Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0613

Construction and demolition waste (CDW) used in reinforced soil mixtures for pavement applications.

Déchets de construction et de démolition utilisés dans les mélanges de sols renforcés pour les applications de couche d'assise de chaussée.

J. A. Lukiantchuki
State University of Maringa, Maringa, Brazil
J. R. M. S. Oliveira, M. S. S Almeida
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
T. B. Silva, L.C. Guideli
State University of Maringa, Maringa, Brazil

ABSTRACT: This work shows the study of the unconfined resistance, tensile strength and resilience modulus of soil mixtures, construction waste, cement and polypropylene fibers, for reuse in pavement. For this purpose, it was used construction and demolition wastes and natural soil collected at a site near the city of Mandaguaçu (Paraná, Brazil). The behavior of the materials used in this work was evaluated by mixing with different proportions of waste, soil, cement and fiber. For the various mixtures studied, it was observed that the mixtures with 50/50 proportions (soil / waste) showed the best performance of unconfined resistance. This result was satisfactory since it enables the reduction of natural soil by 50%. Moreover, addition of cement and fibers in small amounts (0.25%) also increased resistance values.

RÉSUMÉ: Ce travail montre l'étude de la résistance non limitée, de la résistance à la traction et du module de résistance des mélanges de sol, des déchets de construction, des fibres de ciment et de polypropylène, en vue de leur réutilisation sur la couche d'assise de chaussée.À cette fin, il a été utilisé des déchets de construction et de démolition et du sol naturel collectés sur un site situé près de la ville de Mandaguaçu (Paraná, Brésil). Le comportement des matériaux utilisés dans ce travail a été évalué en mélangeant différentes proportions de déchets, de terre, de ciment et de fibres. Pour les différents mélanges étudiés, il a été observé que les mélanges avec des proportions 50/50 (sol / déchets) présentaient la meilleure performance de résistance non confinée. Ce résultat est satisfaisant puisqu'il permet de réduire de 50% les sols naturels. De plus, l'addition de ciment et de fibres en petites quantités (0,25%) a également augmenté les valeurs de résistance.

Keywords: Construction and demolition waste; unconfined strength; tensile strength; resilient modulus, pavement.

1 INTRODUCTION

In most part of the world, the construction industry and building process generate a large amount of natural resources and produces wide quantities of construction and demolition waste (CDW). This context has caused serious problems related to the environmental concerns due to the natural resources exploitation and the limited space available for the disposal of the waste (Arulrajah et al., 2013; Santos, 2017).

In light of the increasing environmental awareness, the use of CDW as a resource has been encouraged (Dhir et al., 2004). The recycling waste materials saves energy, reduces greenhouse emissions and delivers a more sustainable future (Arulrajah et al., 2011).

Considering the importance of this issue, many researchers have been investigating the CDW behavior for geotechnical applications (Arulrajah et al., 2013; Herrador et al., 2012; Leite et al., 2011, Santos et al., 2013; Lukiantchuki et al., 2018). The researchers mentioned above demonstrate that construction and demolition waste has a great potential to be used as aggregate in pavements. CDW is an excellent alternative material for bases and subbases due to its high resistance and its non-expansive behavior (Melbouci, 2009; Molenaar and Niekerk, 2002). Additionally, a recent work (Gómez, 2011) shows that although the composition and gradation have an influence on the mechanical characteristics of the recycled materials, the degree of compaction is the most important factor.

This paper presents the behavior of CDW-soil mixtures reinforced using cement and polypropylene fiber, for base and subbase, pavement applications. The material was characterized under geotechnical tests as grain size distribution, specific gravity, Atteberg limits and compactions tests. The resistance of CDW-soil mixtures was evaluated through unconfined compression strength, tensile strength and cyclic triaxial tests.

2 MATERIALS AND METHODS

2.1 Materials

The construction and demolition waste (CDW) for this research was collected from a recycling site located in the city of Maringa, Parana state, Brazil (Figure 1). In the present work, the selected waste is composed of wastes from concrete, cementitious mortar and soil. All timber, plastic and cords are separated and the waste is crushed into different sized materials.

The natural soil is from a site located in the city of Mandaguaçu, Northern region of Parana state, Brazil. The soil was collected in a superficial layer from the Caiua Sandstone composed of sand clayey and classified as a red dystrophic latosol.

The Portland cement selected was CP II – Z-32, which is composed of 76% to 94% clinker and calcium sulphates and 24% to 6% of pozzolanic materials, respectively.

Figure 1. Recycling site.

In the present work, cement and polypropylene fiber (Figure 2) were used in addition to the natural soil and CDW. The use of fiber was always associated with cement. Table 1 shows the different proportions used for each mixture.

Figure 2. Polypropilene fiber.

2.2 Geotechnical characterization

Figure 3 (a) shows the grain size distribution of the natural soil, used as the matrix, cement and CDW. For natural soil, clay, silt and sand contents were about 17.5%, 6%, and 76.5%, respectively. The coefficient of uniformity (CU) and the coefficient of curvature (CC) were equal to 146 and 40, respectively. According to the Unified Soil Classification, the natural soil was classified as SC (Clayey Sand). Additionally, Figure 3 (a) shows the grain size distribution of the CDW. Clay, silt, sand and gravel contents were about 6%, 17.5%, 61.5% and 15%, respectively. The coefficient of uniformity (CU) and the coefficient of curvature (CC) were equal to 67 and 9, respectively.

Figure 3 (b) shows the grain size distribution of soil-CDW mixtures using 50/50 and 75/25 soil-CDW proportions. As was expected, the gravel and silt contents increased as the CDW content increased, while the sand and clay contents decreased.

Table 1. Sample characteristics.

Mixture	S (%)	CDW (%)	C (%)	F (%)
S_CDW (50/50) 3.5/0.25	50	50	3.5	0.25
S_CDW (50/50) 3.5/0.50	50	50	3.5	0.50
S_CDW (50/50) 7.0/0.25	50	50	7.0	0.25
S_CDW (50/50) 7.0/0.50	50	50	7.0	0.50
S_CDW (75/25) 3.5/0.25	75	25	3.5	0.25
S_CDW (75/25) 3.5/0.50	75	25	3.5	0.50
S_CDW (75/25) 7.0/0.25	75	25	7.0	0.25
S_CDW (75/25) 7.0/0.50	75	25	7.0	0.50

where: S is the natural soil, CDW is the construction and demolition waste, C is the cement and F is the polypropilene fiber.

Compaction tests were carried out to assess optimum water content and maximum dry unit weight for the natural soil, CDW, and soil-CDW mixtures. Proctor compaction tests were performed using standard effort. Natural soil, CDW, and soil-CDW mixture compaction test results are shown in Figure 4. Results show that the maximum dry unit weight is higher for natural soil and as the content of CDW increased the maximum dry unit weight decreased. This behavior can be associated with the water absorption of CDW which increases the optimum water content and decreases the maximum dry unit weight.

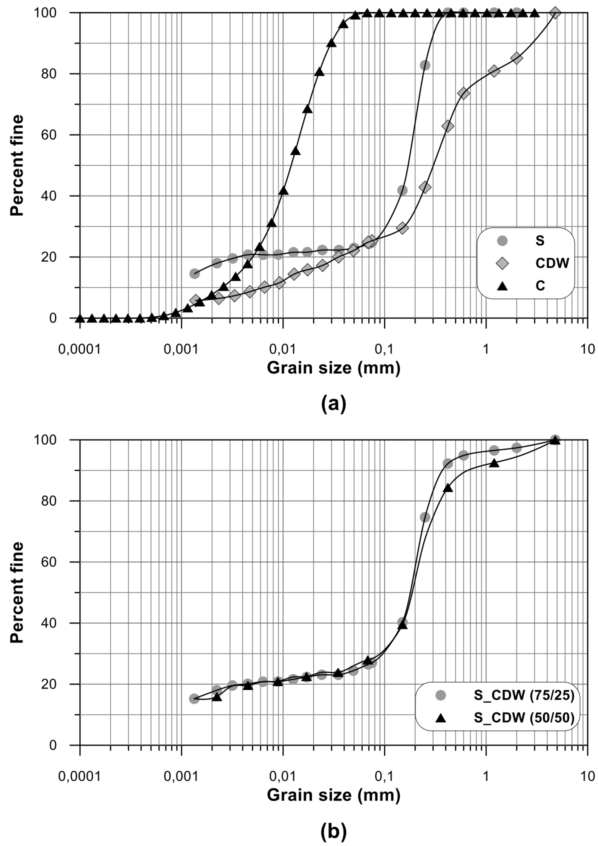

Figure 3. Grain size distribution.

For specimen preparation, first, cement and fiber were added to the soil-CDW mixtures. Next, water was added, in a mixture reaching a water content similar to the optimum water content corresponding to the equivalent compaction curve (Figure 4). The sample diameter and height were 50 mm and 100 mm, respectively. The specimens were wrapped in waterproof plastic and stored (wet room) to cure for twenty-eight days before testing.

2.3 *Unconfined compressive strength (UCS) and tensile strength (TS)*

The undrained shear strength (UCS) and the tensile strength (TS) of the soil-CDW mixtures were assessed using unconfined compression tests and diametral compression test, respectively. For each mixture (Table 1), three specimens were molded, with relative compaction not less than 95%, and tested under unconfined compression. The UCS and TS for each mixture was represented by average values

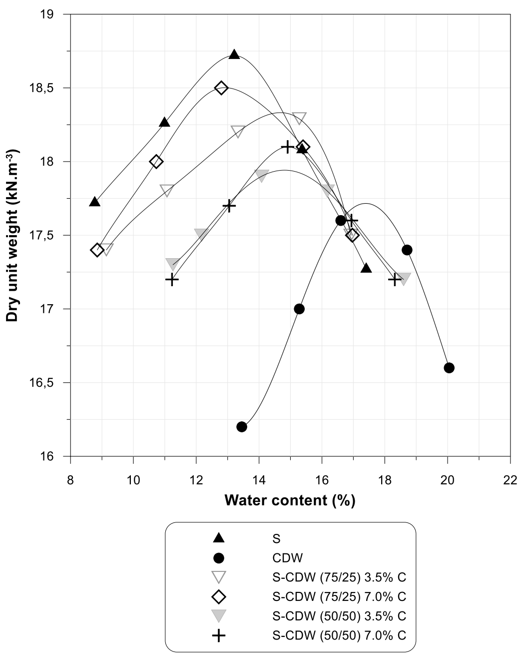

Figure 4. Compaction curves.

Table 2 shows the results for UCS and TS tests, where acceptable mixtures (DNER-ME 201/94) for pavement purpose are highlighted.

Results show that the UCS values increase as the CDW content increases in the mixtures. According to some studies (Gómez, 2011; Poon, 2006), the unconfined compressive strength of CDW increases over time because the minerals can react and generate new cementing chains. Thus, as the S_CDW (50/50) mixtures have a higher amount of CDW than the S_CDW (75/25) mixtures, the UCS should be higher for these mixtures. Cement can also bind with natural soil over time, as more cement hydrates, however this trend is more evident in CDW due to the predominance of non plastic materials such as gravel, sand, mortar, etc.

The influence of the cement content on the UCS values, as shown in Figure 5, was evaluated. The cement content shows a significant influence on the strength values. For all the mixtures an increase of UCS was observed when cement was added, and the mixtures in the proportions 50% showed better behavior. In this way, the results allow to verify that when mixed with other materials the CDW increases the resistance. This behavior may be associated to the effect of cementation, with consequent strength gain, which occurs in the CDW. In addition, this behavior indicates the possibility of increasing the amount of CDW and decreasing the amount of natural soil, saving on the exploitation of natural soil deposits.

Table 2. Results for UCS and TS values.

Mixture	UCS (MPa)	TS (MPa)
S_CDW (50/50) 3.5/0.25	1.59	0.25
S_CDW (50/50) 3.5/0.50	1.26	0.25
S_CDW (50/50) 7.0/0.25	2.38	0.39
S_CDW (50/50) 7.0/0.50	2.37	0.41
S_CDW (75/25) 3.5/0.25	1.34	0.27
S_CDW (75/25) 3.5/0.50	1.20	0.25
S_CDW (75/25) 7.0/0.25	1.96	0.40
S_CDW (75/25) 7.0/0.50	2.24	0.31
S_CDW (50/50) 3.5	0.76	0.19
S_CDW (50/50) 7.0	1.47	0.38
S_CDW (75/25) 3.5	0.66	0.26
S_CDW (75/25) 7.0	1.60	0.36

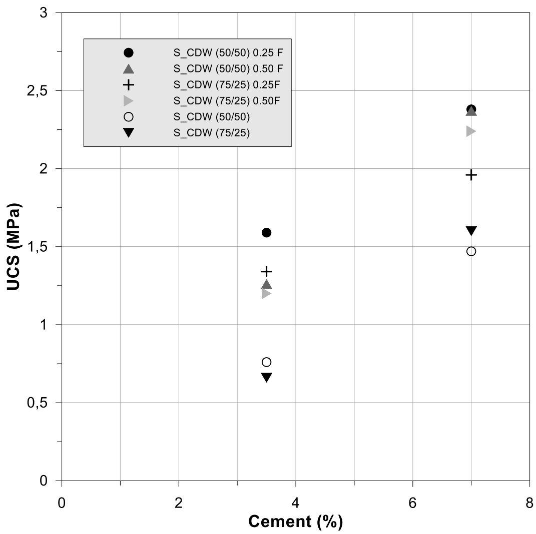

Figure 5. Cement content influence of UCS values.

Figure 6 shows the influence of the fiber on the unconfined compression strength. Results indicate that the increase of fiber contributes with the increase of the UCS to the content of 0.25%. However, it is observed that for the fiber content of 0.5% the UCS decreases, except for the S_CDW (75/25) 7.0 C mixture, where there is an increase in resistance.

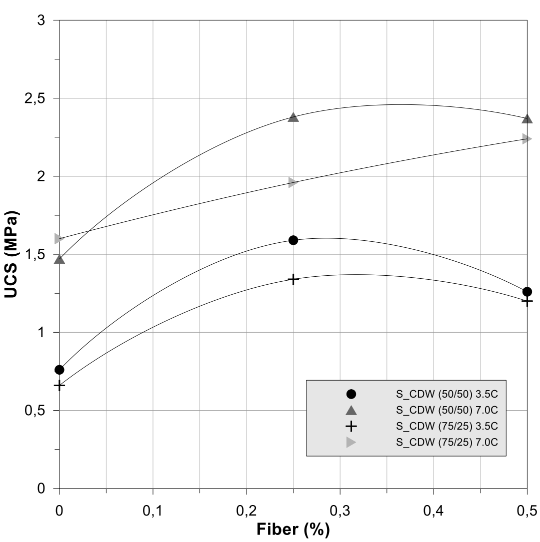

Figure 6. Fiber content influence of UCS values.

It is also observed that the decrease of the UCS is more pronounced for the mixtures with 3.5% of cement, indicating that the smaller decrease of the UCS in the mixtures with 7.0% of cement can also be associated with the effect of the greater percentage of cement in the cement matrix.

2.4 Resilient Modulus (MR)

The influence of polypropilene fibers in the resilient modulus (MR) was evaluated using cyclic triaxial tests. Repeated blows was applied in the sample based on Brazilian Standard recommendations (DNIT 134/2010-ME). The resilient modulus was calculated using Equation 1.

$$MR = \frac{\sigma_d}{\varepsilon_r} \quad (1)$$

where σ_d is the deviation stress applied repeatedly to the sample and ε_r is the correspondent recoverable specific deformation.

Figure 7 show the variation of the MR as a function of the confining tension. It is observed that, despite the dispersion of the results, the MR is directly proportional to the confining tension. For the fiber content (Figure 7), the results indicate that MR has no significant influence when 0.1% fiber is added. For the contents of 0.3 and 0.5%, it was observed that the polypropylene fiber was not efficient, decreasing the MR values when compared to the mixture without fiber. This behavior might be related with difficulties when mixing the fibers with the mixture. Heterogeneous fiber distribution in higher fiber content mixtures may incorporate weak regions within the specimen which can result in decrease of strength related properties.

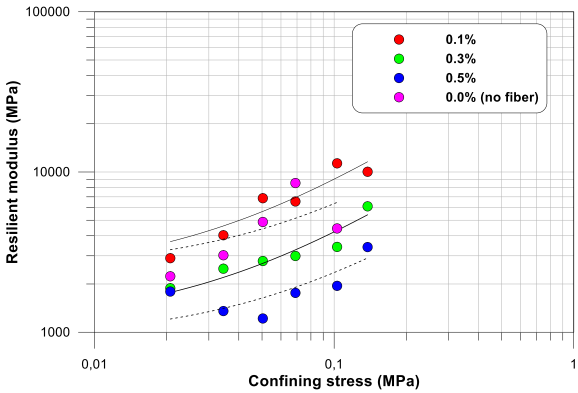

Figure 7. Variation of the resilience modulus with the confining stress.

3 CONCLUSIONS

This work presents a study of unconfined compression strength, tensile strength and resilient modulus in soil and CDW matrices reinforced with polypropylene fiber and portland cement. It was observed that:

1. Regarding UCS, it was observed that the cement content had a significant influence on the resistance values. Additionally, mixtures in the 50/50 proportions showed better behavior. In this way, the results allow to verify that when mixed with other materials the CDW can contribute with the increase of the resistance;

2. The UCS increased for fiber contents of 0.25%. However, it was observed that for 0.50% UCS decreased. The results indicate that there is an adequate fiber content for mixing, and values higher than this not contributes with UCS resistance;

3. Regarding TS, the results indicated that the addition of cement allowed a slight increase in resistance values of tensile. However, no differences in resistance values were observed when CDW content increases; and

4. The addition of fiber showed no change in the TS values. This indicates that the addition of fiber under the conditions studied did not contribute to the increase in resistance. For this case it would be interesting to carry out complementary tests varying the length of the fiber.

5. Finally, the effects of the addition of polypropylene fiber should be better evaluated over time, mainly due to the importance of its effects on the environment concerns.

4 ACKNOWLEDGEMENTS

The authors are very thankful to CNPq (Grant N°448606/2014-3) for the financial support.

5 REFERENCES

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** (8), 1077-1088.

Arulrajah, A. Piratheepan, J. Aatheesan, T. Bo, M. W. 2011. Geotechnical properties of recycled crushed brick in pavement applications, *Journal of Materials in Civil Engineering*, **23**(10), 1444-1452.

Dhir, R. K. Paine, K. A. Dyer, T.D. 2004. Recycling and reconstitution of construction and demolition waste: *Proceedings of the International Conference Organized by the Concrete and Masonry Research Group*, 123-132. MC and Roberts JJ (eds), London, UK.

DNER-ME 201/94. 1994. Soil and cement – unconfined compression test. 4p.

Gómez, A. M. J. 2011. Experimental study of construction and demolition waste for pavement applications. *Master dissertation*, University of Brasilia, Brasilia, 123p. (In Portuguese)

Herrador, R. Pérez, P. Garach, L. Ordóñez, J. 2012. Use of recycled construction and demolition waste aggregate for road course surfacing, *Journal of Transportation Engineering* ASCE,**138** (2), 182-190.

Leite, F. C. Motta, R. S. Bernucci, L. 2011. Laboratory evaluation of recycled construction and demolition waste for pavements. *Construction and Building Materials*, **25** (6), 2972-2979.

Lukiantchuki, J. A. Oliveira, J. R. M. S. Pessin, J. Almeida, M. S. S. 2018. Centrifuge modeling of traffic simulation on a construction layer. *International Journal of Physical Modelling in Geotechnics*, **18** (6), 290-300.

Melbouci, B. 2009. Compaction and shearing behavior study of recycled aggregates, *Construction and Building Materials*, **23**, 2723-2730.

Molenaar, A. A. A.van Niekerk A. A. 2002. Effects of gradation, composition and degree of compaction on the mechanical characteristics of recycled unbound materials. *Transportation Res. Record*, 1787, 73-82.

Poon, C. S. Qiao, X. C. Chan, D. 2006. The cause and influence of self-cementing properties of fine recycled concrete aggregates on the properties of unbound sub-base. *Waste Management and Research*, **26**, 1166-1172.

Santos, E. C. G. 2007. Use of recycled construction and demolition wastes (RCDW) as backfill of reinforced structures. *Master dissertation*, University of Sao Paulo, Sao Carlos, Brazil (in Portuguese).

Santos, E. C. G. Palmeira, E. M. Bathurst, R. J. 2013. Behavior of a geogrid reinforced wall built with recycled construction and demolition waste backfill on a collapsible foundation. *Geotextile and Geomembranes*, **39**, 9-19.