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Permeability properties of self-compacting concrete with coarse recycled aggregates

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HIGHLIGHTS

- Permeability properties of SCC with 20%, 40% and 100% of coarse recycled aggregates were studied.
- According to the air permeability method applied, the SCC mixtures are considered airtight.
- The recycled coarse aggregate incorporation did not significantly affect the water permeability.
- Water capillarity coefficient is slightly decreased when 100% of coarse recycled aggregate is used.
- Water penetration depth is reduced with the increasing of the recycled aggregate in SCC.

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ABSTRACT

This article addresses to the issue of durability related properties of self-compacting concrete (SCC) with the use of coarse recycled aggregates obtained from demolition of concrete structures. The objective was to verify the influence of recycled aggregates on SCC permeability properties. For this purpose four different types of concrete mixes were produced, one of them used as reference with natural coarse aggregates and the others prepared with 20%, 40% and 100% of recycled coarse aggregates. The properties related to the durability of SCC, as air and water permeability and capillary absorption were determined on concrete specimens with and without preconditioning. The results from fresh and hardened concrete properties lead to the conclusion that it is viable to replace natural coarse aggregates by recycled coarse aggregates since the present research does not show any detrimental to the SCC permeability properties.

1. Introduction

The potential use of recycled aggregates in the self-compacting concrete composition increases the ecological value and partly solves the issues of waste disposal sites generated by construction and demolition of structures. In the last two decades, the properties of normal concrete with recycled aggregates were extensively studied [1–6]. From these studies it is known that, comparing with the natural aggregates, the recycled aggregates density is lower and the water absorption is higher. These differences are due to the incrustation of cement paste on the recycled aggregates surfaces. Thus, the increased of the content of recycled aggregates in normal vibrated concrete, both coarse and fine, causes a loss of the mechanical properties. Furthermore, the coarse recycled aggregate shows a greater negative influence than the recycled fine aggregate [7–9]. Also the durability of the recycled aggregates concrete can be strongly affected by the porosity and the high water absorption of the recycled aggregates [10]. The cause is usually associated to the fact that, to reach the same workability, the water demand to produce concrete with recycled aggregates is higher compared to natural aggregates, leading to the increase of the water/cement ratio, thereby, also increasing the porosity of the cementing matrix [8]. The use of water-reducing admixtures may minimize this effect, since they may provide workability to the mixture without increasing the water/cement ratio. The relatively poorer durability properties of recycled aggregates concrete can be adequately compensated by the use of fly ash, either as a replacement of cement or addition, in the concrete mix design [7].

When compared with normal vibrated concrete, the SCC mixtures usually exhibit a better durability potential, even when the mixtures have larger water contents. This is due to increased fines content in SCC, that refines the microstructure and hence the pore network of the material [11]. It is the capillary porosity that greatly affects the permeability of concrete [12]. The permeability of SCC is typically lower than that of ordinary concrete. This is mostly attributed to the superior flow properties, dense microstructure and refined pore. Good flow properties result in superb packing condition due to better consolidation, and thus contribute to reduce the permeability of concrete [13]. So, the SCC mixtures

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could be considered as a good receptor of recycled aggregates. In fact, according to Grdic et al. [14], when coarse recycled aggregate of good quality is used, the total replacement of the natural coarse aggregate by recycled aggregate from demolition of concrete structures has a marginal effect on the compressive and tensile strength reduction. The authors found a reduction of 9% for compressive strength and 13% for tensile strength, at 28 days. Despite the relatively high water absorption of coarse recycled aggregates, they also observed a marginal increasing of recycled aggregates SCC water absorption of 0.4% when compared with control concrete.

In Portugal, the most used demolition processes is based on the simultaneous destruction of the entire building, which results in waste rather heterogeneous. Taking into account the construction demolition wastes heterogeneity, the Portuguese recommendation E 471/2009 [15] limit the incorporation of recycled coarse aggregate in structural concrete production. The replacement of natural aggregates by recycled aggregates is limited by this document in order to avoid large variations of the elastic modulus, creep, shrinkage and durability. The limit is 25% of aggregates composed of 90% minimum of particles from concrete demolition (ARB1) that can be used up to concrete strength class C40/50. When the recycled aggregates composition has a value between 90% and 70% of particles from concrete demolition (ARB2), this can be used up to concrete class C35/45. Regarding that this recommendation was elaborated for normal concrete and there are few studies about SCC with recycled aggregates, hence, in this work, both physical and mechanical properties of SCC specimens have been studied. The results of this research, indeed may serve to guide practical recommendations for recycled aggregates use in SCC mixtures.

A piece of data which is important for the design of SCC mixture with recycled coarse aggregates is the quantity of water absorbed by the recycled aggregate, which is always higher in comparison to the same fraction of the natural coarse aggregate. Normally, the water requirement of normal concrete with recycled aggregates is increased, resulting in significant high total water/cement ratio (W/C), regardless of the use of water-reducing admixtures [16]. The amount of water absorbed by the aggregate was taken into account separately by some researchers [17], in addition to its wetness before mixing and the free water that formed part of the mixture. Other researchers [16,18] consider the total water content for W/C ratio, because it is impossible to separate the effective water content (water absorbed by recycled aggregate and mixing water) from the total water content in the fresh concrete, especially in the case of recycled sand. In the case of SCC with recycled aggregate, Grdic et al. [14] observed small variations in the quantity of water for SCC mixtures to achieve the equal consistency. From the point of view of the concrete durability properties, it is believed that an analogous advantage could result with the use of dry recycled coarse aggregate, since it was observed an highest porosity of the concrete ITZ microstructure around the pre-soaked lightweight aggregate compared with the dry aggregate [19]. Some authors [20,21] argue that this difference on ITZ microstructure leads to a slightly higher capillary suction or water absorption of concrete when pre-soaked lightweight aggregates are used.

Since one of the goals of this study was to identify the influence of coarse recycled aggregates in SCC water permeability, the total water content was considered in the mixtures water/cement ratio.

2. Materials and methods

2.1. Materials

A Portland cement type CEM I 42.5R with density of 3140 kg/m^3 and a mineral addition of limestone powder with density of 2720 kg/m^3 were used as powder materials in the SCC mixtures. The granular skeleton for the fine and the coarse aggregates were defined taking into account the grading reference curves proposed by Nepomuceno and Pereira-de-Oliveira [22]. The fine aggregates mix was done with the proportion in absolute volume being 82% for natural sand (S1) and 18% for natural sand (S2). Fig. 1 shows the resultant grading curve of fine aggregates mix, which was kept constant for all the mixtures produced. Two natural coarse aggregates of crushed granite, CA1 and CA2, were combined on the proportions in absolute volume of 68% (CA1) and 32% (CA2). Two coarse recycled aggregates, RA1 and RA2, classified according E471 as ARB1 aggregates, were sourced from a local construction and demolition waste recycling facility and were combined on proportions in absolute volume of 90% (RA1) and 10% (RA2). Table 1 shows the individual aggregate characteristics. The natural and recycled coarse aggregates have the same maximum size with a very slightly difference in the fineness modulus. It can be also observed in Fig. 1 that the grading curves of coarse aggregates mix were quite similar. Only a slight deviation from general tendency occurs on the grading curve with 100% of recycled coarse aggregate. It means that the particle size of recycled aggregates is slightly higher than other coarse aggregates compositions. These similar coarse aggregates grading curves were used to enable replacement without changing significantly the concrete granular skeleton.

A modified polycarboxylate based superplasticizer, with a density of 1050 kg/m^3, was used to help the concrete mixtures attain self-compacting rheological desired characteristics.

2.2. Mix design of self-compacting concrete mixtures

The methodology of SCC mix design applied in this study was developed by Nepomuceno et al. [23,24] and considers the concrete as a two phase material: the matrix (mortar phase) and the incorporation of coarse aggregates on the matrix (concrete phase). The design parameters of the mortar phase should be defined to obtain simultaneously the desired fresh and hardened properties of self-compacting concrete. For each of these two phases, an adequate reference curve of granular skeleton was defined. Thus the general approach consists of the following stages: selection of the materials; definition of the reference grading curves for the fine and coarse aggregates; studies in mortars and studies on concretes.

At the first stage, the powder materials (cement and additions) should be selected taking into account the level of compressive strength to achieve on hardened concrete. The fine and coarse aggregates should have adequate grading curves to enable the best approximation to the proposed reference curves. Preferably, a modified polycarboxylate based superplasticizer should be selected. On the second stage, the unit volume percentage of fine aggregates and the unit volume percentage of coarse aggregates must be determined separately.

The third stage corresponds to the definition of the adequate parameters for the mortar phase, that includes the unit volume percentage of each powder material in the total volume of the blend of powder materials (Vp), unit volume percentage of each fine aggregate in the total volume of fine aggregates (Vs), as previously defined on the second stage, Vp/Vs (ratio in absolute volume between powder materials and fine aggregates), Vw/Vp (ratio in absolute volume between water and powder materials) and Sp/p% (ratio in percentage between the amounts in mass of superplasticizer and powder materials). For the mortar phase, an interval of variation was defined for the parameters that characterize the flow behavior of mortars (G_m, R_m), in such a way that it leads to self-compacting concrete. The G_m parameter is measured on mortar spread test and R_m is measured on a v-funnel test. Adequate correlations between concrete compressive strength and water to cement ratio are proposed for two types of cements. Since the water to cement ratio is the same for concrete and mortar phases, this parameter can be defined on the mortar phase design. The Vp/Vs ratio should be defined from 0.6 to 0.8, but a value between 0.7 and 0.8 is recommended. Correlations are proposed to estimate the percentage of cement replacement by the addition for different combinations of powder materials as a function of the Vp/Vs ratio and the water to cement ratio previously established. The Vw/Vp and the Sp/p% ratios can be also estimated for preliminary tests based on proposed correlations. However, since the superplasticizer can differ from different suppliers, the water content Vw/Vp and the superplasticizer dosage Sp/p% have to be experimentally adjusted until the mortar presents the adequate flow properties, evaluated in terms of relative spread area (G_m) and the relative flow velocity (R_m). Usually only superplasticizer dosage needs to be adjusted.

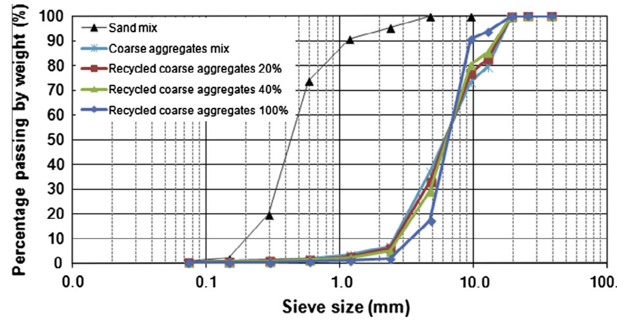

Fig. 1. Grading curves of aggregates mix.