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Influence of natural aggregates typology on recycled concrete strength properties

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HIGHLIGHTS

- The influence of the type of natural aggregate on the strength of recycled concrete is analyzed.
- With rounded aggregates, the recycled concrete strength improve to increase the rate of substitution of recycled aggregate.
- With crushed aggregates exhibited a decrease of 10–25% for the 100% recycled replacement ratio.

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ABSTRACT

This paper reports a study on recycled aggregates concrete to analyze the influence of using two different types of natural aggregates, river aggregates and crushed aggregates, on the strength properties of recycled aggregates concrete. A total of twenty different mixes were analyzed with an effective water/cement ratio of 0.5 and cement contents of 260–300–340 kg/m^3 for recycled rates of coarse aggregates of 0–20–50–100%. The results show that the strength property depends of the type of natural aggregate used and of the recycled replacement ratio. An increment of 15% on compressive strength was obtained for river natural aggregates and 100% recycled replacement ratio, while a decrease of approximately 10–25% was observed for mixtures with crushed natural aggregates performed under similar manufacturing conditions.

1. Introduction

The deep concerns about the significantly climate change which is evidencing during last years has resulted in important worldwide active policies to reduce the quantity of contaminants, with the aim of the environmental preservation [1]. Thus, prompted by International directives, society is gradually becoming more concerned with waste management; the attention on construction and demolition waste (CDW) has increased significantly during the last few years [2]. However, despite waste recycling, the reuse rates of these materials are very low, resulting in the loss of an important opportunity for these materials to be reused for different purposes, with the consequent economic and environmental savings.

A potential destination for the recycled material is as recycled aggregates for structural concrete, an alternative included in various Structural Codes currently in force in European Countries [3,4]. However, there are different factors that inhibit the reuse of recycled materials such as: 1) the ease of obtaining the natural materials, 2) the use of recycled materials generally degrades the strength properties of concrete, and 3) the lack of knowledge regarding the management of these materials required to include them in the manufacturing process.

Regarding the degradations of the strength properties, many research studies on recycled concrete (RAC) have been performed, concluding that the strength properties of RAC decrease by approximately 15–35% over the values of conventional concrete [4,5]. Also results show that the decay level depends on the replacement ratio and the size of aggregates (either coarse or fine) that are actually replaced by recycled ones, mainly caused by the higher water absorption of the recycled aggregate in comparison with natural aggregates due to the residue of the mortar adhering to the original aggregate [6]. However, also there are some reports which that achieve similar (and even higher values) of the strength properties of RAC than homologous NC [7–9]. These contradictory results were described by Pedro et al. [10] after an exhaustive collection of information in the results relative to the incorporation for 100% replacement of natural aggregates by RCA. As explanation

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Notation

CDW	construction and demolition waste
cNA	crushed natural aggregates
d	nominal diameter of aggregates
Ec	elasticity modulus or Young modulus
f_c	compressive strength
f_t	tensile strength on Brazilian tests
NC	normal concrete
R	recycled replacement ratio
REF	original concrete
RCA	recycled concrete aggregates
RAC	recycled aggregates concrete
rNA	rounded natural aggregates
W/C	water/cement ratio
w_{ad}	water volume due to additive
w_{agg}	water in aggregates due to absorption
W_{ef}	free or effective mixing water volume
w_m	added mixing water volume
w_{mc}	residual water in the mixing components
W_{total}	total mixing water volume

of these differences, different authors [5,11] suggested that the final strength level of recycled concrete is influenced by the quality of the original concrete from which the recycled aggregates were obtained. Thereby, Tavakoli & Soroushian [12] goes a step further and indicates that the strength characteristics of recycled aggregate concrete are influenced by key factors from the original concrete, such as the strength of the original concrete (REF), the ratio of coarse to fine aggregate in the REF, the ratio of top size of aggregate in the REF to that of the recycled aggregate, and the Los Angeles abrasion loss and water absorption of recycled aggregate.

Particularly, Pedro et al. [10] conducted a very comprehensive research for different sources of concrete, with RCA obtained from precast rejects and also laboratory made concrete mixes, with target strengths of 20 MPa, 45 MPa and 65 MPa, resulting that the performance losses resulting from the RCA's incorporation are substantially reduced when used medium or high strength sources of concrete's. So, these results confirm the influence of the quality of the source concrete for RCA on the RAC properties. In addition, Lofti et al. [13] analyzed the effect of the type of cement to produce RAC, another factor directly related to the quality of the concrete, resulting that a good choice of type of cement have a decisive effect on the properties of RAC.

Further to the above factors and directly related with the final strength, the type of natural aggregates, which is the major and also very important component on the mixture, is not normally considered by the researchers in the RAC experiments, although it is well known that they induce different strength properties in the NC according to the differences of the shape, size and nature of each one. This effect was detected by Laserna et al. [14], who studied two different typologies of natural aggregates to manufacture RAC; however, the designed concretes used in their experiment considered different dosages while maintaining the total mixing water volume constant between the different recycled series, that is, the effective water volume of each mix decreased as the recycled replacement ratio (R) increased. In consequence, the compared mixes might be induced by the differences in the resulting cementitious matrices for "NC" and "RAC" and the obtained values of strength did not had a successfully comparison, according with de Brito et al. [15] suggestions, since effective W/C ratio between RAC and NC was not keep unaltered for the different R and so, the induced differences of rNC and cNC were not clear.

These differences in behavior due to the conventional type of aggregate on RAC manufacturing may be the main factor inducing the differences observed in various studies (such as Malešev et al. [7], Razaqpur et al. [8], Younis & Pilakoutas [9] or Lofti et al. [16]) regarding most of the results reported in the literature, because the common feature of these experiments is the use of rNA to design the reference dosage of concrete NC and RAC analyzed. However, it is difficult to conclude this assumption for the type of natural aggregate, because there is a lack of experiments comparing rNA and cNA on the RAC studies, both for same conditions of cement volume, effective W/C ratio and initial moisture for aggregates, that clearly influencing the variability in RAC strength [17,18].

The performing of a specific experimentation which can determine if really the use of rNA induces an opposite strength behavior respect to cNA to produce RAC supposes a highly interesting novelty on the recycled concrete manufacturing to enhance trust and increase the use of this recycled material. Thus, for locations whit the possibility to use rNA, companies may consider including RAC as alternative to the NC to develop more sustainable and ecofriendly concrete production processes, avoiding problems in strength due to recycled material of their products.

In addition, to determine the influence of the binders quantity used in the designed mixture on the behavior of RAC is really interesting, since little increments on the cement quantity [19], or adding it on the mixing process in a pre-step together with aggregates helps to improve the strength properties [9,20]. In this way, additionally to the importance of the W/C ratio influence on RAC, with clear proved effect on the final strength and durability properties [21,22], also is highly interesting to know if different cement quantities for similar W/C ratio may induce differences on the strength of RAC, unlike to the usual tendency of the NC [23], and clearly helps to get appropriate dosages design on each case.

Thus, the objective of this study is to analyze the influence of the different typologies of the natural aggregates on the RAC strength properties. So that, the above-described natural aggregate types were studied: rounded (rNA) and crushed (cNA); over 20 real comparative mixes using different recycling ratios (0–20–50–100%) and for different dosages of cement volumes (260, 300 & 340 kg/m^3). To isolate the aggregate type effect and for the comparison to be successful between to reinforcement concrete and RAC on strength properties, the effective W/C is keeping constant between all mixes.

2. Material and methods

The three following subsections describe the materials employed for producing the test specimens, the principal criterions for the mixes design and the experimental methods carried out this study.

2.1. Materials

Two main typologies of natural aggregates were used to produce the concrete and were analyzed: limestone crushed natural aggregates (cNA) and siliceous gravel as rounded natural aggregates (rNA). Both of these sources of raw materials were located in the province of Albacete (Spain).

Thus, [0–4 mm], [4–10 mm] & [10–20 mm] aggregate sizes were used for each typology to achieve a grain configuration of the concrete according to the Fuller curve [23], with a 20 mm maximum aggregate size. The grading was fit to the objective curve by the method of least squares. The obtained mix was considered to be the control conventional concrete (R = 0%), and the recycled mixes were determined using R = 20%, 50% & 100% of the coarse aggregates (d > 4 mm). The replacement was performed according to the volume of the natural aggregates, not the weight.