Partial Safety Factors in the Design of Permanent Reinforced Structures

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ABSTRACT: The following three causes of degradation were considered in the present paper: installation, chemical aggression and creep. The results obtained show that PET woven high strength geotextile used seems to be mainly affected by installation damage. At temperature below vitreous transition and with usual tensile force applied, the creep s not contribute significantly to the deformation of the PET, but is always necessary to asses the effects of coatings.

1. INTRODUCTION

Reinforced soil is a compound material: a relatively large amount of the less costly material, unable to resist tensile stress, like the soil, has its engineering features improved by combining it with a relatively small amount of more valuable material, highly resistant to tensile strength (Allen et al. 1991, Dondi, 1990).
The variables to keep in mind in reinforced soil design include: degradation in ultraviolet light (UV), damage from installation (ID), creep (CR), chemical ageing (CA), biological degradation (BD) and strength reduction due to the presence of connection or junctures (CJ). Their effects on the long-term resistance of the geosynthetic are represented as:

$$S_a = S_{ult} / SF \geq T_{app} \quad (1)$$

where: $SF = SF_{UV} \cdot SF_{ID} \cdot SF_{CR} \cdot SF_{CA} \cdot SF_{BD} \cdot SF_{CJ}$, S_a = long-term strength, S_u = Short-term strength, T_{app} = Force applied.

2. GENERAL FEATURES

In order to verify and amplify the data available in the international bibliography (Troost, 1990) on PET woven geotextiles, a broad-ranging program was launched within the Roads Constructions and Geotechnics Institute of the University of Bologna, for laboratory experimentation on such specimens of Woven PET high strength geotextile (nominal values - warp: $\alpha_f = 400$ kN/m, $\varepsilon_f = 10$ %; weft: $\alpha_f = 50$ kN/m, $\varepsilon_f = 12$ %; O_{90}(dry) = 200 μm).

The experimental program included a series of tensile tests (ASTM-D4595) with uncoated PET specimens ("natural") and with coated PET specimens with a bituminous emulsion based on mineral turpentine solvent. The experimentation analysing the three most common degradation factors for reinforcement geosynthetics (Elias, 1990); mechanical degradation (abrasions, impact) suffered during installation and compacting of the overlying soil; prolonged exposure to strongly alkaline and acid environments; creep behaviour and the effects of temperature.
The installation damage is examined for the most commonly used soil in building risers (see table 1).

Table 1 - Data on the soils used to compact the samples

Sample	1	2	3	4	5
AASHTO	A_{1-a}	A_{1-b}	A_{1-b}	A_3	A_4
USCS	SP	SW	SW	SP	SC-SM
w_L (%)	19.75	17.55	16.45	25.10	20.63
w_P (%)	und	13.45	13.23	und	16.60
I_P	0	4.10	3.22	0	4.03
I_f	und	7.50	10.85	und	6
C_u	5.56	69	100	2	280
C_c	1.3	2.7	2.8	1.5	---
γ_d (kN/m³)	16.75	22.25	23.18	15.43	19.64

Most of the samples obtained as described above were then immersed in buffer solutions at pH 1, 7, 9, 11, and

13, and are still kept there for seasoning. The test schedule has intervals between 0 and 360 days.
The solutions were obtained as follows: the one at pH 1 by means of appropriately diluted citric acid; the one at pH 7 by dissolving preservatives, citric phosphate acid, in water; for higher pH levels (9, 11, 13) by dissolving the appropriate amount of sodium hydrate (NaOH) in water. This is important to specify, as the behaviour of polyester in buffered solutions depends on the type of chemical agent used. It was thereby possible to assess, on a reinforcement with microlesions caused by installation, both the effects of compacting and the aggravation caused by exposure to high pH levels.
As far as creep is concerned, the specimens were kept under a load for several days. In addition to simple tests, some specimens were also subjected simultaneously to thermal cycles, ranging from room temperature (20 °C) to temperatures of 90 °C, approximately every twelve hours beyond its vitreous transition temperature (67 °C).

3. RESULTS

During the test, it was found that in the coated specimens the threads break simultaneously, since the bituminous binder allows the stress to be distributed more evenly. Table 2 shows the characteristics of "natural" and coated PET.

Table 2- Basic values of "natural" and coated PET

Characteristic	"Natural" PET	Coated PET
α_f (kN/m)	360 - 380	360 - 380
ε_f (%)	25	26
J_f (kN/m)	1500	1400

3.1 Installation damage

Allen (1989) has published a paper including experimentation on results obtained of strength on geotextile after installation. Figure 1 show the decreasing of α_f after compaction beneath the soils listed in table 1 obtained in our laboratory.
The bituminous coating, which should act as a protection especially against chemical ageing, actually also protects against installation damage as well.

3.2 Chemical ageing

The resistance remains nearly constant for any chemical environment up to approximately 60 days from the start of the seasoning, as hydrolysis phenomena require a certain amount of time before they can begin making their influence felt. The resistance in a very acid environment (pH=1) remains approximately equal to that in a neutral environment (pH=7); while as we progress towards high pH levels (pH_{MAX} =13) the "natural" PET loses resistance

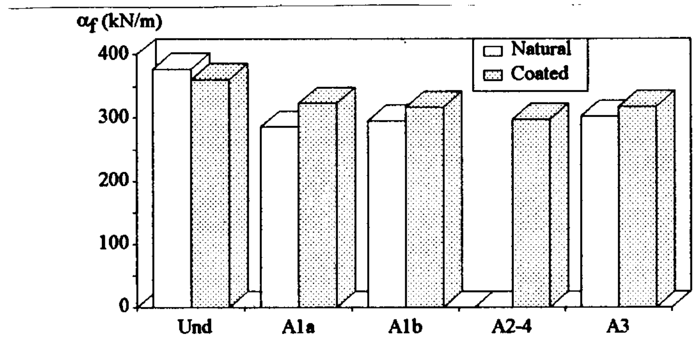

Figure 1 - Average resistance of PET specimens, both undisturbed and compacted under various soils

in proportion to the seasoning time.
As early as pH=11, after 360 days of seasoning, the natural material undergoes a significant reduction in resistance, as shown in figure 2. In this area, the bitumen coating appears to serve its protective function fairly well: the coated PET maintains a nearly constant resistance even at pH 13.

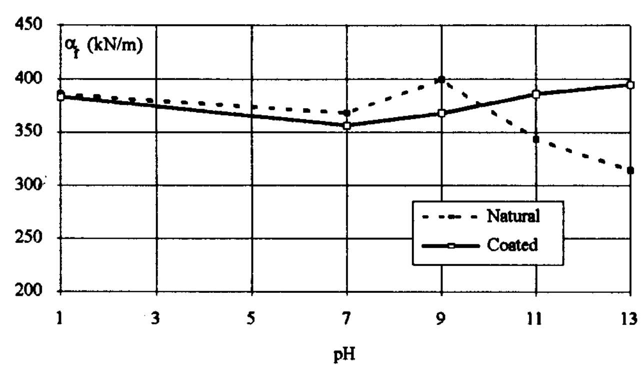

Figure 2. Tensile strength of undisturbed PET samples, seasoned for 360 days at various pH levels

The basic tendency found, then, is reduced resistance in highly alkaline environments, only for "natural" samples, due to hydrolysis.
Failure strain remain constant in coated samples, while they fall in "natural" samples in proportion to the diminished resistance. The average values of α_f, ε_f, and J_f are summarised in table 3.

3.3 Combined chemical ageing and installation damage

For take into account a possible combined action of damaging factors applied in sequence tensile tests were performed on specimens which were seasoned at various pH levels after first being compacted under various soils. We can observe that there is greater damage when compacting inside layers made up of fine materials A_{2-4} rather than gravels such as A_{1-a} or A_{1-b}. This behaviour may be due to the fact that, since the polyester is considerably beneath the vitreous transition temperature, the greater strains damage it more than the punctures or abrasions caused by sharp cobbles. This hypothesis is supported by the fact that the difference in resistance between the "natural" and coated samples is insignificant, since the deformation damage is such that the coating is no longer capable of carrying out its protective function. It is quite interesting to note that, while for "natural" samples installation caused a drop in resistance for all types of soils, when the samples are coated the only significant drop in resistance occurs with type A_{2-4} soil. This damage then also affects long-term behaviour, which only in this instance tends to fall.

Table 3 - Characteristic of specimens after 360 days in an alkaline environment (pH 11 and 13)

Characteristic	"Natural" PET	Coated PET
α_f (kN/m)	300 - 310 (-20%)	360 - 380 (=)
ε_f(%)	20 (-20 %)	26 (=)
J_f(kN/m)	1500 (=)	1400 (=)

4. CREEP

In the creep tests final stress was reached by increasing the constant load by 5 kN/m·s.

4.1 Creep at the environmental temperature (20 °C)

An examination of figure 3 immediately reveals that the deformations in the coated specimens are much greater than those in the "natural" ones.

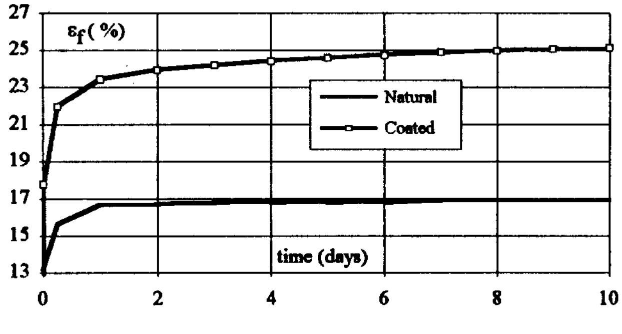

Figure 3 - Deformation of PET specimens subjected to a constant load of 260 kN/m

This fact appears to confirm that the substances covering the material (solvent-based bituminous emulsions) could act as a lubricant between the polymer chains, thus causing an increase in deformation.
In terms of creep, the bituminous protection forms a good defence against chemical agents and installation damage as well, but it will generally make the material more sensitive to the action of creep.

4.2 Creep at high temperatures (thermal cycle 20°- 90° C)

In these tests (see figure 4), a further decrease in the tensile strength was found.
The coated material breaks after a few hours at 255 kN/m, while at the environmental temperature no signs appear of giving way to collapse even after 10 days at 260 kN/m. In addition, as shown in figure 4, the deformations at 90° C are much greater than those that occur at 20 °C, and the portions of the diagram in which $T \geq T_g$ have a greater slope than the other sections.

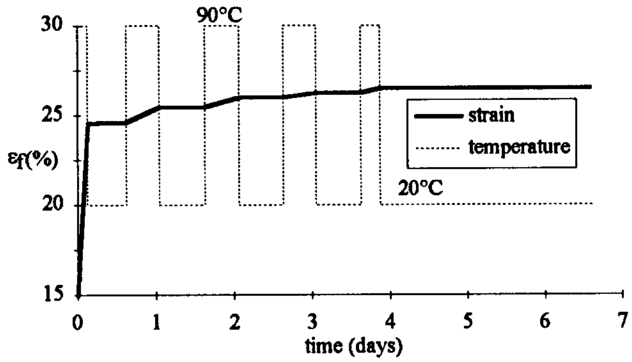

Figure 4. Creep test at 220 kN/m on coated PET subjected to thermal cycles of 20° - 90° C.

Another very interesting aspect that was found in the high-temperature tests is the reduced breakage resistance for creep in "natural" PET. Up to this point, no breakage had been encountered in the uncoated samples, despite the high stress reached (as high as 300 kN/m ~ $0.8 \cdot \alpha_f$). Instead, in performing the test with thermal excursions beyond the vitreous transition temperature as shown in figure 5, breakage is reached after nearly two days under a pressure of 293 kN/m, almost identical to the above. In this diagram it was also possible to read the third creep stage. The last section (quite short, in truth) shows that the sample reached breakage with higher deformation rate than before.
The creep tests that most interest the planner, thus which provide partial safety coefficients, are certainly not those at high temperatures: it is quite unlikely that temperatures close to 90 °C be reached in practice (except in special stages of the work or in the event of a fire), and in any case above the vitreous transition point. One of the

positive aspects of PET over other polymers used to reinforce the land is indeed the fact that at the environmental temperature it is below T_g.
Thus while on the one hand, having a T_g = 67 °C is negative as far as installation damage is concerned (we have seen how PET, due to its vitreous state, is more subject to cuts or abrasions and distortion in the presence of deformation-prone soils such as A_{2-4}), on the other hand this offers obvious advantages towards creep.

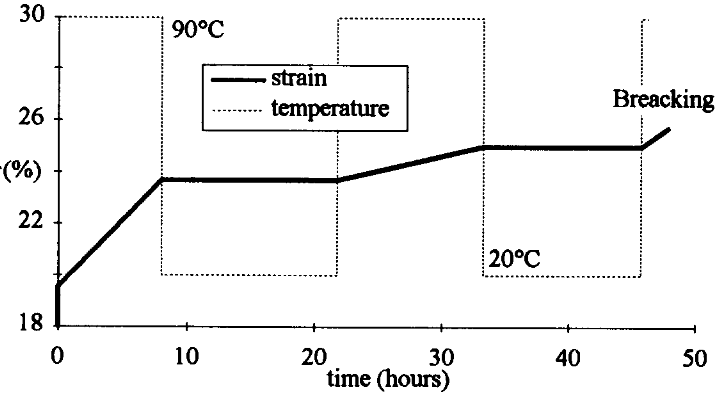

Figure 5. Creep test at 294 kN/m on "natural" PET subjected to thermal cycles of 20°-90° C

5. CONCLUSIONS

The tests run have confirmed that, since the polymer at room temperature is below the vitreous transition temperature, the distortion suffered by the material during installation may indeed cause greater damage than is the case in other polymers, more subject to abrasions or microlesions.
Experiments on specimens inserted in experimental risers showed that a protective film offers a fair protection, as long as soils are not used which deformation-prone to the point of distorting the reinforcement. The same coating generally offers good protection against chemical ageing but increasing creep phenomena.
If seasoned at pH 7-9, in an environment more similar to that found in nature, no appreciable problems are found over time; however, the experimentation continues, as it is still somewhat limited (1.5 years).
A separate mention goes to a coating aimed at protecting the geotextile so as to block hydrolysis, as in many cases the geotextile is in direct contact with hydraulic bonds that create a highly basic environment. First of all it was found that, when the installation damage is fairly serious, the mechanical protection may not be as effective as it was originally. In addition, it is essential to study any changes induced on the reinforcement by the coating, both regarding the resistance (α_{fmax}) and deferred deformation.

Therefore, in order to take all of these aspects into account, partial safety factors are proposed based on the experimentation (Table 5).

Table 5 - Partial safety factors for PET reinforcements inserted in permanent works

PET	"natural"	coated
Installation damage	1.5 - 2.0	1.3 - 1.5
Chemical ageing	1.3 - 1.5	1.1 - 1.3
Creep	2.0	3.0

It will also be a good idea to increase the partial security factor for chemical ageing, as high as 2, in the case of environments particularly aggressive to PET (such as, for example, direct contact with $Ca(OH)_2$, etc.).
Taking these partial safety factors into account, we arrive at a very high overall safety factor (F = 5-6), to which the other factors listed above should be muliplied.

6. REFERENCES

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