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Influence of the water variation on the mechanical properties of concrete manufactured with recycled mixed aggregates for pre-stressed components

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HIGHLIGHTS

- Influence of the water variation on the mechanical properties of recycled mixed concrete.
- Recycled mixed aggregates had 50% of concrete aggregates and 50% of ceramic aggregates.
- Concretes with natural aggregates and with 100% of recycled mixed aggregates have been dosaged.
- Water quantity was different in each one of the recycled concrete manufactured.
- Relationship between the compressive strength and the elastic modulus has a similar trend to the codes.

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ABSTRACT

This work aims to study the influence of water/cement ratio variation on some mechanical properties of concrete made with mixed recycled aggregate when it is used to prefabricate prestressed joists for flooring systems. All natural aggregate was replaced in volume by mixed recycled aggregate that means 50% recycled concrete aggregate and 50% recycled ceramic aggregate. Mixed recycled aggregate includes both, the fine and the coarse fraction. For the different mixtures considered in this research, the volume of water was modified while the mass of aggregates and cement were kept constant. After the curing period, different tests were carried out in order to obtain the most important mechanical properties of these concretes. The results showed a significant decrease of their properties due to the complete substitution of natural aggregates by the recycled material, and because of the water/cement ratio increase.

1. Introduction

Society is increasingly aware of the impact of its actions and therefore requires new proposals which allow achieving the sustainability in many areas of activity. Construction is one of the main human activities, so it is essential to advance in the development of new materials and techniques to make it less aggressive to environment. The nowadays common term "sustainable construction" was defined in the "First International Conference on Sustainable Construction" (1994 – Florida) by Kibert as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" [1].

Construction and demolition wastes (CDWs) constituted in 2010, in Europe, 34.4% of the total waste, which is equivalent to an amount of 860 million tons [2] from which approximately 66% was ceramic or concrete waste [3] as indicated in Fig. 1. Although these residues are mostly inert or comparable to inert, they represent a serious environmental problem because of their huge volume. They are often accumulated with low environmental control and there is an overexploitation of natural resources by rejecting materials that with suitable treatment could be reintroduced into the production process.

Substitution of natural aggregates by recycled aggregates coming from CDWs and its support industry in order to prepare new concrete is a viable option to the problem. In the two past decades, a great number of studies were carried out, not only focused in the aggregates characterization but also in the behavior of concretes with different replacement percentage. Currently, the international standards include guidelines for its use in no structural concretes and sometimes as well in structural ones. The Spanish code of design for concrete EHE-08 [4] considers only the use of a coarse fraction of recycled aggregate coming from crushing of concrete waste with a maximum replacement percentage of 20% without

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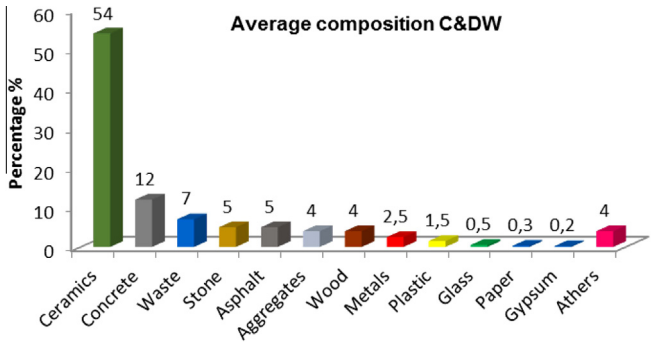

Fig. 1. Composition of CDW's [3].

carrying out any additional studies and it also allows the substitution of 100% by recycled aggregates for no structural concretes. However, other standards extend the application field to recycled aggregates coming from ceramic wastes [5].

Recycled aggregates cannot be considered as a uniform material due to its nature (concrete or ceramic) dependence, as well as the mechanical and physical properties of the basis material (concretes with different strength and composition or ceramics for different purposes) and the presence of subcomponents. Due to that reason, it is essential to follow an intensive control over the whole process from source to the end use. At this point, prefabrication presents clear advantages because allows a high control level in every phase of manufacturing process. Several studies were carried out in different countries regarding to the use of recycled concretes in the field of precast components as for example: paving blocks [6,7], pavement flags [8,9], building blocks [10–12], kerbs and hollow blocks for flooring [13]. With the aim of doing some contribution in this field of research, in this study it was introduced the use of recycled mixed aggregates (RMA) in the manufacturing of prestressed joists for flooring systems. Both, the coarse fraction and the fine aggregate come from recycled aggregates. Different dosages have been used, in which the water/cement (w/c) ratio was modified to evaluate its influence [14]. Subsequently compression and elastic modulus tests were performed to establish some trends in the behavior of the considered concrete.

2. Materials

2.1. Cement

Cement CEM I 52.5 N was used and its main properties are shown in Table 1.

Table 1
Physical, mechanical and chemical properties of the cement.

Type of cement	CEM I 52.5 N
Nominal composition	
Clinker	100%
Addition	0%
Physical prescriptions	
Le Chatelier	0.1 mm
Setting time (initial)	200 min
Setting time (final)	270 min
Mechanical prescriptions	
Compressive strength 2 days	45.6 MPa
Compressive strength 28 days	60.3 MPa
Chemical prescriptions	
Loss on ignition	0.7%
Insoluble residue	0.2%
Sulfur trioxide SO_3	3%
Chloride	0.01%

2.2. Aggregates

Natural aggregates were obtained from limestone nature. Their properties are presented in Table 2.

Recycled concrete aggregates (RCA) used in this study come from wastes generated in a plant specialized in precast concrete products (cleaning of equipment, remains of concrete, defective components and samples) (Fig. 2a). Ceramic aggregates (RBA) come from clay bricks used in ventilation conduits (Fig. 2b).

Both types of wastes were transported separately in order to be processed in a facility specialized in the recuperation and recycling of CDWs. Small quantities of timber, plastics and steel were separated and rejected. Later the usable wastes were crushed, sieved and stored for their new use.

Table 2 presents the test results derived from the characterization of recycled aggregates considered in this study. For the mixing of new concrete in laboratory, the 0/8 mm granulometric fraction, obtained in the recycling facility, was used. Fig. 3 shows the corresponding grading curves of natural and recycled aggregates. In this study the granulometric curve for the used recycled aggregates was not reconstituted to present the same grading than natural aggregates used to prepare the control concrete. Therefore, both the workability and the ratio water/cement may be affected by this factor. No kind of chemical admixtures was added in the fabrication of these concretes.

3. Experimental program

The experimental program included six concrete series fabricated in the laboratory. One series corresponded to an ordinary control concrete with only natural aggregates. The five remaining batches were manufactured with 100% RMA but with different w/c ratios as it is shown in Table 3. RMA was obtained by mixing RCA 0/8 mm and RBA 0/8 mm with a volume proportion of 50% of each.

The control concrete dosage corresponded to that ordinarily used in the prefabrication of prestressed joists by a local specialized precast concrete company that was collaborating with the project (Table 3). This concrete had very dry consistency with a seat of 0 cm on the Abrams cone, a Vebe time between 14 and 18 s and an effective w/c ratio of 0.31. For the rest of batches the 100% of natural aggregates were replaced in volume by the RMA as above was specified. As the volume of water was a main variable to take into account, it was different for any series while the amount of cement was held constant (Table 3). In the mix corresponding to concrete C. RMA 03 it was observed the same consistency than the control concrete. So the water used in the mix was considered optimal. The procedure followed to obtain the concrete workability in the precast facility is based in the experience. It consisted in positioning a cylindrical mold (15 × 30 cm) on the surface of the equipment used to manufacture the prestressed joists. After being fixed, a third of the mold was filled with the concrete and the time taken by the water to appear on the poured mix surface was controlled. In that situation the concrete on top surface presents a characteristic brightness and the concrete mix is compacted. The consistency of concrete is appropriate, very dry, if the time taken by the concrete to be compacted after being poured in the mold is between 9 and 13 s. The procedure is repeated in the rest of two thirds of the specimen. Must take into account that vibration frequency in the machine to prepare the joists is 3500 cycles per minute. In the laboratory a similar technique was followed using a vibrating table with the same frequency. The derived values were linked with those obtained in the consistometer Vebe for the same

Table 2
Properties of the aggregates.

Property	Gravel 4/10	Sand 1	Sand 2	RCA	RBA
Water absorption [%]	1	0.6	0.5	5.77	11.21
Particle density [g/cm^3]	2.65	2.57	2.69	2.48	2.27
Los Angeles coefficient	25	–	–	30	36
Sand equivalent	–	75.5	87	86	88