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Technological characterization and utilization of recycled aggregate in the fine fraction in substitution to the fine natural aggregate for concrete production

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A B S T R A C T

Civil Construction and Demolition Waste (CDW), after screening process, can go through benefication process which enables physical alterations obtaining samples with different granulometry. X-ray diffraction tests were performed in order to identify the mineral components present in the samples. The Scanning Electron Microscopy (SEM) analyzes showed that the samples had rough surface texture with grains present in different formats. The chemical properties are the conditioning factor of the affinity between the aggregate and the binder, and can contribute to the early degradation of the structures. The analysis of physical and mechanical properties is important because, in addition to assessing mechanical strength performance, it also analyzes the performance of CDW concrete. The compression tests and modulus of elasticity of an aggregate are not easy to measure because the particles cannot be tested alone. Test bodies were produced with fractions of 10 %, 20 %, 30 %, 50 %, and 100 % RCD. As a result of the mechanical tests performed in these test bodies it was observed that the fractions with up to 30 % recycled aggregate obtained good compressive strength ranging from 33 MPa to 46 MPa, with modulus of elasticity varying from 24.96 GPA to 31.54 GPA. However, the same result was not obtained for the fractions that had above 50 % recycled aggregate in the concrete trait that had compressive strength ranging from 10.8 MPa to 15 MPa, with modulus of elasticity varying from 11.82 GPA to 14.45 GPA.

1. Introduction

Brazil is a country rich in natural resources, which over the years has accompanied the disorderly growth of its great centers and cities. Due to this vector, the civil construction sector stands out with the extremely intensive use of natural resources. The CDW or rubble as it is popularly called, is all material coming from constructions, reforms, repairs and demolitions of civil works and those resulting from the preparation and excavation of land. These residues after sorting can be benefited by physical changes, becoming differentiated granulometry. About 90 % of the CDWs have recycling potential and can be applied in several areas of construction. Each granulometry is useful in civil construction, therefore, the products generated after the comminution can be used, in general, as sub-bases and non-structural concretes, according to the norms in force for the use of these materials. This study analyzed the behavior of recycled aggregates of fine granulometry of

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4.8 mm > 150 µm, which were submitted to the technological characterization that verified the diversified mineral composition of the samples, before the preparation of the test specimens and the mechanical tests performed to evaluate the behavior of these aggregates in differentiated fractions in the concrete trait. The variations were 10 %, 20 %, 30 %, 50 %, and 100 % of recycled fine aggregate, replacing the natural sand in the original trace of the concrete with high strength initial cement.

2. Material and method

The material was collected after the primary comminution process carried out at the private company Help Rio Entulho e Reciclagem de Materiais LTDA. A 250 kg sample was collected and bagged after the beneficiation process. The tests were carried out with material of granulometry passing through the opening sieve ø ≤ 4.8 mm and that were retained in the opening sieve 150 µm. Samples underwent characterization tests by SEM analysis, XRD, followed by granulometric composition tests, tests of unit specific mass and content of pulverulent materials, in accordance with ABNT standards.

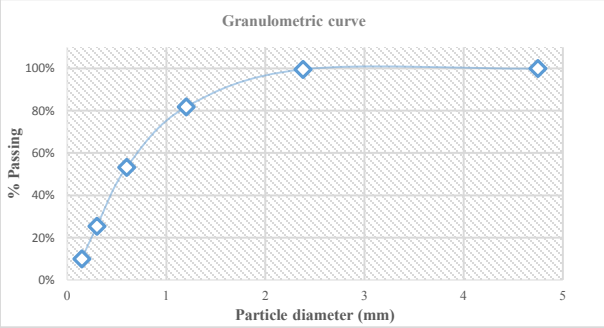

Figure 1. Representation of the granulometric curve of the CDW analyzed

The granulometric composition is based on the distribution of the particles of the granular materials in various dimensions. It is extremely important for a given choice of a viable aggregate because it exerts influence on important characteristics such as shrinkage, increased wear resistance, and changes in workability, costs, and mechanical strength. According to Carneiro et al. (2000), if sand has uniform granulometry, the shape of the grains does not influence, and yet the workability will be compromised. For Cabral (2007) the objective of determining the grain size was to establish the ideal composition that offers the highest possible compactness and also argues that the granulometry and the fine content influence the workability according to the cement dosage. Figure 1 shows the grain size curve of the analyzed material, and the particles are medium sized, with the maximum dimension of 2.38 mm.

Table 1
Composition of the CDW in the analyzed sample

Composition of the CDW sample			
	Sample 1	***Sample 2***	***average***
Rocks	28.43	26.89	27.66
Concrete	22.24	21.47	21.855
Mortar	12.8	16.6	14.7
Ceramic material	20.66	22.57	21.615
Gypsum plaster	4.3	3.2	3.75
Soil	7.9	5.02	6.46

The CDW was added to a predefined concrete trace. The same trait was used for the production of all test bodies used in this study, and only the percentage of fine aggregates underwent changes. After the curing time of the concrete the samples were submitted to tests of resistance to axial compression and modulus of elasticity.

3. Results and discussions

3.1. X-Ray diffraction analysis and scanning electron microscopy - SEM

The analysis of the X-ray diffraction samples of the recycled aggregate in the fine fraction is complicated due to the degree of heterogeneity. According to Figure 2 the presence of gypsum that is a component of Portland cement can be verified. Cabral et al. (2009) observed that the CDW sample in their study was composed mainly of quartz, muscovite, and manganite. According to Sinisterra (2014) the presence of quartz and calcite confirms that they have minerals characteristic of the composition of the limestone aggregates. The kaolinite is also present in the samples of this study and it was characterized by Sinisterra (2014) as clay that may be related to impurities during the

Table 2
Experiments and granulometric fractions

Material	%	Reference	10 %	20 %	30 %	50 %	100 %
Large aggregate	kg/m³	5.90	5.90	5.90	5.90	5.90	5.90
SAND	kg/m³	15.06	14.75	12.05	10.54	7.53	0.00
CDW	kg/m³	0.00	1.51	3.01	4.52	7.53	15.06
Cement	kg/m³	4.32	4.32	4.32	4.32	4.32	4.32
Water	kg/m³	2.13	2.13	2.13	2.13	2.13	2.13
Superplasticizer	g	43.2	43.2	43.2	43.2	43.2	43.2

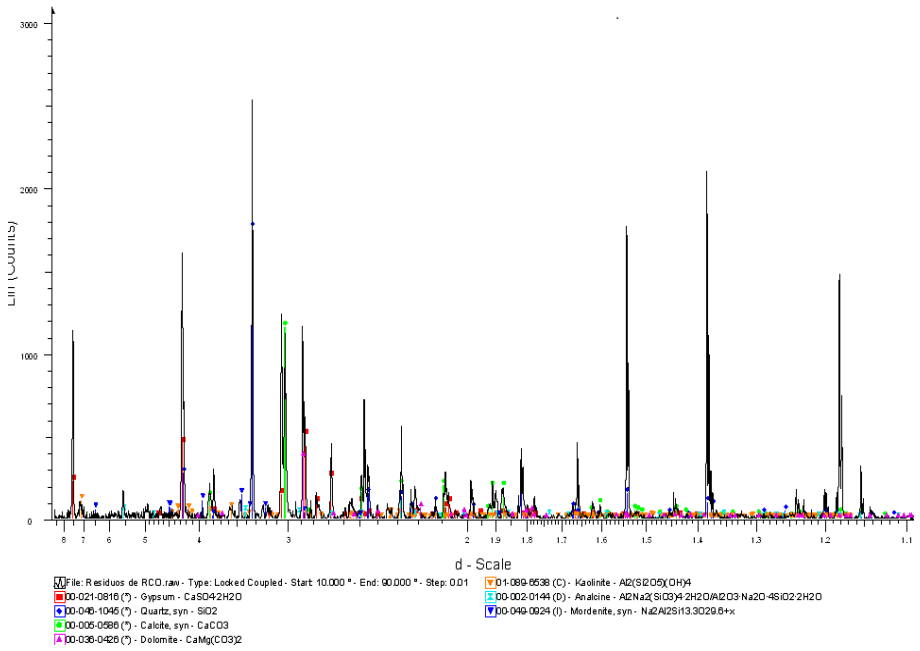

Figure 2. XRD analysis

production process of the aggregates, but may also be constituents of the aggregate of limestone itself. Silva (2014) observed in his study that the mineralogical composition of the CDW confirmed the presence of quartz (SiO_2), calcite ($CaCO_3$), calcium (Na, Ca) $(Si, Al)_4O_8$, and magnetite (Fe_3O_4).

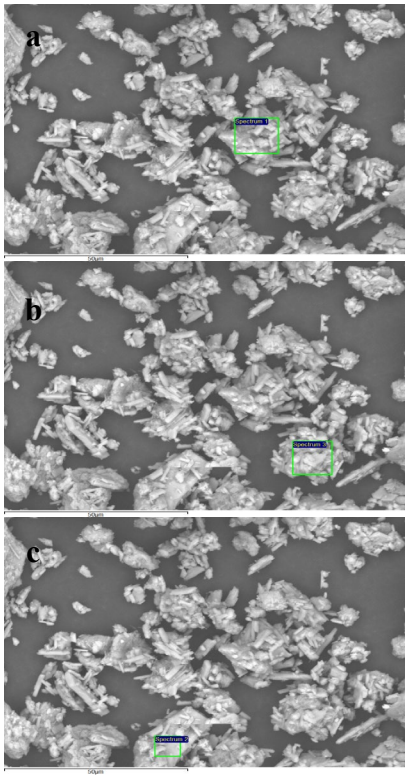

Figure 3. Analyze SEM of the sample

Araújo et al. (2016) pointed out in their study that Lima (1999), which included the physical and chemical variables common to different types of recycled aggregates, and the specific rules and rules for each of them, established a quality standard in the application of these wastes. To obtain a chemical sample of the samples analyzed in this study, it was necessary to submit them, not only to XRD, but to SEM analysis as well.

3.2. Compressive strength tests

Compressive tests and modulus of elasticity of an aggregate are not easy to measure because of the difficulty in testing the particles alone. Nematzadeh et al. (2012) evaluated that the compression test is one of the most important mechanical properties in the characterization of concrete quality. First, compression tests and modulus of elasticity were performed on the test specimens with 100 % and 50 % of fine recycled aggregate, and 100 % of natural aggregate, which was used like reference test specimen. Second, the sequence of compression tests and modulus of elasticity test bodies were tested with fractions of 10 %, 20 %, and 30 % of recycled aggregates, and the tests were repeated in order to establish the final results.

The results show that the mechanical properties of concrete are more affected by the presence of large recycled aggregate fractions than by the small recycled aggregate fractions, which may justify the satisfactory performance of concrete with up to 30 % CDW tested in this research contrary to what Behnood et al. (2015) concluded that concrete with recycled aggregates should have compressive strength up to 25 % lower when

Table 3
Results of mechanical tests

Samples	Force (KN)	Strength (MPa)	Deformation Máxima (με)	Modules of Elasticity (GPa)
CP 10 %	363.03	46.22 ± 0.53	2699.60	31.54
CP 20 %	328.94	41.88 ± 1.9	1996.86	29.31
CP 30 %	262.86	33.47 ± 0.85	3290.64	24.96
CP 50 %	123.12	15.69 ± 2.7	2144.43	14.45
CP 100 %	84.8	10.8 ± 0.82	4173.78	11.82
Reference	276.21	37.46 ± 4.5	3265.1	29.64

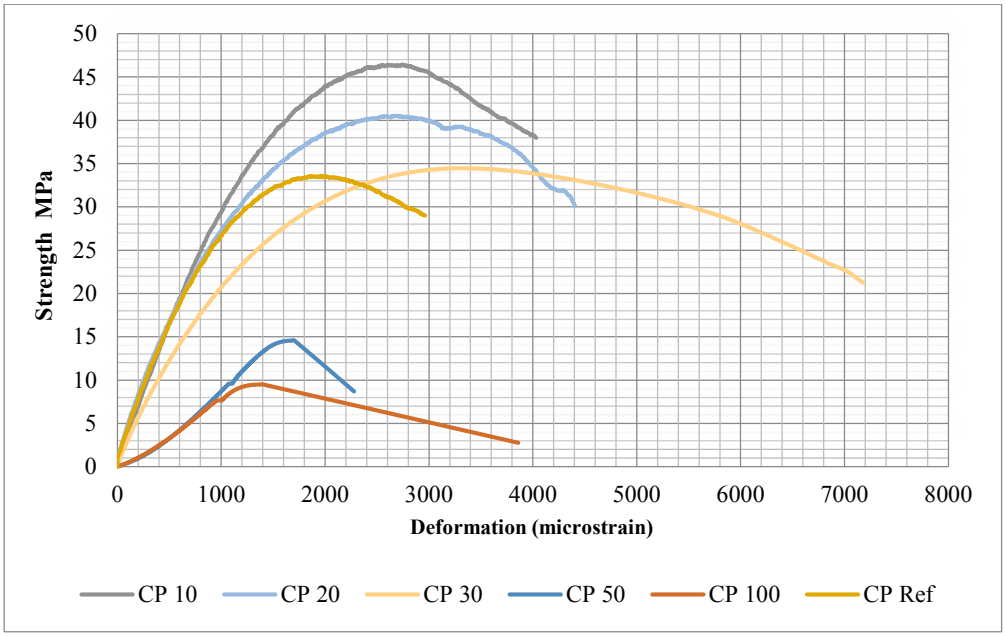

Figure 4. Results of the compression tests of the specimens

compared to concrete with natural aggregates. This lower performance was observed only in traces with fractions with 50 % CDW. In contrast, Pepe et al. (2016) evaluated that the limited use of the recycled aggregate in the structural concrete had insignificant consequences on technological aspects. This observation of the credibility of the results of compressive strength superior to the natural aggregate concrete presented by the concrete with and the results obtained in their research of Cabral et al. (2009), determined that the substitution of the natural fine aggregate for the fine recycled aggregate results in an increase in the compressive strength of the concretes produced, the same result was observed with the substitution of the coarse natural fraction for the coarse recycled fraction. The curves related to the compression tests can be observed in Figure 4.

3.3. Modulus of elasticity tests

Modulus of elasticity is an expression that determines stiffness, and the larger the modulus of elasticity, the more rigid the material (Tanaka et al, 2010). Nematzadeh et al. (2012) defined modulus of elasticity as one of the most important elastic properties of concrete from the point of view of the design and behavior of structures that is often expressed in terms of the compressive strength. For Liu et al. (2014), in addition to being important from the point of view of the design and behavior of structures, the modulus of elasticity is the parameter determined by the structural evaluation and adaptation of structures, also used to estimate structural deviations and to calculate deformation and seismic analysis.

Behnood et al. (2015) pointed out that concrete with CDW fractions must have modulus of elasticity reduced by up to 45 % when compared to concrete with natural aggregates. The author credits that these consequences are due to the fact that the recycled aggregate has a high absorption content of water and lower density besides having the presence of residual mortar on the surfaces of the particles.

According to the graphs presented above, we can point out that Behnood et al. (2015), are correct when they say that the modulus of elasticity of the concrete with CDW reduces abruptly when compared with the concrete with natural aggregates. However, the test specimens of this study with up to 10 % CDW had higher modulus of elasticity than that of the reference specimens, and the specimens with 20 % CDW showed elasticity moduli very close to the specimens which leads us to a conclusion that the presence of up to 20 % CDW does not

significantly alter important mechanical properties such as modulus of elasticity and compressive strength. Although the specimens with 30 % CDW showed a lower modulus of elasticity compared to the reference specimens, the difference between the means was not discrepant.

Araújo et al. (2016) stated in their study that the modulus of elasticity was influenced by the substitution of the natural aggregate by the gross recycled aggregate, presenting a mean reduction of 6 % to 12 % in relation to the reference trait. The mean modulus of elasticity reduction presented in this study was higher than 12 % in relation to CP-50 and CP-100, as shown in Figure 5.

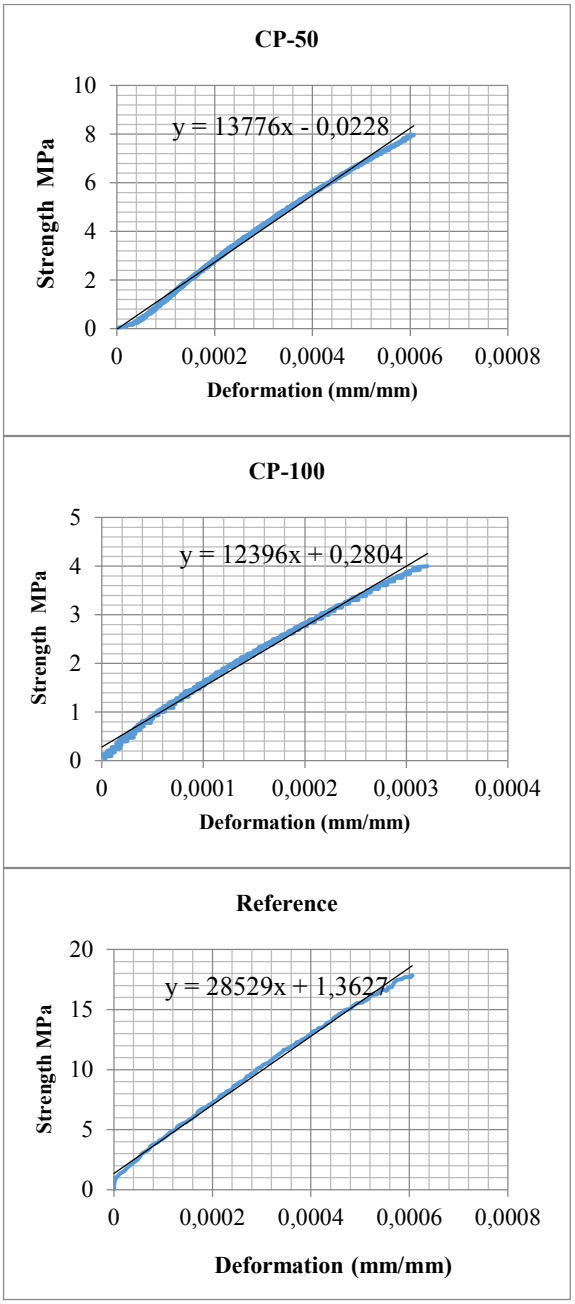

Figure 5. Graph of the modulus of elasticity

4. Conclusions

Recycling of construction waste is essential, either by adjusting the cost of general construction for large companies or preserving the environment. The fact is that it is no longer possible to coexist with these wastes and not take real steps to minimize their impacts.

This work characterized a lot of RCD and analyzed the behavior of the concrete with fractions of 10 %, 20 %, 30 %, 50 %, and 100 % of these recycled aggregates in the fine fraction. The fractions of 10 %, 20 %, and 30 % presented satisfactory behavior, taking into account the reference concrete. The concrete with these fractions of recycled aggregates presented high compressive strength, breaking with standard deformity and did not show a sudden rupture, after reaching the maximum point the compression process continued, they spread without breaking, that is, after the rupture crack was not abrupt, presenting characteristics of ductile material.

For concrete containing 50 % and 100 % recycled waste fractions, the behavior was far from the other fractions and the reference concrete, meaning that the high content of clay and friable materials changed the behavior of the concrete when it had high fractions of CDW.

The results lead to the conclusion that concretes with low fractions of CDW can be used with structural function taking into account that the compressive strength is one of the most important characteristics in the concrete and that the concrete usually has resistance from 15 MPa for foundations and 20 MPa, 30 MPa, 35 MPa, 40 MPa, and 50 MPa for structural concrete. This leads to a conclusion that the presence of up to 30 % CDW influences, but does not drastically reduce either the modulus of elasticity or the compressive strength of the concrete.

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Tehnološka karakterizacija i upotreba recikliranog agregata dobijenog finom frakcijom umesto prirodnog agregata u proizvodnji betona

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I Z V O D

Otpad od građevinskih konstrukcija i ruševina nakon procesa prosejavanja, može proći kroz postupak oplemenjivanja koje omogućava fizičke promene i dobijanje agregata različite granulometrije. Rendgenska difrakciona ispitivanja su izvršena da bi se odredili mineralni sastojci prisutni u uzorcima. Analize skenirajućim elektronskim mikroskopom (SEM) su pokazale da uzorci imaju grubu površinsku teksturu sa zrnima prisutnim u različitim oblicima. Hemijska svojstva predstavljaju bitan faktor za sposobnost sjedinjavanja agregata i veziva, a isto tako mogu doprineti ranoj degradaciji struktura. Analiza fizičkih i mehaničkih osobina je važna ne samo zbog procene svojstva mehaničke snage, već i zbog analize svojstva betona koji sadrži reciklirani agregat. Ispitivanje na pritisak i određivanje modula elastičnosti agregata nije lako izmeriti zato što se same čestiče ne mogu testirati. Dobijeni uzorci su sadržali 10 %, 20 %, 30 %, 50 % i 100 % recikliranog agregata. Kao rezultat mehaničkih ispitivanja izvedenih na ovim uzorcima, primećeno je da su frakcije koje su sadržale 30 % recikliranog agregata imale dobru pritisnu čvrstoću koja je iznosila između 33 MPa i 46 MPa, a modul elastičnosti je iznosio između 24,96 GPA i 31,54 GPA. Međutim, isti rezultat nije dobijen za frakcije koje su sadržale 50 % recikliranog agregata, gde je pritisna čvrstoća iznosila između 10,8 MPa i 15 MPa, a modul elastičnosti je iznosio između 11,82 GPA i 14,45 GPA.