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Structural concrete with simultaneous incorporation of fine and coarse recycled concrete aggregates: Mechanical, durability and long-term properties

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HIGHLIGHTS

- Structural concrete with fine and coarse recycled concrete aggregates (RCA) was studied.
- RCA of different origins were used: from real waste and produced in laboratory.
- The mechanical, durability and long-term performance of concrete with RCA was analysed.
- Similar performances using different RCA can be achieved.
- Total incorporation of RCA in the production of structural concrete is deemed possible.

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ABSTRACT

This investigation intends to analyse the effects of the variation of different types of recycled concrete aggregates (RCA) on structural concrete. For this purpose, two source concrete (SC) mixes, one produced in the laboratory and another in a precasting plant, were considered. The experimental campaign included mechanical, durability and long-term tests: compressive strength in cubes; splitting tensile strength; modulus of elasticity; abrasion resistance; water absorption by immersion and by capillarity; resistance to carbonation; resistance to chloride ion penetration; shrinkage and creep. The recycled aggregate concrete (RAC) mixes were compared with a reference concrete (RC) produced solely with natural aggregates (NA). Concerning the replacement percentages for fine and coarse recycled concrete aggregates (FRCA/CRCA%), the following were considered: 25/25; 50/50; 100/0; 0/100 and 100/100%. The results show that it is possible to achieve similar performances using RCA from different SC but with similar compressive strengths. In fact, RAC mixes achieved results comparable to RC in several properties.

1. Introduction

The properties of recycled concrete aggregates (RCA) and the effects of their incorporation in concrete received the attention of several researchers [1–4]. This material, despite the obvious environmental advantages, presents distinct properties from those of natural aggregates (NA), which have prevented their use on a regular basis [5–6].

The major difference between RCA and NA, in physical terms, is the mortar that adheres to its surface, which is one of the main reasons for quality losses [2,3,6,7]. In particular, the presence of adhered mortar is responsible for reducing the density and significantly increasing the water absorption of recycled concrete aggregates.

Concerning the various types of recycled aggregates (RCA – recycled concrete aggregates, RMA – recycled masonry aggregates, MRA – mixed recycled aggregates), several countries have implemented new specifications or additions to existing ones. Although the practical use of the coarse recycled fraction (CRA) in concrete production is already visible in some countries, the use of the fine fraction (FRA) remains very restricted or even banned. According to Evangelista et al. [8], in the case of the German specification [9–10], in which it was possible to use FRA, there is even a reversal of that trend, that is to say, from 2004 onwards, the abovementioned standard revoked the permission to use fine recycled aggregates in structural concrete elements.

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The restrictive nature of the standards has been criticized by some authors [1,6] and favoured the development of research in which the properties of the recycled aggregates (RA) were related to the performance of the resulting concrete.

For example, Kikuchi et al. [1] obtained satisfactory correlations between water absorption of recycled aggregates and concrete properties. The authors observed that the concrete performance decreased with increasing water absorption of the aggregates.

The survey carried out by de Brito and Robles [11] and de Brito and Alves [12] made a similar comparison but between the density and various properties of the concrete. The authors found that the aggregate combinations with lower density gave rise to mixes with worse performances.

Dhir and Paine [13] investigated the possibility of using an alternative method for RA classification that could overcome the current barriers and concerns. The authors proposed different classes of aggregates based on their saturated density with dry surface, water absorption, abrasion resistance and also with drying shrinkage values.

More recently, Silva et al. [6], following this line of thought and through an exhaustive survey of the literature, proposed a similar approach for the classification of RA. The authors observed that RMA may reach a class that is identical or even superior to RCA, suggesting that recycled aggregates should be classified mainly through their physical properties. The analysis carried out allowed observing that the coarse fraction of the recycled concrete aggregates (CRCA) presents the highest probability of belonging to class A (class to which the best-quality NA belong), being very unlikely to belong to a class inferior to B. For fine recycled concrete aggregates (FRCA), there is a high probability of falling into classes B or C. In turn, the coarse fraction of RMA is very likely to be included in classes C or D, and the authors recommended that this type of aggregate should only be considered in low-grade applications.

In view of the aforementioned literature, RCA are the RA type with the greatest potential to be incorporated in structural concrete. However, their characteristics can be significantly affected by their recycling process, quality of the source concrete (SC) and dimension.

Regarding the influence of the recycling process, the number of processing stages is an aspect to be taken into account, since the density of RCA depends on the amount of adhered mortar. Nagataki and Lida [14] concluded that the more recycling phases there were, the greater the density of the CRCA, resulting from the accumulated loss of adhered mortar. The authors concluded that further processing, while minimizing the amount of old mortar, led to lower rates of recovery of the coarse fraction. They observed that, using jaw crushers and impact crushers, the rate of recovery of coarse aggregates was 60%, decreasing to 35% for further processing (material crushed twice with the mechanical equipment).

In the same study, the authors also analysed the effects of using CRCA from source concrete with different compressive strengths (28.3 MPa, 49.0 MPa and 60.7 MPa) but subjected to the same recycling process. They observed that the density values of the recycled aggregates increased with the increase of SC strength, with differences not exceeding 3%. However, the water absorption was significantly affected. The water absorption of the CRCA from the SC with 28.3 MPa was about 30% higher than the CRCA of the SC with 60.7 MPa. Gonzalez and Etxeberria [15] performed a similar analysis, using source concrete mixes with 40 MPa, 60 MPa and 100 MPa. The results showed similar trends. For density, the maximum variations were about 7% among the CRCA. On the other hand, the water absorption of the CRCA originating from the SC with 40 MPa presented values about 58% higher than the CRCA from the OC with 100 MPa.

Regarding the influence of the CRCA dimension, Juan and Gutiérrez [3] concluded that the amount of mortar adhered increases with the reduction of particle size. The greater amount of mortar adhered to the fine particles can be explained by the recycling processes used, where the use of several processing steps, despite reducing the amount of mortar adhered in the coarse aggregates, increases the amount of paste accumulated in the fine fraction [14,16]. Thus, FRCA is expected to have lower density and higher water absorption than CRCA.

Considering the aforementioned, the objective of the present investigation was to understand the viability of producing structural concrete without incorporating natural aggregates. Thus, it was sought to use quality recycled aggregates, i.e. belonging at least to class B of the RA classification system proposed by Silva et al. [6].

In this sense, only source concrete mixes with average compressive strengths of 75 MPa and subjected to a primary plus secondary crushing process (jaw crusher and hammer mill) were considered. At the same time, SC produced in the laboratory and from precast elements were also considered, in order to try to perceive the associated differences.

It should be noted that the study carried out is part of a research project, and the criteria adopted for the SC are derived from earlier published results [4,17].

In Pedro et al. [4] coarse recycled concrete aggregates from concrete of various strength ranges (15–25, 35–45 and 65–75 MPa) were considered. The results showed that the CRCA of the SC with 65–75 MPa was able to easily fulfil the necessary requirements to be included in class B of Silva et al. [6]. In addition, the RAC produced with them achieved performances comparable to that of the corresponding reference concrete.

In turn, in Pedro et al. [17] the influence of the crushing process of coarse recycled concrete aggregates on the properties of RAC was evaluated exhaustively. For this purpose, two types of CRCA were analysed: one subjected only to primary grinding (jaw crusher), while the other was subjected to primary plus secondary grinding (jaw crusher and hammer mill). The second process allowed obtaining more rounded CRCA and with a smaller amount of mortar adhered to their surface. The concrete produced with these aggregates presented improvements in strength between 7% and 15%, compared to the mixes produced with CRCA subjected to primary grinding only.

In view of the above results, it is now intended to simultaneously incorporate FRCA and CRCA into structural concrete and not to limit its application only to the construction of sub-bases for roads [18]. In the literature, there are some studies on this subject. For example, Corinaldesi and Moriconi [19] also made an attempt to incorporate fine and coarse recycled aggregates in concrete. However, the recycled aggregates presented a varied/mixed composition (70% concrete, 27% ceramic, 3% other constituents), i.e. their source was not exclusively form concrete waste products. For compressive strength values of 30 MPa, the authors found that RAC could achieve results comparable to those of RC by means of using fly ash and superplasticizers (allowing reducing the water/cement ratio of the recycled mixes).

Ajdukiewicz and Kliszczewicz [20] studied the effects of the incorporation of fine and coarse recycled aggregates from medium/high strength (35–70 MPa) demolished concrete on the performance of high-performance concrete (HPC). The authors found that the use of this type of aggregates could be feasible.

Tu et al. [21] also assessed the consequences of the incorporation of FRCA and CRCA in HPC production. The results showed that it is necessary to increase the design strength whenever recycled aggregates were used in the production of high-performance concrete.

Thomas et al. [22] used fine and coarse recycled aggregates from crushed concrete test specimens (existing in/from laboratories). Two types of RCA were considered: with and without the