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ARTICLE

On the Combination of Silica Fume and Ceramic Waste for the Sustainable Production of Mortar

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ABSTRACT

The combined use of silica fume (SF) and ceramic waste (CW) for the production of mortar is studied. Sand is replaced by 5%, 10%, 15% and 20% of CW while a fixed 5% percentage (% wt of cement) of SF is used. The results show that the best results are obtained by using silica fume and ceramic waste sand with 15% weight of sand and 5% wt of cement. With the addition of sand ceramic waste (SCW), the mortar compressive strength and density increase, while the porosity displays an opposite trend. The experimental analysis is complemented with theoretical considerations on the matrix strength and related improvements in mechanical behavior. It is shown that the agreement between the experimental values and the estimated values is good.

KEYWORDS

Mortar; silica fume; ceramic waste; full factorial arrangement; mechanical properties

1 Introduction

The big topic of importance today in cement and concrete technology is the recycling and reuse of industrial waste and by-products, like ceramic and brick wastes [1]. Some recent studies have proven that the use of the remnants of inorganic industrial produces in the production of concrete can make sustainable ceramics industry range from 3% to 7% of daily production [2]. Therefore, recycling it allows it to be used in the construction of many different buildings [3]. After recycling this waste, it was considered to be coarser than the cement particles, which is usually as fine and coarse aggregate in the concrete mixture, up to 35% of tile waste [4].

According to research by Kannan et al. (2017), replacing part of the cement with micro-ceramic powder led to the good improvement of the outstanding mechanical properties of high-performance concrete [5]. MCP has been classified as a material rich in aluminum silicate which indicates significant activity of pozzolanic [5]. The (C-S-H) and (C-AS-H), as the two major strength transfer phases in Portland cement (PC), formed as a result of the consumption of $Ca(OH)_2$ by the reaction of aluminosilicates inside ceramic waste [6].

Cement consumes a large proportion of carbon dioxide is emitted into the atmosphere during its production, which causes many environmental problems [7]. The silica fume (SF) is one of the cementitious additions (SCMs) used due to its improvement concrete/mortar properties [8].

Shubbar et al. [9] showed that SF can considerably growth the hydration level of the paste and the compressive strengths of hardened pastes, mortars and concretes. This improvement in strength comes from bonding the interface between the hardened cement paste and the aggregate. It is evident that the degree of crystal orientation, crystal size and calcium hydroxide content at the interface were decreased by the addition of SF.

Zhang et al. [10] studied the effect of replacing aggregates with ceramic tiles on the properties of concrete. The results indicated that the mechanical strength was improved with replacement of 25%–50% sand and 10%–20% coarse aggregate. Most of the research carried out in such studies used the waste in the form of a powder, and the results were different in terms of their impact on the different properties of mortar and concrete [11].

In this study, the impacts of ceramic wastes used as sand on the properties of mortar were investigated. The combination of SF and CW and their effects as sand aggregates in a sustainable mortar were examined.

2 Materials and Method

2.1 Materials

The *Portland cement (C)* type CEM II/A 42.5 was used, with 3.1 g/cm^3 values of absolute density, 28% consistency and fineness of 4000 cm^2/g, respectively.

The *silica fume (SF)* is obtained from GRANITEX (Algeria region) with specific surface >15 m^2/gr. The properties of cement are shown in Table 1.

Table 1: The chemical, physical properties of cement

Component		C (%)		SF (%)
SiO_2		20.7		> 85
Al_2O_3		04.75		-
Fe_2O_3		03.75		-
CaO		62.92		-
MgO		01.90		-
SO_3		1.98		< 2.5
CL		-		< 0.2
Mineralogical composition of cement				
Item	C_3S	C_2S	C_3A	C_4AF
Content				
	59	14	6	10

The *dune sand (DS)* used with particles ranging from 0.08 to 5 mm in size and fineness modulus M_f of 2.44. Granular analysis was carried out NF EN 933-1 [12].

Ceramic waste aggregates *(CW):* floor and wall ceramics were the material used in this study (obtained from construction and demolitions sites). It was added as aggregates witha grain size of 0.08 to 5 mm .The granulometric distribution of SF and CW used are shown in Figs. 1 and 2.

The *admixture* used in the preparation of our concrete to ensure satisfactory processing fluidity is the super plasticizer "Medaplast SP40" belonging to the family of superplasticizers/high water reducers. It density equal to 1.22.

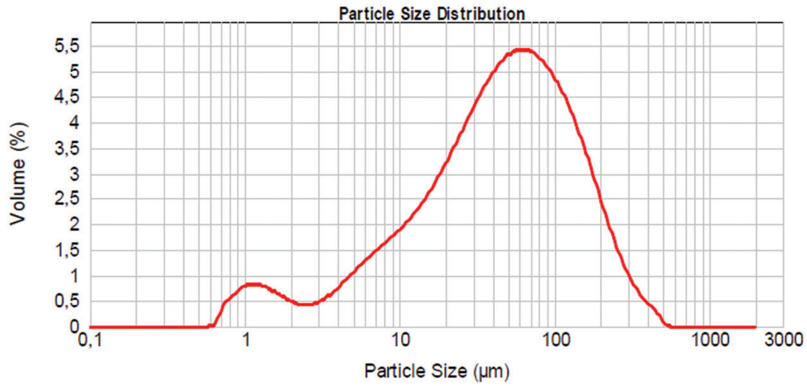


Figure 1: Particle size distribution of SF

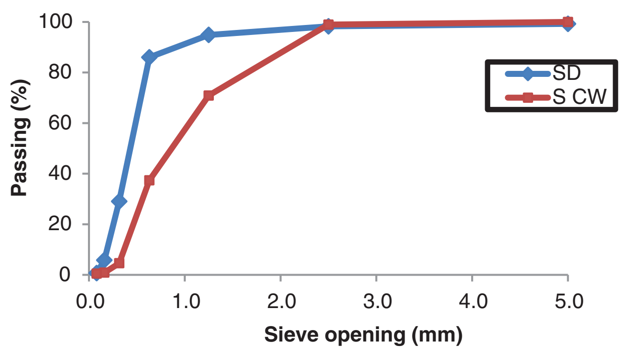


Figure 2: Granular analysis of DS and the CW

2.2 Preparation of Mortar Samples

Four mixtures were produced: a reference mortar (M0) formulated and three mortars containing 5%, 10%, 15% and 20% respectively of CW by weight. These mixtures took the following names (M5, M10, M15 and M20).

The prisms $(4 \times 4 \times 16)$ cm^3 of mortars were prepared according to EN 196-1 [13]. The final compositions of mortars are presented on Table 2.

Table 2: Mortars composition

Mix (g)	M0	M5	M10	M15	M20
Cement	450				
Sand	1350	1282	1215	1147	1080
Ceramic waste	0	68	135	203	270
Silica fume			25		
Water/cement			0.5		

Note: The following designations for the mixture:
C: Cement; SF: Silica fume; SD: Sand Dune;
SBW: Ceramic Waste Sand; M0: Mortar formulated with 0% ceramic waste and 5% of silica fume;
M5: Mortar formulated with 5% ceramic waste and 5% of silica fume; M15: Mortar formulated with 15% ceramic waste and 5% silica fume; M20: Mortar formulated with 20% ceramic waste and 5% silica fume.

Porosity test: the protocol of porosity accessible to water conform the recommendations of AFREM group [14,15].

3 Results and Discussion

3.1 Fresh Density

Based on standard NF EN 196-1, the fresh mortars density was evaluated [13]. From the Fig. 3, it was found that the fresh density increased with increasing of CW content. The elevation in fresh density can be explained by the fact of silica fume and cement density, which contributed to the increase in the density of the mortar. On the other hand, incorporating CW led to an increase in mortar density due to the fact that the density of the SCW used was considerably higher than that of the DS. For example, the fresh density of the M0 was 527 g/cm^3, whereas this value for M15 was 540 g/cm^3.

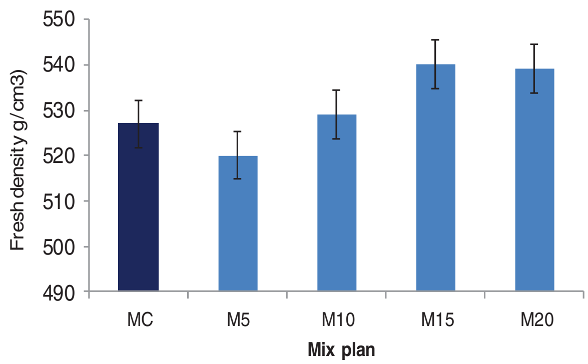


Figure 3: Density of different mortar formulated

3.2 Compressive Strength

As explained in the Fig. 4, the compressive strength increased as the % of SCW increased in mortar until 15% SCW, after this % the compressive strength decreased as the % of CW increased in mortar. Whereas, 15% SWC expressed an improvement in the properties of the mortars, which confirms other research [16].

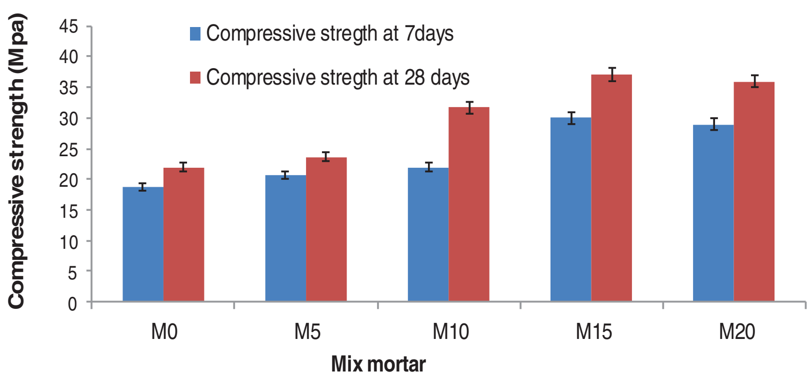


Figure 4: Variation of mortar compressive strength as a function of different percentage of CW at 7 days and 28 days

After 15% we notice a drop in compression (M20), this decrease explained by the development of C-S-H gel influenced by the elements in CW [17,18]. As for the increase in the bonding between the aggregate and the cement paste, it is due primarily to the angular shape and the rough surface of CW. The rough surface of

CW provided a physical anchor while its higher porosity compared to DS increased anchoring between hydrated products and the aggregate (chemical anchoring).

3.3 Effect of Binary Combination of SF and CW

The best result for compressive strength was appeared in 28 days with SF and without SCW is illustrated in Fig. 4.

The compressive increased as the content of SF combined with CW in the mixture. The range of compressive strength at 7th day was between 19 and 30 MPa, while at 28th day was between 22 and 37 MPa. The presence of 25% SF in the mixture explained by the improvement of the resistance. It presents a pozzolanic reaction with clinker hydration products to form dense C-S-H [19].

3.4 Effect of Porosity of Binary Sand on the Mechanical Strength

Fig. 5 indicated that increasing of porosity of SCW influences significantly the compressive of mortar tested but such decreasing was found limited, principally for mortar prepared with binary sand.

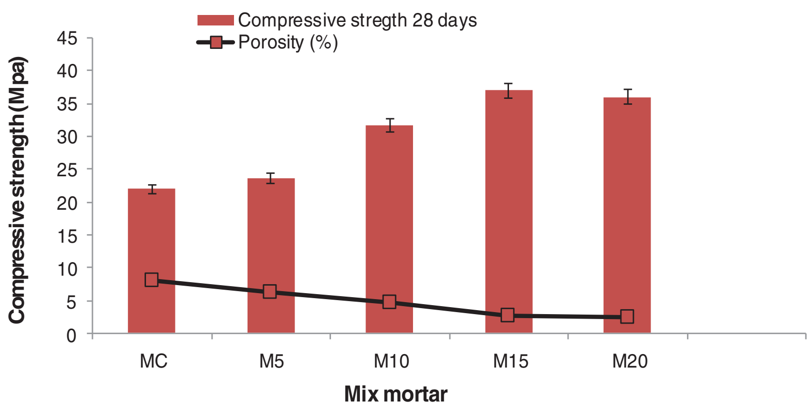


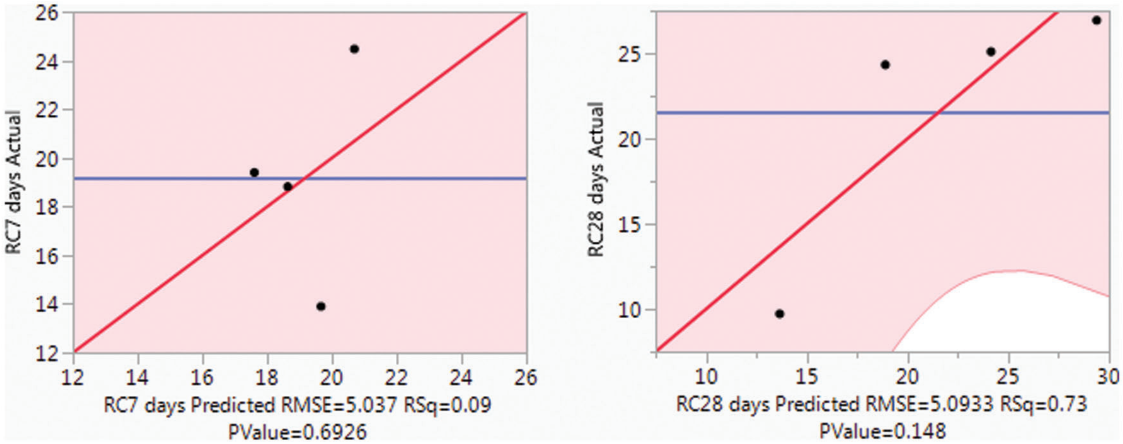
Figure 5: Porosity and compressive strength of mortars as a function of different percentage of CW

In general, the reducing of porosity binary sand results in increasing the compressive of mortar. It is noted that the texture of the sand as well as its porosity have an effect on the resistance of the hardened mortar. From the sample incorporation with different % SCW replacement has minor % of porosity of the mixtures M5, M10, M15 and M20 compared with the reference mortar. This is due to the lower volume of voids inside the binary sand.

3.5 Modeling the Compressive Strength

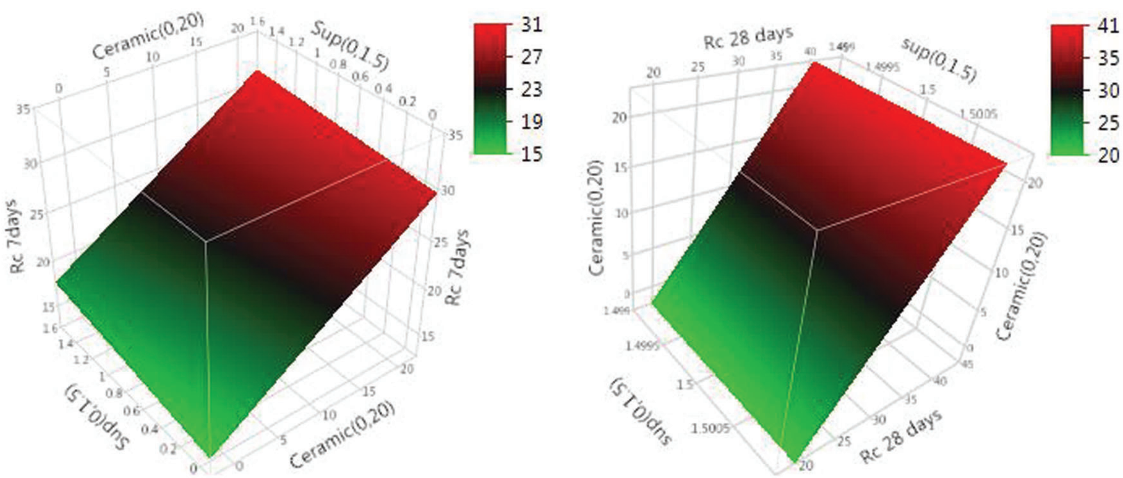
When plotting the observed values of the quadratic model as a function of the predicted values (that is, the relationship between the predicted area and the actual area measured, it is found that the points are placed above the first arithmetic that is desirable (Fig. 6).

The evolution of the compressive strengths as a function of the dosages of ceramic waste has been presented in Fig. 7. It can clearly be stated that the dosage of the ceramic strongly influences the compressive strength. A rise in compressive strength has been observed with the increase in dosage up to 15% beyond 15% of ceramic resistance considerably reduced.



(1a) (1b)

Figure 6: (1a, 1b) Graphs of the values observed according to the expected values (compressive strength at 7 days and 28 days)



(2a) (2b)

Figure 7: Evolution of compression strength at 7 days and 28 days (2a, 2b)

According to the results of estimate of coefficients drawn: the dosage of ceramic effect is larger than the effect of the percentage interaction of E/L. To simplify the model, we will eliminate this term from the equation. Therefore the compressive strength response can be summarized in the following empirical model:

- Compressive strength at 7 days = 19.1475 + 1.5435 [ceramic-7.5]/7.5
- Compressive strength at 28 days = 21.5225–7.8645 [ceramic-7.5]/7.5

4 Conclusions

From the above experimental results, the following conclusions are drawn:

- The substitution of C with 5% to 15% CWS leads to increase in compressive strength beyond 15% a drop in resistance has been noticed;
- The addition of SF with CWS increase density of mortar;

- The porosity of mortar decreased with an increase of ceramic sand;
- The possibility of using the CW residue as an effective compound in the mortar at rates not exceeding 15% of sand;
- The improvements in mechanical behavior allow a good agreement between the experimental values and the estimated values.

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