REUSE OF CERAMIC WASTE AS RECYCLED AGGREGATE IN CEMENT MORTARS

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1. ABSTRACT

The construction sector produces a large amount of waste every year, of which more than half is ceramic-type waste (bricks, tiles, etc.). Therefore, the analysis of alternatives that provide new uses for this waste is of great interest.

The aim of this study is to analyse the viability of using three different ceramic waste products (bricks, ceramic tiles and sanitary ware) as substitutes for natural aggregate in cement mortars. The various wastes were powdered, sieved and remixed to adjust their granulometric distribution to that of standardised sand. The density, water absorption and friability of the aggregates used were determined and later, cement mortars were prepared in accordance with regulation UNE-EN 196-1. The mortars were prepared with silica sand and each type of ceramic waste, with percentages of substituted natural aggregate of 0, 25, 50, 75 and 100%. They were cured in a humidity chamber at room temperature for 7, 28 and 90 days.

All of the mortars produced, in particular those using recycled ceramic aggregate, showed a reduction in density as the percentage of substituted natural aggregate increased, which is due to the lower density of recycled aggregates compared to natural silica sand. Despite the compressive strength of the mortars produced with recycled brick aggregate being slightly lower than that of the control mortar after 28 days of curing (reduction of up to 17.3% for 100% substitution), their compressive strength was greater after 90 days of curing, showing an increase in strength of approximately 15% compared to the control mortar, for an optimum substitution percentage of 50%. The mortars with up to 75% of recycled aggregate from ceramic tile or waste sanitary ware showed compressive strength similar to or slightly greater than the control mortar after 28 days of curing. This tendency was not sustained for longer curing times in the mortars using tile waste, whereas in the case of sanitary ware, its strength increased progressively with the percentage of natural aggregate substituted for recycled aggregate, up to an increase of 10% for 100% substitution.

Despite the three types of waste having different properties, the development of the recycled mortars' compressive strength along with the percentage of silica sand substituted for recycled ceramics was similar after 90 days of curing. The results obtained allow us to conclude that the tested ceramic waste can be sufficient for conventional uses of cement mortars.

2. INTRODUCTION

There is an abundance of mandatory regulations relating to construction and demolition waste management, both on a European as well as on a Spanish level: Directive 2008/98/CE, Directive 1999/31/CE, Law 22/2011 and its amendments in Law 5/2013, Royal Decree 105/2008, Order MAM/304/2002. In the case of the Autonomous Community of Valencia, there is also Decree 200/2004, which regulates the use of inert waste. This regulation provides the definition of Construction and Demolition Waste (CDW), as well as authority over the control of its production and management.

Despite the fact that the generation of CDW in Spain decreased by 56% from 2009 to 2013, according to the CDW Report produced by the Spanish Federation of CDW Management Companies for that period (1), in 2013 it was observed that production of this waste was stable and had an upward tendency, which is verified in the Report on CDW Production and Management from 2011 to 2015 (2). Furthermore, a noticeable increase was observed in the number of CDW recycling plants in Spain: from 61 in 2006, according to the Integrated National Waste Plan (PNIR) 2008-2015 to 386 in 2013 (data from the National Framework Plan for Waste Management (PEMAR) for the period 2016-2022 (3)). In addition, this same source records the objectives to be achieved by 2020, regarding the recycling of CDW, which are 70%.

In terms of the composition of this type of waste, over 50% is from ceramic products, according to the CDW technical sheet from CEDEX (4). Ceramic waste is also generated during the manufacturing process in the ceramic industry. This fact is particularly relevant in the case of Castellón, as according to ASCER (5), 80% of Spain's ceramic covering companies are located in this province.

All of this makes the reuse of ceramic waste products an interesting alternative for more sustainable construction by reusing ceramic waste and reducing the amount of natural resources consumed. Although CDWs are being used increasingly in construction, they are mostly used in levelling, by road companies or for the manufacture of concrete (4). By contrast, there are few studies proposing its use for the manufacture of mortars. In addition, the few existing studies are limited to 7 and 28 days of curing. The aim of this study is to analyse the viability of creating cement mortars that partially substitute natural aggregates for waste products from ceramic tiles, bricks and sanitary ware.

3. MATERIALS AND METHODOLOGY

3.1. MATERIALS USED

For the manufacture of the different mortars, the dosages and materials defined in regulation UNE-EN 196-1 were used as a reference for the determination of the mechanical strength of the cements, using a CEM-I 42.5R type cement, supplied by the company CEMEX. The mixing and curing water came from the supply network.

Natural silica sands were used with three different commercial fractions: Aggregate 0.2/0.6, aggregate 0.6/1.2 and aggregate 1.2/2.0. These fractions were combined to obtain a mix with a similar granulometric curve to standardised aggregate, defined in regulation UNE-EN 196-1.

Recycled aggregates, from three types of waste, were used: ceramic tiles from the area (waste from tiles, stoneware and porcelain stoneware), ground bricks and sanitary ware. The various wastes were ground, sieved and reduced to three granulometric fractions, which were later combined to obtain granulometric curves similar to those of natural aggregate.

3.2. CHARACTERISATION OF AGGREGATES

Although aggregates do not affect the curing and hardening of cement mortar, they have an important role as they transmit charges from the hardened mortar and reduce the retraction of the mix.

Both the mix of natural silica sands as well as those corresponding to the three types of waste were subjected to the characterisation tests indicated in table 1.

Property	Regulation. Test
Resistance to fragmentation	UNE 83115 Measure of the friability coefficient of the sands
Water absorption	UNE-EN 1097-6 Tests for determining the mechanical and physical properties of the aggregates. Part 6: Determination of the particle density and water absorption
Particle density	UNE-EN 1097-7 Tests for determining the mechanical and physical properties of the aggregates. Part 7: Determination of the particle density of the filler. Pycnometer method

Table 1. *Characterisation tests for silica sand and recycled aggregates.*

3.3. COMPOSITION AND CHARACTERISATION OF CEMENT MORTARS

All of the cement mortars were prepared by mixing cement, aggregate and water, in the proportions 1:3:0.5, according to the procedure indicated in regulation UNE-196-1.

In order to evaluate the influence of the quantity and type of ceramic waste on the mortars' strength, the total amount of aggregate was kept the same in each of the mixtures, varying the substitution percentage of the waste being used. A control mixture was made (CON) which acted as a reference mortar, with only silica sand and the dosage: 450 g cement, 1350 g aggregate and 225 g water. Table 2 shows the nomenclature used, as well as the percentages of the natural aggregate substituted for each of the wastes.

Given that there are important differences between the absorption coefficient of natural aggregate and those of the wastes, corrections were made to the amount of water in each mixture, maintaining the effective water/cement ratio constant and equal to 0.5.

AGGREGATE	% SUBSTIT.	CEMENT(g)	SILICA SAND (g)	RECYCLED AGGREGATE (g)
SILICA	0	450	1350	0
TILE	25		1012.5	337.5
	50		675	675
	75		337.5	1012.5
	100		0	1350
BRICK	25		1012.5	337.5
	50		675	675
	75		337.5	1012.5
	100		0	1350
SANITARY	25		1012.5	337.5
	50		675	675
	75		337.5	1012.5
	100		0	1350

Table 2. *Proportions of aggregates in the cement mixtures.*

The quality of the mortars obtained was evaluated using the determination of the properties appearing in table 3, using the mortar without substituted aggregate as a reference.

Property	Regulation. Test
Density of hardened mortar	Weight/volume ratio
Mortar performance: Bending strength Compressive strength	UNE-EN 196-1 Determination of mechanic strengths

Table 3. *Properties of the mortars.*

The density of the hardened test pieces was determined for each of the amounts, as a ratio of their weight and volume, after 7, 28 and 90 days of curing.

The performances of the hardened cement mortars were determined using the bending and compressive strength tests, in a MEH-300 PT/W test machine from Ibertest, at 7, 28 and 90 days of curing in a humidity chamber, in standard conditions (20ºC and immersed in water). The procedure used was the one indicated in regulation UNE-EN 196-1.

The results are expressed as strength increase (GR, %) compared to the reference mortar, calculated according to [Equation 1].

$$GR(\%) = \frac{\sigma RC - \sigma CON}{\sigma CON} \cdot 100 \qquad \text{[Equation 1]}$$

Where σ_{RC} is the compressive strength of the mortar made with ceramic waste and σ_{CON} is the compressive strength of the reference mortar. In all cases, the compressive strength is the result of the average of the individual results of the 6 test pieces obtained from the same mixture. In addition, the standard deviation of these individual values was calculated.

4. RESULTS AND DISCUSSION

4.1. CHARACTERISATION OF THE AGGREGATES

4.1.1 GRANULOMETRIC DISTRIBUTION OF THE AGGREGATES

The composition of the silica sand mixture to be used was obtained by combining the three fractions of commercial aggregate, based on their corresponding granulometric distributions. The granulometric distributions of the ceramic wastes were obtained in the same way. Figures 1 and 2 show the baseline fractions as well as the resulting mixtures in both cases.

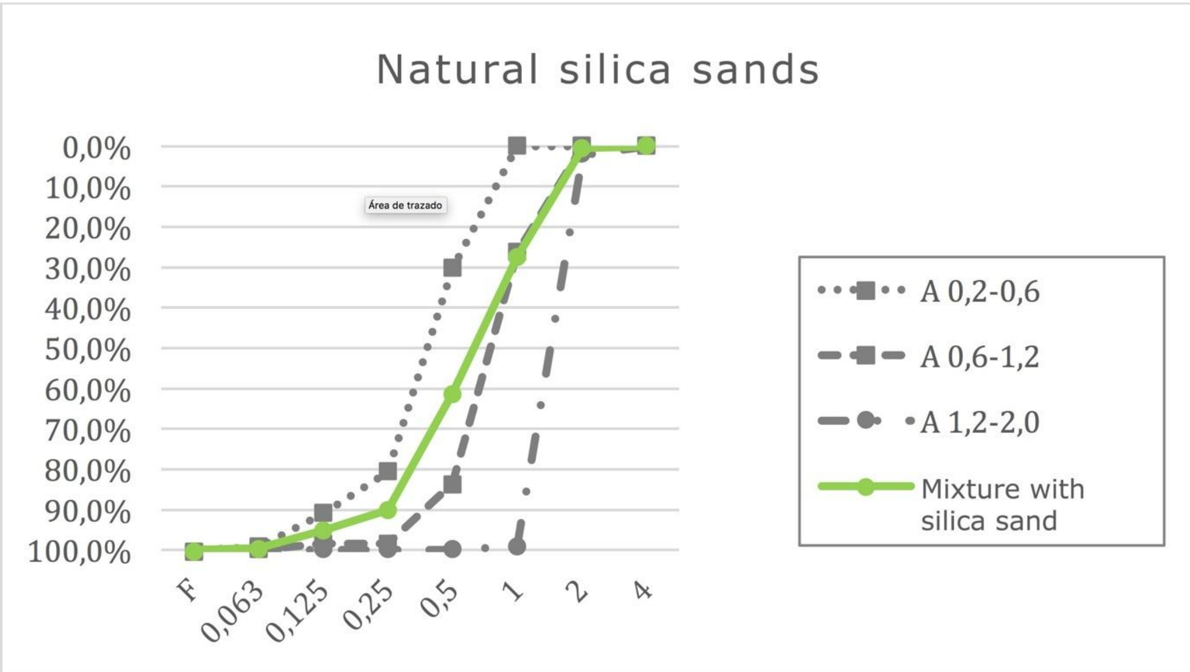

Figure 1. *Granulometries of the fractions of* ***commercial aggregate*** *and the mixture.*

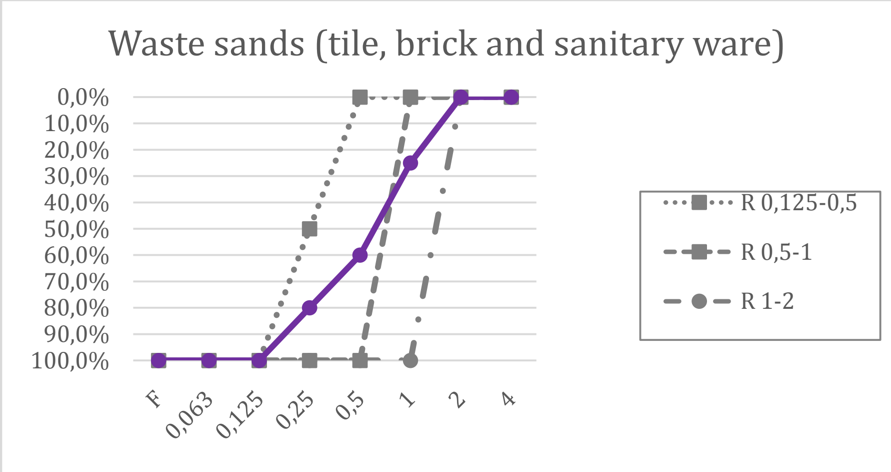

Figure 2. *Granulometries of the fractions of* ***waste*** *and the mixture.*

Figure 3 shows the granulometric distribution of the standardised sand, compared to the curves corresponding to the mixtures with silica sand and with ceramic residues. It can be noted that the curves are largely similar, those of standardised sand and the recycled aggregate being the most similar.

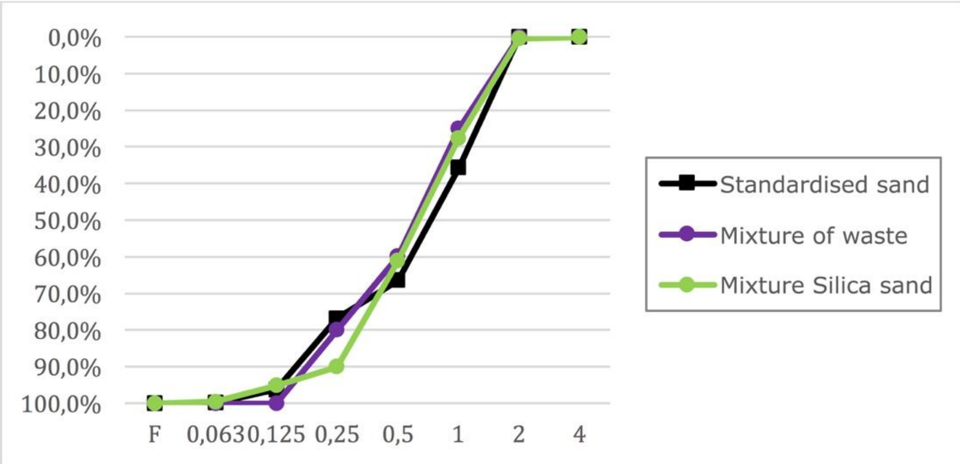

Figure 3*. Granulometric curves of the different aggregates.*

4.1.2 PHYSICAL-MECHANICAL PROPERTIES OF THE AGGREGATES

The results corresponding to the resistance to fragmentation (friability) are shown as a % of loss of mass during the test. As shown in Figure 4, the ceramic tile and brick wastes showed a loss of weight four times greater than the commercial silica sand, while in the case of sanitary waste, the percentage of weight loss only doubled.

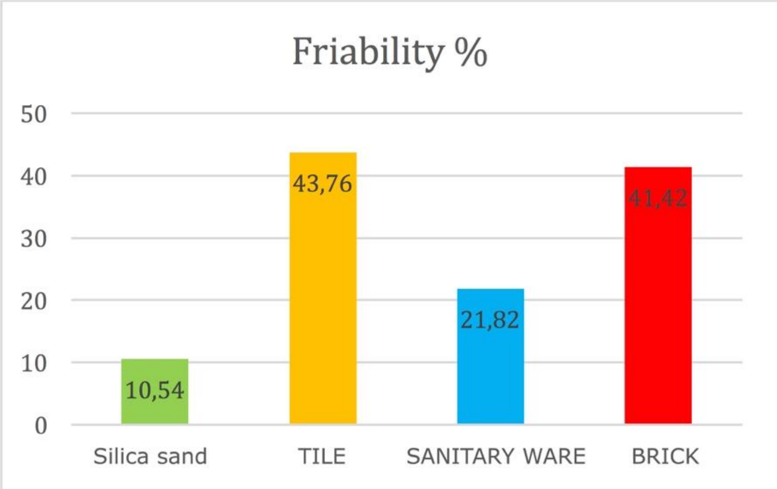

Figure 4. *Friability coefficient of the various aggregates*

The absorption coefficient of each of the aggregates is shown in (Table 4). . The results obtained indicate that the least porous waste of the three comes from sanitary ware. These values were used to make the water corrections to the mixtures.

Material	Absorption coefficient (%)
SILICA SAND	0.8
TILE	15.2
SANITARY	7.3
BRICK	17.3

Table 4*. Absorption coefficient of the aggregates.*

The particle density of the silica sand was greater than those of any aggregate coming from waste, as shown in Figure 5. Among these, the lowest was from the brick waste, due to its high porosity.

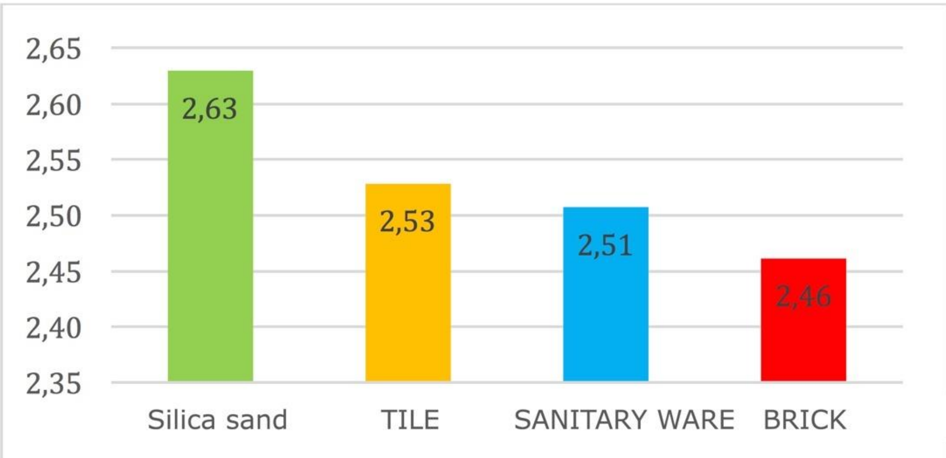

Figure 5. *Particle density of the aggregates (g/cm^3).*

4.2. PROPERTIES OF THE HARDENED CEMENT MORTARS

The performances of the fabricated mortars were evaluated by determining the bending and compressive strengths and density after different curing times:

Density of the hardened mortar.

In Figure 6, it can be observed that the density of all of the mortars reduced when the percentage of substituted aggregate for waste increased, the reduction being greater in the case of brick waste and the least affected being the mortars made with sanitary ware. This data is in accordance with those obtained for the particle density of the wastes: the brick was the waste with the lowest particle density of the three. For the tile and sanitary ware wastes, with similar particle densities, a similar variation was observed in the densities of the corresponding mortars.

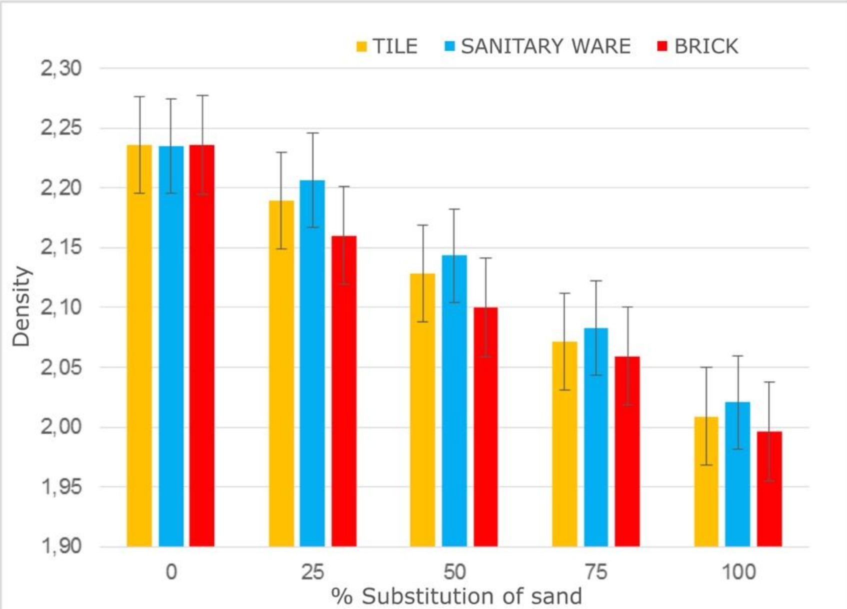

***Figure** 6. Density of the cement mortars*

4.2.2 BENDING STRENGTH OF THE HARDENED MORTAR

The bending strength of each of the dosages and ages (7, 28 and 90 days of curing) was determined as an average value of the three test pieces from each of the mixtures.

Given the scatter usually resulting from bending strength tests, it can only be concluded that with the passing of time an increase in strength is produced and that the results of the mortars with sanitary ware waste are greater than the others.

4.2.3 COMPRESSIVE STRENGTH OF THE HARDENED MORTAR

After the bending strength tests, the compressivestrength of the mortars was evaluated for each of the indicated curing durations. The discussion of the results focused on those of compressive strength, due to their lower spread and, therefore, greater representativeness: the bending strength values were lower and very sensitive to any variation of the test pieces.

Figures 7, 8 and 9 show the increase in compressive strength (% GR) obtained for each type of waste, based on the age at testing and the percentage of substitution of silica sand. The strength of the control mortar was taken as a reference for each age.

The three graphs show that, although the compressive strength of the mortar without substitution (control) at 7 days was greater than the other test pieces, as the curing age increased, this tendency changes.

In the case of the mortars developed with partial substitution of the aggregate for **tile waste** (Figure 7), at early ages there were significant losses in strength with the substitution of the aggregates, however at 28 days of curing the mortars with 25% and 50% of the substituted aggregate gave strengths greater than or similar to those of the control mortar. After 90 days of curing, the mortars with greater than 25% of substituted aggregate lost around 20% strength compared to the control at the same age.

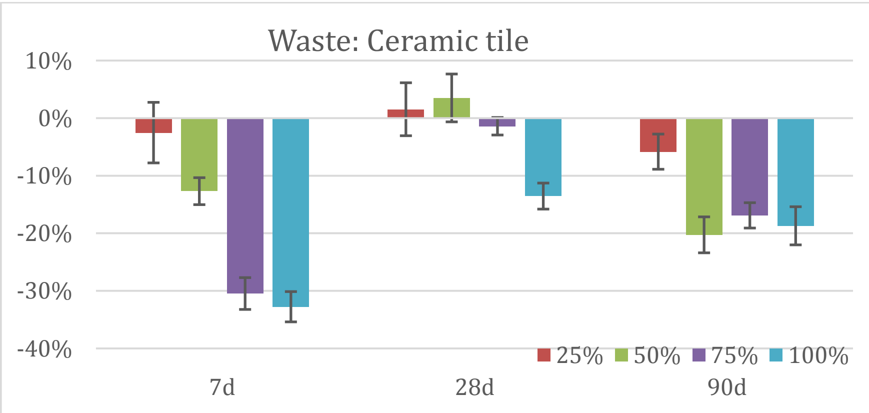

Figure 7. *Increase in compressive strength (%GR) at different ages*

Regarding the mortars made using different percentages of **waste sanitary ware** (Figure 8), they showed a fairly similar behaviour to those of the tiles at 28 days, whereas after 90 days of curing, the results obtained surpassed the strength values of the control mixture. From this it is deduced that these wastes cause an increase in strength in the long term of around 10%, even by substituting 100% of the aggregates.

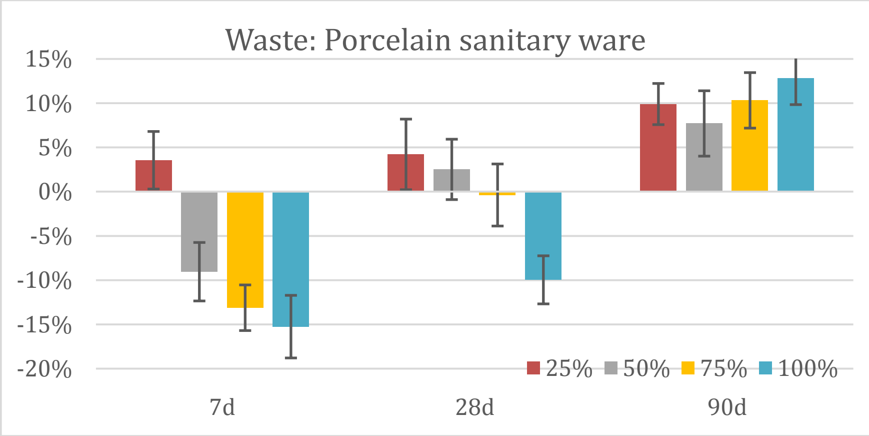

Figure 8. *Increase in compressive strength (%GR) at different ages*

Lastly, for the mortars developed by substituting the silica sand for **brick waste (**Figure 9), it can be observed that after 7 and 28 days of curing, the mortars with substitutions did not reach the compressive strength of the control, although at 28 days those with 25% waste material showed similar results to the control mortar.

However, after 90 days, all of the mortars with substitution of silica sand for brick waste gave greater results than those of the control, between 7% and 12%, those with 50% substitution being those that led to the optimum result.

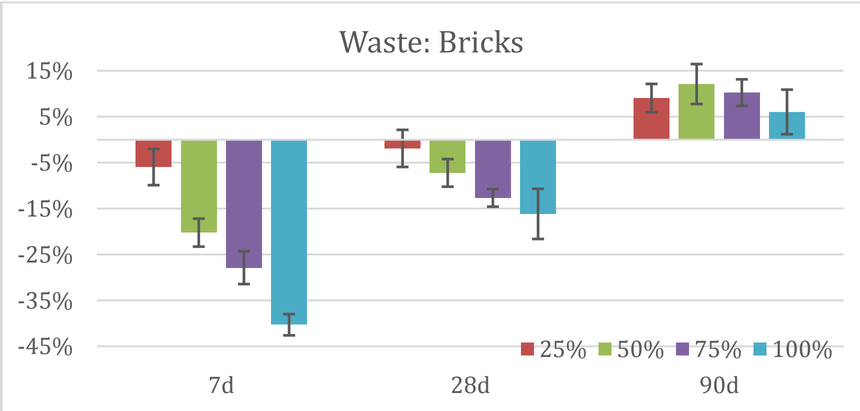

Figure 9. *Increase of compressive strength (%GR) at different ages*

5. DISCUSSION AND CONCLUSIONS

This study characterised aggregates from grinding three waste materials: ceramic tiles, bricks and porcelain sanitary ware, determining their densities and mechanical properties. Next, they were used as a substitute for natural aggregates in the manufacture of cement mortars, obtaining the following results:

1) The use of ceramic waste in the manufacture of mortars caused a reduction in the density of the mortar compared to that made with silica sand aggregates. As has been proven, this reduction is due to the particle densities of the wastes being lower than those of silica sand. This reduction in density was already observed by other authors such as Zhao et al. (7).

2) From the three characterised wastes, waste porcelain sanitary ware showed a particle density and physical-mechanical properties (friability, water absorption) most similar to silica sand, while brick waste was the most different.

3) Generally at **early ages (7 days)**, the substitution of the aggregates causes a loss of strength of the mortars tested: reduction in strength of between 15% and 40% compared to the strength of the reference mortar. At these ages the components of the mortar are beginning to hydrate.

   It is worth indicating that with substitution percentages of 100% of the aggregates at this age, the brick waste produced a reduction in strength of 40%, 33% for ceramic tiles and just 15% for porcelain sanitary ware, compared to the strength of the control at this age.

4) At **28 days of curing**, low percentages of aggregates substituted for waste do not result in a significant loss of strength in the resulting mortars: losses of strength were recorded of between 10% and 15% for 100% substitution of the aggregates in the case of any of the wastes, however with substitutions of 25% or 50% slight strength increases were recorded in all three cases.

   This result matches those obtained by J. Silva et al. (6) for mortars made partially with brick waste.

5) With the passing of time, the compounds become better hydrated, which is shown in an improvement in strength of all of the mortars made with waste sanitary ware or brick, after **90 days** of curing: specifically, for mortars made with 100% of waste from porcelain sanitary ware, a strength increase of 13% was achieved. It is likely that it is due to the behaviour of this waste being more similar to silica sand than the others.

6) At this age, 50% substitution of the aggregates for waste brick led to an increase in compressive strength of 12%. In this case, it is very possible that it is due to the waste behaving as a pozzolan.

7) However, for mortars with tile waste, for 25% substitution a reduction was obtained of 20% compared to the control at the same age of 90 days.

Although it would be necessary to carry out more complementary studies, as a general conclusion it can be highlighted that the manufacture of cement mortars for conventional uses is viable with the substitution of natural aggregates for ceramic waste, without it causing a significant reduction in its physical and mechanical performance, but reducing their environmental impact.

6. REFERENCES

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