USE OF RECYCLED CONSTRUCTION AND DEMOLITION WASTES (RCDW) AS BACKFILL OF REINFORCED SOIL STRUCTURES

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Abstract: The intense population growth brings some environmental concerns due to the need for exploitation of natural resources. The adoption of recycling policies is a basic principle to reach a sustainable development. The construction industry produces a large amount of waste material generated from activities such as demolition, excavation, site preparation and a range of other activities. In this scenario, however, the high potential of recycling the construction and demolition wastes (CDW) has been ignored. Moreover, studies focus mainly on the recycling of CDW for the production of aggregates for use in pavements and concrete, whereas a large volume of soil is found in Brazilian materials recycling plants. These facts justify the effort and research to develop appropriate uses of these materials in geotechnical practice. The present study deals with a new application of the Recycled Construction and Demolition Waste (RCDW) as backfill for reinforced soil structures. The authors have conducted laboratory characterization, pH and direct shear tests on RCDW with the purposes to investigate its geotechnical and chemical properties. Furthermore, in order to compare the behaviour of RCDW to others materials, pullout tests on geogrids have been performed with two others materials: clayey sand [typical soil from the southeast part of the Brazil] and a sand obtained from a local supplier, the last one was chosen following recommendation by FHWA for backfill material. The results have shown that RCDW has low coefficients of variation of its properties and values of alkaline extract that allows its application with geogrids with excellent mechanical behaviour that justify its use for the proposed application. The results of pullout tests with RCDW have shown that the recycled material yielded a better performance when compared with the standard sand.

Keywords: waste, soil reinforcement, laboratory test, large scale, pull-out test, geogrid.

INTRODUCTION

Construction and demolition waste (CDW) constitutes a highly significant proportion of municipal solid waste. Despite the fact that intense population growth brings some environmental concerns due to need of exploration of natural resources, Brazil has not developed a suitable program of CDW recycling. Although important, studies focus mainly on the recycling CDW for the production of aggregates for use in pavements and concrete. However in its Resolution 307, the CONAMA (Brazilian Environmental National Council) states that wastes generated in "[…] site preparation and excavation […]" are classified as CDW. Due to this, huge amounts of soil have been found in Brazilian recycling plants.

On the other hand, economical and technical benefits of construction of reinforced soil structures (RSS) are limited due to the lack of a Brazilian standard concerning material for backfills of RSS. In Brazil, constructors usually consult recommendations adopted in North Hemisphere, which suggest sandy material as backfill. The adoption of such specification may severely increase the costs of RSS due to need of this specific material near the building site.

The drawback factors listed above highlight an interesting perspective of the use of recycled construction and demolition waste (RCDW) as backfill of RSS.

MATERIALS AND METHODOLOGY

Recycled construction and demolition waste (RCDW)

The RCDW used on this work consisted of product of crushing process of mixed material (soil, brick and small particles of concrete), which were sampled at CDW Recycling Municipal Plant of São Carlos (RMPSC). Nowadays, this material is used for repairing municipal rural roads.

Figure 1. Recycled construction and demolition waste

Sampling of RCDW

In the absence of a standard for sampling RCDW, standards concerning other materials were used as guidance. However, before using such standards, a critical assessment was conducted.

RCDW sampling was performed in two different ways, as follows:

- The first consisted of RCDW arriving directly on tarpaulin, which was laid out below the conveyor belt
- The second consisted of sampling of RCDW stored in RMPSC patio area using a backhoe loader

Although it was not the main aim of this work, samplings were performed at different times (Table 1) to evaluate possible temporal variations in the characteristics of the RCDW.

Table 1. Sampling program of RCDW

Sample	Date	Amount (kg)
RCDW-01	April 12th, 2006	137
RCDW-02	April 12th, 2006	160
RCDW-03	May 10th, 2006	166
RCDW-04	May 18th, 2006	154
RCDW-05	August 17th, 2006	4,000

Other materials

In order to compare the behavior of RCDW to others materials, pullout tests on geogrids have been performed with two others materials:

- Sandy soil from São Carlos, hereafter called "soil"
- Sand from a local supplier, which obey the specification of U.S. Federal Highway Association for backfill materials in RSS, hereafter called "sand"

Figure 2 shows the grain-size curves of the reference materials. The main parameters of these materials are presented in Table 2.

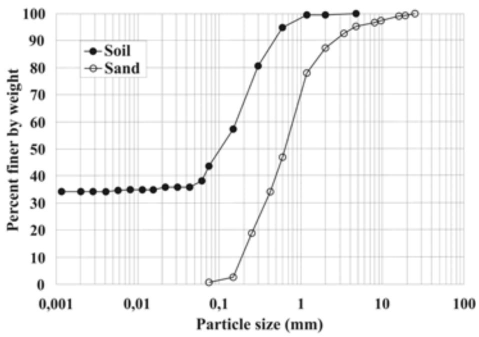

Figure 2. Grain-size curves of the reference materials

Table 2. Main parameters of the reference materials

Parameters	Soil	Sand
Specific gravity, Gs	2.68	2.82
Liquid limit, w_L (%)	39	-
Plastic limit, w_P (%)	21	-
Maximum dry unit weight, $\gamma_{dMÁX}$ (kN/m³)	1.80	1.82
Maximum void ratio, $e_{MÁX}$	-	0.81
Minimum void ratio, $e_{MÍN}$	-	0.55
Optimum water content, w_{ot} (%)	16.0	16.0
Friction angle, ϕ (°)	33	32
Cohesion, c (kN/m²)	20	-

Geosynthetic

The geogrid used for the pullout testing program consisted of a polyester core encased in a tough PVC sheathing. Table 3 summarizes the main properties of the geogrid used in this investigation.

Equipment and instrumentation

Direct shear equipment

The direct shear tests were carried out in Laboratory of Rock Mechanics of EESC (Engineering School of São Carlos), University of São Paulo. Bearing in mind the presence of coarse grained particles in RCDW, it was necessary to use a large scale direct shear equipment, which allows testing samples with dimension of 500x500x500mm.

Table 3. Properties of geogrid

Mechanical proprieties	Value
Longitudinal tensile strength (kN/m²)	61
Transverse tensile strength (kN/m²)	30
Maximum tensile strain (%)	13
Spacing between longitudinal members (mm)	30
Spacing between transverse bearing members (mm)	20
Width of longitudinal members (mm)	6.5
Width of transverse members (mm)	4.5
Thickness of bearing members (mm)	1.2

Pullout test equipment

The pullout tests were conducted in Laboratory of Geosynthetics of EESC. The device was a large scale pullout box (1,500 mm long, 700mm wide, and 480 mm high) built at EESC (Teixeira & Bueno, 1999). Figure 3 shows a view of the large scale device used in this investigation.

Figure 3. View of large-scale pullout test device

Instrumentation used during pullout test included: (i) 50kN cell; (ii) tell-tales fixed along geogrid sample; and (iii) linear variable displacement transducer (LVDT). Besides that, a computer with an acquisition system was also used.

Test procedures

Direct shear test

Initially the RCDW was dried in air, subsequently added water up to desired water content and homogenised. The RCDW was compacted in six 83-mm-thick layer. It was adopted a degree of compaction of 98% and optimum water content of 11.5%. The tests were carried out in multiple stages applying vertical pressure of 50, 150 and 300kN/m², following this order.

Pullout test

The pullout testing program was conducted using the reference materials (soil and sand) and RCDW-05; it obeyed the recommendation from ASTM 6706-01.

Two polyethylene membranes, lubricated with grease, were fixed to internal faces of the walls of the pullout testing box in order to reduce friction between box internal walls and fill material, this procedure was suggested by Palmeira & Milligan (1989). The placement conditions of the materials used in the pullout testing program is listed in Table 4.

Table 4. Placement conditions of the materials used in pullout testing program

Material	Degree of compaction (%)	Number of layers	Thickness (mm)
RCDW	96	6	75
Soil		10	45
Sand		4	112.5

The weight of moistened material required to achieve the target dry unit weight was initially prepared and homogenised. Compaction was subsequently conducted using a manual hammer. After placing the first sample half, the geogrid sample (600mm, long; 495mm, wide) was spread within the box and attached to clamps used to apply the pullout force. Then compaction was resumed up to a height of 450 mm from the box bottom. At that moment, a rubber bag was positioned over material before placing the top cover. A pneumatic system was used to provide a uniformly distributed vertical pressure on top of the fill materials. Vertical pressures of 25, 50 and 100kN/m² were applied in each test. The pullout speed was the same in all tests and equal to 6.8mm/min, following the recommendation of Farrag et al. (1993), which suggest pullout speed of order or less than 6 mm/min.

RESULTS AND ANALYSIS

Characterization

The results of the grain-size analysis of RCDW (Figure 4) revealed a low variability of grain-size distribution curves. This fact reveals that RMPSC adopts a standard of production. All RCDW samples classifies as gravely sand.

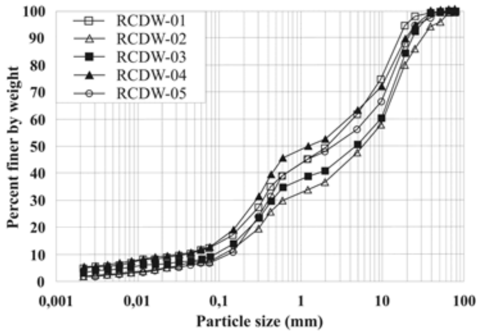

Figure 4. Grain-size curves of RCDW

The Atterberg limit determination tests showed that RCDW has a non-plastic behaviour. This is a positive point to RCDW considering the international recommendation for backfill, which limits the plasticity index.

The result of specific gravity determination (Table 5) of RCDW showed a mean value of 2.819, with a coefficient of variability of 3.1%.

Table 5. Specific gravity determination of RCDW

Sample	Specific gravity
RCDW-01	2.734
RCDW-02	2.716
RCDW-03	2.889
RCDW-04	2.882
RCDW-05	2.875

Proctor compaction test

Proctor compaction test results (Figure 5) showed mean value of unit dry weight equal to 1.844g/cm³, with a coefficient of variability equal to 2.1%. The optimum water content presented mean value of 14.9%, with a coefficient of variability equal to 13.3%.

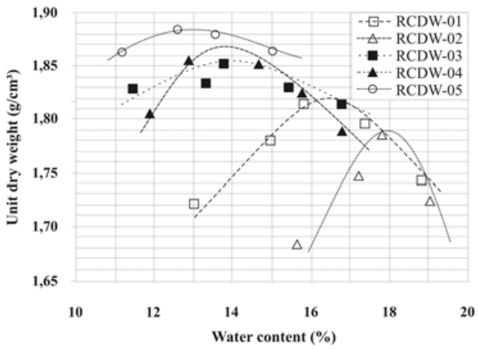

Figure 5. Proctor compaction test results

The grain-size distribution analysis for “compacted” samples and “non-compacted” samples reveals that RCDW did not presented a significantly change due to compaction test (Figure 6). This fact can be explained by RCDW process production (demolition, transportation, storage, crushing and sieving), which subjects CDW to particle breaking. So, at the end of this process, RCDW presents enough strength to the energy used in Proctor compaction test.

pH test

In considering the chemical effect of soil on any buried material, the first most important consideration is its acidity or alkalinity (Billing et al. 1990). The results of pH tests using distilled water showed a mean value of 9.1, with a coefficient of variation of 4.3%. It was observed that RCDW aqueous extract is alkaline. However, this value is within the range suggested by Anderson et al. (1992) for use of polyester geogrid, which does not consider advisable to use polyester in application where environment has a pH greater than 10. Figure 7 presents the results of pH tests.

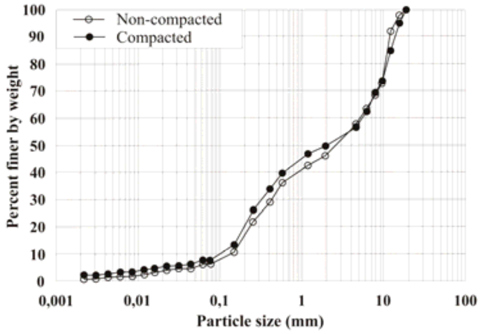

Figure 6. Grain-size distribution curves for "compacted" and "non-compacted" RCDW samples

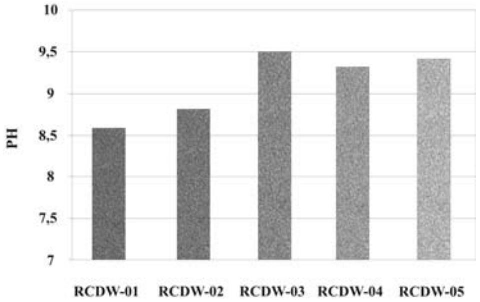

Figure 7. Result of pH tests

Direct shear test

The results of the direct shear test showed a plastic behaviour of RCDW, with stress and displacement increasing to a certain point and a subsequent increase on displacements with no significant changes in stresses (Figure 8).

The volume variation revealed a reduction on sample volume (Figure 9).

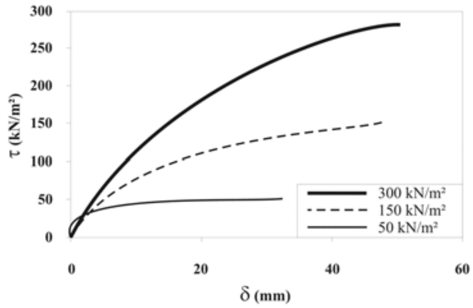

Figure 8. Stress-displacement curves of RCDW

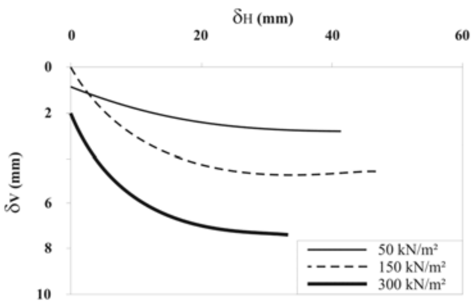

Figure 9. Vertical and horizontal displacement curves of RCDW

The following equation presents the shear strength equation for RCDW:

$$\tau = 13 + \sigma \tan 41^{o}$$

Where τ is the shear strength in kN/m², σ is the total normal stress in kN/m².

It was noted that the friction angle of RCDW (ϕ = 42º) is greater than the friction angle of the reference materials (soil, ϕ = 33º; sand, ϕ = 32º). This fact could justify the use of RCDW in many other geotechnical applications.

Pullout test

Load versus displacement

The following graphs present the results obtained from large-scale pullout tests as a function of internal displacements, using tell-tales attached at different locations from the frontal wall of pullout box.

Vertical pressure of 25kN/m²

All tests carried out with vertical pressure equal to 25kN/m² allowed the complete pullout of the geogrid. It was observed the maximum bearing mobilisation for the element positioned near to load application point, decrease toward back of the geogrid. Such behavior is expected in extensible geogrid.

The sand presented curves with a peak value for the pullout force, followed by increase in displacement with a decrease in pullout force (Figure 10).

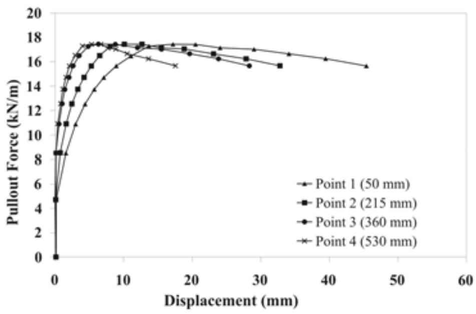

Figure 10. Pullout force versus displacement curves for test on sand under a vertical stress of 25kN/m²

The soil and RCDW tests (Figure 11 and Figure 12, respectively) showed curves with an increase in pullout forces up to a maximum value, followed by increase in displacement without changes in the the pullout force.

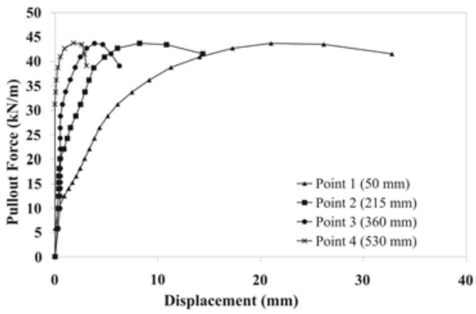

Figure 11. Pullout force versus displacement curves for test on soil under a vertical stress of 25kN/m²

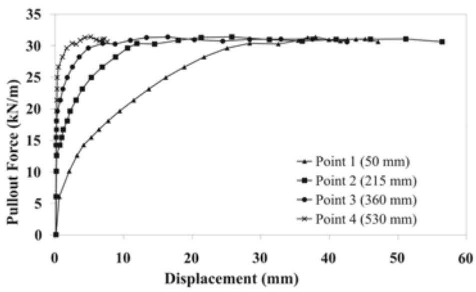

Figure 12. Pullout force versus displacement curves for test on RCDW under a vertical stress of 25kN/m²

The soil presented the highest pullout force. The RCDW showed higher pullout force than sand.

Vertical stresses of 50 kN/m² and 100kN/m²

All pullout tests results presented similar behaviour under both 50 kN/m² and 100kN/m² vertical stresses.

For the tests carried out under verticals stresses of 50 kN/m² and 100 kN/m², the sand showed similar behaviours to that observed on test under 25kN/m². However, it was observed a decrease in pullout force in those bearing members which were more distant from the frontal face wall of the pullout testing box (Figure 13). During the geogrid exhumation (Figure 14), it was observed that the junctions between longitudinal and transversal bearing member had failed.

During the tests with soil and RCDW failure at the non-confined portion of geogrid took place.

Analysing the load versus displacement curve of pullout tests in soil (Figure 15), it was observed that the maximum obtained load (57kN/m) almost reached the ultimate load of the geogrid indicated by its manufacturer, which is 60kN/m.

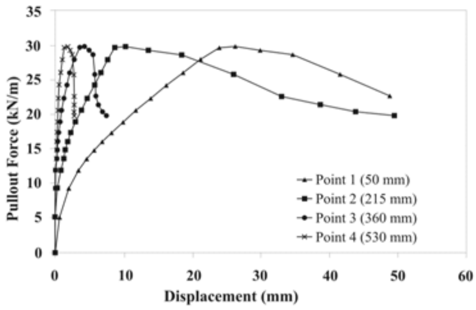

Figure 13. Pullout force versus displacement curves for test on sand under 50kN/m² normal stress

Figure 14. Exhumation of geogrid in a pullout test of geogrid buried in sand

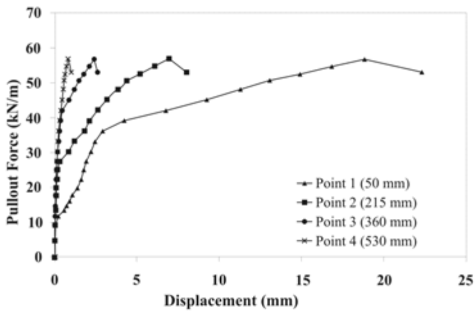

Figure 15. Pullout force versus displacement curves for pullout tests in soil under 50 kN/m² normal stress

The maximum pullout forces for test on RCWD were below the geogrid ultimate tensile load indicated by its manufacturer. This fact can be justified by the anchorage of transverse bearing member due to RCDW particles (Figure 16). The anchorage was responsible for the concentration of stresses on certain portion of geogrid, so inducing the early rupture in such portion. The Table 6 presents a summary of results obtained from pullout testing program.

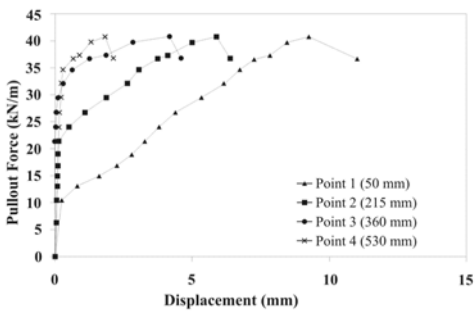

Figure 16. Pullout force versus displacement curves for pullout tests in RCDW under 50 kN/m² normal stress

Adherence factor

I was observed, to all materials, a decrease in the adherence factor due to an increase in the vertical stress (Table 6). Theses results agree with that obtained by Lopes & Ladeira (1996) and Teixeira (1999).

Results show that the soil presented the best values of adherence. The RCDW presented better behaviour than sand, although the latter is the material recommended by FHWA to backfilling of RSS.

Figure 17. Exhumation of the geogrid used in pullout test of a geogrid buried in RCDW

Table 6. Summary of results obtained in the pullout test programme

Vertical pressure (kN/m^2)	Material	Pullout load (kN/m)	Adherence factor*
25	Sand	17.60	0.94
	Soil	43.90	2.29
	RCDW	31.46	1.30
50	Sand	30.36	0.81
	Soil	57.68	1.50
	RCDW	40.97	0.85
100	Sand	37.23	0.50
	Soil	56.50	0.74
	RCDW	49.92	0.52

CONCLUSION

The results have shown that RCDW presents low variability in its properties and values of alkaline extract that allow its application with geogrids with excellent mechanical behaviour, justifying its use for the application described in this paper. The results of pullout tests with RCDW have shown that the recycled material yielded a better performance than that of the standard sand.

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