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Study of the damage induced by recycled aggregates coming from Construction and Demolition Waste (C&DW) on the short-term tensile behaviour of a PET geogrid

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ABSTRACT: The valorisation of Construction and Demolition Wastes (C&DW) is nowadays an imperative since it reduces the use of natural resources and avoids congesting landfills with these inert materials. The use of C&DW in geotechnical works, such as geosynthetic reinforced structures, is an interesting alternative from an economic and environmental perspective. This paper presents the mechanical, chemical and environmental degradation induced by fine grain recycled aggregate coming from C&DW on the short-term tensile behaviour of a uniaxial geogrid manufactured of extruded polyester (PET). In order to study the chemical and environmental degradation a damage trial embankment was constructed using C&DW as filling material. The damage caused by the mechanical actions during installation was also simulated by mechanical damage under repeated loading tests. Wide width tensile tests were carried out on geogrid samples exhumed from the trial embankment after 12 months of exposure, on laboratory damaged samples and on intact samples. Their short-term tensile behaviour is compared. Scanning electron microscope (SEM) images of intact and exhumed specimens are also presented.

1 INTRODUCTION

Minimizing the consumption of non-renewable natural resources for the production of construction materials is considered one of the key aspects to achieve sustainability in the construction sector. The recovery of construction and demolition waste (C&DW) as aggregate is an efficient way to achieve this purpose. Adopting and implementing this principle is particularly relevant for an industry that consumes more raw materials than any other economic activity and produces huge amounts of waste.

Considering the need to find new ways of avoiding landfilling of inert waste and preserving natural resources, recent studies have been carried out on the reuse of recycled aggregates from C&DW in geosynthetic reinforced structures (Arulrajah *et al*. 2014; Soleimanbeigi *et al*. 2019; Santos *et al*. 2013; Vieira & Pereira 2015; Vieira & Pereira 2021; Vieira *et al*. 2016). However, one of the main issues regarding the use of geosynthetics in contact with alternative materials is their durability.

The damage caused by mechanical actions during installation and the chemical and biological degradation are important issues to be considered in geosynthetics behaviour. The changes in their physical, mechanical and hydraulic properties, induced by the above-mentioned degradation processes, can control the performance of the structures where these materials are used.

Within the framework of a research project damage trial embankments have been constructed to study degradation induced by recycled C&DW on different geosynthetics. The

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exhumation of geosynthetic samples from these embankments was done after 6, 12 and 24 months of exposure.

The results herein presented are related to polyester (PET) geogrid samples exhumed after 12 months of exposure to recycled C&DW. The mechanical damage induced by this recycled material on the geogrid was simulated by laboratory installation damage tests.

2 MATERIALS AND METHODS

The geosynthetic used in this study was a uniaxial geogrid manufactured of extruded polyester (PET) (Figure 1a) with aperture dimensions of 30 mm × 73 mm. To minimize the influence of external factors all the samples (intact - as provided by the manufacturers, damaged in the laboratory and exhumed samples) were taken from the same roll of material and tested using the same methods and equipment.

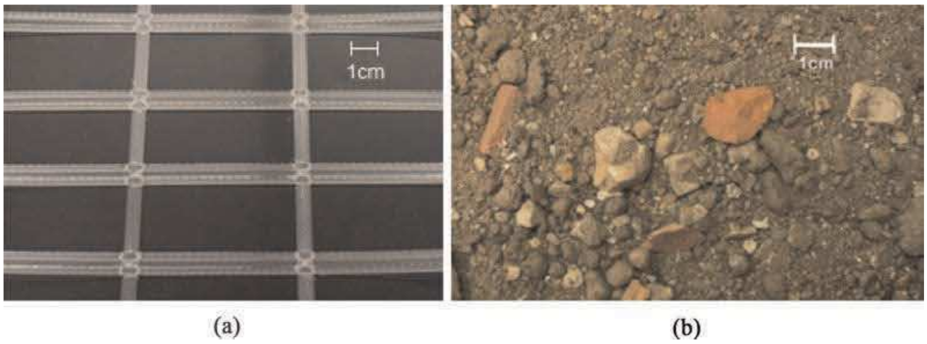

Figure 1. Visual appearance of the material: (a) PET geogrid. (b) recycled aggregate from C&DW.

To study the chemical and environmental degradation induced by a recycled aggregate coming from C&DW (or recycled C&DW) on the short-term tensile behaviour of the geosynthetics, damage trial embankments were constructed. The damage trial 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 (Figure 1b). The particle size determined by sieving and sedimentation is represented in Figure 2a. The predominant constituents of this fine grain recycled C&DW used are concrete, masonry, unbound aggregates, natural stones, as well as, a significant portion of soil (Figure 2b). These recycled materials were provided by a Portuguese Recycling plant located in Centre region.

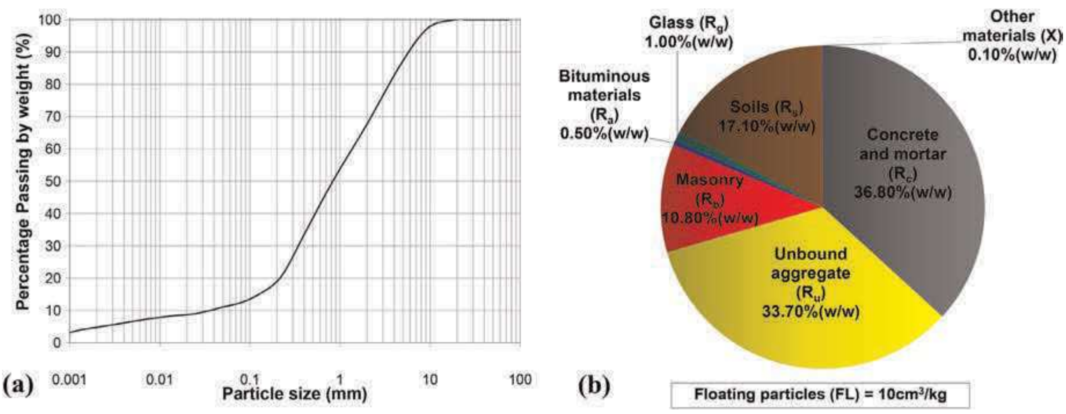

Figure 2. Recycled aggregate from C&DW: (a) particle size distribution; (b) portions of constituents.

After cleaning the foundation from the existing vegetation, a 5 cm-thick layer was placed and compacted and the geosynthetic samples of the first level were carefully positioned without overlapping. Geosynthetic samples were then covered with a first layer of recycled C&DW placed manually to prevent mechanical damage. Additional quantities of filling material were disposed, evenly spread and compacted to reach a lift with final thickness of approximately 0.20 m (Figure 3a). To minimize the installation mechanical damage on the geosynthetics, a lightweight compaction process was adopted (forward compaction plate with weight of 94 kg). Details on embankment construction are available in Vieira & Pereira (2015).

The tensile behaviour of exhumed specimens presented in this paper is related to geogrid samples exhumed after 12 months of installation (Figure 3b). The samples were carefully exhumed to prevent additional damage, being the material just above the geosynthetics removed carefully with the hands.

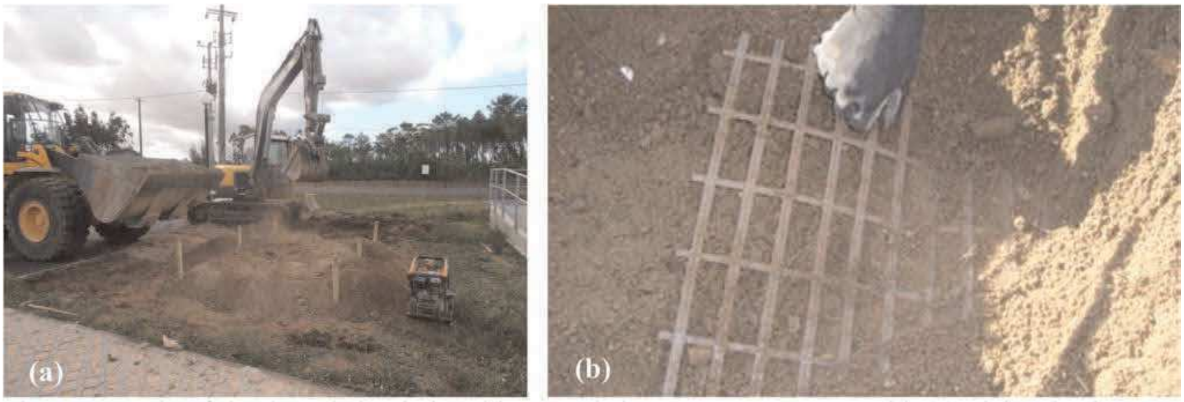

Figure 3. Study of the degradation induced by recycled C&DW on PET geogrid: (a) trial embankments construction; (b) geogrid specimens' exhumation.

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.

Laboratory installation damage tests were also carried out, using recycled aggregate from C&DW similar to the one used in the embankments construction (coming from the same batch), to study the mechanical damage induced by these recycled materials on the geogrid tensile behaviour.

The mechanical damage tests were performed using a laboratory prototype developed at the University of Porto (Lopes & Lopes 2003). The apparatus is composed by a rigid container (300 mm $\times$ 300 mm $\times$ 150 mm) divided in two boxes (where the geogrid and the recycled aggregate from C&DW were placed), a loading plate and a hydraulic compression system.

The geogrid specimens were cut with a width of 200 mm (5 longitudinal bars) and length of 380 mm. Each specimen was placed between two layers of C&DW and submitted to repeated loading. The layer placed under the specimen consisted in two sublayers (each 37.5 mm high) compacted by a flat plate loaded to a pressure of 200 $\pm$ 2 kPa, during 60 s, over the whole area of the test container. The layer placed over the specimen consisted in loose recycled C&DW with 75 mm high. Each specimen was subjected to dynamic loading (ranging between 5 $\pm$ 0.5 and 500 $\pm$ 10 kPa) at a frequency of 1 Hz and for 200 cycles. Finished the loading, the specimen was removed carefully from the test container, avoiding additional damage.

Tensile tests carried out on intact (as provided by the manufacturers), exhumed and damaged specimens were performed in accordance with the European Standard EN ISO 10319 (2015). Five specimens (for each condition) and a strain rate of 20%/min. were used.

3 RESULTS AND DISCUSSION

3.1 *Specimens exhumed from the embankment*

Although the preliminary visual inspections of the exhumed samples have not revealed significant damages. Scanning Electron Microscope (SEM) analyses were carried out to evaluate potential damages in more detail

Figure 4 illustrates SEM images (at 100 × magnification) of intact (Figure 4a) and exhumed specimens of geogrid (Figure 4b). From the analysis of Figure 4 it is visible that small particles of the backfill material have stuck to the geogrid but there is no relevant damage in the exhumed geogrid. Load-strain curves of exhumed geogrid specimens resulting from tensile tests are illustrated in Figure 5a. The mean curve is also represented. The maximum tensile strength (T_{max}), the geogrid 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}) for the five specimens 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 in Table 1. Analysing Figure 5a and Table 1 it is clear the low variability of the results.

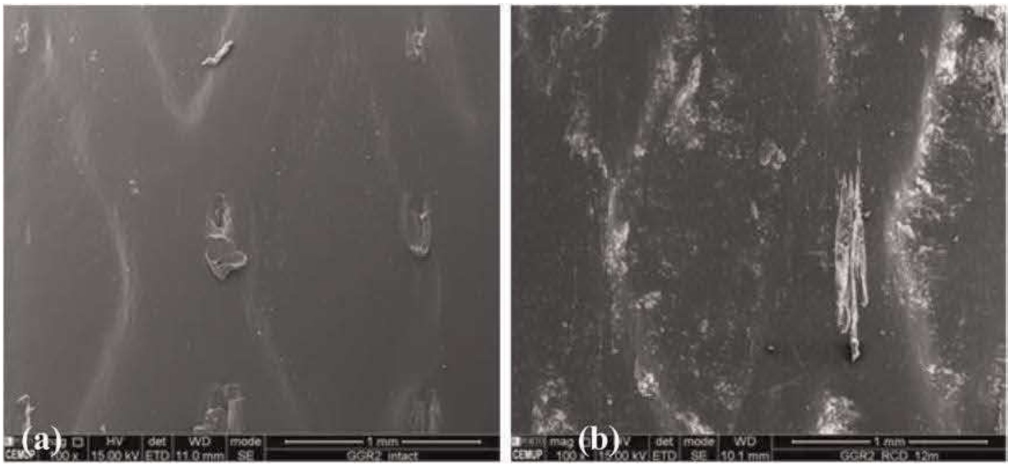

Figure 4. SEM images of PET geogrid specimens (× 100): (a) intact; (b) exhumed after 12 months.

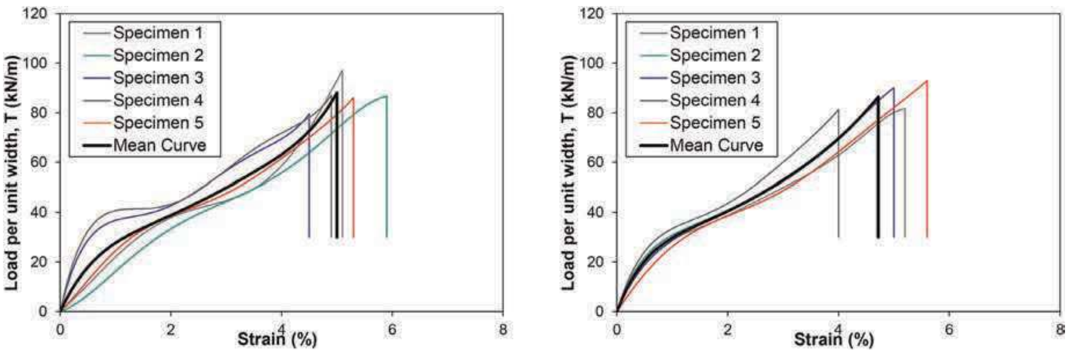

Figure 5. Load-strain curves of tensile tests performed on: (a) exhumed geogrid specimens; (b) geogrid specimens damaged in laboratory.

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

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	97.5	5.1	1892	1908
Specimen 2	87.8	5.9	1366	1489
Specimen 3	79.3	4.5	2134	1750
Specimen 4	86.5	4.9	2164	1747
Specimen 5	85.7	5.3	1925	1618
Mean value	87.4	5.2	1896	1703
Confidence interval of 95%	87.4 ± 8.1	5.2 ± 0.6	1896 ± 397	1703 ± 196

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

3.2 *Specimens damaged in laboratory*

After the laboratory 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 geogrid specimens, as well as the mean curve corresponding to the 5 samples are represented in Figure 5b. Table 2 summarizes the values of maximum tensile strength (T_{max}), geogrid 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.

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

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	82.1	5.2	1941	1579
Specimen 2	85.9	4.7	2048	1829
Specimen 3	90.8	5.0	2024	1817
Specimen 4	80.3	4.0	2180	2008
Specimen 5	91.0	5.5	1931	1641
Mean value	86.0	4.9	2025	1775
Confidence interval of 95%	86.0 ± 6.1	4.9 ± 0.7	2025 ± 125	1775 ± 211

3.3 *Comparison and discussion of results*

The tensile behaviour of intact specimens was reported in a previous publication (Vieira & Pereira 2021). Table 3 summarises the main results. The tensile strength reached in laboratory tests of intact specimens exceeded the mean value provided by the manufacturer. It should also be noted that the maximum tensile force is achieved for a low value of strain (5.6%), meaning that it is a geogrid of high tensile stiffness (around 2025 kN/m for 2% of strain). The comparison of these results with those presented in Tables 1 and 2 points out that of the loss of strength caused either by the exposure to the recycled C&DW for 12 months or by the laboratory installation damage tests is very small (loss of 5% and 7% on average, respectively).

Figure 6 compares the mean curves for intact, exhumed and damaged specimens. The shape of curves is quite similar but the coordinates at failure were shifted. Figure 6 enhances the little influence of this damage processes on the tensile behaviour of this geogrid. It should also be emphasized that the geogrid tensile strength after 12 months of exposure to C&DW and laboratory damage remains higher than its nominal value (80 kN/m).

Table 3. Summary of results of tensile tests carried out on intact geogrid specimens (Vieira & Pereira 2021).

	T_{max} (kN/m)	ε_{Tmax} (%)	$J_{2\%}$ (kN/m)	J_{Tmax} (kN/m)
Specimen 1	89.9	5.5	2037	1635
Specimen 2	100.7	5.8	2078	1736
Specimen 3	82.1	5.2	1942	1579
Specimen 4	91.0	5.5	1931	1641
Specimen 5	97.9	6.0	1971	1631
Mean value	92.3	5.6	1992	1645
Confidence interval of 95%	92.3 ± 9.1	5.6 ± 0.4	1992 ± 79	1645 ± 71

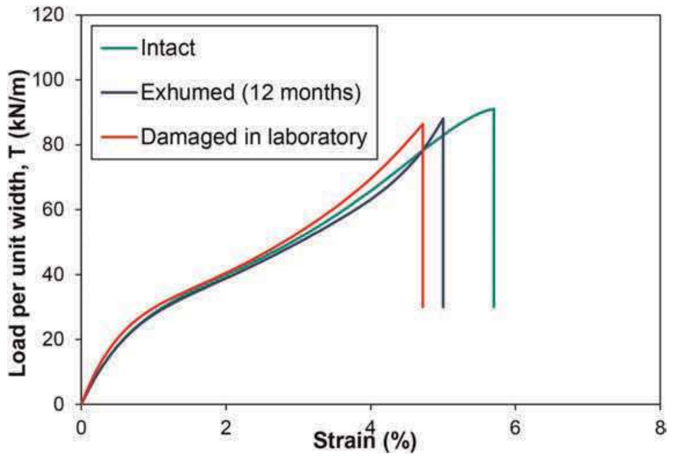

Figure 6. Comparison of mean load-strain curves of intact, damaged in the laboratory and exhumed specimens.

The geogrid tensile stiffness for very small strains (initial stiffness) did not change significantly while an increase on the secant stiffness modulus at ε_{Tmax} (J_{Tmax}) is noticeable. The increase on the secant stiffness was slightly higher in samples damaged in laboratory than in samples exposed 12 months to the recycled aggregate from C&DW.

The damage on geosynthetics used as reinforcement is currently quantified by the retained values of relevant parameters, such as, the tensile strength, the strain at maximum load or the secant stiffness modulus. The retained value of the parameter X can be defined as the ratio between the mean value of the parameter X for damaged or exhumed specimens and the corresponding mean value for intact specimens.

The mean values of the retained tensile strength, R_T, retained peak strain, $R\varepsilon$, and retained secant modulus at 2% of strain, $R_{J2\%}$ are presented in Table 4. As previously mentioned, the mechanical damage induced in laboratory was slightly more pronounced than the effects of exposure for 12 months.

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

Exhumed after 12 months			Mechanical damaged		
R_T (%)	$R\varepsilon$ (%)	$R_{J2\%}$ (%)	R_T (%)	$R\varepsilon$ (%)	$R_{J2\%}$ (%)
94.7	92.9	95.2	93.2	87.5	101.7

4 CONCLUSIONS

The mechanical, chemical and environmental degradation induced by fine grain recycled C&DW on the short-term tensile behaviour of an extruded uniaxial PET geogrid was presented. The research herein reported has shown that the mechanical damage induced in the laboratory is more aggressive than that caused during trial embankments construction. That means that, it is possible to consider that the installation damage during the construction of the trial embankments was, as expected, insignificant and therefore, the damages recorded on exhumed specimens could be attributed to the chemical and environmental degradation.

Results of tensile tests carried out on exhumed specimens have shown that the exposure of this geogrid to fine grain C&DW under real atmospheric conditions for 12 months did not induce geogrid degradation.

Despite the fact that the exposure period of the geogrid to the recycled C&DW was very short compared to the lifetime of the structures, this study allows us to conclude that it is not expected that the use of recycled materials will induce the degradation of geogrids.

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