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Evaluation of mechanical properties and carbonation of mortars produced with construction and demolition waste

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HIGHLIGHTS

- Carbonation and mechanical properties of mortars produced with recycled aggregates were evaluated.
- Five replacement levels and two types of fine recycled aggregates obtained from CDW were analyzed.
- Statistical analysis (ANOVA) and mathematical modeling were used to analyze the results.
- The increase in replacement levels of natural aggregate by recycling reduces the compressive strength of mortars.
- Mortars produced with recycled aggregates showed better CO_2 uptake performance due to carbonation.

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ABSTRACT

The large amounts of waste generated by the construction sector pollute the environment owing to a lack of suitable disposal sites for construction and demolition waste (CDW) and improper methods of disposal. However, these problems provide an incentive to develop recycling alternatives. In pursuit of such alternatives, this study compares the mechanical properties and carbonation depths of mortars produced with two different types of recycled aggregates (RAs): ceramic recycled aggregate (CRA) and mixed recycled aggregate (MRA). The mechanical properties (compressive, flexural, and adhesive strengths), physical properties (porosity, water absorption, and bulk density), carbonation depth over time, and CO_2 uptake were evaluated for mortars made with both the types of aggregates. The mortars evaluated were mixed with different levels of RAs used to replace the natural aggregate (25%, 50%, 75%, and 100%). The results showed that as the natural aggregate was replaced with greater portions of RA materials, the compressive strengths of the mortars were reduced, and increases in the carbonation depths of the mortars were observed for all the sample ages analyzed. The results indicated that the bond strength of a mortar with CRA was higher than that of the natural aggregate reference mortar. The mortars produced with CDW exhibited higher CO_2 uptake potential, being able to sequester up to 170 $g.CO_2/m^2$ of coating. Overall, this study illustrated that the use of CDW as a source of fine mortar aggregates can be considered a valid and sustainable alternative for use in construction.

1. Introduction

Over the past few years, the construction sector has sought solutions for reducing the raw-material consumption, emissions, and waste generation of its activities. Singh and Singh [1] estimate that the amount of solid waste generated by the construction industries will increase from 12.7 billion metric tons to 27 billion metric tons by 2050. Currently, the number of projects utilizing construction and demolition waste (CDW) salvaged from across the life cycles of infrastructure projects is increasing [2,3]. CDW covers a broad range of materials from a variety of origins, including total or partial demolition of infrastructure, civil works, or foundations, as well as by-products from the construction of new buildings [4]. In Brazil, CDW is comprised of primarily concrete waste obtained from demolished structural elements and ceramic waste obtained from removed external and partition walls. Hence, two main types of recycled aggregates (RAs) can be obtained from

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CDW: ceramic recycled aggregate (CRA) and mixed recycled aggregate (MRA).

These aggregates can be employed in manufacturing new concrete [5–9] and mortars [10,11]. The use of different types of aggregates in concrete has been extensively researched with respect to mechanical properties [5,9,12,13] and durability indicators such as chloride penetration [14,15], carbonation depth [5,6,9], and freezing/thawing [16]. The results have indicated that the mechanical properties of concretes with CDW aggregates are poorer than those of reference concrete made with natural aggregates (NAs). Additionally, concrete made with RAs is less durable because the material is more porous. Therefore, the use of CDW as an aggregate in concrete is not recommended for applications in aggressive environments.

The fine fraction of materials (less than 4.8 mm in size) produced by construction-waste recycling plants is generally not used. However, this material accounts for approximately 40–50% of the total mass of CDW collected [2,17]. The use of the fine fraction of CDW in producing mortars offers a method for reusing this waste. To date, only a few studies have been conducted on the use of CDW fines in mortars. Comparisons between the use of RA and NA sands in concrete [9,17–22] state that the fine fraction of CDW was often disregarded because it was believed to be of low-quality and possess poor material properties. However, some few studies have investigated the use of RAs in place of natural sand. Recently, Tiwari et al. [23] evaluated the use of several industrial by-products (such as bottom ash, waste foundry sand, copper slag, plastic waste, recycled rubber waste, and crushed glass aggregate) for potentially replacing natural fine aggregates in the concrete-manufacturing process by determining their strength and durability characteristics. They concluded that concrete waste can be used to slightly improve many concrete properties, depending on the quality, type, and quantity of the waste material used.

Fernández-Ledesma et al. [18] investigated the use of different levels of recycled concrete sand for the replacement of natural sand in mortar production. In this investigation, the analysis of variance (ANOVA) was used to evaluate the significance of the results obtained. The authors concluded that the maximum recommended replacement level of natural sand for indoor mortars without compromising the properties of the mortar is 50% by volume. Corinaldesi and Moriconi [10] evaluated the mechanical properties of mortars manufactured using three different types of RAs: plant recycling rubble, rejected prefabricated concrete, and recycled-brick wastes. The results showed that the bond strength of the recycled mortars was higher than that of the reference mortars, despite poorer mechanical properties. Ledesma et al. [21] evaluated the short and long-term properties of masonry mortars manufactured with five replacement ratios of natural siliceous sand using fine RCAs (0%, 5%, 10%, 20%, and 40% by volume). They concluded that replacing up to 40% of the natural sand in a masonry mortar with a fine RCA is a viable approach for the manufacture of masonry mortars. Neno et al. [24] investigated the use of two aggregated types in mortars manufacture: the river sand and one obtained from crushing concrete blocks until obtaining fine material. Were made four mortars types, maintained constant the particle size distribution, in order to evaluate the influence of aggregate in fresh and hardened states. Was used a 1:4 volumetric proportion with 3 replacement levels (20%, 50% and 100%) of sand by recycled aggregate (RA). The authors investigated the main properties of mortars and verified that a replacement level until 20% in volume is adequate for use in wall rendering.

In addition to the problem of high waste generation, the carbon dioxide (CO_2) emissions associated with the production of cement-based materials should be considered from a sustainability viewpoint. Some studies [25–28] have shown that cement-based materials can capture CO_2 from the atmosphere through the carbonation process, thereby partially compensating for the emissions from cement production, but in reinforced concrete structures, carbonation is undesirable from a durability viewpoint. However, in non-reinforced concrete elements and mortars, carbonation can be relied upon to balance gaseous emissions related to the production of building materials [25]. Furcas et al. [25] employed accelerated test data to investigate the CO_2 capture process of the carbonation of cement and lime mortars, recording a capture of 26.4 and 16.1 g.CO_2/kg at 28 days, respectively, confirming that common mortars can potentially be relied upon for carbon sequestration during their curing process. Although the values seem low, they are significant considering the widespread use of mortars, the long period of their service life, and post demolition [25].

According to Neno et al. [24], the properties of mortars with RAs with small replacement levels can improve their performance, as showed in previous researches [45]. However, substitution levels above 50% generally leads a decrease of physical and mechanical properties, whose difference in performance depends of RA type used. So, the are few investigations concerning the effect of highest replacement levels of NA by different RA types and the possibility of CO_2 uptake for such materials. In this study, investigations were conducted on mortars made with two different types of RAs (CRA and MRA), and their behaviors were compared to traditional mortars made with quartz sand, considering elevated substitution ratios. The areas of focus in this study were on physical properties (dry bulk density and water absorption), mechanical properties (compressive, flexural, and bond strengths), natural carbonation over time, and CO_2 uptake. The results obtained were evaluated using ANOVA to investigate the statistical influence of the variables on the investigated properties.

2. Experimental procedures

2.1. Materials

In this study, Brazilian Pozzolanic Portland cement (similar ASTM C 595 Portland Pozzolanic) was used in the mortar specimens. The density, specific surface, and compressive strength of the cement were 2.74 g/cm^3, 1230 g/cm^2, and 38.7 MPa at 28 days, respectively.

River siliceous sand was used as the NA, the characteristics of which are given in Figs. 1 and 2, and Table 1. The two types of RAs (CRA and MRA) were collected near Porto Alegre (RS, Brazil). After removing the reinforcing steel and other impurities, the raw material was crushed and subsequently sieved. Each type of RA was passed through a 4.76 mm sieve, in which the larger materials retained were returned for crushing. This procedure was

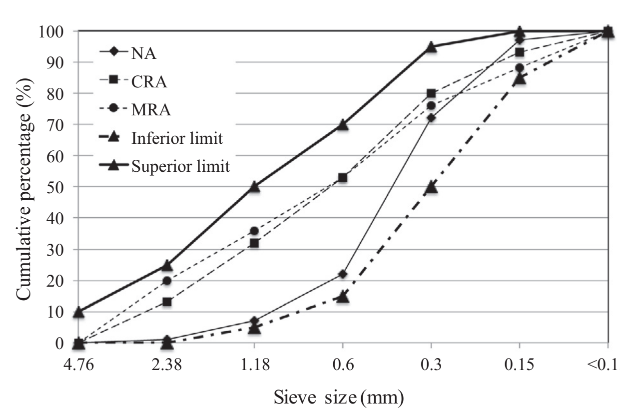

Fig. 1. Particle size distribution of the natural and recycled aggregates.