, such extrapolations should be done with extreme care and precaution. Thus, the extrapolations have been done for lifetimes of 30 years.

For all the type of samples tested, it is observed that the slope of the creep rupture curves is smaller (0.024 to 0.041) than the one of the corresponding intact material (0.051).

It has to be noted that the scatter of results from the creep rupture tests of most of the damaged materials is large and the correlation factor (R²) for those data trend lines can be quite low (ranging from 0.61

to 0.64). These linear interpolations can be improved if some of the results are not considered. However, it was considered useful to keep all the results obtained in the graphs, as they help to understand the dispersion of behaviour observed after DDI, particularly for the most affected samples (after DDI with Soil 1 and CE2).

Nevertheless, from the results available and for a lifetime of 30 years, it can be determined that the rupture of intact GTX-W would occur for a load of 49.7% of the tensile strength of the material.

The European approaches to design use partial reduction factors to represent the different agents that contribute to the reduction of strength of geosynthetics during their lifetime. Traditionally this is done by using different reduction factors and superposing their effects. With the results obtained in this work, the values of the reduction factors for DDI and creep rupture were determined, by considering the synergy between these two mechanisms, using the methodology described by Pinho-Lopes et al. (2000). More details are presented by Pinho-Lopes (2006).

These reduction factors ($RF_{CR,DDI}$) were determined by using the following equation 3:

$$RF_{CR,DDI,syn} = \frac{T_{1min,ref}}{T_{30y,dam}} \quad (3)$$

Where $T_{1min,ref}$ is the load for rupture after 1 minute for the intact samples (reference) and $T_{30y,dam}$ is the load for rupture after 30 years. The values obtained are presented in Table 5. Obviously, the value presented for the intact materials refers only to the effect of creep rupture (as no damage was induced) and can be designated by RF_{CR} .

The values of these reduction factors range from 1.74 to 11.08. This last and highest value corresponds to DDI with Soil 1 CE2, the material and type of sample most affected by the damage induced in field.

Table 5. Partial reduction factors for creep rupture (after 30 years) and damage during installation – considering synergy

GSY	$RF_{CR,DDI,syn}$			
	Intact	Soil 1		Soil 2
		CE1	CE 2	CE 2
GTX-W	1.74	4.37	11.08	1.92

In Table 6 the values for the reduction factors for creep rupture and DDI determined by the traditional approach (superposition of the effects of creep rupture and DDI considered separately) are presented. These factors are determined by multiplying the partial reductions factors for DDI (RF_{DDI}) and for creep rupture (RF_{CR}) by equation 4:

$$RF_{CR,DDI,trad} = RF_{CR} \times RF_{DDI} \quad (4)$$

Table 6. Partial reduction factors for creep rupture (after 30 years) and damage during installation – traditional approach (superposition of effects)

GSY	$RF_{CR,DDI,trad}$		
	Soil 1		Soil 2
	CE1	CE2	CE2
GTX-W	3.08	5.12	1.91

By comparing the values presented in Tables 5 and 6, it is possible to conclude that for Soil 2 the traditional approach gives a good estimate of the values obtained after inducing DDI and creep rupture of this geosynthetic. However, for the values available referring the materials damaged with Soil 1, the traditional approach leads to unsafe values.

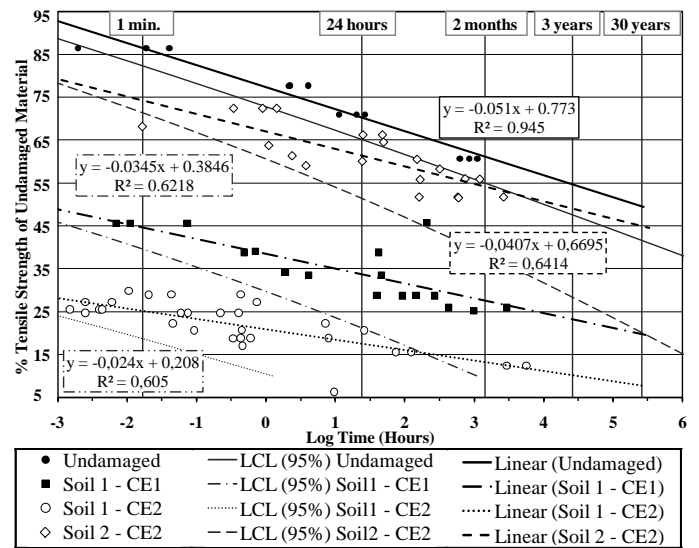


Figure 1. Creep rupture curves obtained for GTX-W

3.3 Creep tests

In this study creep tests were carried out for load levels between 12.4% and 60.7% of the tensile strength of the undamaged GTX-W.

In Figure 2 the results of the creep tests of the GTX-W undamaged and damaged are presented.

For GTX-W, the undamaged specimens loaded with 60.7% of their tensile strength ruptured. The tests of the other specimens, submitted to lower load levels, were stopped after about two months. Therefore, these results should be used with care, particularly when extrapolating values, as there could have been rupture of the specimens for longer times.

Some specimens after DDI also rupture during the creep tests. For this geosynthetic it is evident that the strain ratio increases before rupture, which can be a good indicator that rupture is about to happen.

For the specimens loaded with smaller values of the static load, the strain ratio is constant in time (on a time log scale).

As observed for the other tests results, after damage the scatter of results generally increases.

The strain after one minute of creep test, see Table 7, it is similar for undamaged and damaged samples, with identical levels of applied load. As ex-

pected, the strains obtained for higher load levels applied to the geosynthetics are more important.

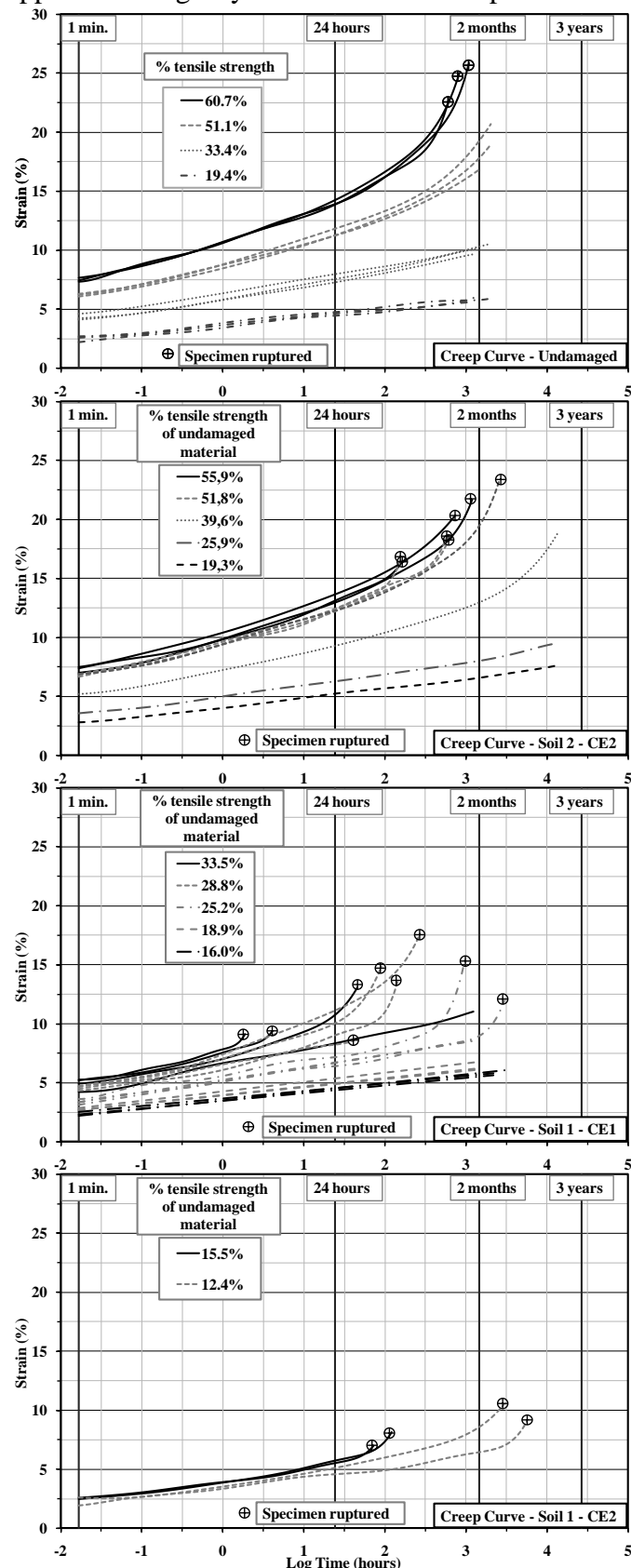


Figure 2. Creep curves of the GTX-W (EN ISO 13431)

In Table 7 the values of the initial strain ratio on time log scale are also presented. This parameter decreases with decreasing applied load level, and it is similar for undamaged and damaged samples with similar load level applied.

Table 7. Strain in percent after 1 minute of creep test and initial strain ratio on log scale time

% tensile strength of undamaged material	Undamaged	Soil 2 - CE2	Soil 1 - CE1	Soil 1 - CE2	Strain (%) after 1 minute of creep test
≈51	6.19	6.82	*	*	
≈34	4.31	*	4.90	*	
≈25	*	3.59	3.36	*	
≈19	2.50	*	2.76	*	
≈16	*	*	2.34	2.54	
≈56 - 60	2.12	2.30	*	*	Initial strain ratio on log scale time
≈51	1.74	1.91	*	*	
≈34	1.25	*	1.73	*	
≈25	*	0.97	1.06	*	
≈19	0.71	0.81	0.69	*	
≈16	*	*	0.66	1.02	

4 CONCLUSIONS

From and for the results presented it is possible to conclude:

- The soil with larger particles is more aggressive (Soil 1) and higher compaction energy (CE2) leads to higher reduction of mechanical properties.
- The partial reduction factors for the combined and simultaneous effect of DDI and creep were analyzed and compared with values for the traditional approach (superposition of effects). In some cases (that correspond to the most severe conditions) the traditional approach leads to unsafe values. These results have to be confirmed by longer time tests.
- For the creep tests, the strains increase with the load level applied to the specimens. The increase in the strain ratio allows anticipation of the rupture.

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