# Study on the use of Construction and Demolition Recycled Materials in construction of geosynthetic reinforced slopes

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ABSTRACT: Recycling or reuse of waste is increasingly an imperative in the construction industry. This paper describes a research project developed to study the suitability of the use of Construction and Demolition Recycled Materials (C&DRM) as filling material of geosynthetic reinforced structures. Results of the mechanical characterization of C&DRM, the degradation induced by C&DRM on the tensile behavior of the geosynthetics, as well as, the behaviour of C&DRM/geosynthetic are presented and discussed. The main conclusions of the research project are pointed out.

*Keywords: Environmental sustainability, Recycled materials, Alternative filling materials, Reinforced slopes*

## 1 INTRODUCTION

The level of exploitation of non-renewable natural resources should be a serious concern to current societies. The environment preservation imposes a good natural resources management and the use of alternative materials, such as recycled wastes. Over the last years the environmental sustainability has been demanding a progressive increase in the waste valorisation in the construction industry. Construction and Demolition Wastes (C&DW) are wastes derived from construction, reconstruction, cleaning of the work site and earthworks, demolition and collapse of buildings, maintenance and rehabilitation of existing constructions. The reuse of C&DW, on the one hand, reduces the exploitation of natural resources (non-renewable) and, on the other hand, avoids congesting landfills with inert wastes coming from buildings and other constructions or infrastructures.

Several studies and applications of Construction and Demolition Recycled Materials (C&DRM) have been performed mainly related to the production of aggregates for use in concrete (Behera et al. 2014; Medina et al. 2014; Rao et al. 2007; Silva et al. 2014) and to be used in base layers of transportation infrastructures (Agrela et al. 2012; Herrador et al. 2011; Jiménez et al. 2012; Poon and Chan, 2006). Apart from some recent studies (Vieira et al. 2016; Vieira and Pereira 2015, 2016; Arulrajah et al. 2014; Santos et al. 2013, 2014), the valorisation of recycled C&DRM in geosynthetic reinforced structures is not a common application.

A research project aiming to contribute to the sustainable application of C&DRM as backfill material in geosynthetic reinforced structures has been developed at University of Porto, Portugal, since 2013. This work presents and discusses results of the physical, environmental and mechanical characterization of C&DRM, as well as the behaviour of interfaces between these recycled materials and different geosynthetics.

## 2 BRIEF DESCRIPTION OF THE RESEARCH PROJECT

The research project "*Sustainable application of Recycled Construction and Demolition Waste (C&DW) in geosynthetic reinforced structures - RCD-VALOR*" deals with a new application of C&DRM, as backfill material for geosynthetic reinforced structures (embankments with steep slopes and retaining walls), studying the possibility of replacing the natural soils used traditionally in the construction of these structures.

Recycling or reuse of waste is increasingly an imperative in the construction industry. This research project intends to broaden the application of C&DRM, particularly the fine portion of these recycled materials (Figure 1) with great difficulties to be used in concrete production. The *RCD-VALOR* project represents a step forward in the way to achieve the targets set by the European Parliament in 2008 (70% of non-hazardous C&DW recycling by 2020).

This research project has comprised several tasks, namely:

i) Physical, mechanical and environmental characterization of different batches of C&DRM;
ii) Characterization of C&DRM /Geosynthetic interfaces through direct shear tests;
iii) Characterization of C&DRM /Geosynthetic interfaces through pullout tests;
iv) Study on the effects induced by C&DRM on geosynthetics short term mechanical behavior;
v) Numerical modelling of geosynthetic reinforced structures constructed with C&DRM as filling material.

To date, three batches of C&DRM collected at different times were studied.

Figure 1: Fine portion of C&D recycled materials available to be used.

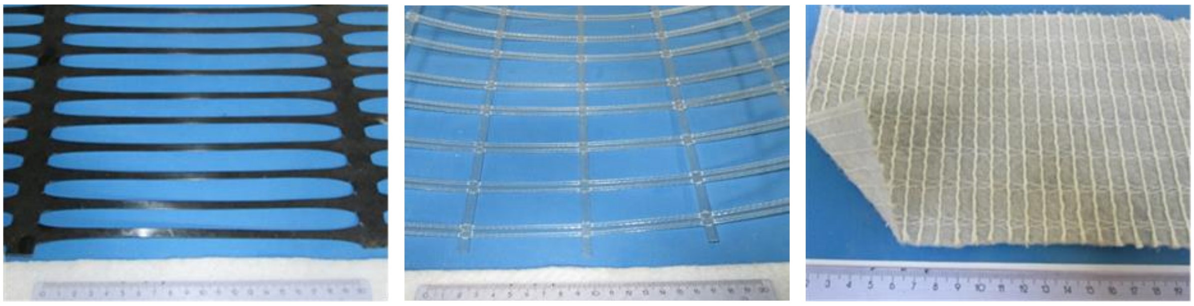
## 3 MATERIALS

As mentioned, the research project was based on the use of fine grain C&DRM. The three batches of recycled material were collected from a Portuguese Recycling Plant located in the centre of the country, resulting from the recovery of mixed C&D wastes coming mainly from the demolition or rehabilitation of housing buildings and cleaning of lands with illegal deposition of construction wastes.

Figure 2 illustrates one sample of the recycled material used in this study. The constituents of the different batches of C&DRM can be found in previous publications (Vieira and Pereira, 2016; Vieira et al. 2016). These recycled materials comprise mainly concrete, unbounded aggregates, masonries and soils.

Figure 2: Sample of C&DRM used in the study (Vieira and Pereira, 2016).

Three commercially available geosynthetics for soil reinforcement were used in this study: an extruded uniaxial high density polyethylene (HDPE) geogrid (Figure 3a), a laid uniaxial geogrid manufactured of extruded polyester (PET) bars with welded rigid junctions (Figure 3b) and a high-strength composite geotextile consisting of polypropylene (PP) continuous-filament needle-punched nonwoven and high-strength PET yarns (Figure 3c). The main properties of these geosynthetics, provided by the manufacturers, are summarized in Table 1.



(a) (b) (c)

Figure 3: Geosynthetics used in the study (ruler in centimetres): (a) GGR1 - uniaxial HDPE geogrid; (b) GGR2 - uniaxial PET geogrid; (c) GCR – geocomposite (Vieira et al. 2016).

Table 1. Main properties of the geosynthetics.

| | GGR1 | GGR2 | GCR |
|---|---|---|---|
| Raw material | HDPE | PET | PP & PET |
| Unit weight (g/m$^2$) | 450 | 380 | 340 |
| Aperture dimensions (mm) | 16×219 | 30×73 | - |
| Mean value of the tensile strength (kN/m) | 68 | 80/20# | 75/14# |
| Strain at maximum load (%) | 11±3 | ≤ 8 | 10 |

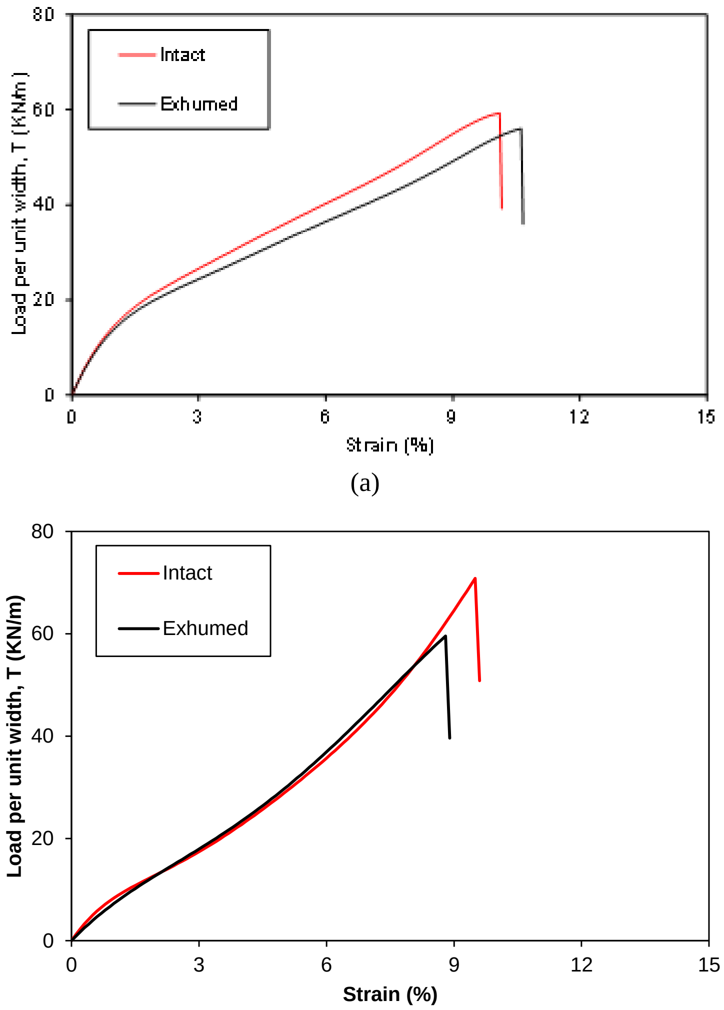
# Machine direction / Cross direction.

## 4 EFFECTS INDUCED BY C&DRM ON GEOSYNTHETICS TENSILE BEHAVIOUR

The mechanical, chemical and environmental degradation induced by C&DRM on the short-term tensile behaviour of the geosynthetics was studied. For this purpose three damage trial embankments were constructed: two of them using C&DRM as filling material and the other one using a granite residual soil, often used in the construction of geosynthetic reinforced structures (Figure 4).
It should be mentioned that these trial damage embankments simply intend to simulate the potential degradation induced by C&DRM on the tensile behaviour of the geosynthetics. Its construction method and dimensions are not adequate for other purposes, namely the analysis of the embankment behaviour. Details on embankment construction and characterization of recycled aggregates are available in (Vieira and Pereira, 2015).

Figure 4: One of the damage trial embankments.

The exhumation of geosynthetic samples took place after 6, 12 and 24 months of exposure to C&DRM or residual soil. After the careful exhumation the geosynthetic samples, they were protected and transported to the laboratory.
Exhumed geosynthetic samples were submitted to tensile tests and Scanning Electron Microscope (SEM) analyses in order to assess the effects induced by the C&DRM or by natural soil on their short-term tensile behaviour.
Laboratory installation damage tests were also carried out, using C&D recycled materials similar to the one used in the construction of the embankments (coming from the same batch).
Even if the period of time between the installation and the exhumation of the geosynthetic specimens are not equivalent to the service life of the structures, the construction of these damage embankments and the quantification of the damage induced give us an estimate of the safety factors related to the mechanical damage and degradation induced by the environment.
Figure 5 compares the mean load-strain curves for intact specimens with the mean load-strain curves for the exhumed specimens after 6 months of exposure. The shape of the curves for intact and exhumed specimens are similar, but the coordinates at failure were shifted in the case of the geogrid GGR1. The geogrid initial stiffness did not change significantly but the secant modulus reduced (Figure 5a).
As regard the geocomposite GCR, the exposure to the C&DRM induced some reduction of its tensile strength but the effect on the geocomposite tensile stiffness is not significant (Figure 5b).




(a)

(b)

Figure 5: Comparison of load-strain curves of intact and exhumed geosynthetic specimens after 6 months of exposure (Vieira e Pereira, 2015): (a) geogrid GGR1; (b) geocomposite GCR.

## 5 BEHAVIOUR OF C&DRM/GEOSYNTHETIC INTERFACES

### 5.1 *Results of direct shear tests*

When it is expected the sliding of the backfill material along the geosynthetic (this occurs typically near the base of the reinforced embankment) the interaction between the two materials should be characterized through direct shear tests. Thus an extensive program of direct shear tests was performed to characterize the behaviour of C&DRM/geosynthetic interfaces.
This laboratory program was developed to analyse the influence of the geosynthetic, the characteristics of the recycled material (3 different batches), the compaction degree and moisture content of the C&D recycled material and the confining pressure.
The direct shear tests were performed on a large scale direct shear apparatus (300 mm × 600 mm), with a constant displacement rate of 1 mm/min and for confining pressure of 25, 50, 100 and 150 kPa. The tests were stopped once the horizontal shear displacement reached approximately 60 mm.
Figure 6 presents the coefficients of interaction, defined as the ratio of the maximum shear stress in a C&DRM/geosynthetic direct shear test, to the maximum shear stress in a direct shear test on C&D material, under the same normal stress, for C&DW samples coming from

batch 2. Inside the shear boxes C&DRM samples were compacted at 90 % of maximum Modified Proctor dry density ($\gamma_{dmax}$ = 19.2 kN/m$^3$) and at the optimum moisture content ($W_{opt}$ = 12.5%).
The coefficients of interaction are in the range 0.70-0.73 for C&DRM/GGR1 interface, ranged from 0.65-0.74 for the interface C&DRM/GGR2 and ranged from 0.70-0.76 for the C&DRM/GCR interface. Even if the materials tested are distinct (two different geogrids and a high strength geotextile), the shear strength of the interfaces are quite similar.
These values are generally consistent with those reported by other researchers for soil–geogrid interfaces.

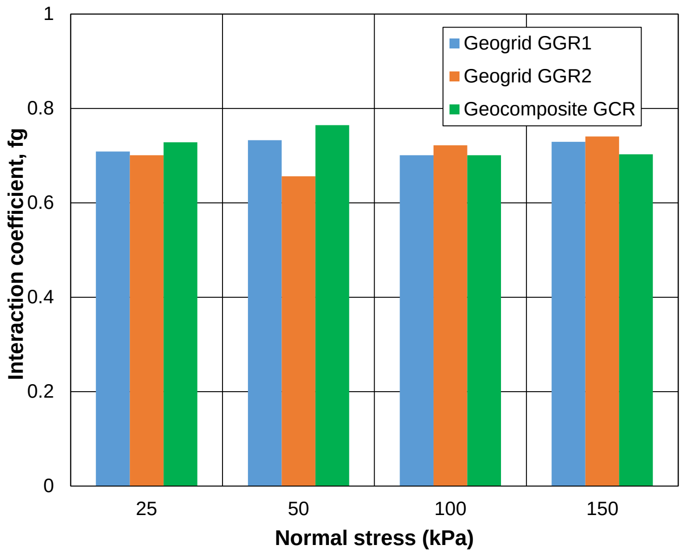



Figure 6: Coefficients of interaction for C&DRM/geosynthetic interfaces as a function of the confining pressure.

## 5.2 *Results of pullout tests*

When a geosynthetic is used as reinforcement element and can be pulled out from the backfill (mechanism particularly important behind the potential failure surfaces), the pullout strength should be evaluated. Thus the characterization of the behaviour of recycled C&DW/geosynthetic interfaces was an important point of this research project. The interaction between C&DRM coming from 2 different batches and the three geosynthetics was studied using a pullout box with dimensions in plan of 1.53m x 1.0m and 0.8 m high.
The influence on the interfaces pullout strength of the geosynthetic type, the compaction degree and moisture content of the C&DRM, the confinement pressure, as well as, the effect of the interface cyclic loading was analysed.
The comparison of the pullout behaviour for one sample of each geosynthetic is illustrated, as example, in Figure 7. Although the tensile strengths of the geosynthetics under analysis are not very different (Table 1), they exhibited different pullout behaviour. Results presented in Figure 7 refer to the same batch and compaction degree of those reported in Figure 6 and the pullout tests were carried out for a confining pressure at the interface level of 16 kPa.
The geogrid GGR1, having a lower tensile strength than that of geogrid GGR2 (Table 1), fails by insufficient tensile strength under pullout test conditions. Geogrid GGR2, being the less extensible geosynthetic, has failed by fails by lack of adherence (pullout).
The geocomposite GCR has exhibited a pullout resistance similar to the geogrid GGR1, but the failure was more ductile, resulting from the progressive failure or sliding of the PET yarns.

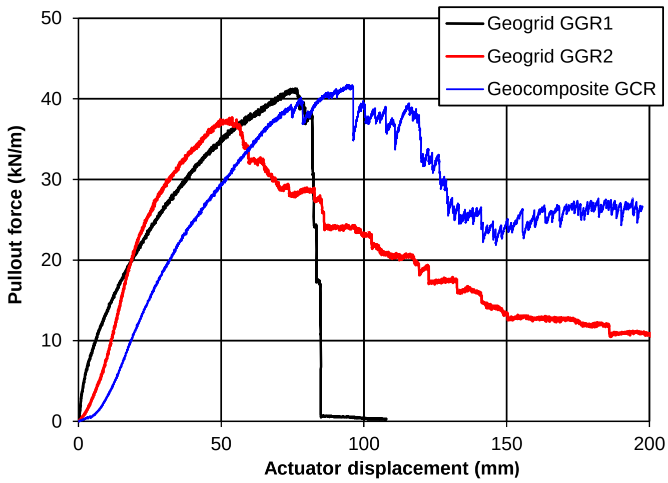



Figure 7: Comparison of pullout behaviour of the geosynthetics used in this study ($\sigma_n$ = 16kPa; $\gamma_{dmax}$ = 19.2 kN/m$^3$; $W_{opt}$ = 12.5%).

## 6 CONCLUSIONS

The main objective of *RCD-VALOR* project was the assessment of the suitability of use C&DRM as filling material in the construction of geosynthetic reinforced structures, replacing the natural soils used traditionally as filling material. This new application represents two benefit: on the one hand, the valorisation of C&DW contributes for a greater environmental sustainability and to achieve the recycling targets set by the European Commission and, on the other hand, it avoids the environmental and economic costs related to the extraction of large volumes of borrow soils.

The developed research project gave rise to the following main conclusions:

- The environmental characterization of C&DRM has shown that these materials meet the acceptance criteria for inert landfill. No environmental concerns were identified.
- Properly selected and compacted C&DRM can exhibit shear strength similar to (or even higher) the backfill materials commonly used in the construction of geosynthetic reinforced structures.
- The coefficients of interaction, based on direct shear test results, reached for C&DRM/geosynthetic interfaces compare well with those reported in the literature for soil/geosynthetic interfaces under similar conditions. Pullout interaction coefficients, estimated through laboratory pullout tests, are also in the usual range of this parameter for soil/geosynthetics interfaces.
- The results of tensile tests carried out on intact and exhumed specimens indicate that the effects of the C&DRM on the short-term load-strain behaviour of the geosynthetics depend on the structure and base polymer of the material. The loss of strength was not very expressive and was similar to that caused by the exposure to a natural soil.

This research project allow us to conclude that the use of C&DRM as filling material in the construction of geosynthetic reinforced structures is a feasible solution.

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