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Durability performance of concrete with recycled aggregates from construction and demolition waste plants

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HIGHLIGHTS

- Concrete with fine and coarse recycled aggregates (RA) from construction and demolition waste (CDW).
- CDW from five recycling plants with a wide variety of compositions.
- Analysis of the influence of the RA's source, composition, size and incorporation ratio.
- Analysis of the feasibility of the use of these RA in terms of concrete's durability performance.

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ABSTRACT

This research intends to analyse the durability performance of concrete with recycled aggregates (RA) from construction and demolition waste (CDW) from various locations in Portugal. To that effect water absorption by immersion and capillarity, carbonation resistance and chloride ion penetration resistance tests were performed.

To better understand the experimental results, the characteristics of the various aggregates (natural and recycled) used in the production of concrete were analysed in detail. The composition of the RA was determined and various physical tests of the aggregates were performed. 33 concrete mixes with RA from different CDW recycling plants were evaluated in order to understand the influence that the RA's collection point, and therefore their composition, has on the characteristics of the concrete mixes produced. Both coarse and fine RA were used to determine the influence of their size on concrete's performance.

The analysis of the durability performance allowed concluding that the use of RA is highly detrimental. This is mostly true when fine RA are used. The carbonation resistance is the property most affected by the use of RA, leading to increases in the carbonation depth between 22.2% and 182.4% for the various RA types. However, the most influencing factor is by far the RA's composition.

1. Introduction

The construction industry is one of the greatest and most active sectors in Europe. The weight of this activity is also reflected on the environment. The construction sector consumes more raw materials and energy than any other economic activity and generates the greatest waste fraction within the European Union (EU). Every year around 3000 million tonnes of wastes are produced in the EU. The construction industry in the EU generates around 900 million tonnes of waste per year [1].

Therefore, recycling this waste is fundamental to reduce the volume of dumped waste. On the other hand, recycling has another environmental advantage, that of decreasing the consumption of natural resources. CDW recycling plants have been proved to be economically viable [2,3] as well as having a positive environmental impact [4,5]. However, for that to be true it is essential that the output from the plants can be absorbed by the market. In other words, there is a strong need to diversify the industrial applications of CDW.

One of the ways of recycling under evaluation is using this waste in concrete production, for which CDW have a great potential.

Unfortunately, nowadays most of these waste products are not reintroduced into the construction sector as aggregates for concrete production, one of the few options that do not use the materials for a less demanding function than the original one (thus avoiding downcycling). One of the main reasons for this fact is the

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absence or conservative stance of regulations that would allow for the use of recycled aggregates in concrete production [6].

Several researches have been implemented recently with the goal of evaluating the use in concrete of ceramic materials [7], concrete [8], glass [9], plastics [10], among others. However, studies on concrete with CDW from recycling plants are still scarce. Most previous researches analysed the use of a single type of RA from CDW and did not compare the effect of CDW with different compositions. On the other hand, there are but few studies that exhaustively analyse the RA used in concrete through the analysis of their composition and physical and chemical tests. Knowing the properties of the RA is fundamental to analyse the results of the concrete tests. It is stressed that researches where fine RA from CDW were used are even scarcer. Furthermore, most of these studies are focused on the mechanical performance. In sum, the existing knowledge on the durability performance of concrete with fine CDW RA is in fact very limited.

In this research it was intended to study the aspects mentioned above. CDW from five recycling plants, located in various regions in Portugal, representative of the variety of CDW compositions in industrialised countries, were collected. The RA's composition was then analysed and the aggregates were subjected to several physical and chemical tests. These tests intend to reach a detailed knowledge of the characteristics of the various aggregates (natural and recycled) used in concrete production. To evaluate the durability performance of concrete, absorption by immersion and capillarity, carbonation resistance and chloride ion penetration resistance tests were performed.

The influence of the RA's source, and therefore of their composition, on the durability of the concrete mixes produced was analysed. Five types of coarse CDW and three types of fine CDW were collected, with the objective of analysing the influence of the CDW RA's size on concrete's durability.

2. Literature review

Concrete's water absorption may be measured through immersion and capillarity tests, among others. The first ones fundamentally measure the open porosity, while the second ones measure the capillary absorption resulting from the pressure differential between free surface of the liquids on concrete's face and the free surface on concrete's capillaries. According to Coutinho [11], the smaller the diameter of the pores in concrete the greater its absorption by capillarity is.

Wainwright et al. [12] studied the water absorption by immersion of concrete with fine and coarse RA from crushed concrete. They observed that the quality of the concrete from which the RA are sourced seems to influence the porosity more than the target strength of the resulting concrete.

Matias et al. [13] determined the water absorption by immersion of concrete with full replacement of coarse natural aggregates (NA) with coarse RA from concrete, and obtained values of 17.5% and 17.2%, according to the type of superplasticizer used. These values are higher than the one for the reference concrete (RC): 13.7%.

Evangelista and de Brito [8] obtained an increase of 45% in water absorption by immersion for full replacement of fine NA with fine RA from concrete. They found that this property varies proportionally with aggregates replacement ratio.

Correia et al. [7] evaluated concrete mixes with 100% of coarse brick RA. The authors obtained an increase of water absorption by immersion of 62% relative to the RC.

Vieira [14] analysed the water absorption by immersion of concrete mixes with fine ceramic RA from bricks and sanitary ware. The author concluded that the full replacement of fine NA caused an increase of 45.2% and 47.0%, for bricks and sanitary ware RA respectively.

Matias et al. [13] checked the influence of the shape of the RA on the water absorption by capillarity of concrete with RA from concrete. The authors observed that the mixes with elongated RA showed increases of around 19% relative to the RC, while the use of rounder RA led only to an increase of 12%.

Correia et al. [7] found an increase of capillary water absorption of 70% relative to the RC when using 100% coarse brick RA.

Figueiredo [15] evaluated the capillary water absorption in concrete mixes with granite RA and with ceramic RA, reaching increases of 37% and 146% respectively, for full replacement of the NA. Thus this author proves that there is a great variation of concrete performance in terms of this property according to the RA's composition.

Vieira [14] observed that the capillary water absorption decreased 30.9% with full replacement of fine NA with fine brick RA. The author refers that these results were unexpected, given the greater porosity of the brick RA and the higher total water/cement (w/c) ratio used. However, because the brick RA contain silica, they may have pozzolanic properties, decreasing their permeability to chloride ions. On the other hand, the author concluded that the use of 100% of fine sanitary ware RA caused a 37.6% increase of the capillary water absorption.

Zaharieva et al. [16] evaluated the capillary water absorption of concrete with fine and coarse RA from a CDW recycling plant. The authors maintained the slump in all the mixes and found that full replacement of coarse NA with coarse RA increased this property by 16%. On the other hand, integral replacement of the NA (fine and coarse) caused an increase of capillary water absorption of 42%.

One of the functions of concrete is to protect the steel reinforcement in order to prevent its corrosion. Therefore, determining the carbonation resistance is fundamental to check the concrete durability and its capacity to keep the reinforcement depassivated.

Evangelista and de Brito [8] evaluated the carbonation depth of concrete with fine RA from concrete and obtained a maximum increase of 65% relative to RC, corresponding to full replacement of the fine NA.

Medina et al. [17] evaluated the carbonation resistance of concrete with sanitary ware ceramic RA. The authors found a slight increase of carbonation resistance (up to 3%) for coarse aggregates replacement ratios up to 25%. The authors justified this trend with the decrease of the volume of pores smaller than 0.067 μm.

Vieira [14] analysed the carbonation resistance of concrete with fine ceramic RA from bricks and sanitary ware. The author concluded that full replacement of the fine RA caused an increase of the carbonation depth of 150.6% and 248.8%, respectively for bricks and sanitary ware RA.

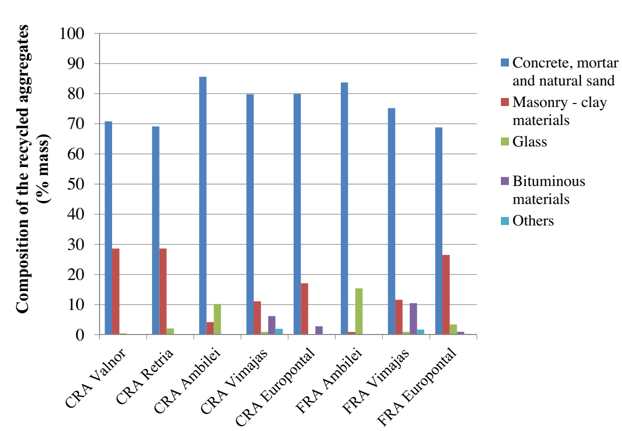

Fig. 1. Composition of the recycled aggregates.