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Mitigation of the negative effects of recycled aggregate water absorption in concrete technology

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HIGHLIGHTS

- A staged-mixing procedure was optimized to regulate the ITZ water flow.
- It is an economical approach to improve RAC, which can be industrially used.
- It allows good workability levels, of RAC, during 3 h.
- A shrinkage test showed that it reduces the sensibility of early age cracking.
- RA properties are inferior to NA properties, reducing the concrete performance.

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ABSTRACT

The widespread use of natural aggregates in construction activities, together with the global population increase, gave rise to a depletion of this natural resource and to progressive increase of its transport distances. On the other hand, the construction and demolition wastes (C&DW) resulting from the construction activities are often deposited in landfills and city outskirts, causing environmental and social problems, such as erosion, deforestation, water contamination and human conflicts. The reuse of C&DW in concrete preparation would be a good solution for both problems. Recycled aggregates show, however, high water absorption due to porosity. At saturation, water flows from the inside to the engaging cement paste matrix and at dryness the opposite process occurs. This water flow breaks the aggregate-cement paste bonds and increases the W/C ratio in the interfacial transition zone, this degrades the fresh and hardened concrete properties.

In this work a staged mixing method based on the aggregate water absorption over time was developed. A staged mixing procedure was optimized to regulate the water flow and manufacture concrete, using recycled aggregates, with levels of workability, strength and shrinkage equivalent to those of conventional concrete. The physical, mechanical and geometrical properties of the aggregates were related to the properties of concrete in its fresh and hardened state. Three types of commercial recycled aggregates were evaluated. Two types of natural aggregates were also studied for comparison purposes.

1. Introduction

Construction activity is a high consuming sector, accounting for the depletion of more than 40% of the energy and more than 50% of natural resources [1,2]. The current consumption of natural aggregates per year and per person is 3–5 tons [3]. The global use of natural aggregate will reach 26–44 Giga Tons per year in 2030 [3]. Construction is also responsible for the production of 50% of the global waste [1]. Recycling of C&DW has been pointed by several governments as a solution to face these problems. Recycling of C&DW is, however, a complex challenge due to the high heterogeneity associated to these materials. Recycled aggregates (RA), prepared of C&DW, generally show lower quality properties than natural aggregates (NA). Studies to define the conditions for their advantageous incorporation in concrete are therefore required [4]. Several works reported that the major problem of RA is their high water absorption capacity due to the high porosity of these materials [5–8]. If the aggregates origin is crushed concrete, the water absorption capacity depends on the porosity of the mortar, attached to the natural stone [5]. The water absorption capacity ranges from 3 to 13%, depending if the old mortar comes from low or high strength concrete, respectively [9,10]. RA obtained from ceramic C&DW can absorb more than 30% of water [10].

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The major challenge of concrete technology is the preparation of concrete showing high performance in both, fresh and hardened states. It is well known that improving the workability reduces the hardened concrete properties and vice versa. The high water absorption of RA makes this optimization even more difficult. Water addition to the mixes results in a higher W/C ratio, increasing the average distance between the binder particles, leading to high concrete microstructural porosity. Moreover, when the aggregates are pre-saturated with water, a water flow takes place from the inside to the involving cement paste matrix. This flow breaks the bonds [5] and leads to a higher W/C ratio in the interfacial transition zone (ITZ), which weakens the strength. It has been reported that the optimum moisture state of RA should be about 80% [11]. This means that with a moisture state of about 80% the highest mechanical properties were reached, keeping reasonable workability levels [7,11].

This work reports a performance evaluation of different concrete mixtures, which were prepared using distinct RA. All aggregates, including the control NA, were pre-wetted with water to its optimum moisture state, before cement addition. Water absorption tests over time allowed the calculation of the extra water and absorption time, required to reach the optimum moisture state. Based on the obtained results, a staged-mixing approach [5] was followed and optimized to obtain the moisture state of the aggregates, before adding the binder to the mixture. After mixing, a slump test over time proved that there was no significant ITZ water flow and consequently no negative effects on the concrete microstructure. Several other aggregate properties were tested and related to the concrete performance in its fresh and hardened state.

2. State-of-the-art

The fresh state properties of recycled aggregate concrete (RAC) depends on the way how water absorption is compensated. When extra water is added to the mixture, the workability of RAC can be better than that of ordinary concrete (OC) at early stages, in about 50% [7]. However, the fast water absorption of RA quickly reduces the workability [7]. If no extra water or superplasticizer is added, the workability of RAC is much lower than that of OC for the same W/C ratio [12], e.g., Mas et al. [13] observed a slump decrease of about 66% by a substitution of only 50% RA. Even if pre-saturating the RA is followed, workability of RAC can be lower, due to the major shape indexes of this kind of aggregates. RAC usually shows a lower modulus of elasticity [14,15] and a higher poisons coefficient [16] in comparison with OC [14,15]. The modulus of elasticity values can reduce in 40–50% and the poisons coefficient can increase 0.02–0.03, in comparison to that of OC. These properties have been related to a lower stiffness of RA. It is known that the percentage and stiffness of the aggregates are the main factors determining the stiffness of the concrete. The compressive strength of RAC is generally lower than that of OC and this reduction depends on the type and content of recycled aggregate [6,16]. It is reported that the compressive strength decrease is proportional to the content of ceramic particles [17] but it also depends on the old mortar, attached to the natural stones, and the ITZ volume increase. The lower compressive strength is usually linked to the water absorption process explained above [16]. For example Mas et al. [13] prepared RAC with mixed RA, with percentages of ceramics between 18% and 25%, percentages of concrete plus unbound aggregates between 69% and 80%. They made a low-strength mixture (18 MPA), with a slump between 6 and 9 cm and a 0.65 W/C ratio, the lower RAC slump was compensated with superplasticizer. By a substitution percentage of 75% RA they obtained a strength decrease of 21%. They also prepared a medium-strength concrete (25 MPa), with a slump between 10 and 15 cm and a high W/C ratio of 0.72, the low RAC workability was compensated with Superplasticizer. In this mixture, by a substitution percentage of only 40% RA, they obtained a strength decrease of 13%. They even executed a high-strength mixture (65 MPa), with a 0.45 W/C ratio and a very low slump between 0 and 2 cm. For a substitution percentage of only 40% RA, they had a very high strength decrease of 49%. Most studies reporting of RAC indicate that, tensile strength is higher or equal than that of OC [11,18,19], other studies even report a lower tensile strength of RAC [13]. For example, Exteberria et al. [11] obtained tensile strengths of +6,0; +19,4% and −1,8% by substitution percentages of 25%; 50% and 100% respectively, whereas Mas et al. [13] obtained decreases of 20%; 13% and 30%, for the above described mixes. The good tensile-strength values of RAC have been associated to a smoother surface, given by the attached mortar, which enables the formation of stronger bond strengths [20]. An alternative explanation is giving by the stiffness. The lower stiffness of RA confers a smaller degree of internal restraint, which attenuates the residual tensile stresses and microcracking perpendicular to the aggregates. Results of shrinkage tests are scarce. Most papers report high shrinkage strains of RAC, caused by higher water absorption [9] and percentage of fines, typical for this type of aggregates [21]. For example, Katz [9] produced RAC with "crushed concrete", were he obtained drying shrinkage increases between 160% and 196%, compared with the reference mix. Some papers report different trends over time, by comparing the shrinkage strain of OC and RAC [22]. Debieb and Kenai [22] produced RAC with "crushed brick", a slump between 60 and 70 mm and compressive strength lower than 25 MPa, the aggregates were pre-saturated during 24 h. They obtained a shrinkage reduction of about 100 μm/m in the first 28 days and a shrinkage increase of about 300 μm/m after 90 days, comparing a 100% RAC mix with a the reference mix. No works about early age cracking are reported and very few results of creep [9] can be found in the literature. However these properties depend on the modulus of elasticity and shrinkage of the concrete. All parameters used to evaluate the durability of concrete are worse in RAC than in OC, due to the porosity of these aggregates. RAC is more permeable (1,6 times higher penetration depth) [22], has a higher water absorption (about 6% after 90 min) [22–24], a lower electric resistivity [25], a greater (1,3–2,5 times) carbonation depth [26] and a lower chlorides resistance than OC [25].

3. Characterization of aggregates

The aggregates were provided by the recycling plant "Multi-Triagem" which collects and manages the C&DW from the SW Algarve, Portugal. Primary reduction of the rubble was made with a shear. Then a primary and secondary crushing was performed using a portable Impact Crusher, fitted with two hammers and a magnetic separator. Finally the aggregates were sieved to obtain the desired fraction. In this work 5 types of coarse aggregates, labeled RA1, RA2, RA3, NA1 and NA2 and two types of fine aggregates, labeled RS and CS, were analyzed. The NA and CS are of crushed limestone and RS is a fine limestone river sand.

3.1. Aggregate test Program

- Constituents of the coarse RA examined according to EN 933-11 [27].
- Particle size distribution according to EN 933-1 [28].
- Size class according to EN 12620 [29].
- Methylene blue according to EN 933-9 [30].
- Sand equivalent according to EN 933-8 [31].