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Recycled concrete aggregate attrition during mixing new concrete

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HIGHLIGHTS

- Recycled concrete aggregate (RCA) attrition during mixing was studied in two pilot mixers.
- Mixing parameters and initial RCA properties influenced the breakage rate.
- Both attrition and cleavage mechanisms influenced the aggregate degradation.
- Angularity of the RCA was reduced by the mixing.

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ABSTRACT

In this work, the recycled concrete aggregate (RCA) friability during mixing was studied in order to better understand the evolution of this material during the mixing process and improve the recycled aggregate concrete mix-design. The influence of some important materials and process parameters was evaluated: initial abrasion resistance and initial moisture of the aggregates, mixer geometry, mixing time and mixing speed. To assess the mixing process effect on the recycled concrete aggregate friability, three different aspects were evaluated; the mass loss (mass of fraction inferior to 2.5 mm) the grading and the angularity evolutions with mixing time of an initially 10–14 mm aggregate. Tests were carried out in two types of laboratory concrete mixers, a planetary 30 l mixer from Skako and an intensive 5 l Erich mixer. The results revealed that in normal laboratory setting of the mixers configuration, the mass loss for natural aggregate (NA) is less than 1% of the coarse aggregate. This percentage reach 3% for good quality recycled concrete aggregate (MDE value of 21) and 5% for lower quality recycled concrete aggregate (MDE value of 27). The mass loss directly depends on the mixing parameters and the degradation of the recycled concrete aggregate drastically increased when the mixing speed was raised to 500 RPM. By analyzing the grading evolution during mixing, it was shown that both cleavage (creation of intermediate size particles) and attrition (creation of small particles) mechanisms influenced the aggregate degradation. However, the configuration of mixing significantly influenced the proportion of attrition and cleavage mechanisms. To complete this work, the angularity evolution showed that recycled concrete aggregate surface becomes smoother and the edges more rounded after mixing.

1. Introduction

Recycled concrete aggregates (RCA) are widely used in road constructions, but a possibility that deserves to be more exploited is certainly their reuse as a substitute for natural aggregate (NA) in concrete. This practice is often hampered by the lack of technical confidence in the practical use. It is largely recognized that the high porosity of the hardened cement mortar attached to the RCA particles [1] alters aggregate water absorption and density [2–4], and it could have adverse effects on the performance of the second generation of concrete. Some authors have determined the residual mortar content (RMC) in RCA using different techniques. Using a heat treatment method, Sánchez de Juan [5] determined that the RMC varies from 33 to 55% for 4/8 mm RCA and from 23 to 44% for 8/16 mm RCA. Abbas [6] obtained that 20% of the 4.75/9.5 mm fraction particles are constituted between 95 and 100% of residual mortar and more than 50% of the particles in 4.75/19 mm fraction are constituted by less than 15% of the residual mortar. Hua Duan [4] also quantified the RMC depending on different sources and preparation methods. He observed that the RMC varies between 14 and 63% for a 5/10 mm aggregate and between 24 and 61% for a 10/20 mm. Belin et al. [7] showed a decrease of RMC with the water to cement ratio of the parent concrete. In his study, Gonçalves [8] summarized the different

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specifications regarding RCA composition of the main consuming countries.

Several researchers have shown that the RCA are more sensitive to fragmentation than the natural aggregates. For instance, Barbudo [9] observed a typical ratio of 2 between the Los Angeles' values of RCA and natural aggregates. Zega et al. [10] showed similar results and demonstrated the influence of the abrasion characteristics of the original natural aggregates: the lesser the abrasion loss of the original natural aggregate, the higher the increase of the abrasion loss in the subsequent RCA. They also showed an increase of the Los Angeles value with the RMC. Also, Dao et al. [11] showed that the Micro-Deval (MDE) value of the RCA is related to the compressive strength of original concrete and to the MDE of the original aggregate, but their study showed that most generally the Micro-Deval value of the RCA is significantly higher than the MDE of the original aggregate. In addition, it has to be noted that the RMC depends on the history of recycling of RCA, i.e. the crushing sequences [12]. Moreover, the kinetics of fracture depends on the degree of liberation of the RCA particles [13]. As a consequence, the sensitivity of RCA to experimental manipulations is much higher than for natural aggregates. Schouenborg et al. [14] illustrated the increase of amount of material passing the 8 mm sieve with the energy of sieving RCA. Also, for a mechanical sieving during 10 min, the amount of passing was 7.9% for a RCA obtained from a 26.5 MPa concrete, 9.5% for a RCA obtained from a 41 MPa concrete and only 0.2% for a natural aggregate. Quattrone et al. [15] shown that the mass of the recycled aggregates decreases when toweling to obtain the saturated surface dry state, during the standard water absorption test procedure.

During industrial processing particles can suffer different breakage mechanisms [16]. Breakage can arise from a number of interactions, including particle impacts onto walls and solid objects in motion such as hammers or blades, or collisions between particles in free space. A granulometric evolution of aggregates under prolonged mixing was observed by González Ortega et al. [17] for concrete produced with barite aggregate which is a natural aggregate characterized by a low resistance. The authors measured the grading before and after the mixing and observed a higher amount of fine particles for aggregates with lower resistance to fragmentation (Los Angeles value of 20 for the reference natural aggregate vs 40 for barite). The increase of the finer particles content was greater for initially moistened barite aggregate. The authors highlighted the high amount of particles below 0.125 mm created.

The operation of mixing the constituents of concrete yields stresses which are expected to produce the separation of the attached mortar from the original natural aggregate and alter the original size and angularity of the RCA. While the effect of the RMC on the increase in water absorption capacity of RCA is largely considered in designing new generation of concrete, the importance of breakage during the mixing process of the degraded RCA abrasion/fragmentation characteristics compared with natural aggregates has not so far been analyzed in detail for RCA. However, combined with the higher porosity and its larger variability, the generation of fine particles during mixing could contribute to explain the difficulty to control the slump and workability loss when producing recycled aggregate concrete [18,19].

The objective of this paper is to provide information on the RCA friability during mixing, in order to improve the control of the mixing process and the design of recycled aggregate concrete. Tests were performed at laboratory scale. The influence of significant materials and process parameters is evaluated: residual mortar content and initial moisture of the aggregates, mixer geometry, mixing time and mixing speed. The mixing process effect is assessed throughout the mass loss, the grading and angularity evolutions of coarse natural aggregates and RCA.

2. Experimental method

2.1. Materials and mix-design

Tests were carried out on a concrete mixture composed of 10/14 aggregate, natural 0/2.5 silico-calcareous sand from Pilier, France, cement CEMI 52.5 from Lafarge Ciments (St Pierre La Cour, France). The most significant physical properties of the materials employed are presented in Table 1 (more detailed properties in Annex A). In all tests, the cement content was 350 kg/m^3, the sand to gravel ratio was 1.0 and the water to cement ratio 0.59. The water dosage was chosen to obtain an initial slump (NF EN 12350-2) [20] between 100 and 150 mm when fixing a mixing time of 300 s (maximum mixing time employed) and using natural coarse aggregates.

The tests compare the behavior of three types of 10/14 coarse aggregates: natural gneiss aggregates from Pontreaux (France) and two RCA differentiated by the Micro-Deval abrasion value (MDE, NF EN 1097-1) [21]. The RCA used in this study are commercially produced by the "Gonesse Recycling Centre" located in France; these aggregates are composed of 99% recycled concrete and 1% of inert materials.

The higher MDE value RCA are obtained by sorting by density the main RCA feed (the material provided by the recycling plant), using a laboratory water jigging technique [22]. The jig box was filled with RCA and once the separation process completed, the material located in the upper third of the container was recovered and used for the tests. The material recovered has then a lower density and a lower abrasion resistance than the initial RCA material introduced; the material of the bottom is discarded.

The abrasion resistance of the aggregates was determined by the Micro Deval test, following the French standards (NF EN 1097-1) [21]. The natural coarse aggregate had a MDE value of 6 (MDE-6), the RCA directly provided by the recycling plant had a MDE value of 21 (MDE-21) and the less dense RCA had a MDE value of 27 (MDE-27).

To perform the different tests, materials were used in Air Dry ("AD") state or in a Saturated Surface Dry ("SSD") state. To obtain the SSD aggregate, the RCA were immersed in water during 72 h and drained 2 h before the mixing test.

2.2. Equipment

2.2.1. Mixers

The tests were conducted in two laboratory pan mixers (Fig. 1): a planetary 30 l mixer from Skako and a 5 l Erich mixer. Both mixers have one agitator and one scraper. In the planetary mixing system a one blade agitator rotates with a nominal speed of 97 rotations per minute (RPM) around an axis turning, together with the scraper, at a nominal speed of 36 RPM. In this kind of mixer the vessel is fixed, the scraper has a circular movement and the blade a planetary movement as shown in Fig. 1a. The Eirich mixer has inclined rotating vessel which typically runs between 45 and 90 RPM, whereas the agitator can have rotation speeds between 50 and 700 RPM. We can have for this kind of mixer two different configurations depending on the sense of the vessel and agitator rotation; a co-current configuration (Fig. 1b) where the vessel and agitator rotate in the same direction and a counter-current configuration (Fig. 1c) where the vessel and agitator rotate in opposite direction. We have to note that the vessel always rotates in the clockwise direction.

In this study, all tests were carried out with the nominal configuration of the Skako mixer. The Eirich mixer was set in co-current and in counter current configurations with mixing speeds of 150, 300 and 500 RPM. The vessel turned at 45 RPM in all cases. The