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Rheological and mechanical properties of concrete containing crushed granite fine aggregate

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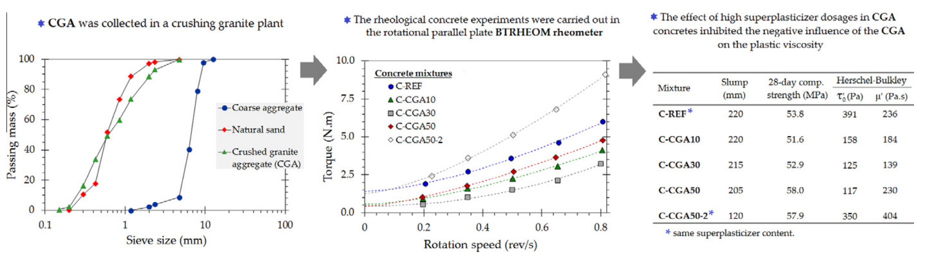
HIGHLIGHTS

- Herschel-Bulkley parameters were obtained from the BTRHEOM rheometer results.
- Natural siliceous sand was replaced by CGA up to 50% in volume.
- The concrete rheology was expressively affected with the use of CGA.
- The compressive strength was not negatively affected by CGA.

GRAPHICAL ABSTRACT



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ABSTRACT

The influence of crushed granite fine aggregate (CGA) on the rheological and mechanical properties of concrete is reported in this work. Concretes were produced with 10, 30, and 50% (in volume of fine aggregates) of CGA, with respect to a reference mixture, which contained a regular siliceous river sand. The reference was designed for a 28-day compressive strength of 50 MPa and a slump ranging from 200 to 220 mm. All concrete mixtures had 20% of rice husk ash as the volume of cementitious materials from the rheological (Brookfield viscometer), and 28-day compressive strength tests of cement-based pastes. The concrete rheology was measured using a BTRHEOM parallel plate rheometer. Experiments were also performed to investigate the concrete air content, compressive strength (at 7 and 28 days), Young's modulus (at 28 days), and water absorption. The results showed that the Herschel-Bulkley model adequately fit the rheology data, and high superplasticizer dosages in CGA concretes inhibited the negative influence of CGA on the plastic viscosity. The compressive strength was not negatively affected, and no significant change was observed in Young's modulus for up to a 50% CGA content. Moreover, water absorption was reduced for concretes containing 30 and 50% of CGA.

1. Introduction

Increasingly, over the last decades, the use of manufactured and recycled aggregates have grown rapidly, especially because the available natural aggregates at cost-effective transportation distances are becoming rare today. Thus, manufactured fine aggregates from the crushing stone industry have been used in different types of concretes [1–4]. Furthermore, when used appropriately, the recycled concrete aggregates can produce high strength concretes [5], self-consolidating concretes [6] and fiber reinforced composites [7].

It is widely known that there are some great advantages while using aggregates from crushing processes or demolition recycled concrete. However, some problems that result from those aggregates need to be better understood, such as the fine particle content [8,9] and the presence of angular grains [10] in crushed aggregates, and heterogeneity and high water absorption [11] in the recycled concrete aggregate, although the manufactured and recycled aggregates can extend the life of the natural resources

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of aggregates. These characteristics are negative, and may strongly compromise the properties of the concrete at both fresh and hardened states.

Although the difference in shape and surface texture of crushed fine aggregates in comparison to natural sands is well-known, few studies are found which speak about the effect of these manufactured aggregates on the rheological behavior of concrete. Westerholm et al. [12] studied the influence of crushed aggregate on the rheological properties, using the Bingham model from rotational viscometer results. They showed that the properties of crushed aggregates, such as the particle shape and content of fine particles, strongly affected the rheology of mortars, with a significant increase in the yield stress and plastic viscosity. Cortes et al. [2] observed that the replacement of natural round sand, by crushed granite and limestone aggregates, increased the paste volume in mortars considerably. Raman et al. [4] reported some negative impact of crushed granite sand (ranged from 10% to 40%) on workability (slump test) and mechanical properties of concrete. In this respect, the negative outcomes were compensated by an adequate mix-design, and by using rice husk ash as a supplementary cementitious material. It is interesting to note that the shape and texture of crushed aggregates may increase the mechanical properties of concrete due to the interlocking effect between paste and aggregate particles [1].

To this extent, the influence of crushed granite fine aggregate on the rheological and mechanical properties of concrete was reported in the present study. All concretes had cement and RHA (20% in volume) as cementitious materials, which were defined from rheological tests, using a Brookfield viscometer, and 28-day compressive strength of cement-based pastes. Rheological concrete measurements were taken from a BTRHEOM rheometer, and it was assumed that fresh concrete behaved as a Herschel-Bulkley fluid. Compressive strength, Young's modulus, and water absorption data were also investigated experimentally.

2. Materials

Brazilian type V Portland cement (high-early strength with 473 m^2/kg Blaine fineness), and a commercially available rice husk ash (RHA, D_{50} of 15.5 μm) were used as cementitious materials. Oxide percentages of the cement and RHA, determined by the X-ray fluorescence method, and the loss on ignition [13], are shown in Table 1. High silica content (92%) and low loss on ignition (3.3%) were observed in the RHA, and these confirmed its pozzolanic characteristic.

CGA was collected in a crushing stone plant, which produces granite coarse aggregates in the state of Rio de Janeiro (Brazil). This undersized material from the crushers of the aggregate process has been used as roadway material. A good quality natural sand (siliceous sand, sourced from the Paraíba do Sul River, Brazil) was also selected to be used as fine aggregate. Coarse aggregate of crushed granite, with 9.5 mm maximum, and polycarboxylate-based Glenium 51 superplasticizer (33% solid content and 1210 kg/m^3 specific gravity) were also used. Particle size distribution [14] and the main physical characteristics of all aggregates are shown in Fig. 1 and Table 2, respectively. The experimental packing density (Φ) of the aggregates was determined by the compaction and vibration test, developed by de Larrard [15], and calculated from Eq. (1).

$$\Phi = \frac{4M}{\pi D_c h \delta} \quad (1)$$

Considering M to be the sample mass (3.0 or 7.5 kg for fine and coarse aggregates, respectively), D_c is the diameter of the cylinder, where the sample is placed during the test, h is the sample height at the end of the test, and δ is the sample density.

The sphericity (S) and roundness (R) of both fine aggregates were estimated using Eqs. (2) and (3), respectively, from the digital images. Based on Goldoni et al. [16], 30 individual particles of each sand, ranged between 1.18 and 4.76 mm, were selected, and the Image J software was used to determine the geometric parameters. The typical shape particles of both natural and crushed sands are showed in Fig. 2.

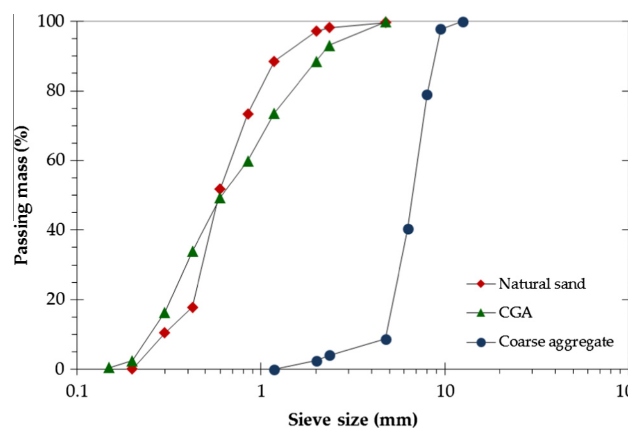

Fig. 1. Particle size distribution of the fine and coarse aggregates.

Table 1
Oxide percentage (by mass) of the Portland cement and RHA.

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	SO_3	MnO	LOI[a]
Portland cement	12.9	3.9	2.2	72.9	0.2	1.0	3.1	0.1	1.6
RHA	91.9	–	0.1	0.8	–	2.2	1.4	0.3	3.3

[a] LOI: loss on ignition.

Table 2
Main physical characteristics of the fine and coarse aggregates.

Material	Density (kg/m^3)	Fineness modulus	Packing density	Sphericity[a]	Roundness[a]
Natural sand	2660	2.49	0.6634	0.83 (7%)	0.68 (15%)
CGA	2640	2.60	0.6684	0.66 (10%)	0.44 (20%)
Coarse aggregate	2670	4.93	0.5348	–	–

[a] Coefficient of variation values are indicated between parentheses.