Chapter

The Effect of Ceramic Wastes on Physical and Mechanical Properties of Eco-Friendly Flowable Sand Concrete

Mohamed Guendouz, Djamila Boukhelkhal, Alexandra Bourdot, Oussama Babachikh and Amine Hamadouche

Abstract

This work aims to study the valorization and recycling of ceramic wastes (wall tiles) as a fine aggregate instead of sand in the manufacturing of flowable sand concrete (FSC). For this, the sand is substituted with the ceramic wastes at different dosages (0, 5, 10, 15, 20, and 25% by volume of the sand). The influence of the ceramic wastes addition on the physical (workability, density) and mechanical (compressive, flexural and elastic modulus) properties of FSC was studied. The results show that the use of ceramic waste as partial replacement of sand contributes to reduce the workability, bulk density and improves the mechanical strengths of FSC according to the use of 25% of wall tiles waste.

Keywords: valorization, recycling, ceramic waste, flowable sand concrete, workability, mechanical strengths

1. Introduction

Due to the increase in coarse aggregates consumption and the availability of large quantities of sand in Algeria, as well as the complexity of designs and reinforcement details in modern structural members, producing fluid concretes for easy implementation and no compaction has become one of the main desires and challenges for building industry. Flowable sand concrete is a new type of concrete that make part of the important building materials permitting to valorize some local resources and waste (dune sand, fillers, waste, garbage and under local products).

In the last years, construction and demolition waste provides a substantial source of natural raw materials for building works by using construction site waste. In addition, the amount of ceramic waste, presents the highest fraction of construction and demolition wastes. Therefore, disposal of a variety of ceramic wastes in an ecofriendly way is the thrust area of today's research.

Several studies have been done on the use of ceramic waste as coarse aggregate, powder and filler in the preparation of cement mortar [1–6], concrete [7–13] and self-compacting concretes [14–16], high strength concrete [17, 18] and ultra-high-performance concrete [19, 20]. Many of them, explored that the use of ceramic waste, as a material in concrete composite, leads to a decrease in workability and density of mixture [2, 3]. The mechanical properties of mortar and concrete incorporating ceramic waste have also studied and analyzed by several researchers [3, 10]. The majority of results showed that, for up to optimum percentage replacement of natural sand by ceramic waste, the mechanical strength of concrete is similar or even better than those containing natural aggregates. Tabak et al. [21] studied the effect of ceramic waste as aggregate (CW), dust (FTDA) and combinations of them to produce concrete. They found an increasing of about 13.53, 16.70, 2.91% and 23.21, 0.10, 19.47% for compressive and flexural strength respectively, at 2, 7 and 28 days. The similar results were also stated by Abadou et al. [5]. They studied the effect of partial replacement for natural sand by ceramic waste with different percentage (10, 20, 30, 40 and 50%) on the performance of ordinary concrete. And they observed that the mechanical properties of ceramic waste mortar increase with replacement of natural dune sand by CW.

The durability properties of concrete counting ceramic wastes were also investigated by several researchers. It found in the study of many authors [1, 5, 10, 18] that there is no significant change in the basic trend of permeation characteristics of this recycled aggregate concrete when compared to the conventional concrete. Tabak et al. [21] demonstrated a reduction of about 0.17% in water absorption of concrete made with recycled ceramic aggregate, when compared to conventional concrete. Elçi [10] studied the effect of total replacement of natural sand by ceramic waste on water absorption and shrinkage of cement concrete. It was observed an increasing in the values of drying shrinkage and water absorption compared to the conventional concrete. Abadou et al. [5] found that the addition of CW in dune sand mortar increases its acids resistance property. It was observed that the mortar made with ceramic waste aggregate shows better resistance to sulfuric (H2SO4) and hydrochloric (HCl) acid solution attack than reference mortar. Hence, the mortar with CW performs well in durability aspect, this addition of ceramic waste, improves the behavior of mortars subject to attacks HCl and H2SO4 acids.

The aim of this research is to study the possibility of recycling ceramic waste without any prior treatment except crushing in order to produce low cost flowable sand concrete. For this the influence of partial replacement of natural sand by ceramic waste on the workability and physic-mechanical properties of the new composite material has been studied and compared to the control FSC. And the optimal proportion of ceramic waste substitution which can give the ecofriendly lightweight flowable sand concrete was then determined.

2. Experimental

2.1 Materials

The used sand in this study is a local material, extracted from the south of Algeria. It presents a siliceous nature as demonstrated by its X-ray Diffraction Analysis (**Figure 1**), and a continuous particle size distribution ranging from 0.08 to 4 mm (as given in **Figure 2**). Hence, their physical properties are presented in **Table 1**. The Scanning Electron Micrograph (SEM) view of their grains is given in **Figure 3**.

Portland cement CEM II/A 42.5 from MASCARA Factory in Algeria was used throughout this study, with a density of 3100 kg/m^3.

The use of fillers in flowable sand concrete composition is essential [22]. Its use helps to improve the compactness of concrete by completing the granular distribution of sand in its finest part. As well as to reducing the cement content and produce a low cost concrete. A marble powder (MP) was used in this study as fillers in FSC mixers with a specific density of 2.73 kg/m^3. And a specific

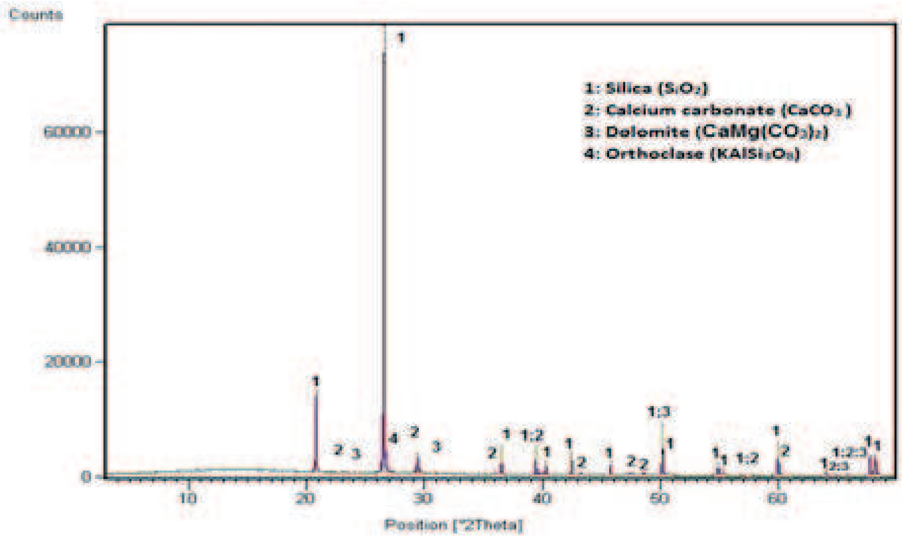

Figure 1.
X-ray diffractogram analysis of sand.

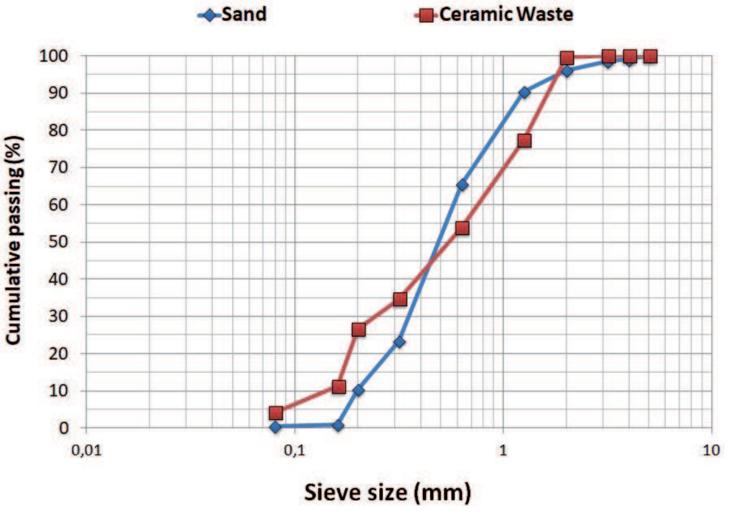

Figure 2.
Particle size distribution of sand and ceramic waste.

Properties	Sand	Ceramic waste
Apparent density (kg/m^3)	1630	1010
Specific density (kg/m^3)	2650	2440
Water absorption (%)	2.00	4.05
Sand equivalent (%)	62.50	—
Fineness modulus	2.25	2.9
Compactness (%)	61	41
Porosity (%)	39	59

Table 1.
Physical properties of sand and ceramic wastes.

surface area measured with the Blaine's permeability meter according to EN 196–6 standard of about 220 m^2/kg.

The ceramic waste used in this study has been obtained from the disposal area of the ceramic factory in Algeria (Ceramic wall tiles). The physical properties of this waste are presented in **Table 1** and their sieve analysis results are shown in **Figure 2**.

After the collection of these wastes, they were crushed and extruded in the form of grains (**Figure 4**), and then used in the manufacturing of FSC by volumetric substitution of natural sand with different percentages (0, 5, 10, 15, 20 and 25%). The Scanning Electron Micrograph (SEM) view of their grains is given in **Figure 5**.

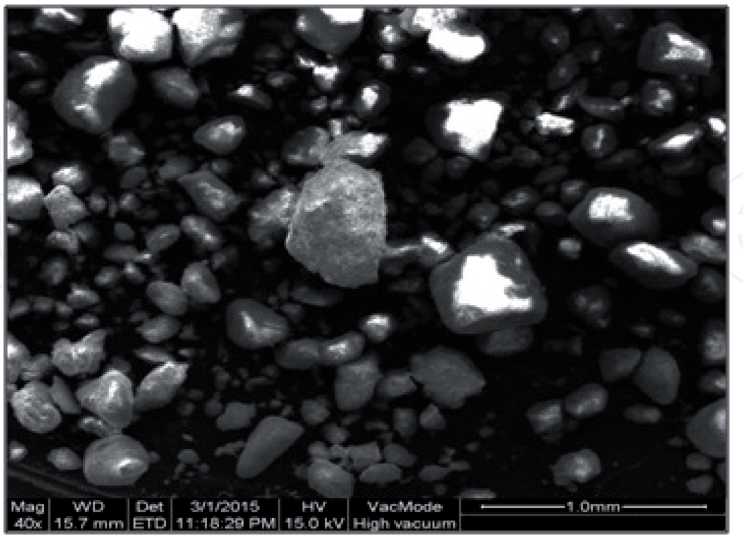

Figure 3.
Scanning electron micrographs of sand, G = 40.

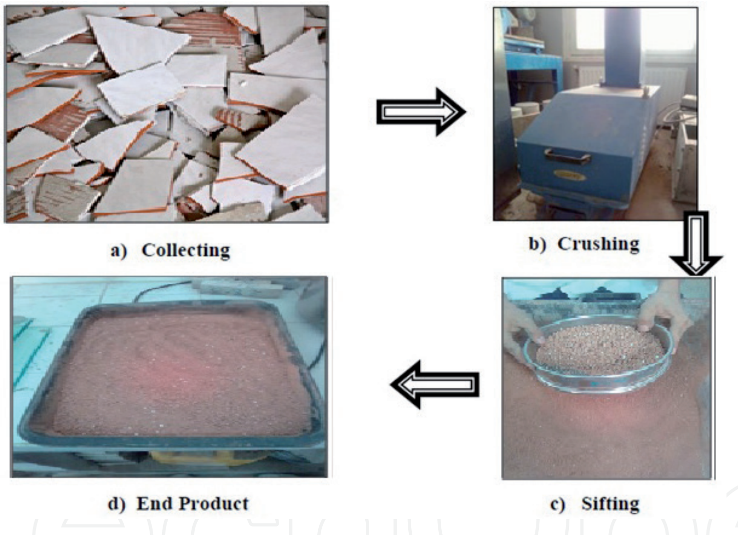

Figure 4.
Stages of obtaining the ceramic wastes.

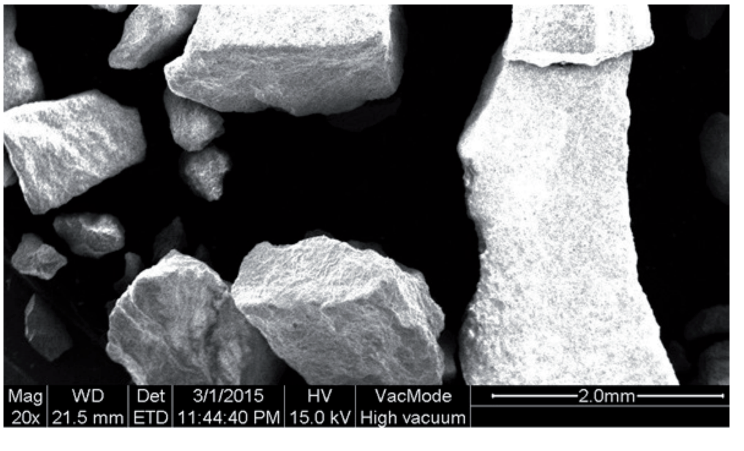

Figure 5.
General aspect SEM micrograph (26X) of ceramic waste.

In this work a polyether–polycarboxylate based superplasticizer 'MEDAFLUID145' in liquid form and chestnut color was used as chemical admixture with a solid content of 30%, specific density of 1.08 g/cm^3, pH equal to 6 and a content of color <1 g/L.

The mixing water used for the different mixes is the distribution drinking water.

2.2 Mix design

In this study, the FSC formulation is based on the theoretical method of Sablocrete project [22]. The CW was incorporated into the mass of flowable sand concrete by partial replacement of sand volume with different percentages from 0 to 25%. The mix proportions of each FSC are given in **Table 2**. As seen from this table and, described below, the mixtures were coded such that, the percentage of CW used were identified in a precise way.

- **CFSC**: Control flowable sand concrete (without waste).
- **FSC CW**: Flowable sand concretes with ceramic waste.

All FSC mixes are manufactured in the laboratory environment by a standard mortar mixer with a capacity of 5 l and all components of FSC mixture were batched by weight. For a better distribution of admixtures within the mass of FSC, superplasticizer was diluted with 40% of mixing water before added to the concrete. It consists to mixes the entire components (aggregate + cement + filler) in the dry state for a half minute. Then, a 60% of mixing water was added and mixed for one minute (1 min) before adding the remaining 40% of water mixed with the superplasticiser and mixed for 1 min. The mixing is stopped after about 3 min before remixing for another one minute (1 min).

All specimens were produced in a laboratory environment at 20°C and 50% relative humidity (RH). After 24 h, they were removed from the molds and placed in water at 20°C and 100% RH until the day of testing.

2.3 Methods

Before casting, the fluidity of FSC was measured by using mini-slump flow diameter test and V-funnel test according to EFNARC (**Figures 6** and 7). For the flow spread test, the truncated cone mold is placed on the plate, filled with the

Constituent	CFSC	FSC CW (%)				
		5	10	15	20	25
Sand (Kg/m^3)	1330	1260	1190	980	1120	1050
Cement (Kg/m^3)	350	350	350	350	350	350
Fillers (Kg/m^3)	250	250	250	250	250	250
Water (l/m^3)	247	247	247	247	247	247
SP (%)*	1	1.4	1.4	1.60	1.70	2
Ceramic waste (kg/m^3)	0	64.7	129.39	194.09	258.5	528.18

Table 2.
Mix proportion of FSC with ceramic waste.

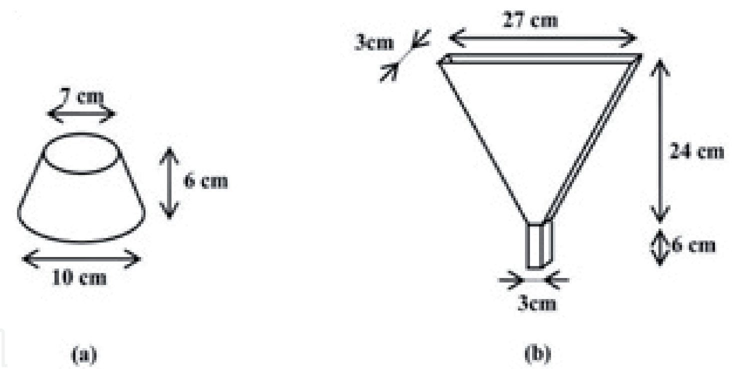

Figure 6.
Workability tests for fresh FSC mixes (a/ mini-slump flow test; b/ V-funnel test).

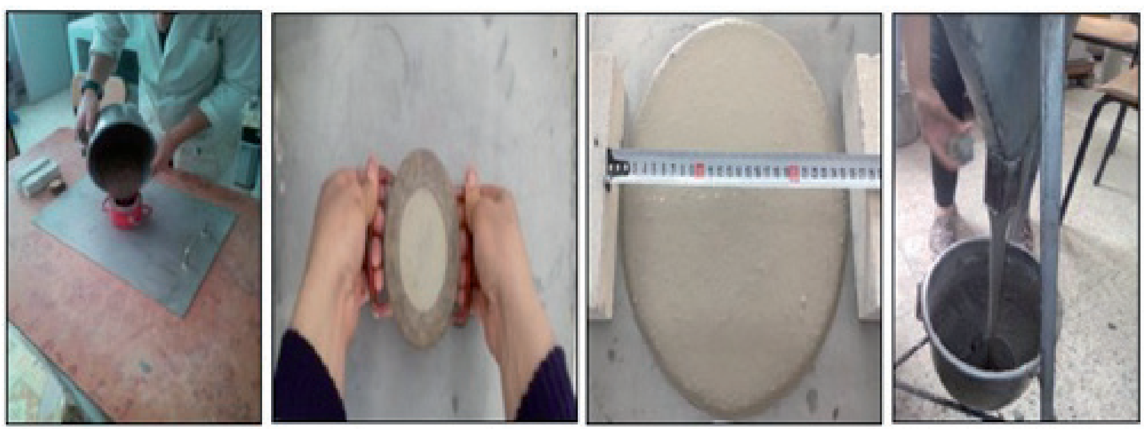

Figure 7.
Fluidity measurement test of FSC.

FSC mixture, and lifted. The subsequent diameter of the mixture is measured in two perpendicular directions, and the mean is taken. For the V-funnel test, the funnel is filled with 1.1 l of FSC mixture, and the V-funnel flow time is that between opening the orifice and the first daylight appearing when looking vertically down through the funnel. The bulk density was evaluated after according to NF EN 12350–6.

The compressive and flexural strength are measured in the hardened state on three 40 × 40 × 160 mm samples at 28 days according to EN 196–1. The flexural strength was measured by a three-point bending test, using a testing machine with a maximum load capacity of 30 kN. The half samples resulting from this test were then submitted to compression test. The modulus of elasticity in compression was measured at the age of 28 days on cylinders of 320 mm in diameter and 160 mm of height by determining the longitudinal deformations during loading using a strain gauge and according to ISO 834.

The microstructure of various FSC mixtures is investigated after 28 days of curing by means of scanning electron microscopy (SEM) for very high magnifications and a video - microscope (Controlab ®) VH-Z25 equipped with a 25x to 175x zoom for low magnifications. The FSC samples were first cut into slices using a diamond saw. From the middle of the mid-slice, a block of 20 × 20 mm was cut. Flat polished epoxy impregnation specimens were used for acquiring backscattered electron images. The SEM observation ware carried out on simple surface after making them conductive by metallization (covering them, under vacuum, with a layer of approximately 10 to 20 nm of gold).

3. Results and discussion

3.1 Characterization of FSC in fresh state

The results of the ceramic waste effect on the slump flow diameter and V-funnel flow time for FSC mixes are given in **Table 3**. The results displayed that the workability of FSC decrease with the increase of ceramic waste. This decrease in workability is maybe due to the high water absorption (**Table 1**), angular shape and rough surface texture of -ceramic waste grain compared to natural sand, which had a rounded shape of the grains (**Figures 3** and **5**). The decrease in workability of concrete, made with CW, was observed also by Abadou et al. [2] Guendouz and Boukhekhal [23] and Daniyal et al. [24].

In order to limit the number of compositions and to be able to compare them in the hardened state on a common basis, the workability was fixed by a constant slump flow diameter, with a value close to 27 mm, and fixed water to binder ratio at 0.4. The workability measure was adjusted by varying the superplasticizer quantity for each mixture contains ceramic waste as reported in **Figure 8**. It is clearly shown from this figure that superplasticizer demand increased with the increase of ceramic waste content in FSC.

Figure 9 shows that the substitution of sand by ceramic waste causes a slight decrease in bulk density of mixes, which is probably due to the lower density of the ceramic waste aggregate grains compared with natural sand (**Table 1**). The decrease in density of concrete made with CW was proved also by many authors [5, 10, 25–29] which reported that the use of ceramic waste as aggregates reduced the concrete density.

Concrete	Slump flow diameter (mm)	V-funnel flow time (s)
CFSC	260	7
FSC 5% CW	250	10
FSC 10% CW	230	13
FSC 15% CW	210	18
FSC 20% CW	190	22
FSC 25% CW	180	26

Table 3.
Properties of FSC mixes at fresh state.

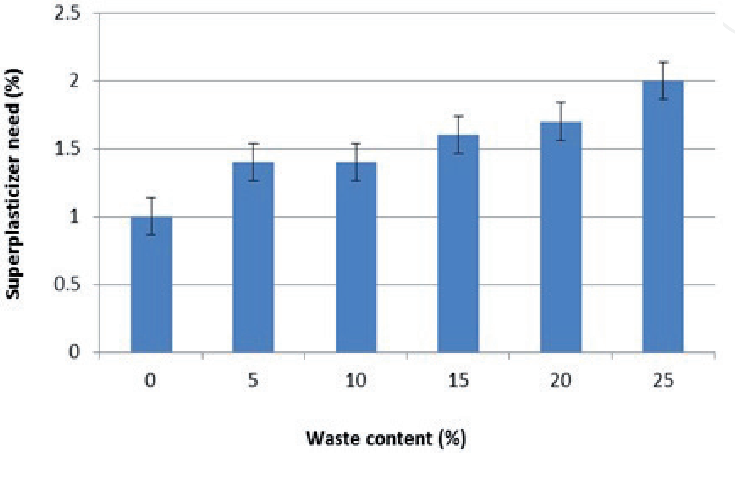

Figure 8.
Superplasticizer need of fresh FSC as function of ceramic wastes content.

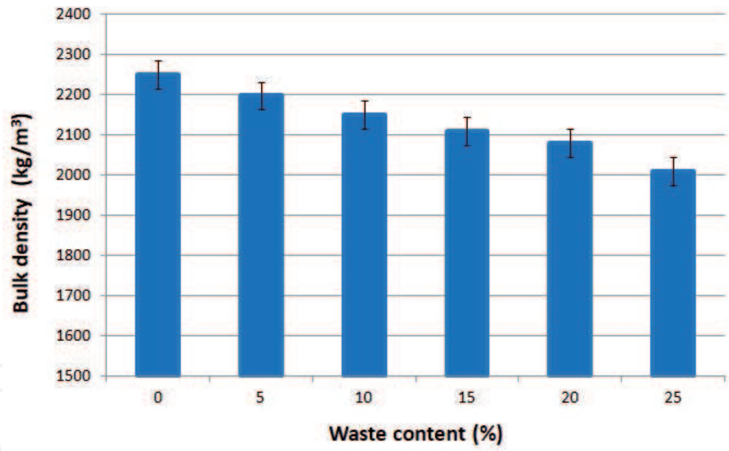

Figure 9.
Bulk density of fresh FSC as function of ceramic wastes content.

3.2 Mechanical properties of FSC in hardened state

The results of compressive and flexural strength for all FSC mixes, at 28 days of age are presented in **Figures 10** and **11** respectively. This results show an improvement in compressive and flexural strength of FSC mixes with ceramic waste for all ages compared to FSC without ceramic waste. An increase of about 30 and 57% was observed at 28 days in compressive and flexural strength respectively, for a replacement ratio of 25% of sand by ceramic waste. This increase in mechanical strength is due to the hardness of ceramic waste grains compared to those of natural sand, and to their rough and irregular shape which fill the void. This later led to higher frictional resistance and improves their good adhesion with the cement paste (**Figure 12**).

Similar results were observed by Abadou et al. [5] for dune sand mortar containing CW. They found an increase in compressive strength of dune sand mortar with 40 and 50% of CW. Elçi [10] has reported similar mechanical properties to those of traditional limestone concrete when using ceramic as recycled aggregates. Anderson et al. [27] studied also the effect of ceramic waste on concrete mechanical strength; they observed an increase in concrete strength with the incorporation of fine ceramic aggregates along with the coarse. Tennich et al. [30] reported that the compressive strength of concrete containing CW is higher than those of concrete made with natural aggregate.

The results of modulus of elasticity tests carried out on the different FSC mixes at 28 days are summarized in **Figure 13**. As shown in this figure, the elastic modulus of all concrete mixes, increases when ceramic waste aggregates content increases.

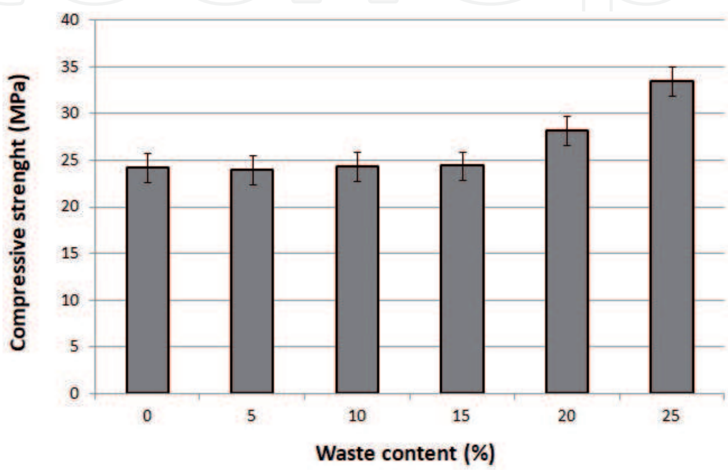

Figure 10.
Effect of ceramic waste on compressive strength of FSC.

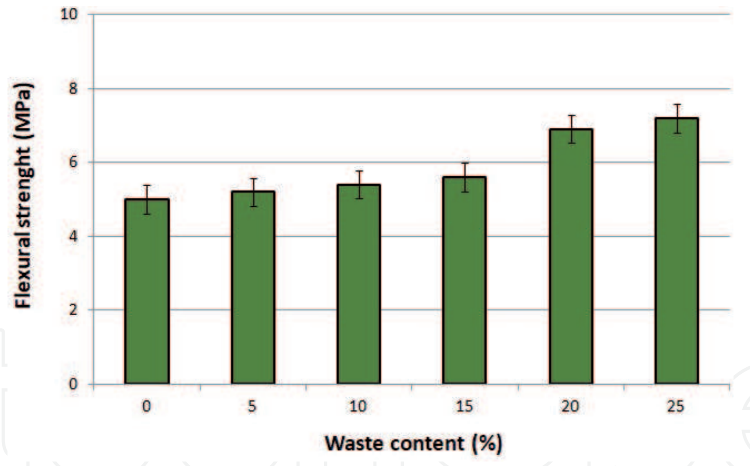

Figure 11.
Effect of ceramic waste on flexural strength of FSC.

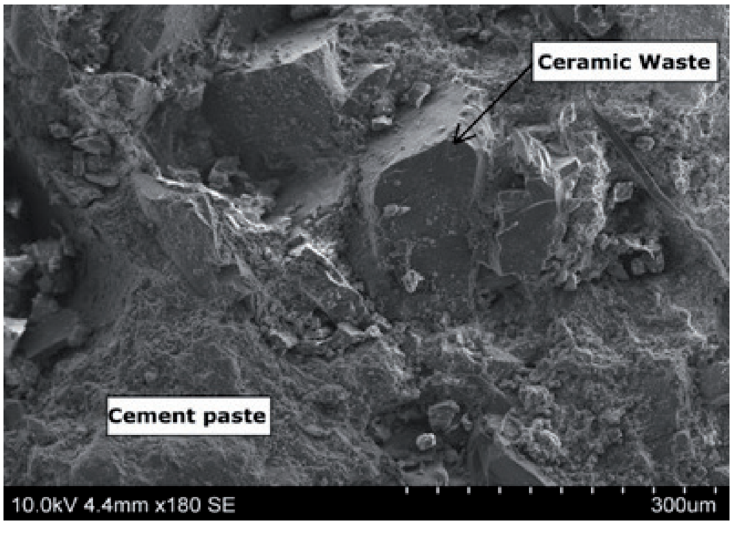

Figure 12.
SEM image showing the good adhesion of CW with cement matrix in FSC.

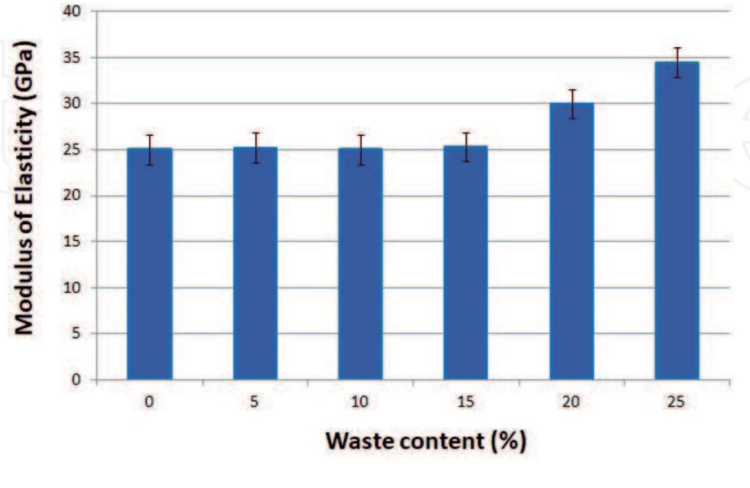

Figure 13.
Elastic modulus of different FSC mixes.

Its value varies between 25 GPa for control flowable sand concrete, and 34.92 GPa for mixtures containing 25% of CW, with a gain of about 28.4%. This increase on modulus of elasticity is due to the high compressive strength of mixtures, the angular particles shape that occupy the voids between sand grains, and to the better adherence between CW and paste. Thus, FSC mixes become more compact and, as a consequence, the modulus of elasticity increased. The modulus of elasticity may be directly related to the compressive strength. The results agree with those in [27] for CW aggregates. Tennich et al. [30] studied the effect of partial replacement of natural sand by ceramic waste with different percentage (0, 20, 35, 50, 65, 80 and 100%) on the elastic modulus of natural concrete. It observed that the elastic modulus of ceramic waste series increased by 27% with 100% replacement. Abadou et al. [5] also reported that the mortar incorporating ceramic waste has a higher modulus of elasticity compared to the ordinary mortar. Contrarily, Elçi [10] found that there was a decrease of in modulus of concrete made with CW compared to reference concrete.

4. Conclusions

From the obtained results in this study, the following conclusions can be drawn:

- The use of ceramic waste as partial replacement of sand in flowable sand concrete lead to decrease its workability.

- The density of flowable sand concrete is decreased when the percentage of ceramic waste increases.

- The use of ceramic waste as sand in FSC improves their mechanical strengths at all ages. An increase of about 30 and 57% in compressive and flexural strength respectively was observed at 28 days when 25% of natural sand were substituted by ceramic waste.

On the basis of the results obtained in this study, it can be concluded that the use of ceramic waste with the local materials in flowable sand concrete manufacturing, is an interesting economic, environmental and technological alternative and is added to the list of materials available in the country.

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