INFLUENCE OF CERAMIC RECYCLED AGGREGATES ON THE PROPERTIES OF PRESTRESSED PRECAST CONCRETE ELEMENTS

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SUMMARY: This work presents the results of an experimental study performed on the mechanical behavior of concrete manufactured with ceramic recycled aggregates (CRA), from precast ventilation ducts, that once made have been rejected by defective. The ultimate objective is to use these wastes to manufacture prestressed concrete joists used in building floors. The coarse fraction and the fine fraction have been considered. The work has been carried out in three phases: characterization of the material, characterization of concrete with CRA and manufacturing and testing of prestressed joists. With the results obtained it is determined the influence of the ceramic recycled aggregate on the properties analyzed. There are not enough studies about prestressed elements that include the replacement of the aggregate in the fine fraction. In view of the results obtained could both of fine and coarse fraction can be used in these applications.

1. INTRODUCTION

Society is increasingly aware of the importance of their actions and therefore demand new proposals aimed at increasing the degree of sustainability in all its activities.

Construction is one of the main human activities where a very large volume of waste were generated. It is essential advancing the creation of new techniques and materials to make it a less aggressive activity with the environment. The term “sustainable construction” was defined in the “First International Conference on Sustainable Construction” (1994 - Florida) by C. Kibert as “the creation and responsible management of a healthy built environment based on resource efficient and ecological principles” (Kibert et al., 1994).

Construction and demolition wastes (CDW’s) constituted in 2010, in Europe, 34.4% of the total waste, which is equivalent to an amount of 860 million tons (Eurostat Yearbook, 2013) from which approximately 66% was ceramic or concrete waste (CEDEX, 2010). Although these residues are mostly inert or comparable to inert,

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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 which with suitable treatment could be reintroduced into the production process.

In the field of prefabricated components, several studies were conducted in different countries regarding to the use of recycled concrete. Such as paving blocks (Poon and Chan, 2006; Soutsos et al., 2011), pavement flags (Soutsos et al., 2012; Jankovic et al., 2012), building blocks (Soutsos et al., 2011; Xiao et al., 2011), kerbs and hollow blocks for flooring (López et al., 2013).

In the study here presented was introduced the use of ceramic recycled aggregates (CRA) in the manufacture of prestressed joists for flooring systems. It has replaced both the coarse fraction and the fine fraction of natural aggregates (González-Corominas and Etxeberría, 2014). Should be noted that, at present, the rules in force in Spain (EHE-08, 2008) prohibits the use of recycled aggregates in prestressed elements.

2. CHARACTERIZATION OF THE MATERIAL

Cement used for specimens and joists was CEM I 52.5 N. Its 2 days compressive strength is 45.6 MPa and 28 days compressive strength is 60.3 MPa. Cement used for nerve-beams was CEM III 42.5 N/SR. Its 2 days compressive strength is 20.7 MPa and 28 days compressive strength is 56.2 MPa.

Natural limestone aggregates have been used. Their properties are listed in Table 1. Grading curves of natural and recycled aggregates are shown in Figure 1.

Ceramic recycled aggregates (CRA) come from clay ceramic blocks used in the construction of ventilation ducts (Figure 2a) that once made have been rejected by defective (Pérez, 2011). The original parts are manufactured under industrial quality controls and not used in any work. By this fact the presence of unusable elements is reduced. The ceramic elements are processed in a recycling plant (Figure 2b) to reduce them and classify them by screening. Thus the appropiate particle size distributions are obtained (Figures 2c and 2d).

In order to characterize the material, granulometry (UNE 933-1), water absorption and density (UNE 1097-6), Los Angeles coefficient (UNE 1097-2) and sand equivalent (UNE 933-8) were determined. These properties are shown in Table 2.

Table 1: Properties of aggregates

Property	*STANDARD*	*Natural gravel 4/10 mm*	*Washed sand 0/4 mm*	*Sand 0/4 mm*
Water absorption [%]	EN 1097-6	1	0.6	0.5
Particles density (□ssd) [g/cm3]	EN 1097-6	2.65	2.57	2.69
Los Ángeles coefficient	EN 1097-2	-	-	-
Sand equivalent	EN 933-8	-	75.5	87

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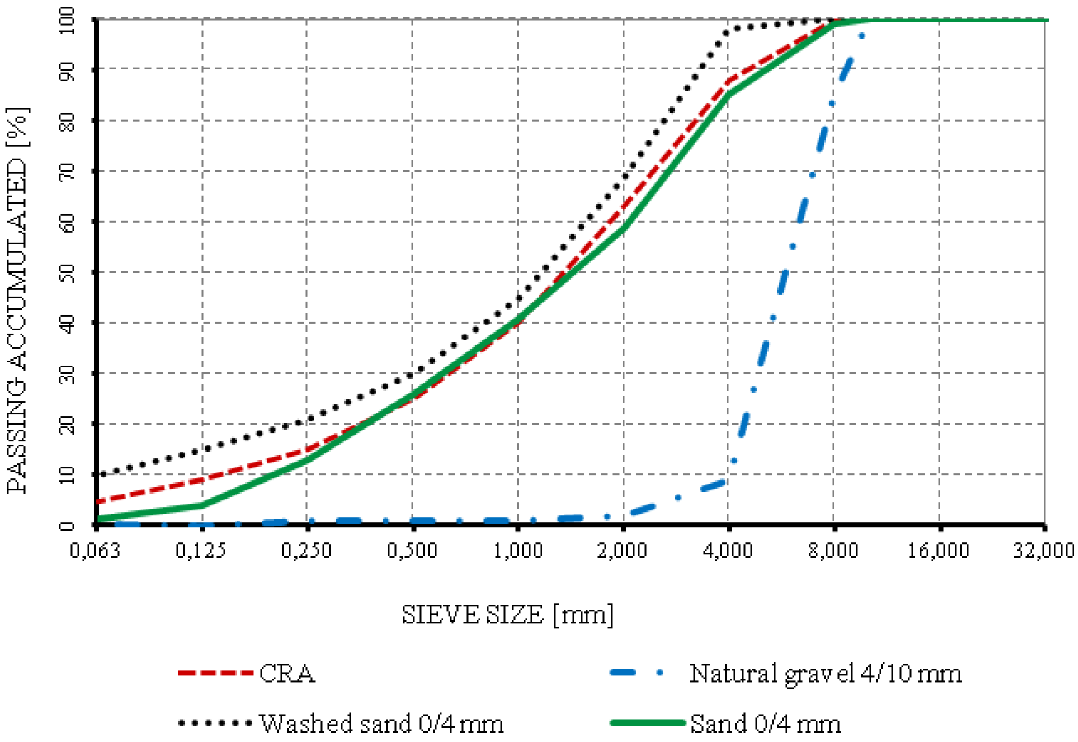


Figure 1: Grading curves of natural and recycled aggregates

Table 2: Properties of CRA by size

Property	*STANDARD*	*CRA 4/31.5 mm*	*CRA 0/4 mm*
Water absorption [%]	EN 1097-6	14.5	10.8
Particles density (□ssd) [g/cm3]	EN 1097-6	2.21	2.31
Los Ángeles coefficient	EN 1097-2	36	36
Sand equivalent	EN 933-8	-	88

2a.- Ceramic wastes

2b.- Recycling plant

2c.- Waste processed

2d.- Detail of particle size

Figure 2: Waste processing

3. CHARACTERIZATION OF CONCRETE WITH CRA

It proceeded to characterizing physical and mechanical the concrete made with recycled aggregates ceramic (CRA). The substitution of natural aggregate by the CRA was made in volume. The substitution levels were 20%, 35%, 50%, 70% and 100%. A control batch was made with natural aggregates.

The control concrete dosage corresponds to that used in the prefabrication of prestressed joists (Table 3). The concrete is dry consistency (Figure 3a) with a seat 0-2 cm on the Abrams cone (UNE-EN 12350-2) and a water/cement ratio of 0.355. In the other batches the natural aggregate was replaced by the CRA in the indicated percentages.

Table 3: Mix proportions per m^3 of concrete

Substitution	*Cement*	*Water*	*Natural grave 4/10 mm*	*Washed sand 0/4 mm*	*Sand 0/4 mm*	*CRA*
[%]	*[kg/m3]*	*[l/m3]*	*[kg/m3]*	*[kg/m3]*	*[kg/m3]*	*[kg/m3]*
0	400	142.0	810.0	1158.0	70.0	0.0
20	400	176.5	648.0	926.4	56.0	307.6
35	400	202.4	421.2	602.2	36.4	538.3
50	400	228.2	210.6	301.1	18.2	769.1
70	400	262.7	63.2	90.3	5.5	1076.7
100	400	314.4	0.0	0.0	0.0	1538.1

The manufacturing of cylindrical specimens of 15 cm diameter and 30 cm in height (Figure 3b) was carried out compacting it using a shaking table. The samples were removed of its mould after 48 h and introduced in a curing chamber for 28 days at 20 ° C and a relative humidity of 95%. Subsequently the concrete density (UNE-EN 12390-7) and water absorption (UNE-EN 13369:2013) were determined (Figure 4). Compressive strength tests were performed (UNE-EN 12390-3) (Figure 5) and tensile splitting strength was determined (UNE-EN 12390-6).

The average values obtained are shown in Table 4. Comparative graphics are shown in Figure 6.

Table 4: Properties of hardened concrete

Substitution	*Density*	*Water absorption*	*Compressive strength*	*Tensile splitting strength*
[%]	*[kg/m3]*	*[%]*	*[MPa]*	*[MPa]*
0	2383	*5.00*	63.6	3.95
20	2338	*5.90*	55.6	4.32
35	2250	*8.00*	51.3	3.75
50	2231	*10.90*	59.0	2.92
70	2154	*11.10*	46.8	3.47
100	1999	*14.70*	40.1	2.77

3a.- Abrams cone

3b.- Cylindrical specimens

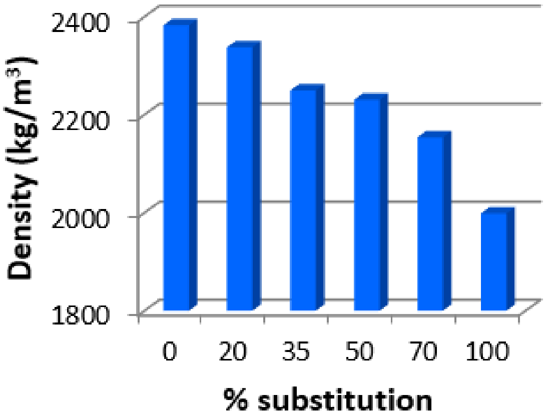
Figure 3: Manufacturing of concrete

Figure 4: Water absorption test

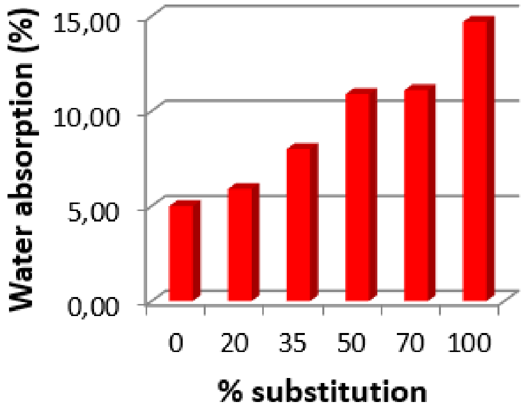
5a.- Start

5b.- End

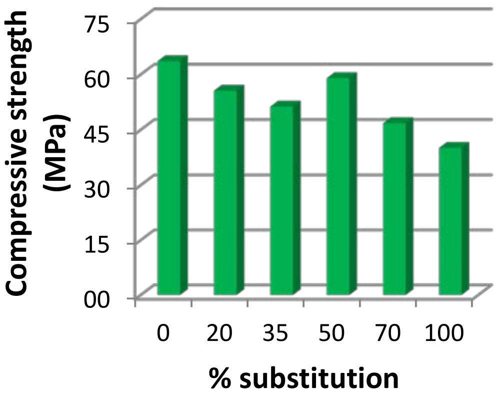
Figure 5: Compressive strength test



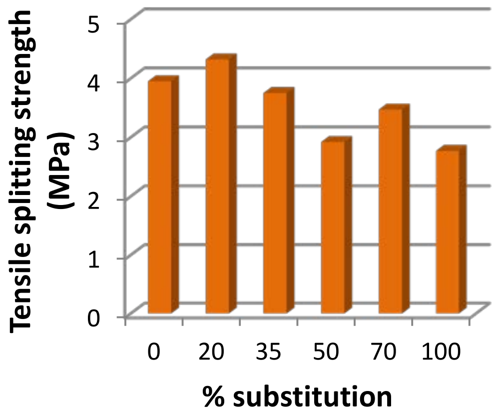
6a.- Density



6b.- Water absorption



6c.- Compressive strength



6d.- Tensile splitting strength

Figure 6: Properties of hardened concrete. Comparative graphics

4. MANUFACTURING AND TESTING OF PRESTRESSED JOISTS

In the last stage four sets of prestressed joists with different substitution levels, and a series of natural aggregate control were made.

The joists were manufactured on the premises of a precast concrete specialized company that collaborate with the project (Figure 7). It used the dosage that reflected in Table 3.

The manufacturing process involves extending prestressing cables along a prestressing bed. The prestressing cables were fixed at the ends and then they were tensioned by hydraulic jacks. A machine on rails poured concrete by vibrocompaction. After reaching the minimun resistance for concrete, the prestressing is transferred by cutting the cables.

Prestressed joists with inverted-t section were made (Figure 8a), of 110 mm of width and 105 mm in height. The prestressing comprises three prestressed cables placed in the F4 and F1 positions (Figure 8b), of 5 mm diameter, Y1770C steel with 1600 N/mm^2 of yield strength. Prestressing parameters are shown in Table 5.

During manufacturing process of the prestressed joists, an excess water respect to the dosage of 35% replacement percentage was detected.

In order to compare the effect of the percentage of substitution on the behavior of the entire section two nerve-beams for each percentage of substitution were made. It considered 200 cm on length, 20 cm in height and 70 cm of width in the upper.

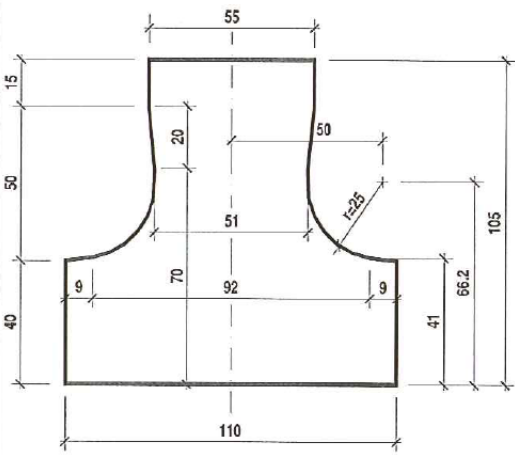
7a.- Manufacturing process

7b.- Joists detail

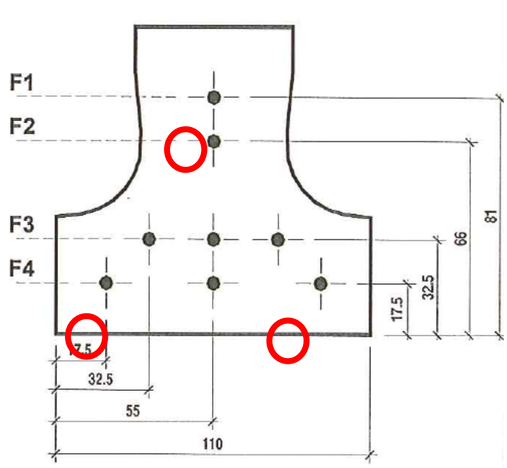
Figure 7: Prestressed joists manufacturing

Table 5: Prestressing parameters

Initial tension [Mpa]	1350
Total losses [%]	28,8
Minimun resistance for tansfer [Mpa]	19



8a.- Geometry



8b.- Prestressing positions

Figure 8: Joist section

Three types of tests were performed:

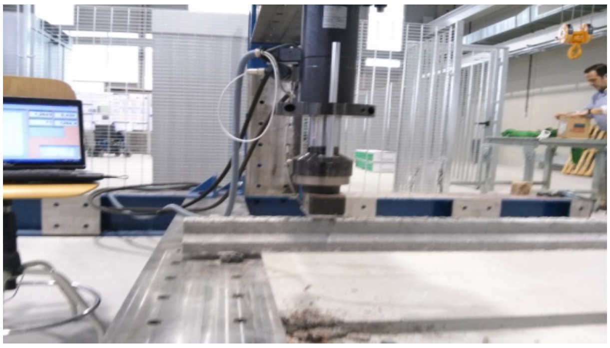
- Type 1: Test on 400 cm length joists supported at two points and under two point loads located at L / 3 from the supports till break occurs (Figure 9). Speed test was fixed in 15 N/s. Tests were performed at 90 days. The rupture occurs mainly by bending, with cracks that raise from the bottom of the joists. The cracks were located within de central third of the joist.

- Type 2: Test on 400 cm length joists supported at two points and under one point load near the support till break occurs (Figure 10). Speed test was fixed in 15 N/s. Tests were performed at 90 days. The rupture occurs mainly by shear, with cracks at 45º, from the support to the load point.
- Type 3: Test on 200 cm length nerve-beams supported at two points under one point load locates at L/2 from the supports till breaks occurs (Figure 11). Speed test was fixed in 50 N/s. The rupture occurs mainly by bending, with cracks that raise from the bottom of the nerve-beam.

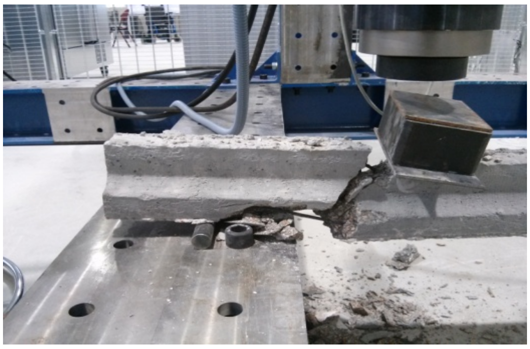
9a.- Start

9b.- End

Figure 9: Type 1 test



10a.- Start



10b.- End

Figure 10: Type 2 test

11a.- Start

11b.- End

Figure 11: Type 3 test

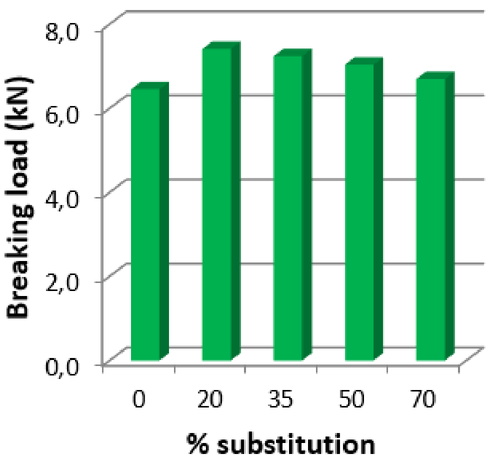
Once the tests ended, proceeded to determine the influence of the degree of substitution on the values of the breaking load. Breaking loads are shown in Table 6. Comparative graphics are shown in Figure 12.

Currently being conducted durability tests on samples of the joists subjected to various types of environment. Are also being conducted determination of resistance to freezing and thawing.

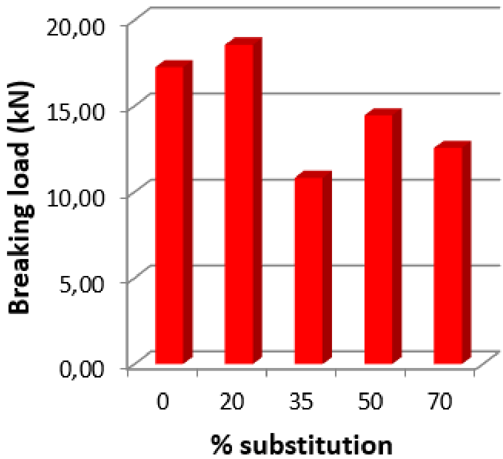
The study of long-term deflections (shrinkage and creep) of prestressed concrete with CRA are ongoing.

Table 6: Breaking loads

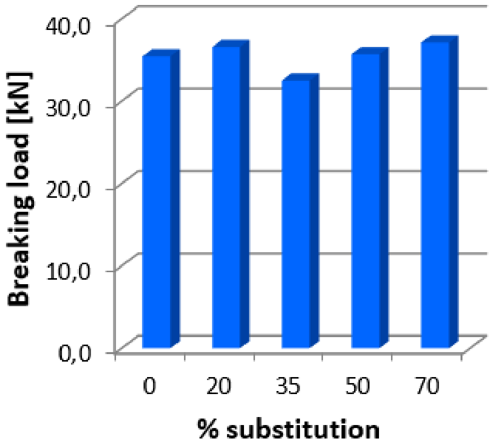
Substitution *[%]*	*Type 1 test* *[kN]*	*Type 2 test* *[kN]*	*Type 3 test* *[kN]*
0	6.5	17.3	35.448
20	7.4	18.6	36.588
35	7.2	10.8	32.516
50	7.0	14.5	35.712
70	6.7	12.6	37.114



12a.- Type 1 test



12b.- Type 2 test



12c.- Type 3 test

Figura 12: Comparative graphics

5. CONCLUSIONS

Based on data obtained from tests conducted were obtained the following conclusions:

- Density of hardened concrete is reduced with increasing degree of substitution. For substitution of 70% the reduction is 9.6%.
- Compared with natural aggregates, CRA have high percentage of water absorption. For substitution of 70% the increase is 22%.
- Compressive strength of hardened concrete is reduced with increasing degree of substitution. For substitution of 70% the reduction is 26%.
- Tensile splitting strength increases 9.4% for substitution of 20%, and it is reduced for the rest of cases. For substitution of 70% the reduction is 12%.
- Bending breaking load of isolated joist is increased with increasing degree of substitution, although there is a maximum for values of 20%. This may be because the control concrete joist could have any defect. All values obtained are higher than those declared by the manufacturer for control joist.
- Shear breaking load of isolated joist is increased 7.5% for substitution of 20% and it is reduced for the rest. For substitution of 35% the reduction is more pronounced. This may be due to

excess water during the manufacturing process. Shear breaking loads for substitution of 35% and 70% are lower than those declared by the manufacturer for control joist.
- Bending breaking load of nerve-beam presents no large variations. Only for substitution of 20% it is reduced 8.3%.

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