Procedia Engineering

Volume 143, 2016, Pages 51–58

Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

Geotechnical and Geoenvironmental Assessment of Recycled Construction and Demolition Waste for Road Embankments

Nuno Cristelo[1*], Castorina Silva[2] Vieira and Maria de Lurdes Lopes[2]

[1]*University of Trás-os-Montes e Alto Douro, CQVR, Vila Real, Portugal*

[2]*University of Porto, Construct, Porto, Portugal*

ncristel@utad.pt, cvieira@fe.up.pt, lcosta@fe.up.pt

Abstract

The reuse of industrial waste has already become a top European priority. Among the most significant contributors to the overall industrial waste volume is the construction industry, which is responsible for 50% of the worldwide consumption of natural resources. Construction and demolition (C&D) materials have been identified by the European Commission as a priority stream because of the large amounts that are generated and the high potential for re-use and recycling embodied in these materials. In order to instigate the reapplication of this waste-based coarse material back in the construction industry, and in structural applications in particular, like road or railway embankments, it is fundamental to properly characterize its mechanical behaviour. However, nowadays the environmental performance is at least as important, which prompts the issue of the quantity and quality of the leachate produced by such applications. The present paper deals with both these concerns, by reporting and analysing consolidated-drained triaxial tests on a fully characterized batch of recycled mixed Construction and Demolition Waste, provided by a Portuguese recycling plant, as well as its geoenvironmental assessment through leaching tests. In order to assist the decision making process regarding the potential use of geosynthetic reinforcement, the triaxial tests were extended to specimens with one geogrid reinforcing layer.

Keywords: Construction and Demolition Wastes, Sustainability, Road embankments, Geosynthetic reinforcement

1 Introduction

Environmental policies have been increasingly aiming the development of sustainability, having included in their list of favourite targets the minimisation of the landfilled waste volumes. One way to promote this reduction is its reuse in the construction industry, thus allowing the disposal of

* Corresponding author

Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.007

significant quantities of residues, since granular materials are widely used in this industry, namely in earth / geotechnical works such as embankments, retaining walls, road bases and railway ballast.

One of the major targets in terms of waste recycling are the Construction and Demolition Wastes (C&DW), which have been inspiring an increasing number of research projects, mainly related to the production of aggregates for use in concrete (Behera *et al*., 2014; Silva *et al*., 2014) and for use in base layers of transportation infrastructures (Agrela *et al*., 2012; Herrador *et al*., 2011; Arulrajah *et al*. 2013; Leite *et al*., 2011).

The application of C&DW in geotechnical works, in particular, has been mainly focused on road base and sub-base layers. Apart from this application, not many references can be found regarding the use of C&DW, with the possible exception of embankments (Vieira & Pereira, 2015). If we also consider the addition of geosynthetic reinforcement, that list becomes even shorter, with a few exceptions (Arulrajah *et al*., 2014; Santos *et al*., 2014; Vieira & Pereira, 2016).

The possible future application of this waste on a regular basis, with clear benefits from an environmental point of view (by mitigating the volume deposited in landfill), depends on the assertion of the mechanical performance, which is not yet a reality due to the absence of specific and complete studies regarding both cost and mechanical behaviour.

The work presented in this paper is part of a wider research project which targeted the potential application of C&DW in geotechnical works and the assessment of the replacement of natural soils, traditionally used in geosynthetic reinforced structures, by recycled C&DW. Therefore, the leachate resulting from C&DW was analysed and compared with relevant international standards, while the mechanical behaviour was assessed through triaxial tests, performed on specimens with and without one layer of geosynthetic reinforcement.

2 Materials and Methods

The following is the detailing of the materials used in this study, as well as a small description of the main tests performed (i.e. leaching and triaxial compression tests). Description of general geotechnical tests was not discriminated since these tests are well-known by the geotechnical research / project community, and thus do not usually need to be further characterized.

2.1 Materials

The recycled C&DW used in throughout this study (Figure 1) was part of a large sample provided by a Portuguese recycling plant. Based on the provided technical sheet, the material is mainly originated from the demolition of single family houses and recovering of C&DW from illegal deposits, i.e. it is a mixed C&DW.

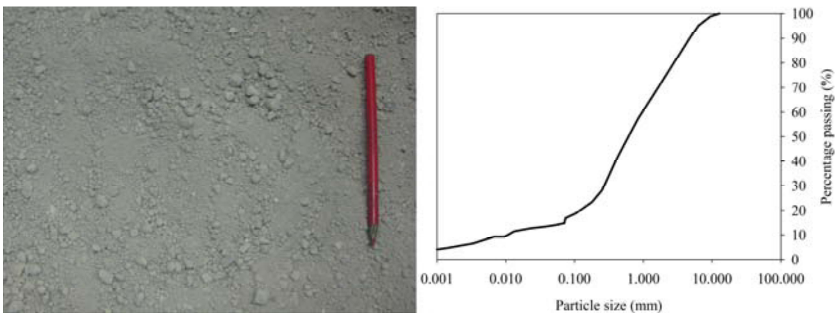

Figure 1: General aspect and particle size distribution of the recycled C&DW

The particle size distribution of the material is also illustrated in Figure 1, while the constituents, determined in accordance with the European Standard EN 933-11 (2009), are listed in Table 1. The results presented indicated that this particular C&DW consists mainly of concrete, unbounded aggregates, masonry and soil.

Constituents	C&DW
Concrete, concrete products, mortar, concrete masonry units, Rc (%)	40.0
Unbound aggregate, natural stone, hydraulically bound aggregate, Ru (%)	36.5
Clay and calcium silicate masonry units, aerated non-floating concrete, Rb (%)	10.8
Bituminous materials, Ra (%)	0.5
Glass, Rg (%)	1.2
Soils, Rs (%)	10.8
Other materials, X (%)	0.1
Floating particles, FL (cm3/kg)	10.0

Table 1: Classification of recycled C&DW constituents

General geotechnical properties are summarized in Table 2. It is clear that the C&DW can be regarded, in terms of particle size distribution, as a well graduated course material, ideal for embankment construction, for instance. The relatively low specific gravity can be explained by the that C&DW material is a mix of different materials, with different specific gravity values.

Property	Values
Minimum void ratio	0.434
Maximum void ratio	0.877
Specific gravity (kN/m3)	25.30
D50 (mm)	0.59
Fines fraction (sieve Nº 200) (%)	16.8
Uniformity Coefficient	81.7
Curvature Coefficient	6.21
Optimum water content (Modified Proctor Test) (%)	9.5
Maximum dry unit weight (Modified Proctor Test) (kN/m3)	20.3

Table 2: Geotechnical properties of the recycled C&DW

The geosynthetic used in this study (Figure 2) is a high strength composite geotextile manufactured of polypropylene (PP) continuous filament needlepunched nonwoven and high strength polyester (PET) yarns in the longitudinal direction (referred as GCR). The technical sheet refers a nominal tensile strength of 75 kN/m.

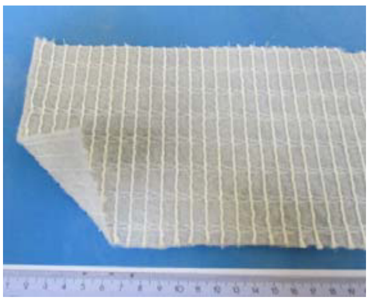

Figure 2: General aspect of the GCR used for reinforcement

2.2 Specimen Preparation

Preparation of the material included drying and de-flocculation by hand. The C&DW was then mixed with water (deionised) for 10 min in a Hobart counter mixer. A water content of 7% was considered, corresponding to 95% of the Modified Proctor test results. The mixtures were then kept in plastic bags for 48 hours at 20ºC ± 1º and 90% RH ± 2%.

The cylindrical specimens were statically compacted to a dry unit weight of 19 kN/m^3, thus targeting a diameter of 70 mm and height of 140 mm, and left inside the mould for 24 hours.

In order to accommodate the geosynthetic reinforcement, the respective thickness was subtracted from the total soil weight, and the water was corrected accordingly.

2.3 Leaching Tests

In order to evaluate the short term release of contaminants of the recycled C&DW, leaching tests were carried out. The eluate was obtained in accordance with BS EN 12457-4 (2002), and was then submitted to chemical characterization, using methods developed for water analysis which were adapted to meet criteria for analyses of eluates.

2.4 Triaxial Compression Tests

Two sets of four consolidated-drained (CD) triaxial compression tests were performed, for the unreinforced and reinforced C&DW, using consolidation isotropic effective stress states (p') of 25, 50, 100 and 200 kPa. A servo-hydraulic testing rig, fitted with a 25 kN load cell, was used to apply the deviatoric load, under monotonic displacement control, at a rate of 0.01 mm/min. Such relatively low displacement rate was used in order to monitor the development of any unexpected pore water pressure. Such concern arise from the fact that the specimens were not saturated at the beginning of the triaxial tests, and thus it was assumed that the reduction in the unsaturated void ratio, during the test, would not be sufficient to develop pore water pressures. The entire stress-strain curve was obtained from each test. The specimen axial deformation was the average of the readouts of two Linear Displacement Transformers (LDT), while an additional LDT was installed to monitor the radial deformation.

3 Results and Discussion

3.1 Leachate Properties

The European Council Decision 2003/33/EC was used as the acceptance criteria regarding the leached maximum concentration for inert landfill. From the analysis of the results presented in Table 3, it can be concluded that only the value of sulphates exceeds the maximum values established by the European and Portuguese legislation.

However, the Directive 2003/33/EC states that "*if the waste does not meet these values for sulphate, it may still be considered as complying with the acceptance criteria if the leaching does not exceed 6000 mg/kg at L/S = 10 l/kg, determined either by a batch leaching test or by a percolation test under conditions approaching local equilibrium.*".

A campaign of percolation tests is already underway to determine if this material can indeed be in compliance with the acceptance criteria.

Parameter	Concentration (mg/kg)	Acceptance criteria (Inert landfill)
Arsenic, As	0.021	0.5
Lead, Pb	<0.01	0.5
Cadmium, Cd	<0.003	0.04
Chromium, Cr	0.012	0.5
Copper, Cu	0.10	2
Nickel, Ni	0.011	0.4
Mercury, Hg	<0.002	0.01
Zinc, Zn	<0.1	4
Barium, Ba	0.11	20
Molybdenum, Mo	0.018	0.5
Antimony, Sb	<0.01	0.06
Selenium, Se	<0.02	0.1
Chloride, Cl	300	800
Fluoride, F	6.1	10
Sulphate, SO4	3200	1000
Phenol index	<0.05	1
Dissolved Organic Carbon	220	500
pH	8.2	-

Table 3: Leaching test results

3.2 Triaxial compression tests

Figure 3 shows the stress-strain curves obtained with each of the two sets of tests, i.e. on the unreinforced and geosynthetic reinforced C&DW.

The tests on the unreinforced material presented a quasi-linear behaviour almost up to the yielding surface, for the effective confining pressures of 25, 50 and 100 kPa. The 200 kPa confining pressure specimen did not presented a clear yielding stress, and instead a continuous stress increase was obtained right until the maximum deformation of 12%. After yielding, the soil stiffness evolution of the 50 and 100 kPa specimens was defined by the confining pressure. In the first case a strain-softening response was obtained, while the 100 kPa presented a strain-hardening response, which again was maintained right until the maximum 12% strain value registered during the tests.

The reinforced C&DW mixtures presented stress-strain curves similar to those of the unreinforced material, also typical of uncemented materials, i.e. without a clear peak stress value at very low strain levels followed by a very abrupt strain softening. Again, the highest confining pressure of 200 kPa showed a less defined yielding stress, with strain-hardening response. The 100 kPa specimen curve showed an elastic-perfectly plastic material, while the lowest confining pressures produced a slightly strain softening post-peak behaviour.

Albeit the similarity of the shape of the curves (for each confining pressure), the maximum stress was significantly affected by the inclusion of the reinforcement, with increases of 49% (152 to 226 kPa), 17% (274 to 321 kPa), 24% (373 to 464 kPa) and 19% (691 to 825 kPa) relatively to the unreinforced C&DW, for the 25, 50, 100 and 200 kPa confining pressures, respectively.

Figure 4 shows the strength envelope in the q vs p_0 space for both the unreinforced and reinforced C&DW. A friction angle (ϕ') of 36.8º and a cohesion intercept of 23 kPa were obtained for the former, while the reinforcement produced an increase of 8% in the ϕ' value (up to 39.8º) and 13% in the c' value (up to 26 kPa). The inclusion of the reinforcement produced a significant increase in the strength parameters, especially considering that the material has a low cementation level. An increase in cementation would increase the stiffness of the C&DW matrix, thus further increasing the role of the reinforcement.

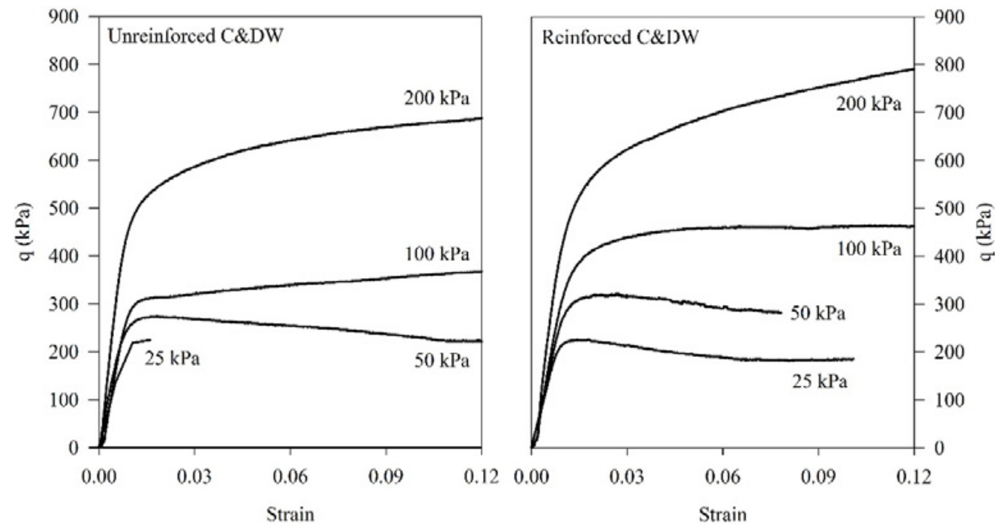

Figure 3: Triaxial compression tests performed on the unreinforced and reinforced C&DW

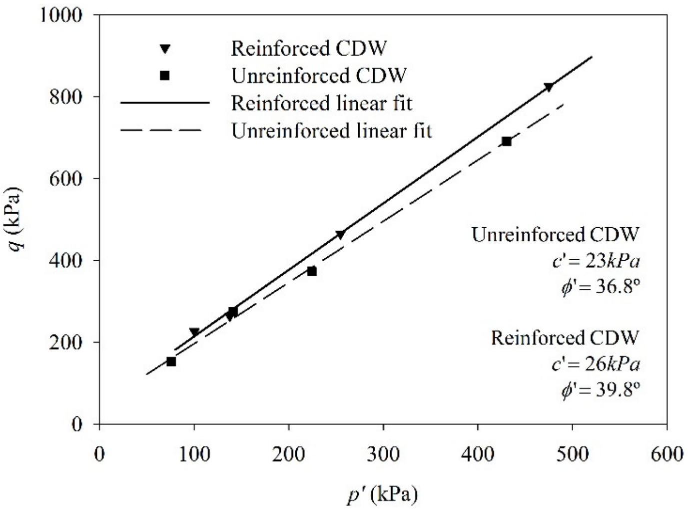

Figure 4: Strength envelops obtained from the triaxial compression strength tests

The materials initial stiffness was clearly affected by the effective confining pressure applied, which is a clear indication of the low cementation of the material. Table 4 presents the results of the stiffness modulus at 50% of the maximum deviatoric stress (E_{50}), where it is possible to conclude that the E_{50} increases, in general, with the confining pressure.

An additional conclusion is the apparently small influence of the reinforcement on the elastic stiffness of the material. This is not surprising, since the reinforcement needs to be significantly extended in order to developed some tensile stress.

C&DW	Consolidation 25 kPa	Consolidation 50 kPa	Consolidation 100 kPa	Consolidation 200 kPa
Unreinforced	26 278 kPa	34 698 kPa	31 366 kPa	56 303 kPa
Reinforced	26 325 kPa	28 375 kPa	32 930 kPa	44 531 kPa

Table 4: Elastic modulus at 50% of the deviatoric stress (E_{50})

Regarding the stiffness degradation with the increasing load (Figure 5), it is interesting to note that, especially for the lower confining pressures, the rate at which the unreinforced C&DW stiffness degrades is significantly higher than that observed in the reinforced specimens. While the stiffness degradation rate of the unreinforced specimens proved to be a function of the confining pressure (i.e. increasing with the decrease in confining pressure), the reinforcement appears to override the influence of such parameter, producing very similar degradation rates among the reinforced specimens, and thus suggesting that the high rates obtained for the low confining pressures are mitigated by the introduction of the reinforcement.

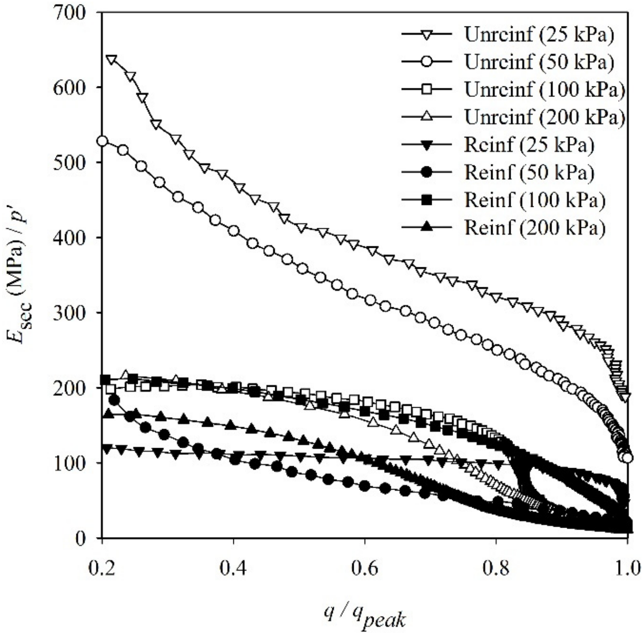

Figure 5: Evolution of the stiffness modulus normalized by the average isotropic stress *p*'

4 Conclusions

This paper focus on the analysis of the main concerns when dealing with the possible substitution of natural aggregates by recycled C&DW. It is of the essence to fully characterize either the mechanical behavior and the environmental performance of the new material, before any real live scale application can be brought to daylight.

Results show that this particular C&DW batch is environmentally sound and in accordance with the limits imposed by the European Directive 2003/33/EC. As such, it can be classified as an *inert material*.

The mechanical behavior is consistent with that of a natural soil, reaching strength envelops and elastic stiffness values competitive with those obtained with a natural granular material with a similar particle size distribution. The introduction of a geosynthetic reinforcement layer produced an increase in maximum load and, although did not increase the material's stiffness, promoted a decrease in stiffness degradation, at least for the lower confining pressure specimens.

Acknowledgements

The authors would like to thank the Portuguese Science and Technology Foundation (FCT) and FEDER for financial support, through the Research Project: FCOMP-01-0124-FEDER-028842, *RCD-VALOR* – Sustainable application of Recycled Construction and Demolition Wastes (C&DW) in geosynthetics reinforced structures (PTDC/ECM-GEO/0622/2012).

References

Agrela, F., Barbudo, A., Ramírez, A., Ayuso, J., Carvajal, M.D. & Jiménez, J.R (2012). *Construction of road sections using mixed recycled aggregates treated with cement in Malaga, Spain*. Resources, Conservation and Recycling, 58, 98-106.

Arulrajah, A., Piratheepan, J., Disfani, M.M. & Bo, M.W. (2013). *Geotechnical and Geoenvironmental Properties of Recycled Construction and Demolition Materials in Pavement Subbase Applications*. Journal of Materials in Civil Engineering, 25, No. 8, 1077-88.

Arulrajah, A., Rahman, M.A., Piratheepan, J., Bo, M.W. & Imteaz, M.A. (2014). *Evaluation of Interface Shear Strength Properties of Geogrid-Reinforced Construction and Demolition Materials using a Modified Large Scale Direct Shear Testing Apparatus*. Journal of Materials in Civil Engineering, 26, No. 5, 974-82.

Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R. & Maiti, S. (2014). *Recycled aggregate from C&D waste & its use in concrete – A breakthrough towards sustainability in construction sector: A review*. Construction and Building Materials, 68, 501-16.

Herrador, R., Pérez, P., Garach, L, & Ordóñez, J. (2011). *Use of recycled Construction and Demolition Waste aggregate for road course surfacing*. Journal of Transportation Engineering, 138, 182-90.

Leite, F.C, Motta, R.S., Vasconcelos, K.L., Bernucci, L. (2011). *Laboratory evaluation of recycled construction and demolition waste for pavements*. Construction and Building Materials, 25, 2972-79.

Santos, E.C.G., Palmeira, E.M. & Bathurst, R.J. (2014). *Performance of two geosynthetic reinforced walls with recycled construction waste backfill and constructed on collapsible ground*. Geosynthetics International, 21, No. 4, 256–69.

Silva, R.V., Brito, J. & Dhir, R.K. (2014). *Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production*. Construction and Building Materials, 65, 201-217.

Vieira, C.S., Pereira, P.M. (2015). *Use of recycled construction and demolition materials in geotechnical applications: A review*. Resources, Conservation and Recycling, 103, 192-204.

Vieira, C.S., Pereira, P.M. (2016). *Interface shear properties of geosynthetics and construction and demolition waste from large-scale direct shear tests*, Geosynthetics International, 23, No. 1, 62-70.