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Structural recycled aggregate concrete made with precast wastes

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HIGHLIGHTS

- The recycled aggregate from wastes of precast structural concrete are clean and of high quality.
- A complete characterization of recycled aggregate and recycled concrete have been performance.
- Substitution of 20% coarse aggregate does not significantly affect the properties of concrete.
- Total replacement of coarse aggregate causes an increase in the amount of cement.

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ABSTRACT

This paper presents the main results of the characterization of recycled aggregate concrete made with precast structural concrete wastes as a case study. The use of recycled aggregates presents two main benefits. On the one hand, there would be an economic and environmental saving because it would not need to deposit waste in landfills. On the other hand, there would be a further economic and environmental saving because it would reduce the need for natural aggregate. However, because of the need of a greater amount of cement not all degrees of substitution present advantages. The results were obtained from four degrees of substitution and different mixing proportions and methods using natural and recycled aggregates and superplasticizers. After obtaining the optimal mixing proportions, the concretes have been fully characterised performing mechanical and durability tests, the methods analysed and the results compared with the literature.

1. Introduction

Humans generate large volumes of construction and demolition waste. Although there are no exact figures, it is estimated that in Spain 325 kg/year per capita is produced, this value being similar to the European average [1].

Construction and demolition waste (CDW) can be defined as waste generated in new construction, repair, remodelling, renovation and demolition. The aim of the Spanish National Plan of Construction and Demolition Wastes [2,3], European 2020 Horizon [4] is to reduce the amount of CDW dumped in landfills through climate action and resource efficiency. The wastes generated by the precast industry, also under the name CDW, are subject to the requirements of another standard, the Spanish National Plan of Industrial Wastes [5]. At present, most of these wastes are carried to landfills, creating a great visual impact on the landscape. The percentage of wastes that come from precast plants or control laboratories is only 5% of the total production of CDW. However, these wastes are of a far superior quality [6–8]. In general, recycled aggregates derived from crushed concrete consist of 65–70% by volume of natural coarse and fine aggregates, and 30–35% by volume of old cement pastes [9]. Furthermore, with the increasing rates charged in landfills and the higher transport costs, these activities are gaining more prominence. However, in terms of CO_2 emissions, the environmental benefit may not be noteworthy if the amount of cement needed is greater than that required in a traditional concrete [10]. If the low quality of recycled aggregates requires increasing amounts of cement to maintain its strength against traditional concrete, recycled aggregates should not be used in structural concretes.

In a general context, the term recycled aggregate refers to "aggregate resulting from the processing of CDW", as defined by the standard prEN 13242 "Aggregates unbound and hydraulically bound for use in civil engineering and road construction" in its version of May 2002 and the prEN 2002 12620 "Aggregates for concrete" April 2002 [11]. These materials are generated as waste during the process of construction, demolition, precast fabrication and testing. A special case of recycled aggregate concretes is those composed of clinker Portland cement and natural aggregates,

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crushed, screened and processed to produce a secondary material called "recycled aggregate concrete" (RAC). Recycled concrete aggregate (RCA) is derived from a single type of primary material: concrete. Its basic composition, as is known, is a paste of cement mixed with natural aggregates, additives and/or additions.

The Spanish standard [12] recommends that the recycled aggregate, from 25 MPa concrete, can be used for both plain concrete and reinforced concrete with a compressive strength not exceeding 40 MPa, its use in prestressed concrete being excluded. Furthermore, recycled aggregates obtained from healthy structural concrete, or high strength concretes, as the one here analysed, could be suitable for the manufacture of structural recycled concrete with compressive strengths higher than 40 MPa [13]. It should be noted that this type of recycled aggregates for structural concrete comes from a high strength concrete so it should present excellent mechanical characteristics, and secondly, its properties should improve.

Therefore, most of the studies and experiments made in this regard seem to agree that the use of recycled aggregate for the manufacture of structural concrete should be limited to only those aggregates from concrete, and they recommend the use of the coarse fraction or fine fraction, pointing out that the quality deteriorates substantially in the case of recycled concrete [6,13–20]. However, the durability properties of the concrete could be improved by using nano silica particles [21], mineral additives [22] or silica fume [23]. Also, the addition of cement to concrete mixtures utilising recycled aggregates produces concrete with mechanical properties comparable to control concretes made with the same w/c ratio [24]. H. Qasrawi used steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete [25]. H. Zhang used silica fume grout and polyvinyl alcohol solution as a method to improve the thickness of the interfacial transition zone (ITZ) [26] and E. Arifi et al. show the effect of fly ash on recycled concrete [27]. E. Anastasiou et al. improved the properties of recycled aggregate using fly ash and steel slag and the fine fraction of recycled aggregates [28].

Moreover, the need for the use of recycled aggregates in construction is based on environmental purposes and sustainability, as an alternative to the problem of the generation of large volumes of waste. As is known, the poor quality of recycled aggregates compared with natural concretes is due to the mortar adhered to its surface [29,29–32]. However, there are great variations in the results; especially those properties related to deformability, such as modulus of elasticity or retraction. This variability in results is largely due to the wide diversity of recycled aggregates regarding where and how they are produced [33–35]. R.V. Silva et al. proposed a performance-based classification for the use of RA in concrete construction, based on their physical properties [36] and C.J. Zega et al. analysed the influence of the type and content of RA on the transport properties of recycled concrete, finding that the durability of recycled concrete can be as good as that of concretes prepared with natural aggregates and is of a similar compressive strength [37]. M. Tuyan found similar results for self-compacting concrete [38].

This work presents the results obtained from the characterisation of recycled aggregate from a precast plant after crushing and screening self-compacting concrete. The aim is to reuse this waste as recycled aggregate in the production of new recycled concrete elements subjected to static [13,38], cyclic [20,21,39,40] and multiaxial loading [21,41].

The waste is selected exclusively from quality structural concretes, which provide high performance recycled concrete very similar to the original concrete made with natural aggregate. In order to verify these, an ambitious experimental program has been devised, described below, in which not only the complete characterisation of the recycled aggregate is contemplated but also its suitability for making structural concrete in the precast industry.

2. Materials and methods

Four mixtures have been studied: a control concrete (CC) with natural limestone aggregate (NA) similar to the structural concrete used in the precast plant and substitutions of 20%, 50% and 100% by weight of the coarse NA by recycled aggregate (RA) have been prepared. RA were obtained from clean structural concrete of precast elements rejected in the quality control of the company Norten PH; rejects due to defects of filling and in no case due to the quality of the concrete with, at least, 25 MPa of compressive strength. The recycled aggregates have been obtained in two stages. The first one, in the precast plant where the waste is produced: the structural elements are crushed to recover the reinforcing steel. Subsequently, the waste is crushed and sieved to a maximum size of 32 mm. Under these conditions, the aggregates are sent to the laboratory where they are analysed in the 1–32 mm fraction and, in parallel, at 4–20 mm fraction. This last fraction is the most appropriate for structural applications.

CEM I 52.5N/SR with a density of 3.11 g/cm^3 and a Blaine specific surface of 361 m^2/kg was used. Table 1 shows the chemical composition of this Portland cement. Table 2 shows the physical and mechanical properties of the coarse limestone aggregate.

The results of the tests described below will be evaluated in accordance with the recommendations contained in the Spanish standard, in order to validate the suitability of the recycled aggregate for making structural concrete.

2.1. Recycled aggregate geometrical and tribological characterisation

2.1.1. Grading

The test to determine the particle size distribution is performed in accordance with the EN 933, Parts 1 and 2: "Determination of particle size distribution. Sieving method".

Coarse recycled aggregates present large contents of particles smaller than 4 mm because of the high friability of the adhered mortar, generated during handling after making the size classification. Thus, it is important to evaluate the fines content of the sample. The method for determining the content of particles smaller than 4 mm is also specified in the EN 933-2 and is quantified by the value of the cumulative percentage of aggregate passing through the sieve of 4 mm.

2.1.2. Fine content

It is well known that RA generates fines during handling due to the material adhered to its surface [42]. Also the presence of fine particles on the surface of recycled aggregate from the cement paste of the old mortar can cause problems of adhesion between it and the new cement paste as well as causing an increase in the amount of mixing water required [6,13,43,44].

The test for determining the fines content is carried out according to the specifications of the UNE-EN 933-2.

2.1.3. Flakiness index

Regarding the form of the recycled aggregate, there is some disparity in the criteria depending on the test method employed, although in general it is considered that the recycled coarse aggregate has a form suitable for structural concrete. The methods for determining the form of recycled aggregates involve the use of optical techniques, electron microscopy, to estimate the shape coefficient or the flakiness index. The flakiness index is determined according to the standard EN 933-3.

2.1.4. Shape index

The determination of shape index is made according to the standard EN 933-4. At least 50 particles for 4/8 and 8/16 fractions and 20 particles for the fraction 16/31.5 have been tested. The main difficulty in performing this test is the method to determine the two dimensions. In this case, a calliper was used. The new optical analysis techniques allow this test to be performed more effectively [45].

Table 1
Chemical composition by XRF of the cement.

Cement	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	MgO	TiO_2	C
CEM I 52,5 N/SR	69.6	18.6	3.1	2.66	3.22	0.54	1.17	0.17	0.47