

Geosynthetics tensile behaviour after exposure to non-conventional fill materials

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ABSTRACT: The use of alternative materials that avoid the extraction of natural resources is currently a key topic in the design and construction of more sustainable structures and infrastructures. Non-conventional materials, such as recycled construction and demolition waste (CDW), have been studied and used in various civil engineering works often in contact with different geosynthetics. While the durability of geosynthetics is a critical aspect when using conventional materials, it becomes even more relevant when alternative materials are used. This work compares the effects on the tensile behaviour of three geosynthetics (two geogrids and a high strength geotextile) after being exposed for 12 months to a fine-grained CDW and a residual sandy-clay soil. The effects induced by damage during installation laboratory tests using the recycled CDW as fill material were also evaluated. The results revealed that the exposure to CDW or to the soil has similar effects on the geosynthetics tensile behaviour.

1 INTRODUCTION

The durability of geosynthetics has been a concern for the construction industry since their earliest days. Although nowadays these concerns are generally overcome when geosynthetics are used in contact with conventional materials (soils and rocks), uncertainties still remain when alternative fill materials are involved.

In recent years, recycled Construction and Demolition Waste (CDW) has gained attention as a substitute for natural materials in civil engineering applications, such as unbound pavement layers (Rahman et al. 2015; Vieira et al. 2016) and geosynthetic reinforced structures (Santos et al. 2014, Vieira et al. 2016), where geosynthetics, particularly geogrids and high-strength geotextiles, are used as reinforcement elements. Hence, assessing the potential degradation these alternative materials may cause to the tensile behaviour of geosynthetics is of great importance.

In this context damage trial embankments intending to simulate the potential degradation (chemical and environmental) induced by alternative fill materials on the tensile behaviour of different geosynthetics are constructed. This paper presents results of tensile tests carried out on geosynthetic specimens exhumed from the embankments after 12 months of exposure. To separate the effects of the exposure to CDW to those of damage during installation, geosynthetic specimens immediately exhumed were also tested. Additionally, laboratory tests were also used to simulate the damage during construction.

2 MATERIALS AND METHODS

2.1 *Geosynthetics*

The study involved three commercially available geosynthetics commonly used for reinforcement purposes (Figure 1): a high-strength composite geotextile, which combines a polypropylene (PP) continuous-filament needle-punched nonwoven with high-strength polyester (PET) yarns, designated as GTX (Figure 1a); a uniaxial geogrid made of high-density polyethylene (HDPE), named as GG1 (Figure 1b); and a uniaxial geogrid composed of extruded polyester (PET) bars with welded rigid junctions, referred to as GG2 (Figure 1c).

The aperture dimensions of the geogrids and the reported tensile strength characteristics of the three geosynthetics are presented in Table 1.



Figure 1. Appearance of the geosynthetics (ruler in centimetres): (a) high-strength composite geotextile (GTX); (b) uniaxial high-density polyethylene geogrid (GG1); (c) polyester geogrid (GG2).

Table 1. Some physical and mechanical properties of the geosynthetics.

Geosynthetic	GTX	GG1	GG2
Aperture dimensions (mm)	-	16×219	30×73
Tensile strength* (kN/m)	75	68	80
Elongation at maximum load* (%)	10	11±3	≤ 8

* Provided by the manufacturer’s technical data sheet.

2.2 Fill materials and trial embankments

Small trial embankments were constructed using a recycled construction and demolition waste (CDW) and a clayey sand, in order to assess whether the presence of non-natural components in CDW—such as cement, glass, etc—leads to increased damage to geosynthetics. Figure 2 shows the particle grain size distribution of both materials.

The recycled CDW was supplied by a Portuguese recycling facility and is composed of concrete, mortar, bricks, soils and other materials. More details on the constituents of the CDW and its leaching behaviour can be found in a previous publication (Vieira &Pereira 2015).

The natural soil used in this study is finer than the recycled CDW and is not a material typically used in the construction of geosynthetic-reinforced structures due to its high fines content.

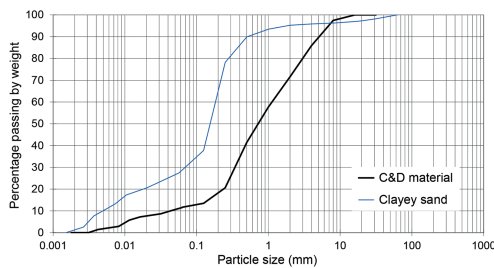


Figure 2. Particle grain size distribution of the fill materials.

The main purpose of the trial embankments was to study the potential chemical and environmental degradation induced by the exposure of the geosynthetics to a recycled CDW and a natural soil (for comparison) and not to assess the damage during installation. Thus, lightweight compaction was used. To separate the effects of the exposure to the CDW to those of damage during installation, a smaller embankment was constructed under the same conditions, from which the geosynthetic samples were immediately exhumed after its completion.

The trial embankments were constructed with plan dimensions of 2 m × 3 m and a height of 0.45 m (Figure 3). Within each embankment, geosynthetic samples (approximately 0.45 m × 1.5 m) were placed at two vertical levels, spaced 0.20 m apart. More details can be found in Vieira & Pereira 2015, Vieira & Pereira 2021.

This study presents results of geosynthetic samples exhumed from the embankment after 12 months of exposure.



Figure 3. Trial embankment: (a) placement and arrangement of geosynthetics; (b) finished embankment with lateral protection with coarse aggregates.

2.3 Damage laboratory tests

The assessment of mechanical damage under repeated loading through laboratory testing is standardized by EN ISO 10722: 2007 for index tests. However, in the present study, recycled CDW was used as the fill material, and the compaction procedure differed from that prescribed in the standard.

The damage laboratory tests were performed using an apparatus developed at the University of Porto (Lopes & Lopes 2003), composed by a rigid container ($300 \text{ mm} \times 300 \text{ mm} \times 150 \text{ mm}$), where the geosynthetics and the filling material is placed, a loading plate and a hydraulic compression system.

Each sample was subjected to dynamic loading with an amplitude ranging from 5 to 500 kPa, applied at a frequency of 1 Hz for a total of 200 cycles. Upon completion of the test, the fill material was carefully removed to prevent any additional damage to the geosynthetics.

2.4 Tensile tests

The tensile behaviour of the geosynthetics was characterized through tensile tests carried out on intact samples (as supplied by the manufacturer), exhumed samples from the trial embankments and samples damaged in the laboratory. The tensile tests were performed using a Universal Testing Machine, on five specimens for each condition, following the European standard EN ISO 10319: 2008 and applying a strain rate of 20%/min.. A video-extensometer was used to measure the geosynthetics strain.

2.5 SEM analyses

A more detailed evaluation of the potential damage was carried out through Scanning Electron Microscope (SEM) analyses. 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, was used.

3 RESULTS AND DISCUSSION

3.1 Influence of the fill material

Figure 4 presents the effect of 12-month exposure to both fill materials on the tensile behaviour of the geosynthetics under study. Figure 4a shows the average value of the maximum tensile force, $T_{\max}$, while Figure 4b presents the secant stiffness modulus at strain of 2%, $J_{2\%}$. The 95% confidence intervals assuming a Student's t-distribution are also shown in both graphs.

The geosynthetic that showed the most pronounced degradation was the GTX, with tensile strength reduction of approximately 29% and 19% after exposure to CDW and clayey sand, respectively. The variation in tensile strength observed for the geogrid GG1 is minimal, with a maximum reduction of approximately 3%.

Similarly to GG1, exposure to both CDW and soil had comparable effects on the tensile strength of geogrid GG2, resulting in reductions of approximately 6% and 7.5%, respectively. It is worth noting that, in its intact condition, this geogrid exhibited a significantly higher maximum $T_{\max}$ than the nominal value declared by the manufacturer (Table 1).

It should be pointed out that, except for the GTX, the mean tensile strength of the exhumed geogrid specimens falls within the confidence interval of $T_{\max}$ for the intact specimens (Figure 4a).

GTX also exhibited the most significant variation in the secant stiffness modulus at strain of 2%, $J_{2\%}$, marked by an increase in this parameter in the exhumed specimens (Figure 4b). After exposure to the fine soil, an increase of approximately 13% in $J_{2\%}$ was observed. This effect is also evident in Figure 5a, which shows a notable reduction in $T_{\max}$ and in the corresponding strain, $\epsilon_{T_{\max}}$, along with a slight increase in the geotextile’s stiffness for strains lower than $\epsilon_{T_{\max}}$.

The observed increase in geotextile’s stiffness may be attributed to the presence of fill particles attached to the geotextile. Figure 6 presents SEM images of the PET filaments, revealing no visible damage, but particles of CDW (Figure 6b) or clayey sand (Figure 6c) can be seen attached to the filaments.

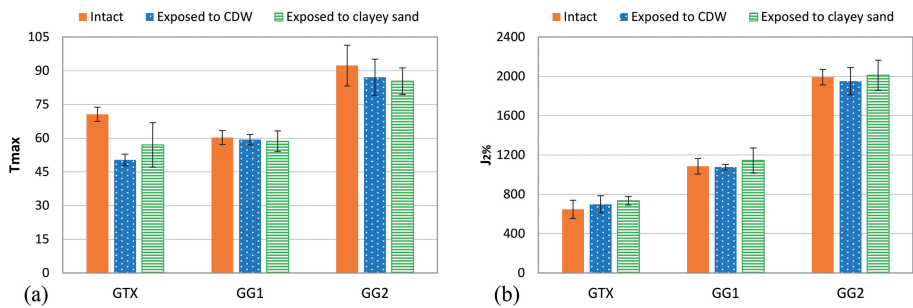


Figure 4. Influence of the fill material on the tensile behaviour of the geosynthetics: (a) geosynthetic tensile strength, $T_{\max}$; (b) secant stiffness modulus at strain of 2%, $J_{2\%}$.

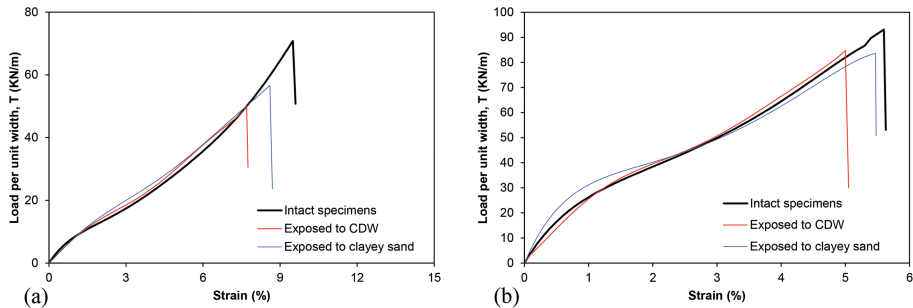


Figure 5. Mean load-strain curves for intact and exhumed specimens: (a) geotextile GTX; (b) geogrid GG2.

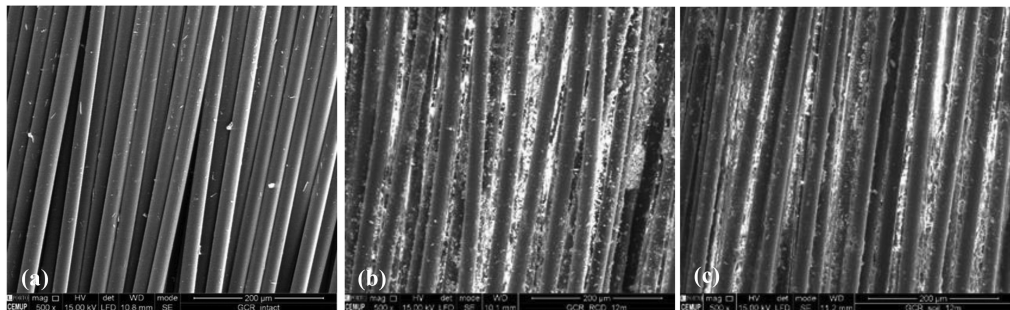


Figure 6. SEM images of GTX specimens (PET filaments): (a) intact specimen ($\times 500$); (b) exposed to CDW ($\times 500$); (c) exposed to clayey sand ($\times 500$).

The effect of geogrids exposure to both fill materials on their secant stiffness modulus at strain of 2%, $J_{2\%}$, was minimal (Figure 4b). While the exposure to CDW resulted in a slight reduction in the stiffness, a marginal increase of $J_{2\%}$ after exposure to fine soil was observed. The increase in the initial stiffness of the geogrid GG2 is also evident in Figure 5b.

It is worth mentioning that the variations of $J_{2\%}$ are of limited significance, as its mean value for the exhumed specimens falls within the confidence interval of this parameter for the intact specimens for all the geosynthetics (Figure 4b).

Figure 7 presents SEM images of the junction between the longitudinal and transverse bars of the GG2 geogrid, with no visible damage.

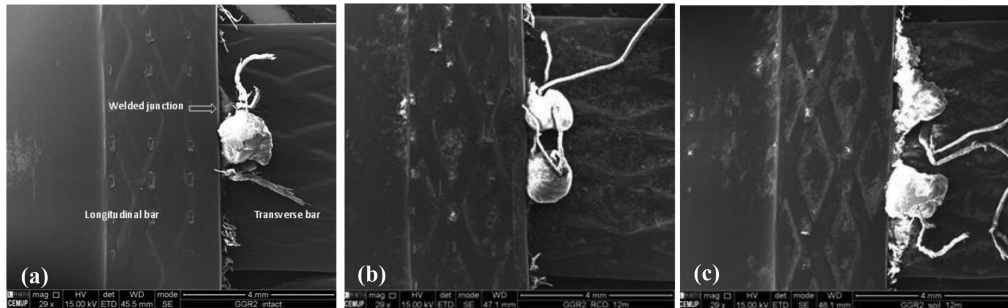


Figure 7. SEM images of GG2 specimens (junction of longitudinal and transversal bars): (a) intact specimen ($\times 29$); (b) exposed to CDW ($\times 29$); (c) exposed to clayey sand ($\times 29$).

3.2 Effect of damage due to compaction

As mentioned in 2.2, lightweight compaction was adopted during the construction of the trial embankments and, to isolate the effects of exposure to CDW from those of damage during installation, geosynthetic samples were exhumed immediately after the construction of one of the embankments. Figure 8 compares the behaviour of the specimens exhumed immediately after installation with that of the intact specimens and those subjected to damage laboratory test.

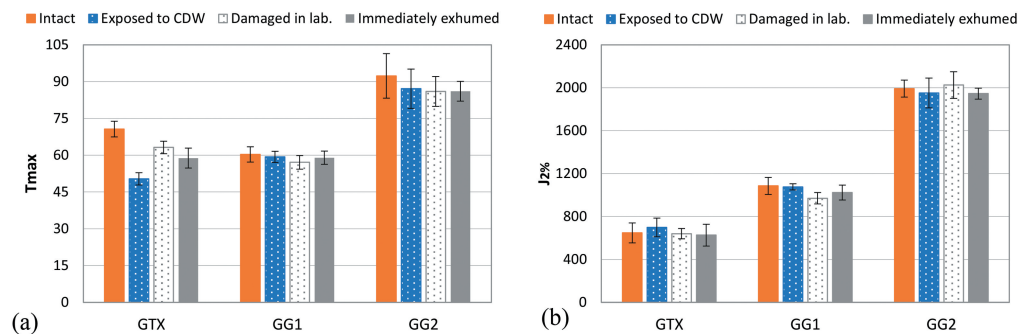


Figure 8. Effect of damage induced by exposure and compaction: (a) geosynthetic tensile strength, T_{max} ; (b) secant stiffness modulus at strain of 2%, $J_{2\%}$.

For the geogrids, the tensile behaviour of the specimens exposed for 12 months to the fill materials and the specimens exhumed immediately was quite similar (Figure 8). This confirms that exposure to these alternative materials over a 12-month period does not lead to significant deterioration in their mechanical performance. The tensile strength, T_{max} , of the geogrids subjected to laboratory mechanical damage was also very similar to those obtained from the specimens exhumed from the embankments. The laboratory damage tests were more adverse to GG1 than its exposure to CDW in the trial embankments. Interestingly, the GG2 specimens subjected to laboratory damage tests exhibited a higher mean value of $J_{2\%}$, but within the confidence interval for intact specimens.

The geotextile exhibited a somewhat different behaviour: the specimens exposed to CDW for 12 months showed a reduction in $T_{\max}$ of approximately 14% compared to those that were immediately exhumed after installation. In contrast to GG1, the damage induced in the laboratory was less severe than that caused by installation and immediate exhumation.

The decrease in the tensile strength of the GTX is likely associated with alterations in the bonding between the PET yarns and the nonwoven geotextile, induced by the handling and exposure to the fill materials, rather than direct damage to these yarns. The PET yarns appeared less aligned and less attached to the non-woven geotextile, which may have contributed to premature failure.

4 CONCLUSIONS

This study aims to characterise the potential degradation resulting from exposure to alternative fill materials, on the tensile response of three geosynthetics. Based on the results of this study, the following conclusions can be drawn:

- among the geosynthetics analysed, the GTX exhibited the most pronounced degradation, with the greatest reduction in tensile strength observed after exposure to CDW;
- the exposure of the HDPE geogrid to CDW and to the fine soil resulted in negligible effects on its tensile strength. The maximum reduction in PET geogrid was around 7.5%;
- the effects of exposure to CDW and to the clayey sand were similar;
- the tensile behaviour of the geogrids exposed to CDW for 12 months was very similar to that of the specimens exhumed immediately after installation;
- for the HDPE geogrid the laboratory damage tests were more adverse than its exposure to CDW, while the inverse trend was observed for the geotextile.

The study will be expanded in the future to examine how these alternative materials affect geosynthetics under real installation conditions.

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