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Mechanical properties of structural concrete with fine recycled ceramic aggregates

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HIGHLIGHTS

- Recycled aggregates obtained from crushed bricks and crushed sanitary ware.
- Influence of aggregates incorporation in mechanical properties of concrete.
- Concrete with recycled crushed bricks presents adequate structural performance.
- Concrete with recycled sanitary ware performs poorly.

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ABSTRACT

The objective of this research is to evaluate the effect of the incorporation of recycled ceramic fine aggregates, obtained from crushed bricks and crushed sanitary ware, on the mechanical properties of concrete. The effects of such incorporation on properties such as compressive strength, splitting tensile strength, modulus of elasticity and abrasion resistance were investigated and are discussed. Seven different concrete mixes were cast to test these hardened properties: a conventional reference concrete and six concrete mixes with replacement ratios of 20%, 50% and 100% of natural fine aggregates by either fine recycled brick aggregates or fine recycled sanitary ware aggregates. All mixes were prepared with the same workability and the same aggregates' size gradation to allow for a valid comparison of results. Results obtained show that concrete with recycled crushed bricks exhibits adequate structural performance. Conversely, concrete with recycled sanitary ware performed poorly compared to the reference concrete, even though this limitation may be offset by the use of superplasticizers.

1. Introduction

Consumption of natural resources and energy has increased proportionately to civilization development and world population growth, and this is one of the biggest environmental concerns today. In addition to the increasing emission of greenhouse effect gases, unbalanced consumption of natural resources will eventually lead to their exhaustion, as in the case of ceramic materials.

According to the Portuguese Centre of Ceramics and Glass,[1] the Portuguese ceramic industry produced, in 2012 only, 10,000 tons of sanitary ware waste and 35,000 tons of brick waste. Adding to this, there is ceramic waste resulting from construction and demolition operations. So, a large quantity of ceramic waste is produced and just a small quantity is recycled, leading to an enormous waste disposal.

The use of recycled aggregates, namely ceramic, in new structural concrete, is beneficial from the viewpoints of environmental protection and reduction in the consumption of natural resources. However, to entirely embrace the use of recycled aggregates in the production of new concrete, it is necessary to fully understand the performance of this type of concrete.

This research addresses the important environmental problem of how to dispose of the waste generated by the ceramic industry and by construction and demolition operations and analyses the feasibility of incorporating fine aggregates from that waste in concrete production, with respect to mechanical performance. Although some studies discussed below have been performed on concrete with incorporated recycled ceramic aggregates, in most of them only the coarse fraction is involved. As a matter of fact, no studies about concrete with fine sanitary ware aggregates were found. So, this experimental programme intends to fill this gap, contributing to the analysis of the viability of the use of this type of aggregates in structural concrete.

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[1] http://www.ctcv.pt/index_eng.html.

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An additional part of the innovation of this research has to do with keeping constant both following factors (unlike most similar studies published in the literature): (i) Size distribution of the aggregates (when replacing natural aggregates with recycled aggregates this distribution was kept constant in order to avoid difficult-to-interpret changes in almost every relevant property of concrete); (ii) Workability (for practical purposes, concrete mixes with different workability levels may not have the same range of applications and therefore should not be directly compared).

2. Literature review

The literature review showed there is a lack of information regarding the influence of the incorporation of recycled ceramic fine aggregates on the mechanical behaviour of concrete, especially for fine sanitary ware aggregates.

The general features of a few selected experimental researches concerning the properties of concrete with recycled ceramic aggregates analysed in the present article are briefly described next.

Mansur et al. [1] tested four families of concrete mixes, each one defined by a given water/cement ratio and consisting of one conventional concrete (concrete made with natural aggregates only) and one concrete with a 100% replacement ratio of coarse natural aggregates by coarse recycled ceramic aggregates (from crushed clay bricks). The compressive and tensile strengths, the modulus of elasticity, the drying shrinkage and the creep of those concretes were determined.

De Brito et al. [2] tested replacement ratios of 1/3, 2/3 and 3/3 of coarse limestone aggregates by coarse recycled ceramic aggregates (from crushed standard hollow red clay wall bricks from a single batch) to determine the compressive and flexural tensile strengths, the abrasion resistance, and the water absorption by capillarity and immersion of concrete.

Khatib [3] tested replacement ratios of 25%, 50%, 75% and 100% of fine natural aggregates (class M sand) by fine recycled ceramic aggregates (bricks obtained from demolished structures, which were then crushed in the laboratory) to determine the compressive strength, the ultrasonic pulse velocity, the density, the dynamic modulus of elasticity, the shrinkage and the expansion of concrete; he made the same analysis for concrete with fine recycled concrete aggregates.

Senthamarai and Manoharan [4] tested six families of mixes, each one defined by a given water/cement ratio and consisting of one conventional concrete (with no recycled aggregates) and one concrete with a replacement ratio of 100% of coarse natural aggregates by coarse recycled ceramic aggregates (from ceramic electrical insulator industrial wastes) to determine the compressive and tensile strengths and the modulus of elasticity of concrete.

Debieb and Kenai [5] tested replacement ratios of 25%, 50%, 75% and 100% of fine natural aggregates by fine, coarse and both simultaneously, recycled ceramic aggregates (crushed bricks) to determine the compressive and tensile strengths, the modulus of elasticity, the water absorption by capillarity, the water permeability and the shrinkage of concrete.

Gomes and de Brito [6] tested replacement ratios of 25% and 50% of coarse limestone aggregates by coarse recycled ceramic and mortar aggregates (from demolished standard partition walls made of hollow red clay bricks and cement-based renders of previously known characteristics) to determine the compressive and tensile strengths, the modulus of elasticity, the water absorption by capillarity and immersion, and the carbonation and chloride penetration of concrete; they made the same analysis for concrete with coarse recycled concrete aggregates.

López et al. [7] tested replacement ratios of 10%, 20%, 30%, 40% and 50% of fine natural aggregates by fine ceramic aggregates (obtained from recovered floor and wall tiles) to determine the compressive and tensile strengths of concrete.

Guerra et al. [8] tested replacement ratios of 3%, 5%, 7%, 9% of coarse natural aggregates by coarse ceramic aggregates (obtained from industrial rejects of sanitary ware) to determine the compressive and tensile strengths of concrete.

Medina et al. [9] tested replacement ratios of 15%, 20% and 25% of coarse natural aggregates by coarse ceramic aggregates (obtained from industrial rejects of sanitary ware) to determine the compressive and tensile strengths of concrete.

The results obtained by these authors, regarding both aggregates' and concrete's properties, are described next. There are other studies on the use of ceramic recycled aggregates in the production of concrete which are focused on durability aspects (e.g. Correia et al. [10], Senthamarai et al. [11], Kenai and Debieb [12], Medina et al. [13]), outside the scope of our paper.

2.1. Aggregates' properties

Mansur et al. [1] stated that coarse recycled ceramic aggregates show higher water absorption when compared to coarse natural aggregates. The values reported are 6.1% and 0.7%, respectively. Regarding the bulk density, they reported that this property is lower for the coarse recycled brick aggregates (2.21 kg/dm^3) than for coarse natural aggregates (2.66 kg/dm^3).

According to de Brito et al. [2], coarse recycled ceramic aggregates have high water absorption (12.0%). They stated that this property is probably the greatest limitation to the use of this type of aggregates in the production of concrete, without loss in mechanical strength, workability or durability. They also reported a lower bulk density for recycled brick aggregates (1159 kg/m^3) than for coarse natural aggregates (1542 kg/m^3).

Khatib [3] achieved water absorption of 14.8% for fine recycled ceramic aggregates, a significantly higher value than the one obtained for natural aggregates (0.8%). He obtained lower bulk density for fine recycled brick aggregates (2050 kg/m^3) than for coarse natural aggregates (2650 kg/m^3) and fine recycled concrete aggregates (2340 kg/m^3).

Senthamarai and Manoharan [4] reported that ceramic waste has lower water absorption than natural aggregates. The values reported are 0.7% and 1.2%, respectively. Regarding the bulk density, they obtained lower bulk density for coarse recycled ceramic aggregates (2.5 kg/dm^3) than for coarse natural aggregates (2.7 kg/dm^3).

Debieb and Kenai [5] reported water absorption of 14.0% for fine recycled ceramic aggregates and of 1.0% for natural aggregates. They concluded that the higher water absorption of crushed brick aggregates is due to their high porosity. The authors reported a lower bulk density for fine recycled brick aggregates (2496 kg/m^3) than for fine natural aggregates (2978 kg/m^3).

Gomes and de Brito [6] obtained 16.3% for the water absorption of coarse recycled ceramic and mortar aggregates whereas a value of 2.3% was reported for coarse natural aggregates. The values of bulk density were 2160 kg/m^3 for coarse recycled aggregates and 2616 kg/m^3 for coarse natural aggregates.

López et al. [7] and Guerra et al. [8] stated that, despite being similar, the bulk density of natural aggregates is higher than the one of recycled ceramic aggregates.

Medina et al. [9] stated that coarse sanitary ware aggregates has higher water absorption than coarse natural aggregates. However, the results reported, respectively 0.6% and 0.2%, showed that these properties are very similar for recycled and natural aggregates. Regarding bulk density, they reported that this property is higher for coarse natural aggregates (2630 kg/m^3) than for coarse recycled ceramic aggregates (2390 kg/m^3).