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Heterogeneity of recycled concrete aggregates, an intrinsic variability

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HIGHLIGHTS

- Heterogeneity of Recycled concrete aggregates (RCA) is one of their critical properties.
- RCA sorted by density were characterized.
- A given granular class of RCA can exhibit very large physical heterogeneities.
- Heterogeneity of RCA mainly depends on their cement paste content.
- Water jig is a very efficient method to sort RCA by density.

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ABSTRACT

Recycled concrete aggregates (RCA) are composed of two different materials: natural aggregate and attached cement paste. It is generally admitted that finer the RCA greater is the quantity of adhered cement paste. In this study it is shown that for a given granular class, very large disparities may be present in the adhered cement paste content, which could generate dispersion of the results of characterization tests of RCA. The heterogeneity of a narrow granular class of coarse RCA (6.3/10 mm) was investigated by sorting samples according to their densities using a water jig. The water jig sorting was essentially a separation by density and not by size. It was shown that the average water absorption after an immersion in water during 24 h was about 5% for a representative sample of the feed RCA, before sorting tests, while for the homogenous specimens separated by density, the water absorption ranged from 2% to 9%. The distribution of the water absorption in a sample of 120 kg of RCA was well estimated by a log-normal distribution. This intrinsic heterogeneity of RCA implies being able to have representative samples with sufficient accuracy, not only concerning the size but also the mineral composition of grains in the stockpiles of RCA. So, after discussing the results of this study, water jig appeared to be an efficient tool to separate RCA and obtain representative samples for their characterization.

1. Introduction

Many countries have made great efforts to deal with large quantities of construction and demolition wastes (CDW) in order to reintroduce them into the construction life cycle. However, the reuse of these wastes to produce new concrete has not been widely adopted yet, and landfill is still the main solution for removing these materials [1,2]. On the other hand, different studies have been conducted to develop concrete production with recycled concrete aggregates (RCA) that comply with applicable codes and standards [3–19]. Until now, only a small percentage of natural aggregates were replaced by these materials to formulate concrete. The difficulty in the use of RCA in new concrete is related to their high water absorption and its temporal heterogeneity. Due to their high porosity [5,11], RCA absorb part of the mixing water which may reduce concrete workability unless the absorbed water is taken in account in the mix design. A poor estimation of the water absorption coefficient (WA) of RCA leads to inadequate effective water for the recycled concrete, the latter induces poor mechanical properties (excess in the mixing water) or poor workability of recycled concretes (lack of water). Pre-saturation of RCA before mixing could appear as a potential technical solution. However, pre-saturation before mixing is a complex task that is most generally not applied in recycled concrete manufacturing. Therefore, better knowledge of in-situ RCA water absorption capacity is necessary.

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More generally, sophisticated characterization (mineral composition, particle size distribution, particle shape, abrasion, density, water absorption and cement mortar content) must be carried out to get a better understanding of the effects of RCA on recycled concrete production and performance [20–24]. Thus, the first step of characterization is to extract a representative sample and determine various properties according to the intended recycling paths [25]. Natural aggregates may present heterogeneities, but the procedures described in European standards for sampling and characterization make it possible to produce materials that are sufficiently consistent for the purposes of construction. On the other hand, RCA are composed of natural aggregates but also of hardened cement paste and other impurities that are not homogeneously distributed in the different granular classes. Hence RCA have a much significant heterogeneity compared to natural aggregates.

Therefore, the heterogeneity of recycled concrete aggregates limits their use due to the uncertainty in their expected behavior [13,14]. Indeed, a wide dispersion of results can be observed in the literature, mainly caused by the different sources and quality of original concretes that are recycled [15–18]. These results highlighted the heterogeneity and the inaccurate characterization measurement of RCA and confirmed the necessity to control their properties for different applications [13,19].

It was already demonstrated that the density increases and the adhered cement paste content decreases with the size fraction of the crushed concrete [26–28]. It was also shown that, in situ, crushed concrete obtained from CDW is always mixed with other crushed materials like brick, asphalt, gypsum, glass and so on. In the literature, jigs were proposed to concentrate the concrete particles and/or to diminish the impurities of a mixed recycled aggregate as a result of a density sorting [29–34].

The objective of this paper is to show that even in a given granular class of well controlled industrially manufactured coarse RCA, large disparities may be present in the adhered cement paste content, generating dispersion in the properties of the RCA. A laboratory water jig was used to sort crushed concrete aggregates with different densities in three generations. Homogeneous density samples of RCA were characterized in order to determine water absorption, granular size distribution, densities, porosity and cement paste content, to assess their statistical distribution in the original material.

2. Experimental method

2.1. Materials

6.3/10 mm RCA sourced from the "Gonesse Recycling Platform" located in France and composed of 99% recycled concrete and 1% of other inert materials were used in this study. A narrow granular fraction was chosen in order to emphasize the differences in density rather than the differences in particle size. Main physical properties of the RCA employed were determined according to the NF EN 1097-6 standard. The average of the results of 4 tests on 4 samples of 1–2 kg each and the corresponding standard deviation were the following:

- Water absorption coefficient (WA) 4.88 ± 0.11%
- Real dried density in water (ρ_{rd}) (NF EN 1097-6) 2.31 ± 0.01 g/cm^3
- Absolute density in water (ρ_a) (NF EN 1097-6) 2.60 ± 0.01 g/cm^3.

2.2. Water jig

The sorting of RCA was conducted in a batch scale water jig, model Alljig® S 400 from AllMineral with a capacity of approximately 20 kg per batch (Fig. 1). The total mass studied was about 120 kg. The complete jigging device consists of a separating chamber supported on a perforated plate (Ø = 1 mm), which is allocated on a tank containing water, which in turn is pulsed into the jig container by means of an air flow controlled by a rotary piston valve and a knife gate valve. Thus, the jigging stroke and the frequency of pulsation can be regulated by adjusting the valves. During the tests, the particle bed within the jig container is submitted to numerous cycles of expansion and contraction by means of the pulse of water, which creates the conditions for particles of different densities to move with different vertical velocities. The net result is the bed stratification according to the particles density and/or particle size distribution with the concentration of the lighter fraction in the upper layers and the denser fraction in the lower layers of the bed. The separating chamber was assembled by overlying 6 layers of PlexiGlass (400 × 400 × 25 mm), so that after each test, the bed can be vertically sliced in 6 different fractions. For all test cases, the pulse frequency, bed expansion and jigging time were kept constant at 90 RPM (rotations per minute), 5 cm and 120 s, respectively.

2.3. Characterization of RCA

2.3.1. Water absorption WA

The water absorption coefficient determined after 24 h of immersion in water, noted WA, was measured by the pycnometer method according to the European NF EN 1097-6 standard. It involves immersing a dry sample in a pycnometer filled with water to measure the sample mass increase due to the penetration of water in the pores. The WA was determined using Eq. (1)

$$WA = (M_{SSD} - M_{OD})/M_{OD} \quad (1)$$

where M_{SSD} is the Saturated Surface Dry (SSD) mass after 24 h of saturation in water, and M_{OD} is 48 h-oven-dry mass (at 75 ± 5 °C) of the sample after the test.

The drying temperature was fixed to 75 °C instead of 110 °C in order to avoid a loss of chemically bound water from adhered cement paste [35].

Fig. 1. Water jig, AllMineral Company, model Alljig S 400/600X400®.