Fine Aggregates of CDW: Feasibility of Its Application in the Manufacture of Mortars for Laying

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Abstract. One of the problems faced by the sector of civil construction currently is related to the difficulty to obtain environmental licenses for the extraction of natural aggregates, in due to the environmental impacts caused by such activity. The objective of this study is to propose the replacement of natural sand and gravel with aggregates of construction and demolition waste (CDW) in the production of mortar for laying. For the characterization of the mortars were determinate the consistency index, water retention, specific gravity, tensile strength in flexion and compressive strength. The CDW fine aggregates replaced the natural sand, in mixtures of mortar without to prejudice mortar properties.

Keywords: Recycled aggregates; CDW; concrete; mortar.

1 Introduction

Solid waste has been a topic of discussion for some decades around the world. Developed countries like Germany, Austria, South Korea and Wales recycle over 50% of all their waste produced. However, in underdeveloped countries, the lack of awareness of population in general, the reduced investment in new recycling plants and the lack of knowledge regarding the possibilities of using recycled material may justify the low recycling rates [1]. According to data collected by the Ministry of the Environment of the Brazil, through a report carried out by the Institute of Applied Economic Research [2], it is estimated that Brazil loses R$ 8 billion (~1.2 billion EUR) per year due to no recycling all waste with recyclable potential. According to the Secretary of State and Environment and Sustainable Development of the state of Minas Gerais, Brazil, the civil construction activity is a great waste generator, with waste arriving of civil construction to represent 40% to 70% of the total mass of waste generated in the Brazilian cities [3]. On the other hand, civil construction is the industry with the greatest potential to absorb its own waste produced.

CONAMA Resolution No. 307 of Brazil [4], which normalized the main issues related to CDW, defined as waste from construction, renovations, repairs and demolitions of construction works, as well as those resulting from the preparation and land excavation. The Article 10 of the aforementioned document indicates that the Class A CDW, after sorting, must be reused or recycled in the form of aggregates or sent to a landfill Class A waste from material reserve for future uses.

The use of recycled aggregates in the production of mixtures can provide advantages such as the use of all mineral components of the waste (bricks, mortars, ceramic materials, sand, stones etc.), without the need to separate any their; possibility of using a larger portion of the debris produced, such as of demolitions and small works that do not support the investment in equipment for grinding/crushing; and the possibility of improvements in the performance of concrete in relation to conventional aggregates, when using low-consumption cement. However, due to its variability and heterogeneity of the composition, generate unreliability in applications of greater economic value and responsibility [5].

Construction and demolition waste (CDW) valorization in a new production process has been widely studied in all the world. Many authors study the use of fine recycled aggregate and evaluate as a replacement of natural sand in coating mortars [6–10] Researches range from the analysis of the characteristics of recycled materials, potential of mineral processing to produce high quality recycled sand by comminuting mixed CDW [11], the behavior of cementitious renderings incorporating very fine recycled aggregates [12], separability studies for removing particles with a high content of cement paste from natural fine aggregate particles (quartz/feldspars) [13]. The goal is to increase the waste recycling rates and mitigate the sand scarcity in many world regions.

Despite being an ecologically correct initiative, in tune with the new environmental laws and normative codes, the use of recycled materials requires several precautions, mainly, in relation to the high percentage of recycled aggregates in the mixture. This fact which can lead to significantly increased water absorption, decreased cohesion and increased drying shrinkage of the units [5]. In another aspect, there are difficulties in releasing the environmental license for the extraction of natural aggregates due to the environmental impacts generated, the search for alternative technologies and studies related to the replacement of aggregates is intensified by CDW aggregates.

This is an exploratory work aimed to evaluate the physical and mechanical properties of mortar for laying produced with fine recycled aggregates from CDW. The experimental procedures were carried out at the Soil and Technology Laboratory of Constructions of Faculty of Santo Agostinho, at Montes Claros-MG, Brazil. The study consisted of comparative analysis of mortar mixtures with total replacements of the natural aggregates by fine CDW aggregates, analyzing the influence on consistency, retention of water, specific gravity and mechanical strength.

2 Materials and methods

2.1 CDW Aggregates

The recycled aggregates used for the production of mortar was originated from concrete, mortar, ceramic and asphalt waste. They are classified as Class A waste, which are reusable or recyclable as aggregate, according to Resolution CONAMA No. 307 [14]. According to NBR 10004 [15], waste is classified as Class II B – Inert, which can be disposed of in landfills or recycled. According to NBR 15.116 [16] it is possible to classify the material as ARM (Mixed Recycled Aggregate), as it has less than 90% by mass, of concrete fragments.

The materials were supplied by a local recycling plant and went through four fundamental steps: screening, primary reduction, crushing and screening. The screening operation aimed to eliminate unwanted components (i.e., plaster, plastics, rubbers, woods, cardboard, paper, metals and organic matter), which harm the technical and environmental characteristics of the recycled product. Two particle sizes of recycled aggregates were obtained for analysis. The small plant is shown in Fig. 1 as well as the crushing process carried out from the mobile impact crusher. By the color of the fine aggregate, shown in Fig. 1(A) and (B), it possible to observe if it is a recycled aggregate that contains a considerable amount of ceramic material. In Fig. 1(C) can be seen the coarse aggregate fragments of mortar and concrete and gravel surrounded by cementations material and fragments of ceramic and asphalt material.

Fig. 1. Recycled aggregates: (A) fine aggregate, (B) coarse aggregate being produced and (C) large aggregate.

The incorporation of aggregates from CDW with a majority composition of concrete, presents better results and with less dispersion, compared to recycled aggregates consisting mainly of masonry [17]. For this reason, the use of the latter is usually limited to concrete applications. Thus, the fine aggregate obtained, being composed mostly of powder from ceramic waste was used for the mortar mixtures in this work.

2.2 Mortar production

The production of mortar adopted standardized procedures in the standard NBR 16541 - Mortar for laying and coating walls and ceilings - Preparation of the mixture for carrying out trials [18]. It should be noted that this fine recycled aggregate was a by-product of the production of large aggregates with its properties being unknown. As the present work was exploratory in scope, progress was made without proceeding to any characterization and the mass mix was adopted 1 : 5.871 : 1.438, of Brazilian cement CP IV 32, fine aggregate and water. The reference mix used fine natural washed sand as aggregate for comparison with CDW sand illustrated in Fig. 1(A).

With regard to mortars for laying masonry and wall cladding, Sousa and Bauer emphasizes that "workability is one of the most important properties of mortars, given its obligation, so that it can be conveniently used (with easy handling), showing its full potential during the coating execution process" [19]. Being aware that the w/c ratio has a crucial influence on the properties of any mortar (or concrete), in this work it was decided to adjust (slightly) the amount of water in the mix to ensure that all mortars had the same consistency index (flow table).

2.3 Mortar tests

The test to determine consistency was performed according to NBR 1327 - Mortar for settlement and coating of walls and ceilings – Determination of consistency index [20]. For the test was carried out (Fig. 2), a vibration densification table was used for consistency index, a metallic mold, and a socket, in addition to a metallic ruler and a measuring tape. After preparation of the mortar, it was used to fill the mold, placing it from centered on the table and filling in three successive layers of equal heights, applying to each of them, respectively, fifteen, ten and five strikes with the socket, evenly distributed.

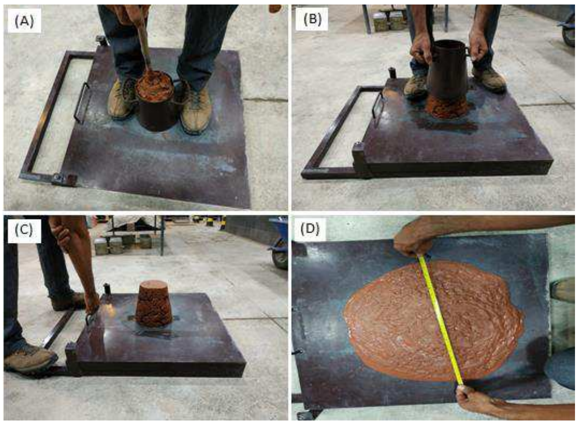

Fig. 2. Flow table test: (A) filling the conical mold with mortar; (B) removal of the conical mold vertically; (C) activation of the compaction by vibration; (D) measurement of mortar spread.

The mortar was flattened with a metal ruler close to the edge of the mold, with short reciprocating movements along the entire surface, eliminating the particles around the mold with the aid of a dry and clean cloth. Then the mold was removed vertically, and the table was activated for a consistency index with 30 drops in 30 seconds. Then, three measurements of the mortar spreading were performed, with the help of a measuring tape. These measurements performed on three diameters taken in pairs of uniformly distributed points along the perimeter of the three measurements and recorded. The consistency index mortar corresponded to the average of the three diameter measurements, being expressed in millimeters and rounded to the nearest whole number, recording the water/dry materials ratio used in the mortar mixture.

The water retention test was performed according to NBR 13277 - Mortar for laying and coating of walls and ceilings – Determination of water retention [21]. The main appliances used in the test were the mold with rigid plate and weight of 2 kg, filter paper discs, socket metal, beveled metal ruler, a scale with a resolution of 0.1 g and a stopwatch. To the execution of the test, the empty mold was weighed recording the weight, the dry filter papers were weighed and, after preparing the mortar, the mold was filled with 10 portions of mortar with assistance of the spatula. Afterwards, the mold edge was cleaned, and the mold was weighed with mortar. Subsequently, two gases, twelve discs of filter paper were placed on the mold surface, the rigid plate and the weight of 2 kg, and, after two minutes, the weight and plate were removed, and the mass was recorded of the wet filters – see Fig. 3. Then, the water retention and the water-to-fresh mortar factor were calculated.

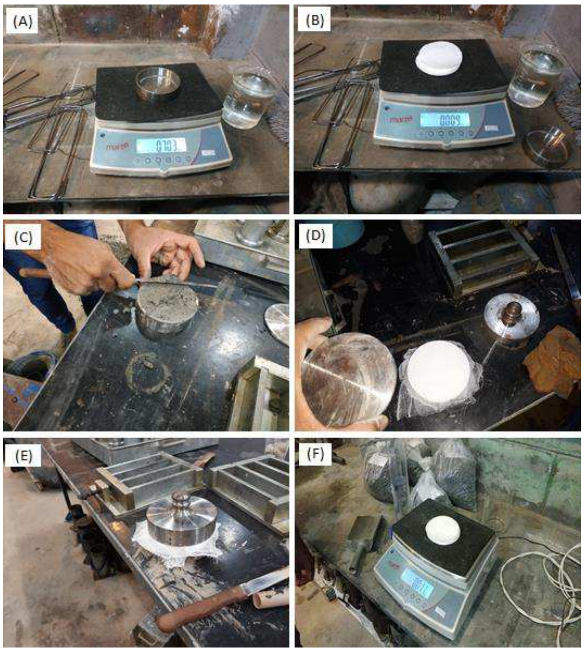

Fig. 3. Determination of water retention: (A) weighing of the empty mold; (B) weighing of dry filter papers; (C) filling the mold with mortar; (D) positioning gases and filter papers on the mold surface; (E) plate positioning rigidity and weight on the filter papers and mold surface; (F) weighing of wet filter papers.

The specific gravity test was performed according to NBR 13278 - Mortar for laying and coating of walls and ceilings - Determination of mass density and incorporated air content [22]. The main equipment used for the execution of the test were scales with resolution 0.1 g; a rigid, cylindrical container of non-absorbent material; and spatula. To run the test, the mortar to be used was prepared and, immediately after the mortar preparation, the empty container was weighed. Soon after, the container was filled with water and its volume.

Then, with a spoon, portions of the mortar were gently introduced into the container, forming three layers of approximately equal heights, applying, in each layer, 20 blows along the perimeter of the mortar, each blow corresponding to the entrance and the out of the spatula in the vertical position and, after the last layer, 5 strokes were applied with the socket. The container was then leveled with the spatula, in two orthogonal passes to each other, making back-and-forth movements, with a 45o inclination in relation to the mortar surface. At particles adhered to the outer wall of the container were removed and the mold mass was weighed with the mortar, recording it – see Fig. 4. Then, the specific gravity of the mortar (in the fresh state) was calculated.

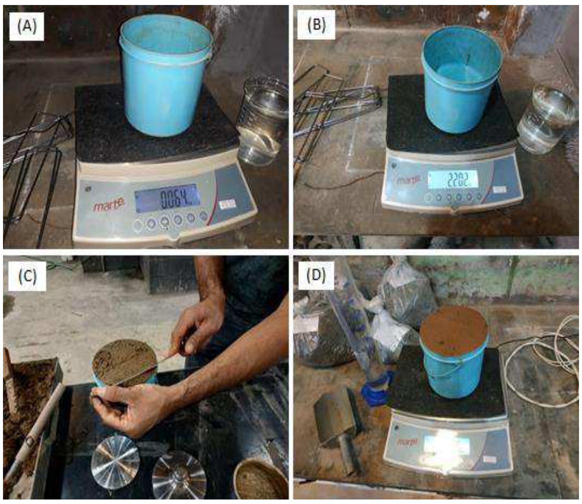

Fig. 4. Determination of density: (A) weighing of the empty container; (B) weighing m of the container with water; (C) filling the container with mortar; (D) weighing of container with mortar.

The mechanical strength tests were performed according to NBR 13279 - Mortar for laying and coating of walls and ceilings - Determination of tensile strength in bending and compression [23]. Two metallic prismatic molds were used, with three compartments of dimensions 4x4x6 cm^3 each for molding 6 specimens for each type of mortar, totaling 12 specimens. In addition to this equipment, a table for compaction by vibration, spatulas, metal ruler; hydraulic press. To carry out the test, the mortar was prepared. Then, three prismatic specimens, by age (7 and 28 days), were molded. With the help of the spatula, the mortar was spread in each compartment, forming a uniform layer. Then, the vibration densification table was activated with 30 falls in 30 seconds – see Fig. 5. Identical process occurred for the second layer. Subsequently, the specimens were leveled with the aid of a metal ruler. At the age of 48 hours, specimens were demolded.

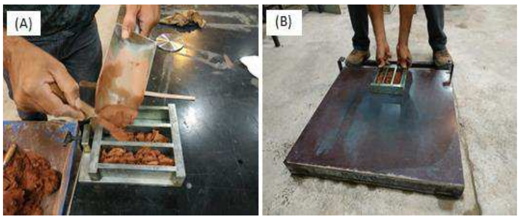

Fig. 5. Molding of specimens: (A) filling of mold compartments of with mortar; (B) consolidation of the mortar with the aid of the consolidation table by vibration.

The flexural tests of the specimens took place at the ages of 7 and 28 days. The specimens were positioned on the support devices of the test equipment so that the flat face does not stay in contact with the support devices or the charging device. The distance between the supports was 14 cm. The load was applied continuously until the specimen ruptured – Fig. 6(A) and (B). To determine the compressive strength, according to NBR 13279 [23], the halves of the three test specimens of the flexural tensile test, with the same care regarding the positioning of the faces and application of the load. Then the load was applied continuously until the specimen ruptures – see Fig. 6(C) and (D).

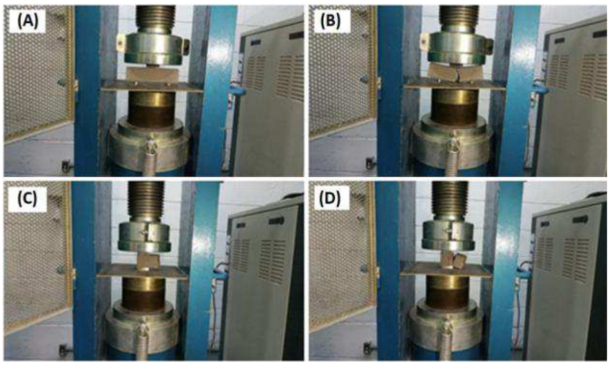

Fig. 6. Carrying out the flexion (A, B) and compressive (C, D) tests: (A) positioning of the specimen the support devices of the test equipment; (B) specimen after rupture; (C) positioning of the specimen in the support devices of the test equipment; (D) specimen after rupture.

3 Results and discussion

The flow table results found for the mortar specimens produced with CDW aggregates and for natural sand were 53 cm and 52 cm, respectively. To obtain close results, it was necessary to adjust the water content. The water added to the mortar with natural aggregates was +50 g. This addition has been added in a total of 2 kg of cement. These results allow one to verify that the mortar that reached the greatest spread was the produced with construction waste, even without the addition of extra water. In this sense, for the case of study, it is concluded that the mortar produced with this CDW aggregates is more workable when compared to the mortar with natural sand. Martinez et.al [9] analyzed three types of recycled fine aggregate with higher water absorption compared to natural sand, obtaining absorption values between 5% and 10% what are acceptable for recycled mortars [9]. As mentioned by Sabbatini [24], workability is associated essentially to consistency and expresses ease of handling. It is considered that a mortar it is workable when it is easily distributed after being seated, not sticking to the tool in the moment it is being applied, not segregating when transported, not hardening in contact with absorptive surfaces and remaining plastic long enough for handling.

The difference in the results was due to the fact that the CDW aggregate had a greater amount of fine in relation to natural sand mortar, a fact that interferes with cohesion, a property that it depends on the proportion of fine particles in the mixture and which is directly linked to consistency. As stated by Gomes [25], consistency results in effects of the actions of internal forces such as cohesion, friction angle and viscosity, which influence the change of shape of the mixture. Therefore, the water content, the shape and texture of the grains of the aggregates and the granulometry interfere in the consistency of mortars. The results found by Kruger et al. [7] showed that the RCD powdery material did not significantly interfere in the properties of consistency, water absorption and void index for additions of up to 12%. However, from the fraction of 20%, the higher the content of powdery material used, the greater the damage to the properties of the mortars. For the 30% content of powdery material, a 40% drop in compressive strength and 28% increase in absorption was observed in relation to the 20% addition content [7].

The results obtained in the water retention test of mortar samples presented very close values. It is noticed that the total replacement of natural sand by waste from construction does not considerably affect water retention. Approximate retention of water values, 97.10% for the mortar produced with construction waste and 97.28% for the mortar produced with natural sand can be considered efficient in this regard question. The property is fundamental for the development of mortar strength in the hardened state and directly influences cement hydration and adhesion phenomenon between the components of the mortar with the substrate.

In regarding to the specific gravity tests of the mortar specimens, specific gravities were recorded higher for natural sand (2060.4 kg/m^3) compared to mortar with CDW aggregate (1962.8 kg/m^3). Natural sand is mainly composed of quartz, which is a material that it has low porosity, which gives it greater density. Kruger et al. [7] concluded that, as the percentage of powdery material increases, there is a reduction in specific gravity. With 12% of powdery material (18.55% of incorporated air content) it reached a density of 1780 kg/m^3. After washing the material, they found 7.79% of incorporated air and 2019 kg/m^3 [7]. CDW aggregates are composed of lighter materials, such as ceramic material and cement paste. The Fig. 7(A) expresses the results obtained in the test for determining the tensile strength in flexion, at 7 and 28 days,

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with the respective standard deviations of the specimens. Comparing the results obtained from the mortars produced with the aggregates of CDW, the mortar produced with natural sand has reached flexural tensile strengths slightly higher than mortar produced with recycled aggregates. It was also observed that the mortar samples produced with construction waste, showed a decrease in strength of 24.3% from 7 to 28 days, as shown in Fig. 7(A).

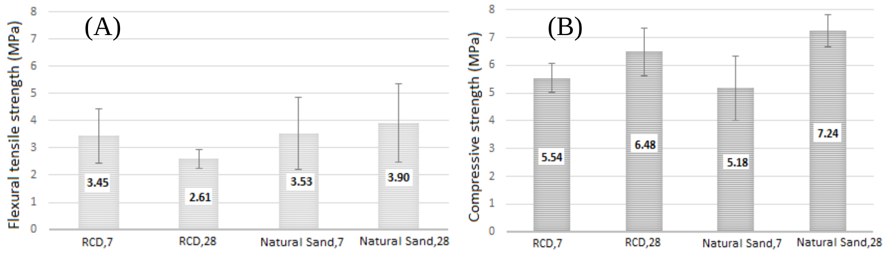

Fig. 7. (A) Flexural tensile strength; (B) Compressive strength.

There is no justification for this decrease. It is believed that this observation is due to the variability associated with this property to which the variability of the aggregates used is added in mixtures. The LNEC Specification E 471 [17] emphasizes that fine recycled aggregates have a high percentage of grains with a dimension less than 0.063 mm, compromising the mechanical strength. Fig. 7(A) also allows verify that the mortars composed of natural sand presented a strength gain of almost 10% from 7 to 28 days, as expected. The mortar with CDW aggregates, even presenting a water-cement factor inferior to the natural sand mortar, it presented flexural strength at 28 days 10.4% less than natural sand mortar. The Manual on Solid Waste from Civil Construction [26] emphasizes, on the mixed recycled aggregate (ARM), that the possibility of the presence of polished faces in ceramic materials, such as floors and tiles, can negatively interfere in the compressive strength of concrete, similarly to mortars.

The Fig. 7(B), illustrating the results obtained in tests determining the compressive strength at 7 and 28 days. The results show that there are no losses or gains of strength markedly when changing between natural sand and CDW sand. At 7 days to CDW sand mortar showed greater strength than natural sand mortar. However, at 28 days the opposite was observed. However, in both cases, considering the respective standard deviations, it appears that such variations are within the margin of error of the test.

Other studies have similar results. Azevedo et.al (2020) concluded that the partial replacement of natural sand by the CDW presents potential for improvement of the main technological and environmental properties of mortars, contributing to a clean production mortar, with 25% of CDW composition being the most suitable for use in building construction [6]. Martinez et al (2016) mention that, for mixes with 100% of recycled mortars, the mechanical strength is poorer compared to mixes made with natural sand, but both compressive and bond strength values of recycled mortar comply with established standards, allowing its use in construction using studied recycled aggregate in suggested proportions (1:3 or 1:4) [9].

In addition to the results found, the results showed by Carasek et al. [8] concluded that despite the distinct composition of the RCDs, when the same crushing process is used, very similar particle size distributions are obtained; however, other characteristics are different in these aggregates and these influence the behavior of the mortars and depend on the origin of the residue [8]. Then, it is important to mention that within the RCD segment, its composition is generally very diverse, ranging from organic substances, such as wood, or inorganic substances, such as metals, glass and minerals. This causes difficulty in its precise characterization, namely because each material has different specificities and environmental impacts [27]. Thus, thinking about increasing the quality of the product is thinking about the quality of its screening.

As one of the oldest records of encouraging the promotion of new products with greater durability, with the improvement of the quality of products made from RCD, the Dutch Research Center (CUR) is cited, which develops specifications for the use of recycled aggregates since 1984. The case of Germany is interesting because it is one of the EU countries that produces more CDW (214 million tons in 2002) and, even so, one of those with the highest recycling rate (85%). Among the existing guidelines in Germany, for example, the main one in the field of recycling and waste management comes from 1996, defining principles that go towards a closed cycle, establishing a hierarchy of treatments similar to the inverted pyramid existing in Portuguese legislation, which prioritizes waste prevention [27].

4 Conclusions

This research contributed to demonstrate the technical feasibility of replacing fine aggregates by fine recycled aggregates, contributing to a reduction in the mass of landfilled waste and conservation of natural resources. From the tests carried out for the characterization of mortars for laying with fine waste aggregates from CDW it is concluded that the mortar with fine CDW sand presented performances satisfactory in the properties analyzed: consistency, water retention, specific gravity and strength.

The total replacement of natural sand by fine recycled aggregate in mortars for laying is technically viable regarding the physical and mechanical properties analyzed. If introduced in the construction processes in replacement to natural fine aggregate, may provide a minimization of impacts environmental issues arising from industrial processes, release of industrial yards, in addition to add value to solid wastes.

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