Damage Induced by Recycled Aggregates on the Short-Term Tensile Behaviour of a High-Strength Geotextile

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Abstract

This paper presents the mechanical, chemical and environmental degradation induced by recycled Construction and Demolition Wastes (C&DW) on the short-term tensile behaviour of a nonwoven polypropylene (PP) geotextile reinforced with polyester (PET) yarns. In order to study the chemical and environmental degradation a damage trial embankment (2m x 3m in plant) was constructed using recycled C&DW as filling material. The damage caused by the mechanical actions during installation was also simulated by installation damage laboratory tests. Wide width tensile tests were performed on geotextile samples exhumed from the trial embankment after 12 months, on laboratory damaged samples and on intact (as-received) samples. Their short-term tensile behaviour is compared. Scanning electron microscope (SEM) images of intact and exhumed specimens are also presented.

Keywords: Recycled aggregates; Construction and Demolitions Wastes; Geosynthetics; Geosynthetics degradation; Geosynthetics damage

1 Introduction

Recycled Construction and Demolition Wastes (C&DW) have been increasingly used as recycled aggregates in pavement sub-bases and other road construction applications (Vieira and Pereira, 2015a). Furthermore, unpaved roads constructed with recycled C&DW materials can be effectively reinforced with geosynthetics, where they may also have separation (soil layers with different particle size distribution) and drainage functions. However, one of the main questions of using geosynthetics in ground applications is their durability. This aspect is particularly significant if an alternative aggregate is being used.

The damage caused by mechanical actions during the installation and the chemical and the biological degradation are important issues to be considered in geosynthetics behaviour. The changes in their

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physical, mechanical and hydraulic properties, induced by the above-mentioned degradation processes, can control the performance of the structures where these materials are used.

The available long-term tensile strength of a geosynthetic (AASHTO, 2012; FHWA, 2010), T_{al}, or the design strength for the ultimate limit state (BS 8006, 2010), can be estimated as:

$$T_{al} = \frac{T_{ult}}{RF_{ID} \times RF_{CR} \times RF_D} \qquad (1)$$

where T_{ult} is the ultimate tensile strength (per unit width), RF_{ID} is the installation damage reduction factor, RF_{CR} is the creep reduction factor and RF_D is the durability reduction factor (that accounts for the strength loss caused by chemical and biological degradation of the polymers used in the geosynthetic). Instead of the durability reduction factor, RF_D, the British Standard BS 8006 (2010) considers two reduction factors: a reduction factor for weathering, RF_W, and a reduction factor for chemical/environmental effects, RF_{CH}.

To study the chemical and biological degradation induced on geosynthetics by recycled aggregates coming from C&DW, damage trial embankments were constructed. The exhumation of geosynthetic samples was predicted after 6, 12 and 24 months of embankments construction. The results herein presented are part of a broaden research project and are related to high-strength geotextile samples exhumed after 12 months of installation.

In order to minimize the installation damage of the geosynthetics during the embankments construction, a lightweight compaction process was adopted. The mechanical damage induced by the recycled aggregates on the geotextile was simulated in laboratory, carrying out installation damage tests, but using recycled C&DW as damaging material.

2   Materials and Methods

This research study was carried out using a commercial available geosynthetic, frequently used as reinforcement, consisting of a polypropylene continuous-filament needle-punched nonwoven and high-strength polyester yarns (Figure 1). In order to study the effects of recycled C&DW on the short-term tensile behaviour of this geocomposite (or high-strength geotextile), intact (as supplied by the manufacturers), damaged (in the laboratory) and exhumed specimens were taken from the same roll and they were tested using the same methods and equipments.

Figure 1: Photograph of the high-strength geotextile (ruler in centimeters).

In order to study the chemical and biological degradation induced by recycled C&DW on three distinct geosynthetics, damage trial embankments were constructed (Figure 2). It should be noted that their construction method and dimensions (2m x 3m in plan and 0.45m high) are not adequate for other purposes, namely the analysis of the embankment behaviour. The results herein presented are related to geotextile samples exhumed after 12 months of installation (Figure 2b).

The trial damage embankments were constructed using fine grain recycled C&DW, coming mainly from maintenance works or demolitions of small buildings and cleaning of lands with illegal deposition of C&DW. At the lateral slopes of the embankment, coarse aggregates from recycled C&DW were deposited to prevent erosion by rain water (Figure 2a). As previously mentioned, with the purpose of minimizing the installation mechanical damage of the geosynthetics, a lightweight compaction process was adopted (forward compaction plate with weight of 94 kg).

The predominant materials of the recycled C&DW used in the embankments construction are concrete, mortar, unbound aggregates, natural stones, as well as, a significant portion of soil. These recycled materials were provided by a Portuguese Recycling plant located in Centre region. Details on embankment construction and characterization of recycled aggregates are available in (Vieira and Pereira, 2015a).

After 12 months of the trial embankment construction, the geotextile samples were carefully exhumed to prevent additional damage. The exhumation begun with the removal of the aggregates placed on the lateral slopes of the embankment, as well as the vegetation that grew up over the embankment. Then the fill material was manually removed with hoes and shovels until reaching the geosynthetics, being the material just above the geosynthetics removed carefully with the hands.

| (a) | (b) |

Figure 2: Trial embankments: a) one of the embankments at the end of construction; b) plant roots crossing the geotextile during exhumation.

A laboratory procedure for the evaluation of mechanical damage, caused by granular material, under repeated loading is standardized (EN ISO 10722, 2007). To analyse the mechanical damage induced by these recycled aggregates on the geotextile tensile behaviour, laboratory installation damage tests were also carried out, using recycled C&DW similar to the one used in the construction of the embankments (coming from the same batch).

The mechanical damage tests were performed using a laboratory prototype developed at the University of Porto (Lopes and Lopes, 2003). The apparatus is composed by a rigid container (300 mm × 300 mm × 150 mm) divided in two boxes (where the geotextile and the C&DW were placed), a loading plate and a hydraulic compression system. The material and the compaction procedure used in these mechanical damage tests did not follow the standard EN ISO 10722 (2007) since it describe an index test procedure.

Each geotextile specimen (250 mm wide and 500 mm long) was placed between two layers of the recycled aggregate. The recycled C&DW material was placed inside each box, at its air-dried water content, with relative density of 70%. The aggregate was compacted in four 3.75mm thick layers to the target unit weight. At the end of the assembly process, the specimen was subjected to a dynamic loading with amplitude ranging from 5 to 500 kPa at frequency of 1 Hz and for 200 cycles. Finished the repeated loading, the aggregate was removed carefully to avoid additional geotextile damage.

To study the damage induced by these recycled aggregates on the geotextile short term tensile behaviour, tensile tests were carried out on intact (as supplied by the manufacturers), exhumed and damaged specimens. The tensile tests were performed in accordance with the European Standard EN

ISO 10319 (2008) on five specimens (for each condition) and with strain rate of 20%/min. Further details on test procedures and specimens preparation can be found in Vieira and Pereira (2015b).

3 Results and Discussion

3.1 Specimens Exhumed from the Embankment

Visual inspection of exhumed geocomposite samples revealed that the nonwoven geotextile was damaged by plant roots, some of them with a few millimetres in diameter (Figure 2b). Apart from these located damages, other damages visible to the naked eye were not detected. In order to evaluate the damages in more detail, Scanning Electron Microscope (SEM) analyses were carried out.

The SEM analyses were performed using a High resolution Environmental Scanning Electron Microscope with X-Ray Microanalysis and Electron Backscattered Diffraction analysis (Quanta 400 FEG ESEM / EDAX Genesis X4M) from the Materials Centre of University of Porto.

SEM images of intact and exhumed specimens of geocomposite are illustrated in Figure 3. Figure 3 (b) shows that fibres fixing the PET yarns to the base geotextile are still present even if they seem to be unrolled. PET yarns did not reveal significant damages but they are disjoined. Very small particles are held to the yarns.
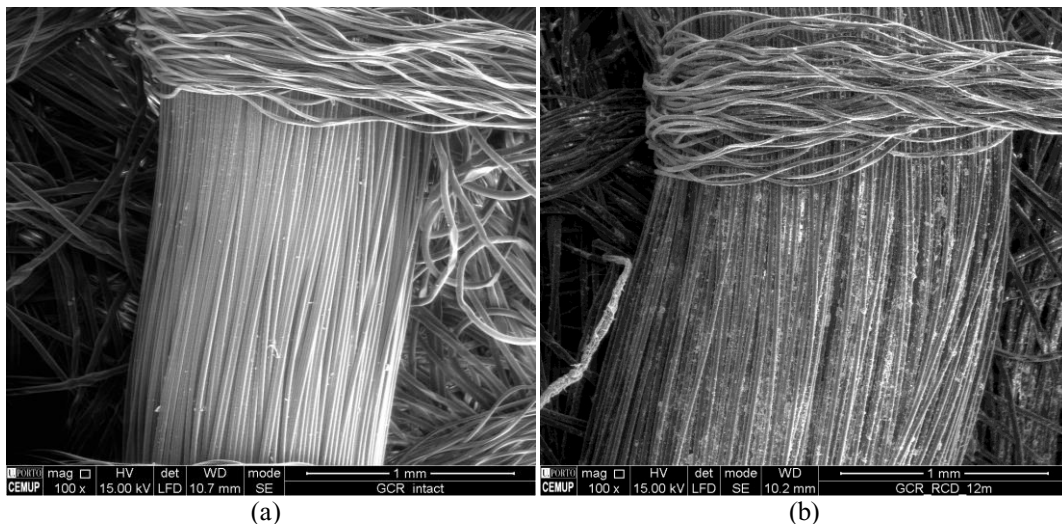

| | mag □ | HV | det | WD | mode | | | mag □ | HV | det | mode | WD | |
| CEMUP | 100 x | 15.00 kV | LFD | 10.7 mm | SE | 1 mm — GCR_intact | CEMUP | 100 x | 15.00 kV | LFD | SE | 10.2 mm | 1 mm — GCR_RCD_12m |

(a)   (b)

Figure 3: SEM images of geotextile specimens (×100): (a) intact; b) exhumed after 12 months.

Figure 4 presents the load-strain curves of exhumed geotextile specimens subjected to tensile tests carried out according to EN ISO 10319 (2008). The mean curve is also represented in Figure 4. The maximum tensile strength (T_{max}), the geosynthetic strain for T_{max} (ε_{Tmax}), the secant stiffness modulus at strain of 2% ($J_{2\%}$) and the secant stiffness modulus at ε_{Tmax} (J_{Tmax}) are summarized in Table 1. The mean values of these parameters and the 95% confidence intervals assuming a Student's t-distribution were also included.

The tensile behaviour of intact specimens was presented in a preceding publication (Vieira and Pereira, 2015b). It would be expected that the variability of the results for exhumed specimens would be greater than that of intact specimens, due to the different mechanisms that could contribute to the geosynthetics damage. However, tensile tests carried out with intact specimens have shown similar variability of that of exhumed specimens (coefficient of variation for the tensile strength equal to 3.6% and 4% for intact and exhumed specimens, respectively).

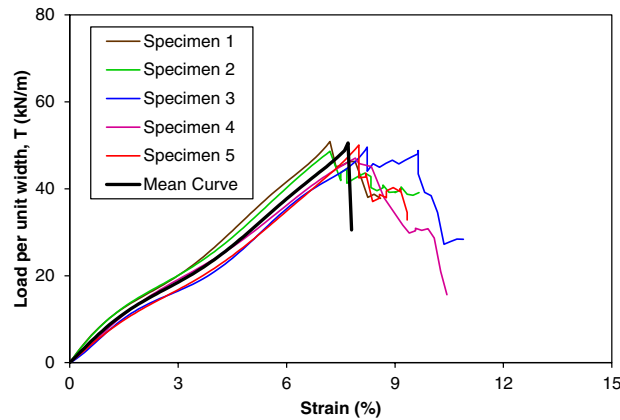The tensile behaviour of exhumed and intact specimens will be compared and discussed in section 3.3.

Figure 4: Load-strain curves of tensile tests performed on exhumed geotextile specimens.

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	50.7	7.2	758	705
Specimen 2	48.8	7.2	772	681
Specimen 3	51.9	8.2	639	632
Specimen 4	47.8	7.8	706	610
Specimen 5	52.6	8.0	615	657
Mean value	50.4	7.7	698	657
Confidence interval of 95%	50.4±2.5	7.7±0.6	698±86	657±47

Table 1: Summary of results of tensile tests carried out on exhumed specimens.

3.2 Specimens Damaged in Laboratory

The visual inspection of geotextile specimens after the laboratory mechanical damage tests did not reveal any cuts or tears. Apart from the aggregate particles that remained adherent to the geotextile, the geocomposite was like intact (Figure 5).

Figure 5: Geotextile specimens after laboratory mechanical damage.

After the mechanical damage tests, the specimens were subjected to tensile load tests following similar procedures to those used for intact or exhumed specimens. The load-strain curves of damaged geotextile specimens, as well as the mean curve corresponding to the 5 tensile tests are represented in Figure 6. Table 2 summarizes the values of maximum tensile strength (T_{max}), geocomposite strain for T_{max} (ε_{Tmax}), secant stiffness modulus at strain of 2% ($J_{2\%}$) and at ε_{Tmax} (J_{Tmax}). The mean values of these parameters and the 95% confidence intervals assuming a Student's t-distribution were also tabulated.

The comparison of the results will be presented in sequence, however comparing right now Table 1 and Table 2, one can conclude that the mechanical damage induced in laboratory is significantly less aggressive than the exposure of the geotextile to the recycled aggregates for 12 months.
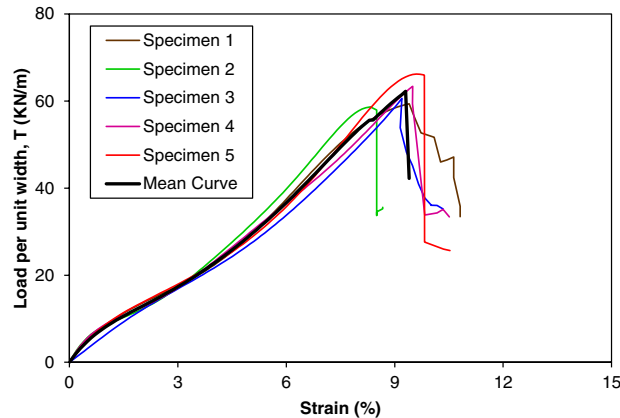

Figure 6: Load-strain curves of tensile tests performed on geotextile specimens damaged in laboratory.

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	60.8	9.4	677	649
Specimen 2	63.9	8.3	608	766
Specimen 3	61.7	9.2	601	674
Specimen 4	63.4	9.5	631	668
Specimen 5	66.1	9.8	685	673
Mean value	63.2	9.2	640	686
Confidence interval of 95%	63.2±2.6	9.2±0.7	640±48	686±57

Table 2: Summary of results of tensile tests carried out on laboratory damaged specimens.

3.3   Comparison and Discussion of Results

Table 3 summarizes the results of tensile tests carried out on intact specimens, presented in a preceding publication (Vieira and Pereira, 2015b). The comparison of these results with those presented in Tables 1 and 2 points out the significant degradation (loss of 29%, on average, of tensile strength) caused by the exposure to the recycled C&D material, while the loss of tensile strength of mechanically damaged specimens was about 10%. On the other hand the effects on the geocomposite tensile stiffness is not significant (Figure 7). The decrease on the secant stiffness modulus at ε_{Tmax} (J_{Tmax}) is obvious since the geocomposite fails for smaller strains (Table 1, 2 and 3).

It is important to mention that the high tensile strength of this geocomposite (when compared to other geotextiles) results mainly from the polyester (PET) yarns. Even if the visual inspection and SEM images (Figure 3) did not reveal significant damages in PET yarns, the binding of the yarns to the nonwoven geotextile remained weak, which may have caused their premature failure. This phenomenon

is also, probably, the main reason for the decrease of the geocomposite tensile strength when it was damaged in the laboratory.

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	70.1	9.2	693	765
Specimen 2	67.6	10.0	605	676
Specimen 3	73.7	10.7	648	691
Specimen 4	69.0	9.7	742	714
Specimen 5	72.7	9.2	549	793
Mean value	70.6	9.7	647	728
Confidence interval of 95%	70.6 ± 3.2	9.7 ± 0.8	647 ± 93	728 ± 62

Table 3: Summary of results of tensile tests carried out on intact specimens (Vieira and Pereira, 2015b).
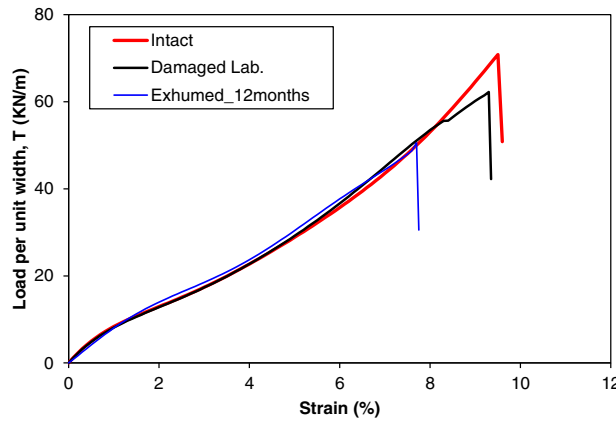

Figure 7: Comparison of mean load-strain curves of intact, damaged and exhumed specimens.

The retained values of relevant parameters, such as, the tensile strength, the strain at maximum load or the secant stiffness modulus, are frequently used to quantify the damage on geosynthetics. The retained value is defined, in this paper, as the ratio between the mean value of the parameter (tensile strength, peak strain or secant modulus, respectively) for damaged or exhumed specimens and the corresponding mean value for intact specimens.

Table 4 summarises the mean values of the retained tensile strength, R_T, the retained peak strain, R_ε, and the retained secant modulus at 2% of strain, $R_{J2\%}$.

As previously mentioned, the mechanical damage induced in the laboratory is not significant being the loss of strength mainly due to the different positioning of PET yarns. The damage caused by the exposure to the recycled C&DW was mainly on the tensile strength, since a slight increase on the secant stiffness was observed.

Exhumed after 12 months			Mechanical damaged		
R_T (%)	R_ε (%)	$R_{J2\%}$ (%)	R_T (%)	R_ε (%)	$R_{J2\%}$ (%)
71.3	78.9	107.9	89.4	94.9	98.9

Table 4: Mean values of retained tensile strength, R_T, retained peak strain, R_ε, and retained modulus, $R_{J2\%}$.

4 Conclusions

The main objective of this research is the characterisation of the changes in load-strain behaviour of geosynthetics used as reinforcement material due to the potential degradation induced by a fine grain recycled C&D material. SEM images allow us to conclude that the installation damage (induced by the embankment construction process) was not very significant. Visual inspection and SEM images did not reveal significant damage in PET yarns of the geocomposite, although some damage produced by plant roots on the nonwoven geotextile (base of the geocomposite) could be identified.

Theoretically the mechanical damage induced in the laboratory should be more aggressive than that caused during embankments construction. That means that, it is possible to consider that the installation damage during construction was not very significant and therefore, the geotextile exposure to the recycled C&DW under real atmospheric conditions for 12 months is responsible for a significant loss of strength.

It should be pointed out that the results and conclusions presented in this paper are preliminary results from a broaden research project. Broadening conclusions will be reached when possible the exhumation of specimens submitted to longer periods of exposure and the results compared to those caused by the exposure to a natural aggregate.

Acknowledgments

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