Synergy between mechanical damage and abrasion of a composite geosynthetic and its variability

Synergie entre le dommage mécanique et l'abrasion d'un composite géosynthétique et sa variabilité

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ABSTRACT In this paper results of tests to assess the effect of mechanical damage (generally associated with installation processes) and abrasion are presented. Laboratory tests were carried out. The material tested is a composite consisting of two overlapped geosynthetics: a nonwoven geotextile and a woven geogrid. The composite was submitted to each referred agent (mechanical damage and abrasion damage) in isolation and sequentially, in order to assess an eventual synergetic effect. The effect of the damage induced in the short-term mechanical properties of the geosynthetic was assessed. The variability of these properties was assessed by using either 1 or 3 tests per sample. Abrasion damage (either isolated or combined with mechanical damage) was the most critical mechanism, leading to higher reductions of tensile strength. Increasing the number of tests used to characterise the samples from 1 to 3, has reduced the variability of the properties assessed, although the tensile strength values decreased and the peak strain and secant stiffness modulus for 2% strain increased. The number of characterisation tests carried out per sample didn't affect the trends observed associated with the damage induced. Some synergisms were observed for mechanical and abrasion damage.

RÉSUMÉ Dans cet article on présente les résultats des tests pour évaluer l'effet des dommages mécaniques (généralement associés aux processus de l'installation) et de l'abrasion. Des essais en laboratoire ont été effectués. Le composite a été soumis à chaque agent visé (dommages mécaniques et à l'abrasion) isolément et séquentiellement, afin d'évaluer un éventuel effet synergique. On a évalué l'effet des dommages induits dans les propriétés mécaniques à court terme du géosynthétique. La variabilité de ces propriétés a été évaluée à l'aide de 1 à 3 tests par échantillon. Les dommages dus à l'abrasion (quoi que ce soit isolée ou combinée à des dommages mécaniques) étaient le mécanisme plus critique, menant à des réductions plus élevées de résistance à la traction. L'augmentation du nombre de tests utilisés pour caractériser les échantillons de 1 à 3, a réduit la variabilité des propriétés évaluées, bien que les valeurs de résistance à la traction ont diminué et la résistance à 2% de déformation et la déformation à l'effort de traction maximale a augmenté. Le nombre d'essais de caractérisation effectués par échantillon n'a pas affecté les tendances observées associées à des lésions induites. Des synergies ont été observées pour les dommages mécaniques et ceux dus à l'abrasion.

1 INTRODUCTION

Nowadays geosynthetics are used widely in geotechnical engineering. To ensure acceptable design and performance their durability should be adequately considered. Usually the durability is grouped into (Koerner 2005): endurance (including installation damage, creep, stress relaxation, abrasion and compressive creep); and degradation (including oxidation, UV radiation, hydrolysis and biological and chemical agents). Each group includes several agents and mechanisms affecting the durability of geosynthetics. In design it is necessary to identify the main parameters affecting each group and how they are reflected on the functional properties of geosynthetics.

This paper refers to the study of two endurance durability agents acting combined – mechanical and abrasion damage. Mechanical damage usually is a consequence of installation procedures, as the operations for handling and placing the geosynthetics on site and from the compaction actions associated with the placement of fill material can be severe. For most non-reinforcement applications of geosynthetics installation damage can become the most significant stresses for design (Shukla 2002), depending for example on the soil used as fill material and the compaction actions. In some applications geosynthetics also suffer abrasion during service (usually due to cyclic relative motion (friction) between a geosynthetic and contact soil). Examples include: geosynthetics in railways, temporary roads, canal revetments, sea shores with sediments and sliding masses washing up and down (Watn and Chew 2002). Thus, in some applications, geosynthetics have to withstand mechanical and abrasion damage, maintaining minimum values of relevant functional properties.

This paper contributes to assessing if synergy (either positive or negative) between mechanical and abrasion damage can occur and whether the current design approaches (superposition of independent effects) can capture the response of geosynthetics. This paper aims to contribute to understanding endurance durability by analysing the combined effect of mechanical damage and abrasion on tensile properties of one geocomposite using laboratory tests. The variability of those properties was assessed by using either one or three tests per sample.

The tests performed to induce damage are laboratory index tests. The results cannot be used directly for design, unless the damage induced can be correlated with that under real conditions (for example, for specific fill material, compaction actions and geosynthetic).

2 GEOSYNTHETICS

A composite geosynthetic consisting of two overlapping geosynthetics (Figure 1) was studied: a nonwoven geotextile consisting of continuous mechanically bonded polypropylene filaments (GTX) over a woven geogrid composed of high modulus polyester fibres knitted in a flat orientation and covered with a protective polymeric coating (GGR). The materials were tested overlapped and on the machine direction. Nominal values of some properties of the geosynthetics are included in Table 1: mass per unit area (mua_{nom}); peak tensile strength and elongation at peak at machine direction, respectively, T_{nom} and ε_{nom}.

Pinho-Lopes & Lopes (2014) have assessed some physical and hydraulic properties of the same composite. Results for a similar study were presented by Rosete et al. (2013) for geotextile GTX and for geogrid GGR studied individually.

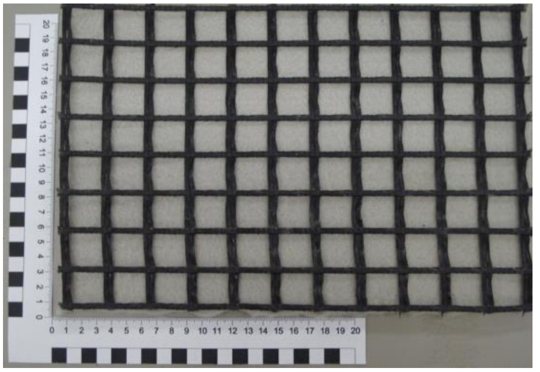

Figure 1. Composite tested (GTX+GGR).

Table 1. Nominal values for some properties of the geosynthetics.

Property	Test method	GTX	GGR
mua_{nom} (g/m^2)	EN ISO 9864	1000	-
T_{nom} (kN)	EN ISO 10319	55	55
ε_{nom} (%)	EN ISO 10319	105.0	10.5

3 TEST PROGRAM

The test program consisted in performing laboratory tests to induce mechanical damage and abrasion damage, in isolation and combined (mechanical damage followed by abrasion damage), on the geocomposite. Later wide-width tensile tests were performed to characterise the different samples (undamaged and after damage).

3.1 Mechanical damage tests

The mechanical damage was induced using an index laboratory test described in EN ISO 10722:2007. In this test each specimen is placed between two layers of a synthetic aggregate and submitted to cyclic loading. The equipment consists in a frame and a container. The container is divided into a lower and an upper box with plan section of 300 mm x 300 mm and 150 mm of total height.

On the lower box of the container, below the specimen, two sub layers of aggregate (75 mm high in total) are placed, each compacted with a flat plate loaded to a pressure of 200 kPa during 60 s (over the whole area of the test container). The geosynthetic is placed on top of these layers free of folds and wrinkles. The upper box is assembled and filled with loose aggregate (75 mm high). During the test the load plate (100 mm x 200 mm) is centred on the container and enables applying cyclic loading ranging between 5 kPa and 500 kPa at a frequency of 1 Hz for 200 loading cycles. At the end of the tests the specimen is removed carefully from the test apparatus, examined for any visual damage and then subjected to a characterisation test, to measure the changes on its properties.

The artificial aggregate is a sintered aluminium oxide (*corundum*) with grain sizes between 5 mm and 10 mm. According to the test standard when necessary the aggregate should be sieved to eliminate the fraction smaller than 5 mm. After 20 uses the aggregate is to be discarded.

3.2 *Abrasion damage tests*

The abrasion damage was simulated in laboratory using the procedures described in EN ISO 13427:1998. In this test the abrasion to which geosynthetics may be exposed to is represented by abrasive sandpaper.

The equipment used is a prototype (Figure 2) which allows for specimens larger than those described on the test standard: area of geosynthetic in contact with the abrasive of 220 mm x 300 mm (instead of 50 mm x 200 mm imposed on EN ISO 13427:1998). The equipment consists of two plates: the upper plate, which is stationary and where the specimen is fixed; and the lower plate with the abrasive (P100), able to move along a horizontal axis under controlled pressure.

During the test a pressure of 6 kPa is applied to the specimen and the abrasive is rubbed against it for 750 cycles (1 cycle = 1 double pass). The specimen is then removed carefully and subjected to a characterisation test.

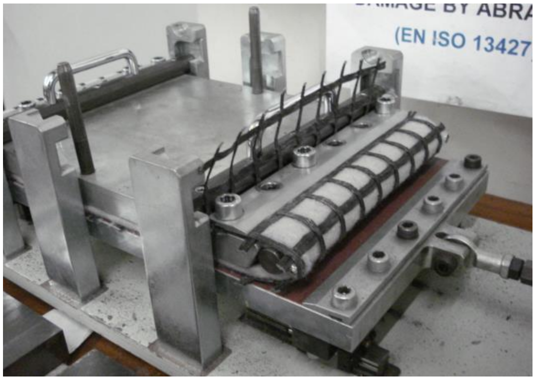

Figure 2. Equipment for the abrasion damage tests.

3.3 *Short-term tensile response*

To characterise the changes on the short-term tensile response of the composite, wide-width tensile tests were performed (EN ISO 10319:2008). To avoid lateral contraction during the tests, the dimensions of the specimens under tensile forces are 200 mm (width) and 100 mm (length). The specimen is fixed on the jaws of the equipment, which are chosen to limit the sliding of the specimen in the clamping area during the test.

During the test each specimen is submitted longitudinally to an increasing tensile force at a strain rate of 20% per minute, until rupture. The strains were measured with a video-extensometer over an initial length of 60 mm centred on the specimen. Each test includes a minimum of five valid specimens to characterize each sample.

4 RESULTS AND DISCUSSION

The results of the tests used to characterise the samples are summarised in Table 2: mean values of tensile strength (T_{max}, kN/m), strain at break (ε_f, %) and secant tensile stiffness modulus at 2% of strain ($J_{sec\ 2\%}$, kN/m) and the corresponding 95% confidence intervals, estimated assuming the results can be approximated by t-student distribution functions. Results for 1 test per sample (identified with 1t) and 3 tests per sample (identified with 3t), for the intact geocomposite and after mechanical damage, after abrasion damage and after mechanical and abrasion damage are presented.

To quantify the changes due to the damage induced the residual values of relevant properties were determined. R_Y is the residual value (in %) after damage of the property Y, determined as the ratio between the mean value of Y for the damaged sample (Y_{dam}) and the corresponding mean value for the undamaged sample (Y_{und}).

Table 2. Mean values of tensile tests results, with 95% confidence interval, for 1 and 3 tests per sample.

Sample		T_{max} (kN/m)	ε_f (%)	$J_{sec\ 2\%}$ (kN/m)
Intact	1 t	58.1±5.9	16.6±6.4	621.6±88.4
	3 t	59.3±2.5	16.6±1.7	580.0±42.5
Abrasion damage	1 t	23.7±5.7	11.8±1.8	370.5±64.5
	3 t	22.8±1.8	11.8±0.7	354.3±22.8
Mechanical damage	1 t	56.1±6.5	15.9±2.6	509.7±73.8
	3 t	54.2±2.1	16.1±1.2	512.0±31.4
Mechanical and abrasion damage	1 t	21.4±3.4	10.4±1.5	382.2±25.6
	3 t	20.8±1.0	10.6±0.6	369.1±22.9

4.1 Observed damage

Pinho-Lopes & Lopes (2014) summarise naked eye observations of the geocomposite after the damage induced, which can help understanding the tensile response measured.

After mechanical damage observations showed fibre cutting on geogrid GGR and incrustation of fine particles on the surface of geotextile GTX. Some specimens exhibited small holes on the geotextile GTX and part of the ribs of geogrid GGR suffered partial removal of the protective coating and crushing.

The structures of the geocomposite after abrasion damage and after mechanical damage followed by abrasion damage were similar (more severe for the later, Figure 3).

These were quite different from those described for a single exposure to mechanical damage. There was a significant and generalised detachment of the protective coating, and splitting of some ribs of geogrid GGR. The superficial layer of geotextile GTX became partially disintegrated and many filaments were grouped into clumps perpendicular to the direction of motion in the abrasion test. The constituent elements of geotextile GTX and geogrid GGR became physically connected. According to Pinho-Lopes & Lopes (2014), the mechanical damage allowed for additional detachment of filaments and superficial disaggregation during the sequential abrasion damage tests.

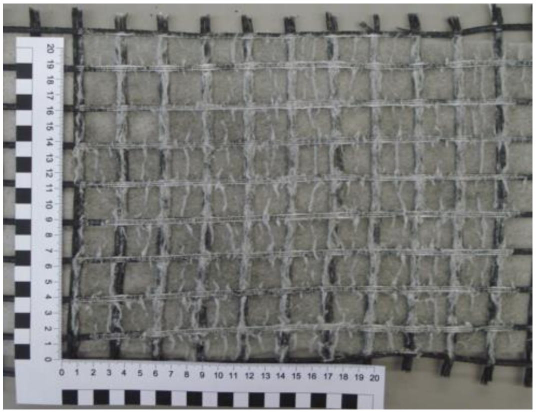

Figure 3. Specimen of the geocomposite after sequential mechanical and abrasion damage tests.

4.2 Tensile strength

The tensile strength of the geocomposite was little affected by a single exposure to mechanical damage, as the corresponding residual tensile strength found was always higher than 95% (for 1 test) or 91% (for 3 tests). However the tensile strength of the geocomposite was severely reduced after abrasion damage (either in a single exposure or combined with mechanical damage). The residual tensile strength after abrasion damage was 41% (1 test) or 38% (3 tests), and after mechanical and abrasion damage it was 37% (1 test) or 35% (3 tests).

Increasing the number of tests performed resulted in slightly lower values for the mean tensile strength. However, the 95% confidence intervals obtained for the tensile strength became narrower when using a larger number of tests. The 95% confidence intervals normalised to the corresponding mean value were reduced 58% (undamaged sample) to 68% (after mechanical damage combined with abrasion damage).

4.3 Peak strain

The peak strain of the composite was less affected by the damage induced, in both single and multiple exposures to mechanical and abrasion damage, than is tensile strength. The peak strain residual values ranged between 96% and 97% after mechanical damage (1 or 3 tests, respectively) and 62% and 64% after mechanical damage combined with abrasion damage (1 or 3 tests, respectively).

Increasing the number of tests performed resulted in higher values for the peak strain and the corresponding 95% confidence intervals became narrower. The 95% confidence intervals normalised to their mean value were reduced 54% (after abrasion damage) to 73% (undamaged sample).

4.4 Secant tensile stiffness modulus for 2% strain

Traditionally installation damage is associated with loss of resistance. Some authors (for example Pinho-Lopes & Lopes 2013 and Allen and Bathurst 1994) suggested the secant stiffness modulus could be a more rational quantity to represent the resistance to damage of some geosynthetics (such as woven polyester geogrids and polyethylene geogrids, according to Allen and Bathurst 1994).

The residual secant stiffness module ranged between 60% and 61% after a single exposure to abrasion damage (1 or 3 tests, respectively) and 82% and 88% after a single exposure to mechanical damage (1 or 3 tests, respectively).

For the composite studied, independently of the number of tests used per sample, when submitted to abrasion damage (either isolated or combined with mechanical damage) the residual secant stiffness module obtained were less conservative than the corresponding tensile strength values. The opposite trend was observed after a single exposure to mechanical damage.

As for the other quantities, using a larger number of tests to characterise each sample led to higher stiffness modulus and lower normalised 95% confidence intervals (7% lower after mechanical damage followed by abrasion damage to 63% lower after abrasion damage).

4.5 Load-strain curves

Figure 4 summarises representative load-strain curves for the four types of samples studied. These curves represent the complete response of the geocomposite measured in the tensile tests (until rupture). It is likely that such high strains are never achieved in real applications.

The tensile response of the geocomposite studied exhibits two peaks. The first peak (strains between 10% and 17%, depending on the sample) corresponds to the rupture of geogrid GGR (nominal peak strain of 10.5%), while the second peak (strains between 94% and 105%, depending on the sample) refers to geotextile GTX (nominal peak strain of 105%).

For most applications the strains on the geosynthetics will be very low. Thus, only the initial part of the load-strain curves, up to the first peak, is discussed. The load-strain curves clearly show the effect of the damage induced, by the reduction of the peak parameters and of the stiffness of the samples. After abrasion (in a single exposure or combined with mechanical damage) the reduction of parameters is obvious. The changes observed visually help understanding the differences found for the mechanical response of the geocomposite.

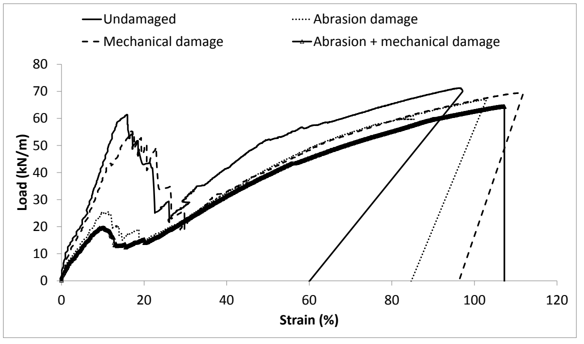

Figure 4. Representative load–strain curves of samples of the geocomposite (undamaged and after laboratory damage tests).

When submitted to a similar test program (by Rosete et al. 2013), the structure of geogrid GGR changed after damage. Such changes were mostly due to abrasion damage and included the removal of the protective coating, as well as splitting of some ribs. For geogrid GGR the connections between components are likely to be weak points to abrasive actions. Abrasion was identified as the critical damage mechanism for geogrid GGR. For geotextile GTX Rosete et al. (2013) didn't identify a critical damage mechanism, as the material endured well both mechanical and abrasion damage (isolated or combined).

For this geocomposite (geotextile GTX and geogrid GGR) abrasion was found the most critical mechanism of damage, reflecting the sensitivity of geogrid GGR to abrasion. Although the two geosynthetics (geotextile GTX and geogrid GGR) became connected after abrasion damage (isolated or combined with mechanical damage), the response of geogrid GGR was still predominant.

4.6 Reduction factors

Reduction factors for the tensile strength and the secant stiffness modulus (Table 3) were determined using the test results to represent the effects of the abrasion and the mechanical damage induced. These values result from index laboratory tests and cannot be used directly for design, unless they are correlated to specific site conditions. The minimum value for these reductions factors is 1.0.

The reductions factors reflect the changes in the properties discussed previously. For the tensile strength the reduction factors for the geocomposite using 1 test are less conservative than those obtained using data from 3 tests per sample. For the secant stiffness modulus the opposite trend was observed. The lower variability of the properties after 3 tests is not evident from the reduction factor values, as they are obtained from the mean value of the corresponding property.

If the secant stiffness modulus is used as a representative functional property of the response of the geocomposite, the corresponding reduction factors are 32% to 45% lower than for the tensile strength after abrasion damage, isolated and combined with mechanical damage, respectively.

To assess a possible synergetic effect between the damage mechanisms considered, reduction factors representing the traditional approach to design were determined (Table 3). The traditional reduction factors for mechanical and abrasion damage were obtained by multiplying the corresponding reduction factors for single exposures to abrasion damage and mechanical damage (considered independent).

For the tensile strength the traditional approach is less conservative than that considering synergy, which indicates that, if the damage induced in laboratory is found representative of that obtained under realistic conditions, the combined effects of mechanical and abrasion damage should be considered (when relevant) rather than their superposition. For the secant stiffness modulus an opposite trend was observed, as the traditional reduction factors were 26% or 18% higher than the corresponding values obtained considering synergy, after 1 or 3 tests, respectively.

Table 3. Reduction factors for the tensile strength and the secant stiffness modulus obtained from the results and using the traditional approach, for 1 and 3 tests.

Sample		RF_{Tmax} (kN/m)	$RF_{Jsec\ 2\%}$ (kN/m)
Abrasion damage	1 t	2.46	1.68
	3 t	2.61	1.64
Mechanical damage	1 t	1.04	1.22
	3 t	1.09	1.13
Mechanical + abrasion	1 t	2.72	1.63
damage (synergy)	3 t	2.85	1.57
Mechanical x abrasion	1 t	2.55	2.05
damage (traditional)	3 t	2.85	1.85

5 CONCLUSIONS

This work refers to assessing tensile properties of a composite after mechanical damage and abrasion damage, in isolation and combined, induced using index standardised test procedures. The composite was formed by overlapping two geosynthetics (woven geogrid GGR and nonwoven geotextile GTX). The existence of synergetic effect and the variability of the properties were investigated. The main conclusions are:

- The structure of the geocomposite was affected by the damage induced and the two geosynthetics became bonded.
- Abrasion damage (either isolated or combined with mechanical damage) was found the most critical mechanism for the geocomposite, leading to higher reductions of tensile strength.
- For the secant stiffness modulus the reductions after abrasion were not as important as those of tensile strength, confirming that for woven geogrids using the tensile strength to represent the resistance to damage can be too conservative.
- Increasing the number of tests used to characterise the samples from 1 to 3, has reduced the variability of the tensile strength, the peak strain and the secant stiffness modulus for 2% strain of the geocomposite.

- The tensile strength was reduced when a larger number of tests were performed, but the peak strain and the secant stiffness modulus for 2% strain have increased.
- The number of characterisation tests carried out per sample (either 1 or 3) didn't affect the trends observed associated with the damage induced.
- The traditional approach to consider the effect of both mechanical and abrasion damage on the secant stiffness modulus was found conservative; the opposite trend was observed for the tensile strength of the geocomposite.

If these conclusions are confirmed for real conditions the combined effects of mechanical and abrasion damage should be considered when relevant, rather than their superposition.

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STANDARDS

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