Resistance of nonwoven geotextiles against mechanical damage under repeated loading and abrasion

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ABSTRACT: The installation procedures (which may provoke mechanical damage) and abrasion can cause unwanted changes in the physical, mechanical and hydraulic properties of the geotextiles, affecting their performance. This work evaluates the resistance of two nonwoven geotextiles (with different masses per unit area) against two degradation mechanisms: damage under repeated loading and abrasion. First, the geotextiles were exposed to each degradation mechanism in isolation and, then, exposed successively to mechanical damage under repeated loading and abrasion. The damage suffered by the geotextiles (during the degradation tests) was evaluated by visual inspection and by monitoring their mechanical properties (by tensile, tearing and static puncture tests). Based on the changes occurred in the mechanical properties, reduction factors were determined. The reduction factors obtained in the successive exposure to mechanical damage under repeated loading and abrasion were compared with the reduction factors obtained by the traditional methodology for the combined effect of those degradation mechanisms.

Keywords: geotextiles, degradation, mechanical damage, abrasion, reduction factors

1 INTRODUCTION

In their applications, the geosynthetics can be exposed to many degradation agents capable of affecting their short and long-term behaviour. The most common degradation agents include: chemical species (like acids or alkalis), oxidation, weathering agents, biological agents, creep or abrasion. The installation procedures may also cause damage to the geosynthetics. In many applications, the geosynthetics must perform their functions for a long period of time, being therefore important to evaluate their resistance against degradation. This work evaluates the resistance of two geotextiles against two degradation mechanisms: mechanical damage under repeated loading and abrasion.

The damage that occurs during the installation process (for example, cuts in fibres or other components, tears, holes, abrasion or reduction in mechanical strength) is originated essentially from handling the geosynthetics and from the placement and compaction of backfills over them (Pinho-Lopes & Lopes, 2010). In some applications, the stresses suffered by the geosynthetics during the installation processes can be higher than those in service, and therefore need to be considered in design (Shukla, 2013). The abrasion process results from cyclic motion (friction) between the geosynthetics and a contact surface.

Reduction factors are often used in design to account for the degradation that geosynthetics suffer over time. Each reduction factor normally represents a decrease in resistance (known or estimated) due to the action of one, or more, degradation agents. The number and type of reduction factors to be considered in design depends on the design method and on the particular conditions of the construction. For instance, in reinforcement applications, the tensile strength of the geosynthetics is typically affected by a set of reduction factors, representing the effects of mechanical damage, creep, atmospheric agents and chemical and biological agents.

The actual design methods do not consider the occurrence of interactions between the degradation agents of the geosynthetics. The standardized tests available for evaluating the durability of geosynthetics and most studies found in literature about this theme also consider the isolated action of the degradation agents. However, in real cases, the geosynthetics will hardly be under the action of a single degradation agent. Thus, the damage occurred in the geosynthetics will always be due to the combined effect of various degradation agents, being possible the occurrence of interactions between them. Indeed, the combined effect of two degradation agents can be different (more severe) from the sum of their individual actions (Carneiro, 2014).

In this work, two geotextiles with different masses per unit area were exposed to mechanical damage under repeated loading, abrasion and mechanical damage under repeated loading followed by abrasion (combined action). The main goals of the work included: (1) determination of the effect of the degradation mechanisms in some mechanical properties of the geotextiles, (2) evaluation of the existence of interactions between the degradation mechanisms and (3) comparison of the reduction factors obtained for the combined effect of mechanical damage under repeated loading and abrasion by the traditional methodology (determination of the reduction factors in isolation for each degradation mechanism and further multiplication) and by the successive exposure to both degradation mechanisms.

2 EXPERIMENTAL PROGRAM

2.1 *Geotextiles*

This work studied two nonwonven needle-punched geotextiles with different masses per unit area. The designations used for the geotextiles (G250 and G450) were related with their nominal mass per unit area (250 and 450 g.m^{-2}, respectively). The main characteristics of the geotextiles can be found in Table 1.

Table 1. Main characteristics of the geotextiles

Geotextile	Polymer	MUA* (g.m^{-2})	Thickness** (mm)
G250	Polypropylene	262 (19)	2.37 (0.13)
G450	Polypropylene	470 (20)	3.55 (0.22)

*mass per unit area (determined according to EN ISO 9864)
**determined according to EN ISO 9863-1
(in brackets are the obtained standard deviations)

The sampling process (for the characterisation and degradation tests) was carried out according to EN ISO 9862. The specimens (prepared in the machine direction of production) were cut from positions evenly distributed over the full width and length of the geotextiles (supplied in rolls), but not closer than 100 mm to the edges. The specimens for the same degradation test were taken from different longitudinal and transverse positions of the roll.

2.2 *Degradation tests*

Initially, the geotextiles were exposed in isolation (single exposure) to the actions of mechanical damage under repeated loading and abrasion (description of the experimental conditions of these tests in the following subsections). Then, the geotextiles were exposed consecutively to mechanical damage under repeated loading and abrasion (multiple exposure).

2.2.1 *Mechanical damage under repeated loading tests*

The mechanical damage under repeated loading tests (for simplification, hereinafter called by mechanical damage tests) were carried out according to EN ISO 10722. The geotextiles were placed between two layers of a synthetic aggregate (*corundum*) and were subjected to dynamic loading between (5 ± 0.5) kPa and (500 ± 10) kPa at the frequency of 1 Hz for 200 cycles. The aggregate (grain size between 5 and 10 mm) was sieved (5 mm aperture sieve) after every 3 uses (the particles retained in the sieve were reused) and totally discarded after 20 uses. The test-equipment (a prototype) was formed by a container (rigid metal box where the geotextiles and *corundum* were placed), a loading plate and a compression machine.

2.2.2 *Abrasion tests*

The abrasion tests were performed according to EN ISO 13427. These tests consisted in placing the geotextiles in a stationary platform where they were rubbed by a P100 abrasive. The abrasive (installed in a sliding plate) was moved under controlled pressure (6 kPa) along a horizontal axis. The test ended after 750 cycles (each cycle corresponded to a double passage of the abrasive by the geotextiles).

2.3 *Evaluation of the damage suffered by the geotextiles*

The damage occurred in the geotextiles (during the degradation tests) was evaluated by visual inspection and by monitoring some mechanical properties. The mechanical characterisation of the materials was carried out by tensile tests (EN ISO 10319), by tearing tests (ASTM D4533) and by static puncture tests (EN ISO 12236). The experimental conditions of the mechanical tests are summarized in Table 2.

Table 2. Experimental conditions of the mechanical tests

Mechanical test	Tensile test	Tearing test	Static puncture test
Test standard	EN ISO 10319	ASTM D4533	EN ISO 12236
Specimens type	Rectangular	Rectangular	Circular
Specimens size	200 mm x 100 mm*	76 mm x 200 mm	150 mm**
Number of specimens	5	10	5
Test speed	20 mm.min^{-1}	300 mm.min^{-1}	50 mm.min^{-1}

*length between grips; ** diameter between grips

The mechanical parameters determined in the tensile tests were tensile strength (T, in kN.m^{-1}) and elongation at maximum load (E_{ML}, in %). Tearing strength (F_T, in N) was the parameter obtained in the tearing tests. The puncture tests included the determination of static puncture resistance (F_P, in kN) and push-trough displacement (displacement at maximum force) (h_P, in mm). The tensile and tearing tests were performed in the machine direction of production of the geotextiles.

Some results are presented in terms of retained strength (RS, in %). The RS was obtained by diving the resistance (tensile, tearing or static puncture) of the damaged samples by the respective resistance of the 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 (T, F_T and F_P) of the geotextiles. 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 the following equation:

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

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

By the traditional methodology, the reduction factor for the combined effect of mechanical damage and abrasion ($RF_{MD+ABR\ TRAD}$) was obtained according to equation 2.

$$RF_{MD+ABR\ TRAD} = RF_{MD} \times RF_{ABR} \qquad (2)$$

The reduction factors presented in this work correspond to specific conditions (in many cases, more drastic than those expected in field) and cannot be generalized or applied directly in design. For being used in design, the reduction factors must be analysed case by case, having into account the particular conditions of the constructions. In addition, it is essential to ascertain to what extent the conditions imposed in the degradation tests effectively represent the conditions of the construction.

3 RESULTS AND DISCUSSION

3.1 *Geotextile G250*

The degradation tests had different effects in geotextile G250 (different types of visible damage). The mechanical damage test caused cuts in fibres, small holes and the imprisonment of fine particles (arising from the fragmentation of *corundum*) in the nonwoven structure (Figure 1b). The abrasion test provoked cuts in fibres and the disintegration of the surface of the geotextile (in contact with the abrasive). The fibres lined up and formed clusters perpendicularly to the direction of motion of the abrasive (Figure 1c). Finally, the damage induced by the successive action of mechanical damage and abrasion was similar to the damage caused by abrasion (single exposure), but more marked (more fibres were cut and the clusters were bigger) (Figure 1d).

The mechanical damage test caused a significant reduction in the tensile strength of geotextile G250 (retained tensile strength of 53.7%) (Table 3). This decrease was accompanied by a reduction in elongation at maximum load (from 64.8% to 41.0%). The changes in tensile properties induced by the abrasion test were less pronounced than those provoked by the mechanical damage test. Indeed, after the abrasion test, geotextile G250 had a higher retained tensile strength (77.0%) and the reduction occurred in elongation at maximum load was lower (from 64.8% to 55.6%). The successive exposure to both degradation mechanisms caused the highest reductions in tensile strength (retained tensile strength of 39.3%) and in elongation at maximum load (decrease from 64.8% to 35.9%).

Like for tensile strength, the degradation tests also led to considerable reductions in the tearing strength of geotextile G250 (Table 4). The highest decrease was, once again, provoked by the successive exposure to both degradation tests (retained tearing strength of 44.4%). The lowest reduction in tearing strength (decrease of 16.1%) was found after the abrasion test.

The changes occurred in tensile strength and tearing strength (after the degradation tests) were relatively similar. Indeed, both properties had identical retained strengths after the same degradation tests.

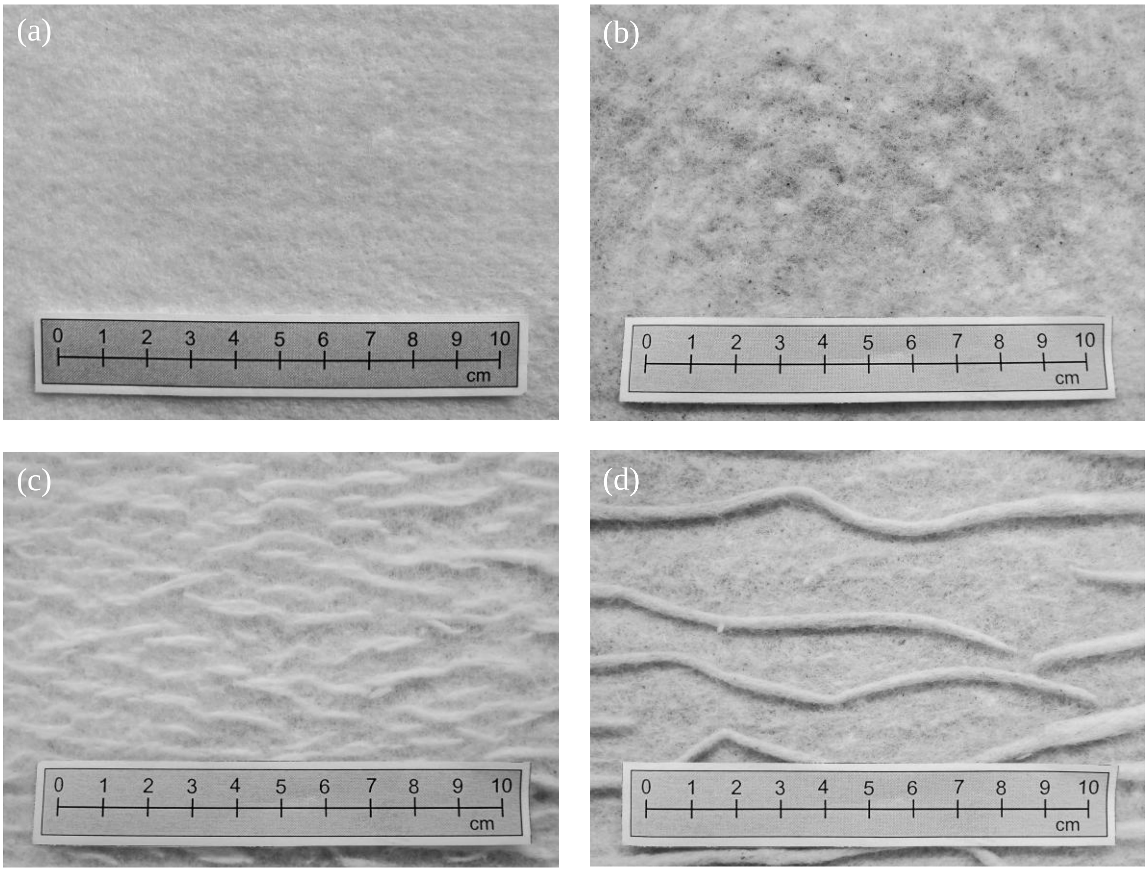

Figure 1. Geotextile G250 before (a) and after the degradation tests: (b) after mechanical damage; (c) after abrasion; (d) after mechanical damage followed by abrasion.

Table 3. Tensile properties of geotextile G250 before and after the degradation tests

Degradation test	T (kN.m^{-1})	E_{ML} (%)	RS (%)	RF
Reference (undamaged)	16.40 (1.97)	64.8 (4.9)	---	---
Mechanical damage	8.81 (1.46)	41.0 (4.9)	53.7	1.86
Abrasion	12.62 (1.25)	55.6 (5.9)	77.0	1.30
Mechanical damage + Abrasion	6.44 (1.15)	35.9 (2.4)	39.3	2.55

(in brackets are the obtained standard deviations)

Table 4. Tearing properties of geotextile G250 before and after the degradation tests

Degradation test	F_T (N)	RS (%)	RF
Reference (undamaged)	423 (48)	---	---
Mechanical damage	236 (22)	55.8	1.79
Abrasion	355 (37)	83.9	1.19
Mechanical damage + Abrasion	188 (26)	44.4	2.25

(in brackets are the obtained standard deviations)

Similarly to what happened for tensile and tearing properties, the degradation tests were also responsible for relevant reductions in the static puncture properties of geotextile G250 (Table 5). Like before, the combined action of mechanical damage and abrasion provoked the highest reduction in mechanical strength (retained puncture resistance of 51.2%). The mechanical damage test (single exposure) caused a decrease in puncture resistance (retained puncture resistance of 56.2%) not much different from the reduction induced by the successive exposure to mechanical damage and abrasion. The abrasion test was again the less damaging, leading to a decrease in puncture resistance (retained puncture resistance of 95.6%) lower than in tensile and tearing strengths (retained tensile and tearing strengths of 77.0% and 83.9%, respectively). The push-trough displacement suffered a reduction after the mechanical damage test (single exposure) and after the successive exposure to both degradation tests (no relevant changes were found after the abrasion test).

Table 5. Puncture properties of geotextile G250 before and after the degradation tests

Degradation test	F_P (N)	h_P (mm)	RS (%)	RF
Reference (undamaged)	3.40 (0.17)	64.8 (2.5)	---	---
Mechanical damage	1.91 (0.22)	47.1 (0.8)	56.2	1.78
Abrasion	3.25 (0.22)	65.0 (0.9)	95.6	1.05
Mechanical damage + Abrasion	1.74 (0.30)	50.0 (2.2)	51.2	1.95

(in brackets are the obtained standard deviations)

Due to the large reductions occurred in mechanical strength, the highest reduction factors (between 1.95 and 2.55) were obtained for the combined effect of mechanical damage and abrasion. By contrast, the isolated action of abrasion led to the lowest reduction factors (between 1.05 and 1.30), reflecting the absence of very pronounced changes in the mechanical strength of geotextile G250.

3.2 *Geotextile G450*

The visible defects induced by the degradation tests in geotextile G450 were very identical to those described for geotextile G250 (section 3.1). However, the changes occurred in the mechanical properties were different, depending on the characteristics of the materials. The evolution of the tensile, tearing and static puncture properties of geotextile G450 can be found in Tables 6, 7 and 8, respectively.

Table 6. Tensile properties of geotextile G450 before and after the degradation tests

Degradation test	T ($kN.m^{-1}$)	E_{ML} (%)	RS (%)	RF
Reference (undamaged)	25.68 (1.07)	65.6 (4.7)	---	---
Mechanical damage	22.54 (0.96)	58.1 (3.2)	87.8	1.14
Abrasion	24.99 (0.93)	66.1 (5.2)	97.3	1.03
Mechanical damage + Abrasion	21.82 (0.62)	57.1 (5.1)	85.0	1.18

(in brackets are the obtained standard deviations)

Table 7. Tearing properties of geotextile G450 before and after the degradation tests

Degradation test	F_T (N)	RS (%)	RF
Reference (undamaged)	507 (44)	---	---
Mechanical damage	447 (56)	88.2	1.13
Abrasion	499 (25)	98.4	1.02
Mechanical damage + Abrasion	435 (40)	85.8	1.17

(in brackets are the obtained standard deviations)

Table 8. Puncture properties of geotextile G450 before and after the degradation tests

Degradation test	F_P (N)	h_P (mm)	RS (%)	RF
Reference (undamaged)	5.93 (0.43)	63.1 (4.2)	---	---
Mechanical damage	5.24 (0.25)	56.0 (2.1)	88.4	1.13
Abrasion	5.75 (0.38)	63.6 (2.7)	97.0	1.03
Mechanical damage + Abrasion	4.92 (0.47)	52.2 (3.7)	83.0	1.21

(in brackets are the obtained standard deviations)

The changes in tensile properties (caused by the degradation tests) were less pronounced for geotextile G450 than for geotextile G250 (with lower mass per unit area). For example, after the successive exposure to mechanical damage and abrasion, geotextile G450 still had a relatively high retained tensile strength (85.0%), contrasting with the very pronounced reduction occurred in geotextile G250 (retained tensile strength of 53.8%). Like for the tensile properties, the reductions occurred in the tearing and puncture properties were also more marked in geotextile G250 than in geotextile G450.

The isolated effect of abrasion caused only minor changes in the mechanical properties of geotextile G450 (retained strengths between 97.0% and 98.4%). Similarly to what happened for geotextile G250, the isolated effect of mechanical damage provoked higher reductions in the mechanical properties of geotextile G450 (retained strengths between 87.8% and 88.4%) than the isolated effect of abrasion. However, the difference between the damage (decrease in resistance) induced by the degradation tests (single exposures) was more pronounced in geotextile G250. The combined effect of mechanical damage and abrasion led to the highest reductions in the mechanical properties of geotextile G450 (slightly higher than the isolated action of mechanical damage). Like for geotextile G250, the reductions occurred in the tensile strength, tearing strength and puncture resistance of geotextile G450 were relatively similar (identical retained strengths after the degradation tests).

The geotextile G450 (with higher mass per unit area) was more resistant against the degradation tests than geotextile G250. Indeed, the reductions occurred in the mechanical properties tended to be higher in geotextile G250 than in geotextile G450. The reduction factors obtained for geotextile G450 were relatively close to 1 (between 1.02 and 1.21), demonstrating its highest resistance when compared to geotextile G250 (reduction factors between 1.05 and 2.55).

3.3 *Comparison of reduction factors: successive exposure vs. traditional methodology*

The reduction factors obtained in the successive exposure of the geotextiles G250 and G450 to mechanical damage and abrasion were compared with the reduction factors determined by the traditional methodology for the combined effect of the degradation mechanisms (determination of the reduction factors in separate for each degradation mechanism and further multiplication) (Figures 2 and 3).

Relatively to geotextile G250 (Figure 2), the reduction factors obtained in the successive exposure to mechanical damage and abrasion were slightly higher than those obtained by the traditional methodology for the combined effect of both degradation mechanisms. This indicated that the reduction factors obtained by the traditional methodology may not be representing correctly (underestimating) the combined effect of mechanical damage and abrasion. Indeed, the traditional methodology was less conservative, resulting in lower reduction factors.

For geotextile G450 (Figure 3), the reduction factors determined by the traditional methodology for the combined effect of mechanical damage and abrasion were similar to those obtained in the successive exposure to both degradation mechanisms. The traditional methodology gave slightly lower reduction factors, but the differences were practically negligible (the higher difference was observed for puncture resistance - reduction factors of 1.21 and 1.16).

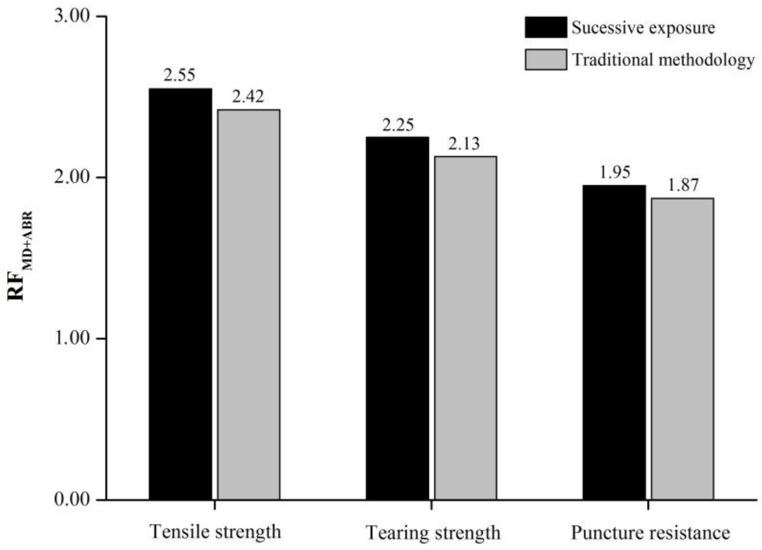

Figure 2. Comparison of the RF_{MD+ABR} obtained for geotextile G250 by the traditional methodology and in the successive exposure to both degradation mechanisms.

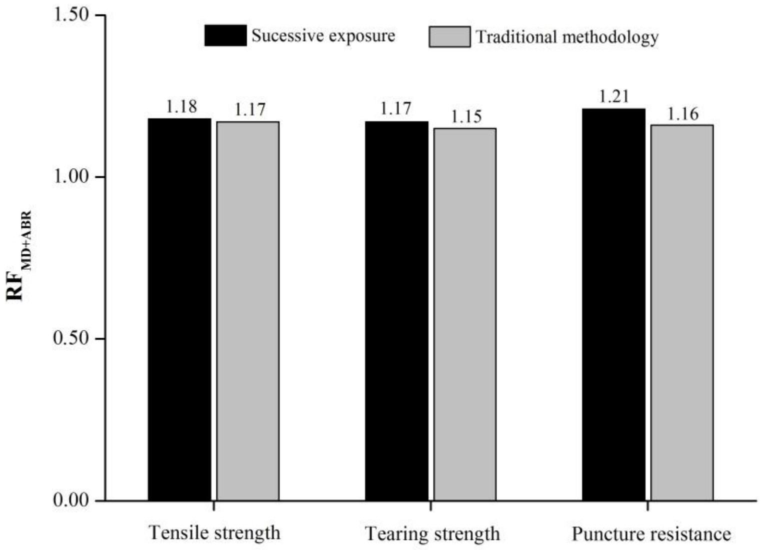

Figure 3. Comparison of the RF_{MD+ABR} obtained for geotextile G450 by the traditional methodology and in the successive exposure to both degradation mechanisms.

The reduction factors obtained by the traditional methodology tended to be slightly lower than those obtained in the successive exposure to mechanical damage and abrasion. This showed that the multiplication of two reduction factors (each representing the isolated effect of a degradation mechanism) may not represent with accuracy the combined action of the two degradation mechanisms (interactions may occur between the degradation mechanisms). However, it is important to highlight that the differences found between the reduction factors calculated by the traditional methodology and those determined in the successive exposure to mechanical damage and abrasion were not very pronounced. Similar studies carried out with other geosynthetics led to higher differences (Escórcio *et al.*, 2016).

Finally, it is important to remember that the reduction factors presented in this work correspond to particular degradation conditions and cannot be applied in design. No studies were carried out in order to find the relation between reality and the degradation conditions (based in standard degradation tests) imposed to the geotextiles.

4 CONCLUSIONS

The degradation tests (isolated and successive exposures to mechanical damage and abrasion) induced some relevant reductions in the mechanical properties of the geotextiles. The isolated action of abrasion was less damaging (lower reduction in mechanical properties) than the isolated action of mechanical damage. The successive exposure to mechanical damage and abrasion tended to cause higher reductions in the mechanical properties than the single exposures to the degradation mechanisms. The reductions occurred in tensile strength, tearing strength and puncture resistance (after the same degradation test) were relatively identical. The geotextile G450 (with higher mass per unit area) was much more resistance against degradation (better preservation of the mechanical properties) than geotextile G250.

The reduction factors obtained in the successive exposure of geotextile G250 to mechanical damage and abrasion were different (slightly higher) than those determined by the traditional methodology for the combined effect of both degradation mechanisms. Therefore, the traditional methodology may not always be able to represent accurately the resistance changes caused by the combined effect of two degradation agents. For geotextile G450, the differences were practically insignificant.

The definition of reduction factors with more reliability (having into account the interactions that may occur between the different degradation agents) may contribute to improve the application of geosynthetics in Civil Engineering. Indeed, the definition of accurate reduction factors will allow a better design.

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