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Characterization of recycled aggregates construction and demolition waste for concrete production following the Spanish Structural Concrete Code EHE-08

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ABSTRACT

Construction and demolition waste can be used as recycled aggregate in construction. The more thoroughly the waste is treated, the higher the quality of the aggregate. However, high-quality aggregate is expensive, and thus, economically unviable in countries where natural aggregate is cheaply obtained. This paper examines the characteristics of recycled aggregate, resulting from of a non-exhaustive production process. This aggregate was found to contain impurities, such as crushed clay brick, crushed ceramic materials, and gypsum. The tests used to analyze this material were those recommended in the Spanish Structural Concrete Code (EHE-08). The results obtained were then compared with the guidelines in this code, which regulate the use of this material as a component in structural concrete. The result showed that none of the fractions fulfilled all the requirements in this especially in the case of the fulfillment of guidelines established to certain properties of the recycled aggregate, basically water absorption sulfate content, and chloride content. In contrast, particle shape, density, assessment of fines and resistance to fragmentation were in compliance with the EHE-08 recommendations.

1. Introduction

Concrete is the world's most widely used construction material, but at the same time, it is not an environmentally friendly material because it destroys and uses up large quantities of natural resources and it is also a source of environmental impact because after its use, it is generally deposited in landfills [1]. In recent years, the recyclable potential of construction and demolition (C&D) waste has made it a target of interest and the main focus of waste management polices encouraging minimization, reuse, recycling, and valorization of the waste as opposed to its final disposal in landfills [2,3].

Recycled concrete aggregate differs from natural aggregate in that it is mainly composed of two materials, namely, the original aggregate and adhered mortar [4,5]. However, it often contains impurities, such as crushed clay brick, crushed ceramic materials, and gypsum contributing to the existence of contaminants, for example chlorides, sulfates, siliceous gel, oil, or other harmful materials. Adhered mortar, impurities, and contaminants have a negative influence on the physical, mechanical and chemical properties of the recycled concrete [1,4–7].

Many European countries and regional governments within these countries have established regulations and procedures in an effort to encourage the reuse of these materials in construction applications [8–10]. In Spain, there is no national law regulating the environmental assessment of recycled materials. As a result, the environmental agencies of the various regional governments are mainly responsible for regulating the use of secondary materials in road building and other construction applications [3]. However, there are various technical specifications for materials used in construction. For example, the Spanish Structural Concrete Code EHE-08 sets out the specifications for concrete structures. More specifically, Article 28 gives the requirements for aggregates, and Annex 15 lists the specifications for recycled aggregates [11].

In the province of Granada (Andalusia, Spain), C&D Waste Management Planning has been implemented, and the resulting program manages these types of waste in some stationary recycling plants. Recycled aggregates, which can be used in construction and other recyclable products (e.g. plastic, wood, and metal) were thus recovered, and the rest of the materials were deposited in landfills. This plan was implemented with a view to achieving the objectives in Royal Decree 105/2008 [12], which regulates the production and management of C&D waste.

The characteristics of the recycled aggregate depend on the production process in the C&D waste plant [4,5,13] just like the properties of the demolished concrete [14]. In consequence, there are important differences between the characteristics of the recycled aggregates produced at different plants. In fact, even materials from the same plant can show composition changes, depending on the characteristics of demolition source [13].

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In this context, the material produced in C&D waste treatment centers in Granada must comply with technical and environmental specifications in order to be of sufficiently high quality for potential applications. This paper characterizes the recycled aggregate from one of the previously mentioned C&D stationary recycling plants, operating in Granada (Spain). The Spanish Structural Concrete Code (EHE-08) recommends a battery of tests for such material, which include particle size distribution, sand equivalent test, fines content, flakiness index, particle density, water absorption, the Los Angeles degradation test, and the chemical analysis of chlorides, water-soluble sulfates, total sulfur compounds, and organic matter.

2. Materials and methods

2.1. The C&D waste treatment process

For this study, samples were taken from a stationary recycling plant, located south of the province of Granada. The C&D waste treatment process at these installations consists of a simple impact crushing, and separation with vibrating screens. Metallic elements are removed by a magnetic conveyor belt and impurities, such as plastics, paper, glass, and gypsum are extracted by hand before the crushing process. Three different fractions of recycled aggregates are produced by the plant: 10/50 mm, 6/10 mm, and 0/6 mm. Non-recyclable fractions are deposited in a landfill.

2.2. Sampling program

The samples studied were collected from the C&D waste treatment plant according to the UNE-EN 932-1 [15] and UNE-EN 932-2 [16]. Four different fractions were studied: the sample 001 was the unselected fraction resulting of simple impact crushing before the vibrating screen process; the samples 002, 003 and 004 were the 10/50, 6/10 and 0/6 mm recycled aggregates produced in the plant respectively.

2.3. Laboratory procedures

The battery of tests was in accordance with the recommendations in Article 28 of the EHE-08. Three samples of each fraction have been selected to make each test and finally average values were determined. Table 1 shows the properties of the aggregate studied, the testing method used, the Spanish standard applied, the limits established, and the aggregate fractions tested.

2.3.1. Maximum and minimum size of aggregates

The maximum (D) and minimum (d) size of aggregates is defined in EHE-08 [11] and the general requirements, depending on the aggregate type and sieve opening according to UNE-EN 933-2 [17], have been summarized in Table 2.

2.3.2. Aggregates denomination

The EHE-08 [11] provides general criteria for the designation of aggregates in accordance with the following scheme:

$$GR - d/D - IL - N$$

where

- GR refers to the aggregate group, namely, coarse aggregates (AG), fine aggregates (AF), and fines (FN);
- d is the minimum aggregate size (mm);
- D is the maximum aggregate size (mm);
- IL is the presentation of the aggregates, i.e. rounded (R), crushed (T), and mixture (M);
- N is the aggregate nature, i.e. limestone (C), siliceous (S), dolomite (D), artificial (A), and recycling (R).

These requirements were used to characterize the aggregate samples in our study.

2.3.3. Geometrical requirements

2.3.3.1. Particle size distribution. The EHE-08 [11] specifies the optimal particle size distribution of coarse aggregate, sand, and fines that can be used to make concrete. The aggregate should be large enough for the ratio D/d to be greater than 1.4. The purpose is to obtain a uniform grading in all sizes, which is conducive to greater

Table 2
General requirements to maximum (D) and minimum size (d) of aggregates [11].

		Percentage that pass across the sieve (in mass)				
		$2D$	$1.4D$	D	d	$d/2$
Coarse aggregate	$D > 11.2$ ó $D/d > 2$	100	98–100	90–99	0–15	0–5
	$D \leqslant 11.2$ ó $D/d \leqslant 2$	100	98–100	85–99	0–20	0–5
Fine aggregate	$D \leqslant 4$ y $d = 0$	100	95–100	85–99	–	–

Table 1
Properties of recycled aggregates studied, samples tested, test methods Spanish standard applied, limits established considering the Spanish Structural Concrete Code EHE-08 [11].

Properties and test method			Spanish standard applied	Limit value	Fraction
Geometrical	Particle size distribution. Sieving method		UNE-EN 933-1:1998 [18]	See Fig. 1	001 002 003 004
	Assessment of fines	Percentage of fines	UNE-EN 933-1:1998 [18]	1.5%	001 002 003 004
		Sand equivalent	UNE-EN 933-8:2000 [19]	General conditions I, IIa, IIb >70 Rest of cases >75	004[a]
Physical–mechanical	Particle density		UNE-EN 1097-6:2001 [20]	No limit	001 002 003 004
	Water absorption		UNE-EN 1097-6:2001 [20]	<5%	001 002 003 004
	Resistance to fragmentation. Los Angeles abrasion		UNE-EN 1097-2:1999 [21]	<40	002[b]
Chemical	Chlorides content		UNE-EN 1744-1:1999 [22]	Mass and reinforced concrete <0.05% Pre-stressed concrete <0.03%	001[c]
	Water-soluble sulfates		UNE-EN 1744-1:1999 [22]	<0.8%	
	Total sulfates		UNE-EN 1744-1:1999 [22]	<1%	
	Organic matter content		UNE-EN 1744-1:1999 [22]	Coarse aggregates <1% Fine aggregates <0.5%	

[a] The test is only applicable to sizes between 0 and 4 mm.
[b] The test is only applicable to sizes between 14 and 10 mm.
[c] The test is only applicable to sizes between 16 and 0 mm.