A SUSTAINABLE ALTERNATIVE FOR CERAMIC TILE WASTES

Debueno Pradillas, Patricia[1]; Tomás Catalán, Ana Ester[2]; Reig Cerdà, Lucía[2]; Pitarch Roig, Ángel[2]; Palencia Guillén, Juan José[2]

[1]Higher School of Experimental Science and Technology – Technical Architecture - Universitat Jaume I – Spain

[2]Department of Mechanical Engineering and Construction- Universitat Jaume I- Spain

1. ABSTRACT

Ceramic tiles are products that are widely used in the construction sector and which, at the end of their useful life, are usually deposited in landfills or, in the best of cases, used as a filling material. The analysis of alternatives that will allow the reuse of this waste material is of special interest in the province of Castellón, where there is a high concentration of companies devoted to the manufacture of ceramic tiles. This paper discusses the feasibility of using ceramic wastes as a replacement for natural aggregates commonly used in the manufacture of structural concrete.

Firstly, the physical properties of ceramic aggregates were compared with those of natural limestone aggregates, determining, in order to do so, the particle size distribution, water absorption and true and bulk densities of both types of aggregate. Concrete was then mixed with natural aggregate (control mix) and with percentages of replacement of natural aggregate with ceramic tile waste of 20% and 30%. The workability of the fresh concrete was determined, as well as compressive strength after 28 days curing at room temperature.

The results obtained indicate a higher content of fine material in the ceramic aggregates, as well as a greater water absorption, resulting in a loss of workability on replacing natural aggregates with ceramic wastes. In spite of this, the concrete

developed in the study did not demonstrate any loss of mechanical strength after 28 days curing. Therefore, the preliminary results indicate that it is possible to use ceramic tile wastes as a partial substitute for natural aggregates in structural concrete. However, future studies need to be carried out in order to evaluate the influence of these ceramic aggregates on the workability and durability of the recycled concrete developed.

2. INTRODUCTION AND BACKGROUND

The mandatory regulations at a European level relating to the management of construction and demolition waste include Directive 2008/98/CE and Directive 1999/31/CE, while on a national level we have Law 22/2011, Royal Decree 105/2008 and Order MAM/304/2002. In the case of the Valencia Region, there are no specific compulsory regulations governing the management of construction and demolition waste, although the standards applicable in Catalonia and Madrid (RD 201/1994 RD or Law 5/2003 respectively) can be taken as a reference, bearing in mind their voluntary nature at all times.

In accordance with the report by the Ministry of the Environment and Rural and Marine Affairs, issued by the government of Spain in 2010, the number of recycling plants in Spain has increased, from 58 in 2006 to 120 plants registered in 2009 (1), indicating an expected increase in waste reuse.

According to data provided by the Department of infrastructures, Territory and the Environment of the *Generalitat Valenciana*, corresponding to 2013 (2), 80% of construction and demolition waste could be reused. However, only 17% of this is reused, while the remaining 83% is simply dumped in landfills.

In addition, according to the 2010 data from the Ministry of the Environment and Rural and Marine Affairs, provided by the government of Spain (1), 54% of the total waste from construction, demolition or restoration corresponds to waste from ceramic products.

Ceramic wastes are also generated during the manufacturing processes in the ceramic industry. This fact is particularly relevant in the case of Castellón, since more than 75% of the factories producing ceramic tiles and intermediate products in Spain are located in this province (data provided by the Spanish Ceramic Tile Manufacturers' Association, ASCER) (3).

Therefore reusing ceramic tile wastes in the preparation of structural concrete is viewed as an interesting alternative that makes it possible to develop a more sustainable product, by reusing ceramic waste and reducing the amount of resources consumed.

Although numerous studies have been conducted on the properties and the suitability of using different types of ceramic waste in the production of structural concrete, there is almost no information about its use as a partial substitute for natural aggregates.

3. OBJECTIVES

The aim of this paper is to study the feasibility of the use of waste from ceramic tiles as a partial substitute for natural limestone aggregates in the manufacture of structural concrete. The properties of the recycled aggregates were compared with those presented by the natural aggregates. Different percentages of replacement of the natural limestone aggregate with ceramic waste were used, and the workability and strength of the concrete produced were assessed.

4. METHODOLOGY

4.1. MATERIALS USED

Cement type CEM-II/a-l 42.5R was used to make the different concrete mixes. The water for mixing and curing came from the mains supply and polymer superplasticiser in aqueous SKP 380 solution was added as an additive.

The natural limestone aggregates used were of three different fractions: Coarse aggregate 10/20 (10/20 CAL), medium aggregate 4/16 (4/16 CAL) and fine aggregate 0/4 (washed and unwashed) (0/4 CAL).

As for the recycled aggregate, due to its proximity and the many tile industries located in the Castellón area, recycled aggregates from real ceramic tile wastes from the area, with two different particle size fractions, was used: CER 4/16 and CER 0/4. This material contained different kinds of ceramic tiles: wall tiles, stoneware tiles and porcelain tiles.

4.2. CHARACTERISATION OF THE AGGREGATES.

The following table lists the tests carried out in order to characterise the aggregates, both those from ceramic tiles and the natural ones, as well as the requirements laid down by the structural concrete instruction EHE-08 (4).

The percentages that appear throughout the paper correspond to percentages by weight.

Property	Standard. Test	EHE-08 limit values
Wear resistance (adapted)	UNE-EN 1097-1 Tests for mechanical and physical properties of aggregates. Part 1: Determination of the resistance to wear (Micro-Deval).	-
Particle size distribution	UNE-EN 933-1 Tests for geometrical properties of aggregates. Part 1: Determining of particle size distribution. Sieving method.	1.5%(coarse aggregate)
Percentage of fines		6-16% (fine aggregate)

Assessment of fines	UNE-EN 933-8 Tests for geometrical properties of aggregates. Part 8: Assessment of fines. Sand equivalent test.	>70 (general cond. I, IIa, IIb) >75 (any)
Bulk density	UNE-EN 1097-3 Tests for mechanical and physical properties of aggregates. Part 3: Determination of loose bulk density and voids.	-
Bulk density		-
Water absorption (coarse agg.)	UNE-EN 1097-6 Tests for mechanical and physical properties of aggregates. Part 6: Determination of particle density and water absorption.	5% <7% (substitution natural gravel less than 20%) <5% (substitution natural gravel more than 20%)
Water absorption (fine agg.)		5%
True density	UNE-EN 1097-7 Tests for mechanical and physical properties of aggregates. Part 7: Determination of the particle density of filler. Pycnometer method	-

Table 1. *Characterisation tests of natural aggregate and recycled aggregate and their limit values, according to EHE-08*

Wear resistance, according to the standard EN 1097-1 test method, was adapted both in the case of fine and coarse aggregates. A Tecnotest Micro-Deval D510 apparatus was used, in which 0.5 kg aggregate to be tested was inserted into the steel drums along with 2.5 kg of 10 mm diameter steel balls and 2.5 litres of water. In the case of the coarse aggregate, the sample between the 5 and 10 mm sieves was used, while for the fine aggregate, that between 0.125 and 2 mm was tested. After 1,500 revolutions at 100±5 rpm, the aggregates were sieved to separate particles smaller than 2 mm (coarse aggregate) and 0.063 mm (fine aggregate). The material retained by the corresponding sieve was washed and dried at 105°C to constant weight. The results are expressed as mass loss relative to the initial mass.

4.3. MIXES OF MANUFACTURED CONCRETE.

The dosages were designed to obtain a concrete with a compressive strength of about 42 MPa. The mixes were considered according to the durability criteria specified in Table 37.3.2.a of the EHE-08 (designated IIb, in Table 8.2.2 of the EHE-08) (4), according to which a minimum cement content (300 kg/m^3) and a maximum w/c ratio (0.55) were used.

In order to study the influence of the type and quantity of aggregate on the properties of the concrete, both fresh and hardened, both the water:cement ratio (w/c = 0.5) and the amount of superplasticiser (1% of the weight of cement) were kept constant, and only the amount of recycled ceramic aggregate replacing the natural aggregate was modified.

Three different mixes were prepared, their composition being indicated below: all of them contained 300 kg/m^3 cement, 150 kg/m^3 water (added directly to the mixture) and 3 kg/m^3 superplasticiser. The first of the mixes contained only natural limestone aggregate and was used as a control mix (CONT). The other two contained a 20% substitution of the limestone aggregate (all the intermediate fraction plus 6% of the finest limestone aggregate) (CER20) and 30% (all the intermediate fraction plus 16% of the finest natural aggregate) (CER30). The recycled aggregates were used as supplied.

4.4. CHARACTERISATION OF THE FRESH AND HARDENED CONCRETE

To assess both the workability and the quality of the concrete made, the tests indicated in Table 2 were conducted.

Property	Standard. Test
Workability of fresh concrete	UNE-EN 12350-2 Testing fresh concrete. Part 2: Slump test.
	UNE-EN 12350-3 Testing fresh concrete. Part 3: Vebe test.
Hardened concrete strength	UNE-EN 12390-2:2009 Testing hardened concrete. Part 2: Making and curing specimens for strength tests
	UNE-EN 12390-3:2009 Testing hardened concrete. Part 3: Compressive strength of test specimens
Fresh concrete density	UNE-EN 12390-7:2009 Testing hardened concrete. Part 7: Density of hardened concrete.

Table 2. *Test assessing the concrete made (fresh and hardened)*

The concrete was prepared according to Standard BS 1881-125:2013. While the consistency of the fresh concrete was determined using the Abrams cone (UNE-EN 12350-2) and, in the case of very dry concrete, also using the Vebe consistometer (UNE-EN 12350-3).

To determine the hardened concrete strength, cylindrical specimens were made, 15 cm in diameter and 30 cm in height, with the fresh concrete. Subsequently these specimens were demoulded and cured in a moist chamber at 20°C and 98% humidity, following the procedure established in Standard UNE-EN 12390-2.

The density and compressive strength of the specimens hardened after 28 days curing in an Ibertest MEH-300 PT/W test machine, were determined in accordance with UNE-EN 12350-3.

5. RESULTS AND DISCUSSION

5.1. PHYSICAL AND MECHANICAL PROPERTIES OF THE AGGREGATES.

Although the aggregates do not intervene in the setting and hardening of concrete they play an important role given that they occupy about 80% of the volume of the concrete.

The natural aggregates used in the manufacture of structural concrete, usually limestone in the Valencia Region, have to comply with the limitations provided for in Chapter 28 of the Instruction on Structural Concrete, EHE-08 (4). Recycled aggregate is considered as being all that arising from the demolition of healthy structural concretes and high-strength concretes. In any case, it should always be confirmed that they meet the specifications of Standard EHE-08, Appendix 15 (4). Recycled concrete should be manufactured using recycled aggregates together with either rolled or crushed natural aggregates. Standard EHE 08 indicates that the recommended amount of recycled aggregate for concrete manufacturing must be no more than 20% of the coarse aggregate, and in case of using a larger amount than this, precautions need to be maximised while making the concrete, because of the large amount of impurities that these aggregates may contain.

The particle size distribution and the fineness modulus (FM) of natural limestone aggregates (CAL) and those from ceramic tiles (CER) are shown in Figure 1.

A great similarity can be seen in the curves for the finest fractions of natural aggregates and the recycled ones. It can also be observed that the curve for the intermediate limestone aggregate is quite similar to that of the coarse fraction of the recycled aggregate. In both cases, the recycled aggregates display a greater quantity of particles smaller than 0.063 mm.

The fineness modulus (FM) for the recycled coarse aggregate is very close to the natural medium-size aggregate and also those of the finest fractions of both types of aggregate.

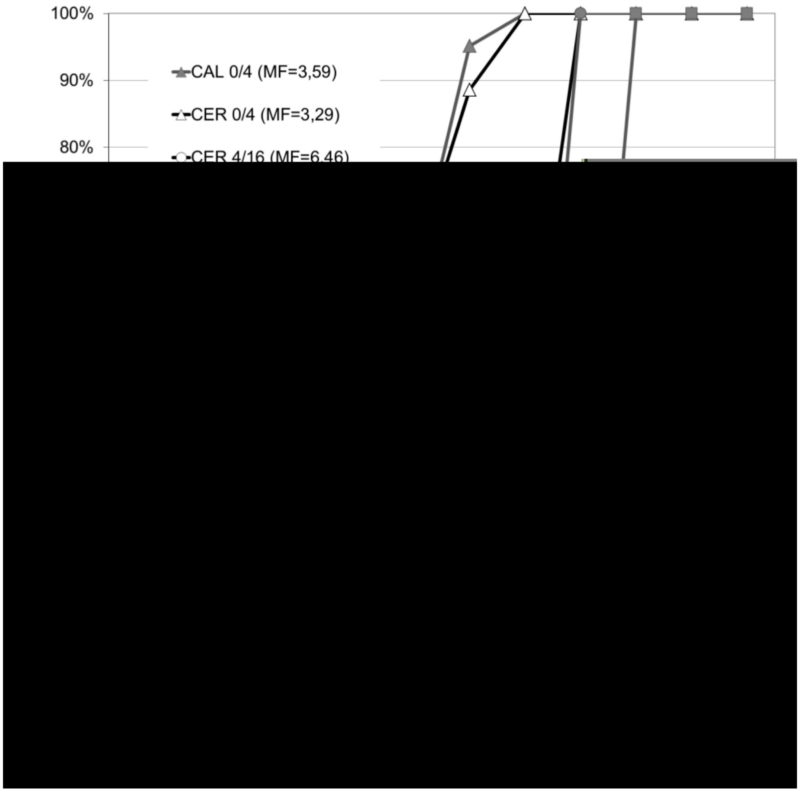

Figure 1. *Particle size distribution curves and fineness modulus for the aggregates.*

As can be seen from the curves, the CER 0/4 ceramic aggregate fraction contains a large amount (7.55%) of particles smaller than 0.063 mm, while the percentage of fine limestone aggregates was less than 0.02% for the CAL 4/16 and CAL 10/20 fractions, and 3.92% for CAL 0/4. All the values meet the specifications established by Table 28.4.1.a of the EHE-08 instruction for natural aggregates in any kind of environmental exposure (> 1.5% for coarse aggregate, > 6% for fine aggregate), with the exception of the lowest fraction of the recycled aggregate. In view of this result, the recycled aggregates of a smaller size have a limited use (they should not be used in marine environments, in the presence of chlorides or in specific kinds of exposure: IIIa, IIIb, IIIc, IV, Qa, Qb, Qc, H, F y E) (Tables 8.2.2 and 8.2.3a, EHE-08).

Other physical and mechanical properties of the recycled aggregates and the medium and fine fraction of the limestone aggregates (which have a particle size distribution similar to that of the recycled aggregates) were also analysed, and are shown in Table 3.

The true and bulk densities of the limestone aggregates are greater than those corresponding to the aggregates from ceramic tiles, due to the high porosity of the latter. The opposite occurs with the results obtained for water absorption: that of the recycled aggregates is greater than the limestone aggregates, with the difference being most notable in the case of the finest fractions. We can attribute the difference to both the high porosity and to the large amount of fines (which increase the absorption surface) in ceramic tile wastes.

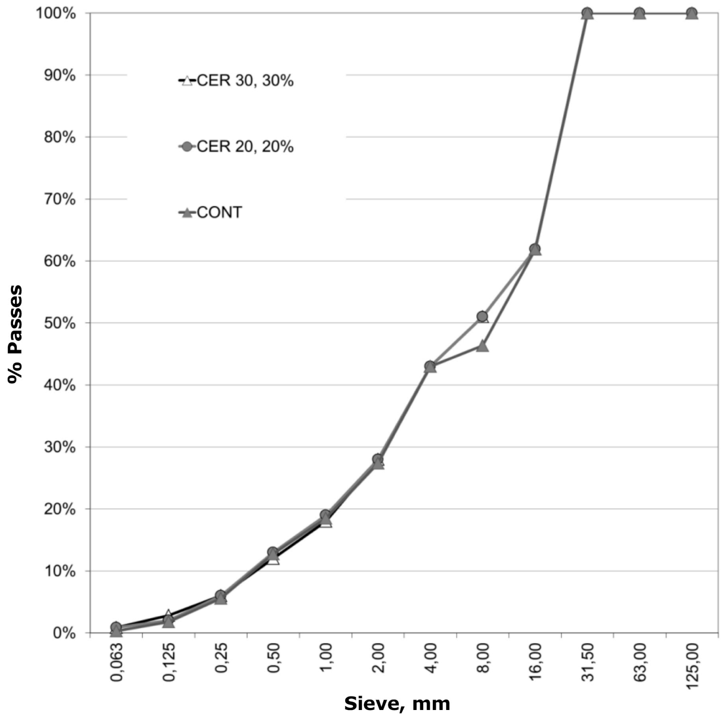

Figure 2. *Particle size distribution of the mixtures of aggregates*

5.3. CONSISTENCY OF THE FRESH CONCRETE

The consistency data were measured using the Abrams cone and, in cases in which the mixture was very dry, also with the Vebe consistometer. The results of both tests are shown in Figure 3: for each mix the Abrams cone test is presented together with the Vebe consistometer test. The workability of the concrete decreases as the amount of recycled aggregate is increased, which can be attributed to a greater water absorption and a higher percentage of fine particles, in the pastes with the highest percentage of ceramic aggregate.

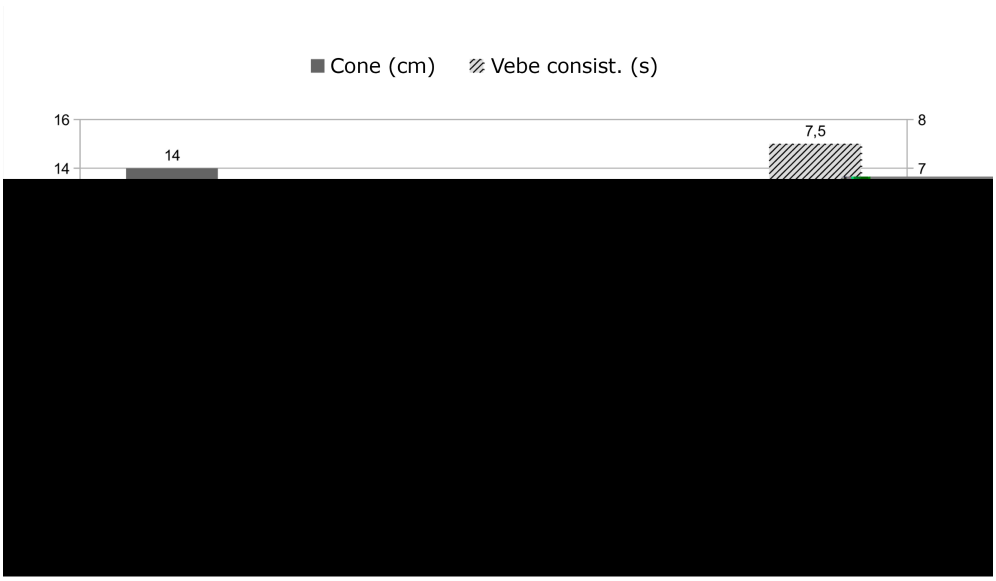

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Figure 3. *Consistency of the fresh concrete*