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Resistance of a nonwoven geotextile against mechanical damage and abrasion

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Abstract

The installation procedures (which induce mechanical damage) and abrasion can cause unwanted changes on the properties of the geotextiles. In this work, a nonwoven polypropylene geotextile was subjected to three degradation tests: (1) mechanical damage, (2) abrasion and (3) mechanical damage followed by abrasion (successive exposure). The damage caused by the degradation tests was evaluated by tensile, tearing and static puncture tests. Based on the changes occurred in the mechanical properties, reduction factors were determined. Results showed that the degradation tests provoked relevant reductions in the mechanical strength of the geotextile (higher reductions in the successive exposure to both degradation tests). The reduction factors for the combined effect of mechanical damage and abrasion obtained in the successive exposure to both degradation tests were different (slightly higher) than those obtained by the traditional methodology (determination of reduction factors separately for each degradation test and further multiplication).

Keywords: Geosynthetics; geotextiles; nonwoven; mechanical damage; abrasion; reduction factors.

1. Introduction

Geotextiles are polymeric materials widely used in the construction of many civil engineering structures (like waste landfills, roads, railways, reservoirs or coastal engineering structures) due to technical, economic and environmental advantages. These materials are able to perform many different functions, such as separation, protection, reinforcement, filtration or drainage.

In their applications, the geotextiles can be in contact with many agents capable of having a negative impact on their short and long-term behaviour (deterioration of their physical, mechanical or hydraulic properties). The most common agents and/or types of degradation include: installation damage, abrasion, creep, action of liquids (like water or leachates), oxidation, weathering and the action of biological agents [1].

The damage that occurs during the installation process is originated essentially from handling the geotextiles and from the placement and compaction of backfills over them [2]. For some applications, the stresses due to the installation process can be higher than those in service [3]. The abrasion process results from a cyclic motion (friction) between the geotextiles and a contact surface [4].

Reduction factors are often applied in the design with geotextiles to account for the degradation that occurs over time. For example, for reinforcement applications the properties of the geotextiles are typically affected by a set of reduction factors related with installation damage, creep, atmospheric agents and chemical and biological agents [5,6]. Each partial reduction factor is determined separately (not considering the possibility of interactions between different degradation agents).

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The global reduction factor (used in design) is found by multiplying the different partial reduction factors.

The reduction factor for installation damage should be preferably obtained by field installation damage tests with similar conditions to real ones [7]. The reduction factors are very sensitive to the conditions used in the degradation tests, which implies some caution in their determination (the reduction factors need to represent accurately the degradation under real conditions).

A laboratory procedure (EN ISO 10722 [8]) has been developed to induce mechanical damage in geotextiles (and other geosynthetics). This method has been used by many authors to try to simulate installation damage conditions. However, the laboratory damage tests are unable to reproduce always the installation conditions or installation damage. This way, the term mechanical damage is used in this paper.

The standard tests for durability evaluation, the design methods and most studies found in literature about the durability of geotextiles consider the isolated action of the degradation agents. However, in real situations, the geotextiles will often be in contact with more than one agent. Thus, the damage suffered by the materials will always be the combined action of the different agents, which may be much different from the sum of their individual actions [9].

This paper studies the resistance of a geotextile against mechanical damage and abrasion. The main objectives of the work included: (1) determination of the effect of the degradation mechanisms in many properties of the geotextile and (2) comparison of the reduction factors obtained by the traditional methodology and by a new approach (successive exposure to both agents) for the combined effect of mechanical damage and abrasion.

2. Experimental description

2.1. Geotextile

The geotextile studied in this work was a nonwoven needle-punched made from polypropylene fibres with a linear mass of 8 denier and a length of 75 mm. The fibres were stabilized against the effects of thermo and photo-oxidation (the identity and the concentration of the stabilizers were not revealed by the producer). The geotextile had a mass per unit area of 300 g/m^2 and a thickness of 2.51 mm.

The sampling and preparation of test-specimens (for the characterization and degradation tests) were carried out according to EN ISO 9862 [10]. The specimens (prepared in the machine direction of production) were taken from positions evenly distributed over the full width and length of the sample (supplied in roll). The area next to the edges of the roll (about 100 mm) was rejected. The specimens for the same test were taken from different longitudinal and transverse positions of the roll.

2.2. Degradation tests

The geotextile was exposed to three degradation tests: (1) mechanical damage, (2) abrasion and, finally, (3) mechanical damage followed by abrasion (successive exposure to both degradation mechanisms).

The mechanical damage tests followed the guidelines of EN ISO 10722 [8]. The geotextile specimens were placed between two layers of a synthetic aggregate of aluminium oxide (corundum) and subjected to dynamic loading (ranging between 5 ± 0.5 and 500 ± 10 kPa) at the frequency of 1 Hz for 200 cycles. The grain size of corundum ranged from 5 to 10 mm. The equipment (a prototype) employed in the mechanical damage tests was formed by a test container (rigid metal box where the specimens and corundum were placed), a loading plate and a compression machine (a full description of the equipment can be found in [11]).

The abrasion tests were performed according to EN ISO 13427 [12]. These tests consisted in placing the geotextile in a stationary platform where it was rubbed by a P100 abrasive. The abrasive (installed in a slider plate) was moved under controlled pressure (6 kPa) along a horizontal axis (cyclic uniaxial movement) for 750 cycles. The equipment (a prototype) used in the abrasion tests was in compliance with the requisites of EN ISO 13427 [12].

2.3. Evaluation of the damage caused by the degradation tests

The damage suffered by the geotextile (in the different degradation tests) was assessed by visual analysis and by monitoring the evolution of some mechanical and physical (thickness) properties. Thickness (obtained at 2 kPa pressure) was determined according to EN ISO 9863-1 [13]. The mechanical characterization included tensile tests (according to EN ISO 10319 [14]), tearing tests (following the guidelines of ASTM D4533 [15]) and static puncture tests (according to EN ISO 12236 [16]).

The mechanical characterization tests were performed in a tensile machine from *Lloyd Instruments* (model LR 50K) equipped with a load cell of 5 kN (also from *Lloyd Instruments*). Elongation was measured using a video-extensometer. Thickness was determined with a *Karl Schröder KG* equipment.

The mechanical properties obtained in the tensile tests were tensile strength (TS, in kN/m) and elongation at maximum load (E_{ML}, in %). Tearing strength (F_T, in N) and static puncture resistance (F_P, in kN) were the parameters obtained in the tearing and static puncture tests, respectively.

The confidence intervals for the obtained results (95% confidence) were calculated according to Montgomery and Runger [17]. Some results are expressed in terms of retained resistance (RR, in %). This parameter was obtained by dividing the resistance (tensile, tearing or puncture) of the damaged samples by the respective resistance of reference samples (undamaged).

2.4. Determination of reduction factors

Reduction factors (RF) were determined based on the changes occurred (during the degradation tests) in the mechanical properties of the geotextile. The reduction factors for the effects of mechanical damage (RF_{MD}), abrasion (RF_{ABR}) and mechanical damage followed by abrasion (RF_{MD+ABR}) were obtained by:

$$RF = R_{Reference}/R_{Damaged} \quad (1)$$

where $R_{Reference}$ and $R_{Damaged}$ represent, respectively, the mechanical resistance (tensile, tearing or puncture) of the geotextile before and after the degradation tests.

The reduction factors obtained in this work correspond to particular conditions and cannot be generalized nor applied directly in design. The reduction factors to be used in design must be assessed case by case, taking into account the exact conditions of each construction.

3. Results and Discussion

3.1. Visual evaluation of damage

The degradation tests led to different types of damage in the geotextile. The mechanical damage tests caused cuts in fibres, small holes and imprisonment of fine particles (arising from the fragmentation of corundum) in the nonwoven structure of the geotextile.

The abrasion tests led to cuts in fibres, which lined up and formed clusters perpendicularly to the direction of movement of the abrasive. These tests also provoked a shrinkage of about 2.5% in the specimen's width.

The type of damage caused by the successive exposure to mechanical damage and abrasion was similar to abrasion (single exposure), but more marked (more fibres were cut and the clusters tended to be bigger). Fig. 1 compares the damage found in the geotextile after the different degradation tests.

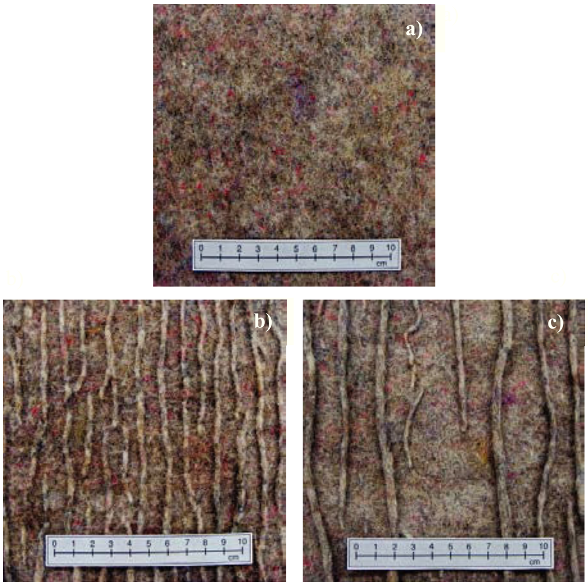

Fig. 1. Nonwoven geotextile: a) after mechanical damage (global appearance similar to undamaged – the defects cannot be seen at this magnification), b) after abrasion and c) after mechanical damage followed by abrasion.

3.2. Evolution of thickness

The degradation tests caused some relevant changes in the thickness of the geotextile. Indeed, the thicknesses after abrasion (4.39 ± 0.10 mm) and after mechanical damage followed by abrasion (4.21 ± 0.14 mm) were higher than the reference thickness (2.51 ± 0.11 mm). These increases in thickness were due to the clusters of fibres formed at the surface of the geotextile after those tests (Figs. 1 b) and c)). By contrast, the mechanical damage tests did not cause significant modifications in thickness (2.59 ± 0.11 mm).

3.3. Evolution of mechanical properties

The mechanical damage test caused a decrease in the TS and E_{ML} of the geotextile (reductions of 38.2% and 25.8%, respectively). The changes in tensile properties induced by abrasion (reduction of 20.2% in TS and no relevant changes in E_{ML}) were less marked than those provoked by the mechanical damage test. The highest reductions in tensile properties were observed after the successive exposure to both degradation tests (60.1% decrease in TS and 44.3% decrease in E_{ML}) (Table 1). The mean curves "tensile force-elongation" (obtained before and after the degradation tests) are illustrated in Fig. 2. In addition to changes in TS and E_{ML}, these curves also show that the degradation tests provoked a reduction in stiffness at higher elongations.

Table 1. Tensile properties of the geotextile, before and after the degradation tests.

Degradation test	TS (kN/m)	E_{ML} (%)	RR (%)
Reference	15.43 (± 0.93)	103.5 (± 11.8)	-
MD	9.53 (± 1.32)	76.8 (± 12.4)	61.8
Abrasion	12.31 (± 1.23)	99.9 (± 17.9)	79.8
MD + Abrasion	6.16 (± 1.55)	57.4 (± 9.1)	39.9

(in brackets are the 95% confidence intervals)

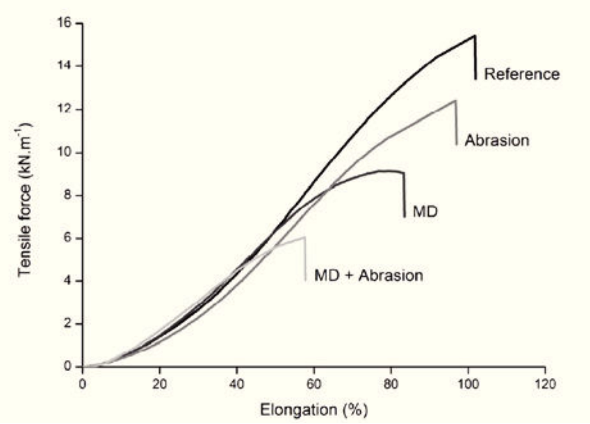

Fig. 2. Mean curves "tensile force-elongation" obtained before and after the degradation tests.

Like for TS, the degradation tests also led to relevant reductions in F_T (Table 2). The highest decrease was once again caused by the exposure to both degradation tests (reduction of 47.2% in F_T). The lowest reduction in F_T (17.9%) was found after the abrasion test.

Table 2. Tearing properties of the geotextile, before and after the degradation tests.

Degradation test	F_T (N)	RR (%)
Reference	375 (± 25)	-
MD	252 (± 18)	67.2
Abrasion	308 (± 30)	82.1
MD + Abrasion	198 (± 36)	52.8

(in brackets are the 95% confidence intervals)

Similarly to what happened for TS and F_T, significant reductions were also found in F_P after the degradation tests (Table 3). As before, the successive exposure to mechanical damage and abrasion provoked the highest decrease (reduction of 55.9% in F_P). The abrasion test was again the less damaging.

The changes occurred in TS, F_T and F_P were relatively similar (retained resistances very close). For instance, the retained resistances ranged from 79.8% to 82.8% after abrasion. This way, the degradation tests affected identically the different mechanical properties (TS, F_T and F_P) of the geotextile.

Table 3. Static puncture properties of the geotextile, before and after the degradation tests.

Degradation test	F_P (kN)	RR (%)
Reference	2.79 (± 0.20)	-
MD	1.76 (± 0.60)	63.1
Abrasion	2.31 (± 0.45)	82.8
MD + Abrasion	1.23 (± 0.34)	44.1

(in brackets are the 95% confidence intervals)

3.4. Reduction factors

Due to the reductions occurred in mechanical strength, the highest reduction factors (between 1.89 and 2.50) were found for the successive exposure to mechanical damage and abrasion. The isolated effect of abrasion led to the lowest reduction factors (between 1.21 and 1.25). The reduction factors obtained in the different degradation tests can be seen in Table 4.

Table 4. Reduction factors obtained in the degradation tests.

	TS	F_T	F_P
RF_{MD}	1.62	1.49	1.59
RF_{ABR}	1.25	1.22	1.21
RF_{MD+ABR}*	2.50	1.89	2.27

(* successive exposure)

By the traditional methodology (considers the isolated effect of the degradation agents), the reduction factor for the combined effect of mechanical damage and abrasion can be obtained by multiplying the reduction factors determined individually for each agent (RF_{MD} x RF_{ABR}). Fig. 3 illustrates a comparison between the reduction factors thereby obtained and those found in the successive exposure to both agents.

The reduction factors found in the successive exposure to mechanical damage and abrasion were higher than those obtained by the traditional methodology for the combined effect of both agents. The highest difference was found for TS (reduction factors of 2.50 and 2.02, respectively). By contrast, for F_T, the difference was quite small (1.89 and 1.82, respectively).

The previous results indicate that the reduction factors determined by the traditional methodology may not be representing correctly (underestimating) the combined action of mechanical damage and abrasion. Indeed, the traditional methodology was less conservative, tending to give smaller reduction factors.

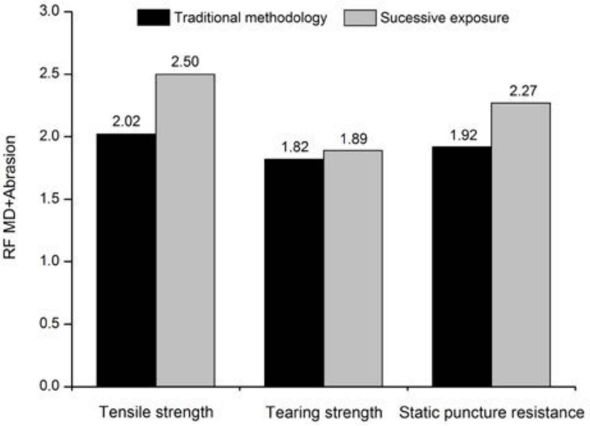

Fig. 3. Comparison of the reduction factors (RF_{MD+ABR}) obtained by the traditional methodology and by the successive exposure to both degradation agents.

4. Conclusions

The degradation tests caused relevant decreases in the tensile strength, elongation at maximum load, tearing strength and static puncture resistance of a nonwoven geotextile. The decreases provoked by the mechanical damage tests were more pronounced than those caused by the abrasion tests. The successive exposure to both degradation mechanisms led to the greatest reductions in the mechanical properties of the geotextile. Within each test, the mechanical properties (tensile strength, tearing strength and static puncture resistance) were identically affected (similar retained resistances).

The reduction factors found in the successive exposure to mechanical damage and abrasion were higher than those determined by multiplying the reduction factors obtained individually for each degradation mechanism (traditional method). Therefore, the multiplication of two reduction factors (each representing a degradation mechanism) may not always represent accurately the combined action of both mechanisms.

The definition of reliable reductions factors (taking into account the interactions that can occur between the different agents and/or degradation mechanisms) may contribute to improve the application of geosynthetics in civil engineering. Indeed, a better definition of these factors (more accurate) may led to a better design. For recognizing interactions in the degradation process of the geosynthetics, further studies (with more materials and different combinations of degradation agents) are being carried out by our research team.

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References

[1] R.M. Koerner (Ed.), Designing with Geosynthetics, Prentice-Hall, Upper Saddle River, New Jersey, USA, 1999.

[2] M.J.F. Pinho-Lopes, M.L. Lopes, Durability of Geosynthetics, FEUP Edições, Porto, Portugal, 2010.

[3] S.K. Shukla, Fundamentals of Geosynthetics, in: S.K. Shukla (Eds.) Handbook of Geosynthetic Engineering, 2nd ed., ICE Publishing, London, UK, 2011, pp. 1-54.

[4] A. Rosete, P.M. Lopes, M. Pinho-Lopes, M.L. Lopes, Geosynth. Int. 20(5) (2013) 358.

[5] D.M. Carlos, J.R. Carneiro, M. Pinho-Lopes, M.L. Lopes, Int. J. Geosynth. Ground Eng. 1 (2015) 9.

[6] ISO/TR 20432: Guideline for the determination of the long-term strength of geosynthetics for soil reinforcement, 2007.

[7] R.J. Bathurst, B. Huang, T.A. Allen, Geotext. Geomembr. 29 (2011) 323.

[8] EN ISO 10722: Geosynthetics - Index test procedure for the evaluation of mechanical damage under repeated loading. Damage caused by granular material, 2007.

[9] J.R. Carneiro, P.J. Almeida, M.L. Lopes, Constr. Build. Mater. 73 (2014) 586.

[10] EN ISO 9862: Geosynthetics – Sampling and preparation of test specimens, 2005.

[11] M.P. Lopes, M.L. Lopes, Geotecnia 98 (2003) 7.

[12] EN ISO 13427: Geotextiles and geotextile-related products – Abrasion damage simulation (sliding block test), 1998.

[13] EN ISO 9863-1: Geosynthetics – Determination of thickness at specified pressures. Part 1: Single layers, 2005.

[14] EN ISO 10319: Geosynthetics – Wide-width tensile test, 2008.

[15] ASTM D4533: Standard test method for trapezoid tearing strength of geotextiles, 2011.

[16] EN ISO 12236: Geosynthetics – Static puncture test (CBR test), 2006.

[17] D.C. Montgomery, G.C. Runger (Ed.), Applied Statistics and Probability for Engineers, 5th ed., Wiley, New York, USA, 2010.