ADVANCES IN MATERIALS SCIENCE, Vol. 24, No. 1 (79), March 2024

sciendo

DOI: 10.2478/adms-2024-0007

Belkacem Djoual[1], Ratiba Mitiche Kettab[2], Abderrahmane Ghrieb[3], Tayeb Bouziani[4], Rebih Zaitri[3*]

[1] Mechanical and Materials Development Laboratory, University of Djelfa, 17000, Algeria
[2] Civil Engineering Department, National Polytechnic School of Algiers, Algeria
[3] Department of Civil Engineering, University Ziane Achour, 17000, Djelfa, Algeria
[4] Structures Rehabilitation and Materials Laboratory, University of Laghouat, 3000, Algeria

** belkacem.djoual@univ-djelfa.dz*

THE INFLUENCE OF MINERAL ADDITIVES AND SANDS ON THE PERFORMANCE OF SELF-COMPACTING SAND CONCRETES

ABSTRACT

The chosen plan for our case study is a network mixture design consisting of 21 mixtures. The application of this method has proven to be immensely useful in studying the influence of composition parameters (composite design) and the utilization of various types of mineral additives (mixture design). The application of the Design of Experiments (DOE) method, based on a statistical approach, allowed for a better understanding of the effect of formulation parameters, including the proportion of alluvial sand (75%), dune sand (25%), the total amount of sand kept at constant percentages, the dosages of brick powder, limestone filler and ceramic powder (all varying from 0 %, 20 %, 40 %, 60 %, 80 %, and 100 %), while keeping the dosage of superplasticizer and the water/binder ratio constant. This approach helped to understand the interactions between these parameters and their impact on the process. Mathematical models relating the variations of these parameters to the workability and compressive strength of such concrete mixtures have been established. The results obtained show that the workability of SCSC (expressed by slump flow and V-funnel flow) improves with the increase in the dosage of limestone filler (FC), brick powder (PB), and ceramic powder (PC), with element having a different impact, be it alone or in a combination. Moreover, they all improved the behavior of SCSC in both the fresh and hardened states. The experiment shows that increasing the proportions of FC and PC in the mixture, whether linear, binary, or ternary, leads to a significant improvement in compressive strength. Furthermore, better strength is observed in the ternary mixture at 28 days, with a strength of 43 MPa, with the following proportions (FC 70%, PB 20%, PC 10%). Finally, the result at 180 days of 48 MPa confirms the following proportions (PC 60 %, FC 30 %, PB 10 %) The compliance of some SCSC compositions was tested according to the recommendations of the French Association of Civil Engineering.

Keywords: *statistical analysis; formulation parameters; mineral additives; mechanical strength; workability*

INTRODUCTION

It is worth emphasizing that SCSCs are expected to be stable and must show no signs of either static segregation or dynamic segregation. This condition can be satisfied by using a super plasticizer and a suitable paste volume. Numerous studies reported in the literature have shown the favorable effects of micronized mineral additions on the properties of concretes in the fresh state [1] and the hardened state [2], in particular the limestone fillers (LF) which are the most widely used additions [3]. However, little research work has been conducted using additions such as granulated blast furnace slag and glass powders. Moreover, it should be noted that the influence of mineral additions on the fluidity of concretes depends on the dosage, type, fineness and shape of the particles [4]. This work is particularly limited to the study of the influence of the type and dosage of the additions on the characteristics of the fresh concrete and also on the compressive strength of the formulated SCSCs. It is important to remember that the goal sought here is to formulate an SCSC containing optimal quantities of additions that can provide the mixture with the characteristics of a self-compacting concrete and the mechanical strengths of an ordinary concrete. For this, it was deemed necessary to conduct a study on using mineral additions, such as LF, BP, and CP, in order to better understand their influence on the properties of SCSCs.

For the purpose of complementarity and comparison, three combinations of additions were adopted; These are unary, binary and ternary. The effects of these different combinations of additions on the mechanical performance, such as the compressive strength and flexural tensile, of the prepared mixes was thoroughly investigated as well.

Furthermore, it was shown that, nowadays, mineral additions play an extremely important role in concrete technology. It was also revealed that the use of some of these additions in the preparation of concrete is highly important in the strategy of sustainable development, because it allows the reduction of CO_2 emissions during the production of cement. It also helps to achieve better economic and efficient waste management and lower energy consumption. The main benefits of using mineral additions have been widely studied and discussed in numerous studies. Some of these research works have particularly focused on the use of silica fume [5, 6], red mud [7], fly ash [8, 9, 10, 11], marble powder [12, 13, 14], porcelain polishing residues [15], glass powder [16, 17], quarry dust, and fine recycled concrete, in the formulation of various types of concrete. This would certainly help to eliminate many wastes from the environment and keep it clean. It is worth indicating that a number of building, industrial and agricultural wastes can be utilized as fine aggregate materials. In a study carried out by Senthamarai and Manoharan [18], it was found that approximately 30% of materials employed in the ceramic manufacturing industry go to waste which, if not carefully and wisely utilized, can pose a serious environmental problem due to their improper or unsafe disposal. In this regard, a number of research projects have been conducted for the purpose of studying the eventuality of employing the ceramic wastes as aggregates instead of natural aggregates, or as a filler to partly replace cement [19]. The ceramic powder (CP) could be used with an optimal percentage of 50%. Eldieb and Kanaan [20] showed that incorporating 10% of ceramic powder (CP) in the mixture provided concrete with a high compressive strength. However, high amounts of CP may negatively affect the strengthening bars used in concrete [21]. In addition, it has been reported that high performance concretes (HPCs) were successfully prepared using CP with a replacement level ranging from 20% to 40% [22]. In this context, Lasseuguette et al. [23] carried out an experimental study that used two types of ceramic powders, i.e. the white and red ceramic powders, which were incorporated in the concrete mixture. This research team found out that the white CP was more reactive. This was certainly due to the difference observed in the chemical and mineralogical compositions of the types of ceramics.

The incorporation of ceramic and brick waste is an important technique for improving the properties of concrete and mortar, such as workability, strength, and durability. These additives significantly impact the Rheology of cement materials (directly related to strength development) and the durability of hardened materials.

The purpose of this work is to formulate a Self-Compacting Sand Concrete (SCSC) with optimized additives that allow the mixture to exhibit the characteristics of a High-Performance Concrete (HPC) while maintaining the mechanical strengths of ordinary concrete. In our study, we focused on examining the influence of the type and dosage of the additives on the rheological properties (static stability, etc.) and mechanical properties (compressive strength and flexural tensile strength) of the formulated SCSC.

We studied the influence of mixing two types of sand (alluvial sand and dune sand) and the addition of mineral additives (variations in the type and dosage of mineral additives: limestone filler FC, brick powder PB, and ceramic powder PC).

In the first stage, we focused on various mineral additives (FC, PB, PC) with different dosages (the sum of these ratios must always equal 1) and determined their influence on the performance of SCSC.

We then studied the influence of these additives on the rheological and mechanical behavior of the concrete that exhibited the best performance by substituting a portion of the alluvial sand with dune sand (constant water content, constant superplasticizer dosage, and a constant E/L ratio). We observed a positive impact on the concrete's behavior, with variations in magnitude depending on the chemical composition and particle size distribution of the additives.

In parallel with this work, we utilized simple, and rapid test for assessing the workability and the stability of SCSC. The validation of this test was conducted through several experiments where we compared and correlated the results of the new test with other tests. The validity of the results of this test was also demonstrated through different statistical analysis including (ANOVA).

MIXTURE DESIGN APPROACH

Several statistical modeling techniques are commonly used to evaluate the relative importance of primary mixture parameters and their interconnected effects on the relevant properties of Self-Compacting Concrete (SCC) [24, 25, 26, 27, 28, 29]. In this specific study, an experimental approach based on mixture design was employed. Unlike traditional non-mixture designs like factorial and response surface designs, all variables in this approach represent proportions of constituents within a mixture. Since these proportions always sum up to 1, the final component's proportion depends on the sum of all other proportions. In this mixture scenario, the factors are not independent, impacting the design process [30].

A simplex-lattice mixture design was implemented, involving three factors and five levels, to assess the influence of three different types of mineral additions (LF, BP, and CP) on the characteristics of SCCs. The remaining components of SCCs (sand, cement, superplasticizer, and water) were held constant. The simplex-lattice design is a comprehensive approach that populates the experimental space with a triangular grid of combinations, as depicted in Figure 1. The number of combinations (C) in this design is determined by the following equation:

$$C_{q+m-1}^{m} = \frac{(q+m-1)!}{(m)!(q-1)!} \tag{1}$$

where:

C: The number of combinations, q: represents the number of factors and m: represents the number of levels.

In the case of three factors and five levels, the total number of combinations to be considered is 21. By employing this methodology, a mathematical model can be established to describe the effect of different proportions and blends of three types of mineral additions on a specific property. For this study, a second-degree model was utilized, incorporating three non-independent variables (proportions of LF, BP, and CP) and five levels. The model is represented as follows:

$$Y = b_1 \times LF + b_2 \times BP + b_3 \times CP + b_4 \times (LF.BP) + b_5 \times (LF.CP) + b_6 \times (BP.CP) \qquad (2)$$

Where:

The response (Y) is determined by the model coefficients (b_1, b_2, b_3, b_4, b_5, b_6). In equation (2), the coefficients (bi) within the model represent the impact of the respective variables on the response variable Y. These coefficients are computed using a standard least-square fitting method. An analysis of variance is conducted to assess the importance of each term within the model. The residuals are utilized to compute the variance of the coefficients, which sets the standard for assessing the significance of each coefficient [30]. The obtained results were subjected to analysis using JMP7 statistical software.

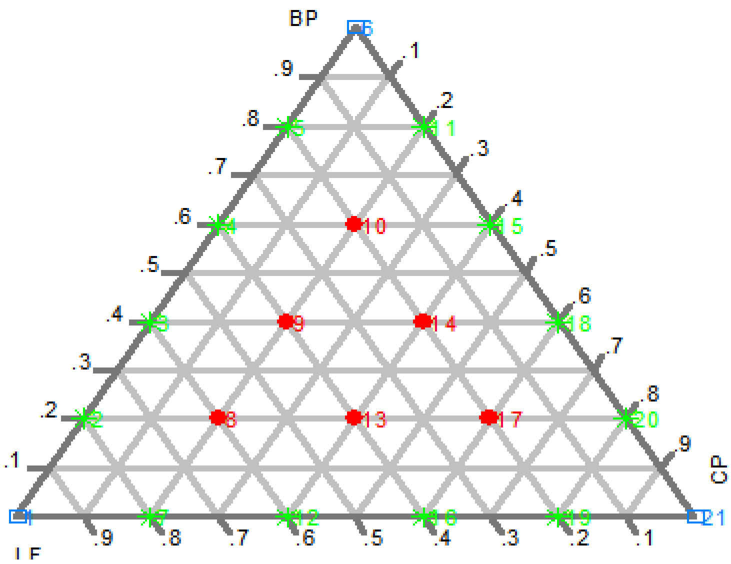


Fig. 1. Plan used for the study of the influence of mineral additions on the properties of SCSC

Significance of JMP7 statistical software

In the present study, the creation and analysis of the design of experiments are carried out using the statistical software JMP7. It offers an intuitive interface for advanced statistical analysis, making it accessible to users without extensive statistical expertise. It enables hypothesis testing and precise statistical inferences, thus promoting data-driven decision-making.

With its advanced features, including visualization tools and comprehensive analysis capabilities, JMP7 simplifies complex data comprehension and insight extraction. It's highly customizable to meet various research needs, making it invaluable to professionals and researchers in different fields. In summary, JMP7 is a crucial tool in data analysis and statistics [28, 31], improving understanding and supporting strategic decision-making based on data.

MATERIALS

Cement

It should be noted that, in this study, it was deemed useful to use Portland cement CEM II/B -CPJ 42.5-ES NA443 which is highly resistant to sulphates. This type of cement is generally employed in concretes intended to be used in aggressive environments; it is taken as reference cement. It contains at least 95% clinker, and the rest is made up of secondary constituents such as gypsum which serves as a setting regulator. The physicochemical and mechanical characteristics of sulphate resistant cement are summarized in Table 1.

Table 1. *Physicochemical and mechanical characteristics of sulphate resistant cement (SRC)*

Properties	Content
Density (g/cm^3)	3.15
Compressive strength at 2 days (MPa)	≥10.0
Compressive strength at 28 days (MPa)	≥42.5
Beginning of cement setting (min) at 20°C	145 - 185
End of cement setting (min) at 20°C	230 à 280
C3S (%)	52.13
C2S (%)	23.55
C3A (%)	6.76
C4AF (%)	12.13
CaO, L (%)	-
Gypsum (%)	5.0
Additions	Without

Mineral additions used

The three types of minerals used in this study, which are readily available and easy to extract, are limestone powder, brick powder, and ceramic waste powder (sanitary).

Characteristics of Limestone Fillers (LF)

In this study, we focus on Type 1 fillers according to the EN 206-1:2004 standard. These are limestone fillers ranging from 0 to 100 µm, derived from crushing rocks in the quarry area in the province of Médéa, Algeria. The rocks are of a dolomitic limestone nature. Limestone fillers have an absolute density of 2.70 t/m3.

The main characteristics provided by the producer have been summarized in Table 2. These fillers are primarily composed of calcite, with a $CaCO_3$ content of 88.5%. The MgCl content recorded is very low, less than 0.6%. This result was also confirmed by X-ray diffraction, which showed a high level of calcite, as well as dolomitic limestone $CaMg(CO_3)_2$. The Blaine fineness of the fillers, measured at 270 m2/kg, is similar to that of the cement used, which averages around 400 m2/kg. The clay content, indicated by the blue value of 0.58 g/100g, particularly demonstrates that the fillers are nearly free of clay. This value complies with the NF P 18 508 standard, which allows for up to 1 g/100g of clay.

Limestone filler is often ground into a fine powder, with particle size varying depending on its intended use. The particles can be very fine.

Table 2. *Physicochemical characteristics of the Limestone Filler*

Properties	Content
Absolute density(kg/m3)	2700
Apparent density (kg/m^3)	1530
Activity index	0.79
Density	2.72
Loss on ignition	36.30
SiO_2	0.76
Al_2O_3	0.41
Fe_2O_3	0.23
CaO	54.90
MgO	0.61
K_2O	0.24
Na_2O	0.04
SO_3	0.61
Cl^-	0.05

Brick Powder (BP)

The powders used in the composition of our research concrete are sourced from brick waste recovered at the "AMOURI Toufik" brick factory dump, located in the southern part of the city of Laghouat, Algeria, in the Boussâada industrial zone. They are readily available in large quantities.

After collection, these powders were sorted and reduced into small pieces using a crushing machine Subsequently, they underwent a grinding process in a "Los Angeles" machine equipped with 11 metal balls to generate impacts inside the drum of the device. The test was conducted by running the machine for 500 cycles at a constant speed ranging between 30 and 35 cycles per minute.

This operation was followed by a dry manual sieving of the crushed product, and the fine particles recovered are characterized by their fineness with a diameter less than 80µm (micrometers) as determined by sedimentation according to the NF P 94-057 standard. They are used as a metallic additive. The chemical and physical properties of this powder are listed in Table 3, The preparation of the additives is carried out at the LME (Laboratoire de Génie Civil), University of Laghouat, Algeria.

It is noteworthy that as the brick waste content increases, the silica content (SiO_2=66.52%) increases as well, and the calcium oxide (CaO) content decreases. This suggests a change in the cement hydration kinetics, thereby impacting the physicochemical and mechanical properties of the concrete.

Ceramic waste powder (Sanitary) (CP)

We gathered discarded sanitary ceramic materials, sourced from a landfill within the industrial district north of Laghouat city, Algeria. Subsequently, these materials were transported to the laboratory for further processing. The waste materials encompassed items such as bathtubs, standard sinks, toilets, bathroom sinks, and kitchen sinks. After subjecting them to purification, drying, and grinding into small particles utilizing the grinding machine depicted them as mineral additives in our research to examine their impact on concrete behavior.

Subsequently, the grinding process was carried out using the "Los Angeles" machine, following the same method used for brick waste. Manual sieving was then performed to obtain fine granules with a diameter of 80 micrometers (µm). The chemical and physical properties of this powder are presented in Table 3. The main constituents are silicon dioxide and aluminum oxide. We observed a predominance of silica in all materials (over 65% for brick powder and over 60% for sanitary ceramic waste). Then, in decreasing order of oxide percentages, there are aluminum (Al_2O_3), calcium (CaO), iron (Fe_2O_3), and potassium (K_2O). Both sulfur trioxide (SO_3) and sodium oxide (Na_2O) are present in quantities less than 1% in trace amounts.

Mineralogical analysis was conducted at UATL using X-ray diffraction (XRD). Scanning electron microscopy (SEM) images were also employed to support the study of metal additives used to enhance their granular morphology and composition, which indicated the presence of CRLCP at the University of Laghouat in Algeria (see Figures 2, 3 and 5).

Table 3. *Physicochemical characteristics of the two mineral additions used*

Properties `	Brick Powder(BP)	Ceramic Powder(CP)
SiO_2	66.52	62.00
Al_2O_3	14.20	21.50
Fe_2O_3	5.45	2.11
CaO	6.06	4.89
MgO	2.35	0.54
K_2O	2.09	1.20
Na_2O	0.73	0.63
SO_3	0.15	0.02
Cl^-	-	-
Tio^{2-}	-	4.26
loss	-	2.10
Loss on ignition	1.00	-
Physical properties		
Absolute density(kg/m^3)	3115.38	2660
Apparent density (kg/m^3)	7654.30	1462
Density	-	-
M fineness (cm^2 /g)	5200	3734

X-ray diffraction of the mineral additions used.

In order to determine the surface characteristics of the mineral additives, figure 2 shows the Calcite and Quartz nature of (LF and CP) and the Kaoliuite nature of BP.

The SEM photos (obtained by Scanning Electron Microscope) are presented in Figure 3. Figure 3 presents the results of a Scanning Electron Microscopy (SEM) test conducted on various mineral additives. This test provides valuable insights into the particle shapes of the materials under examination. The study includes an analysis of the following additives: (a) ceramic powder (CP) particles characterized by their smooth and rounded shapes, (b) limestone filler (LF) particles that are smaller in size, and (c) brick powder (BP) particles exhibiting a rough and angular morphology.

As evident from the figure, brick powder appears coarser with angular particle shapes, while limestone filler and ceramic powder exhibit finer particles with less pronounced angularity.

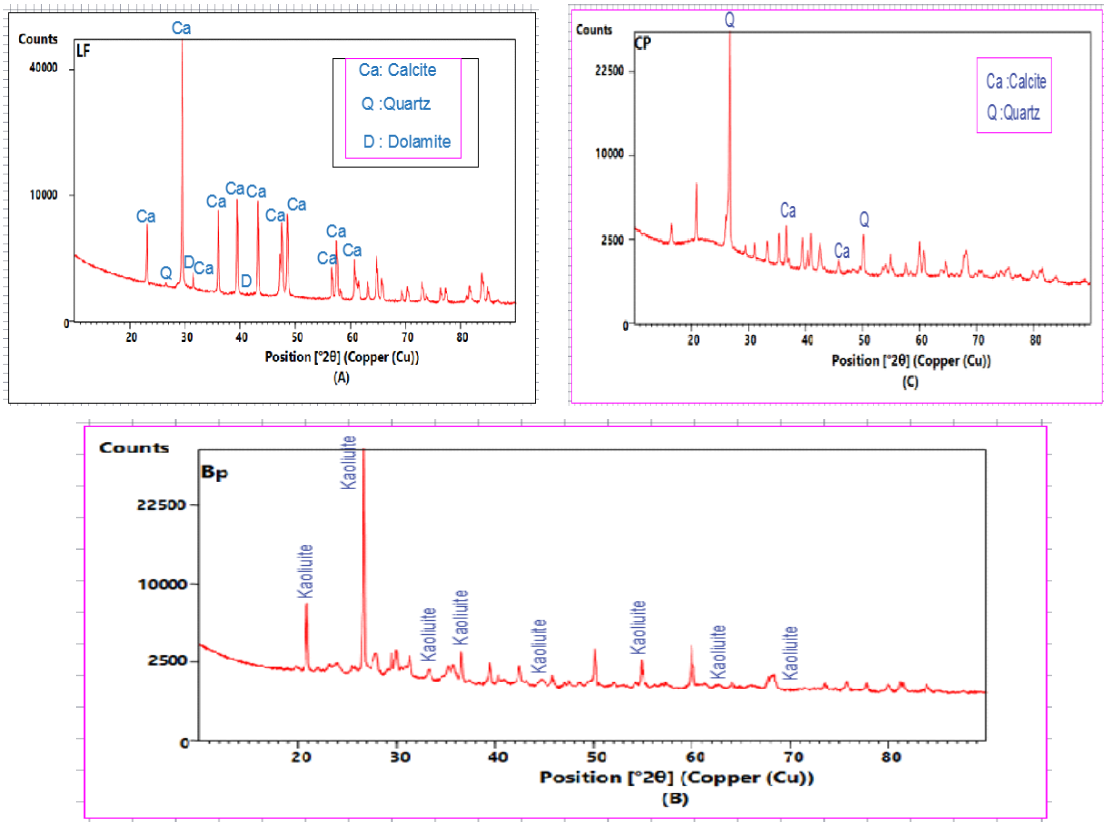


Fig. 2. X-ray diffraction of the mineral additions used

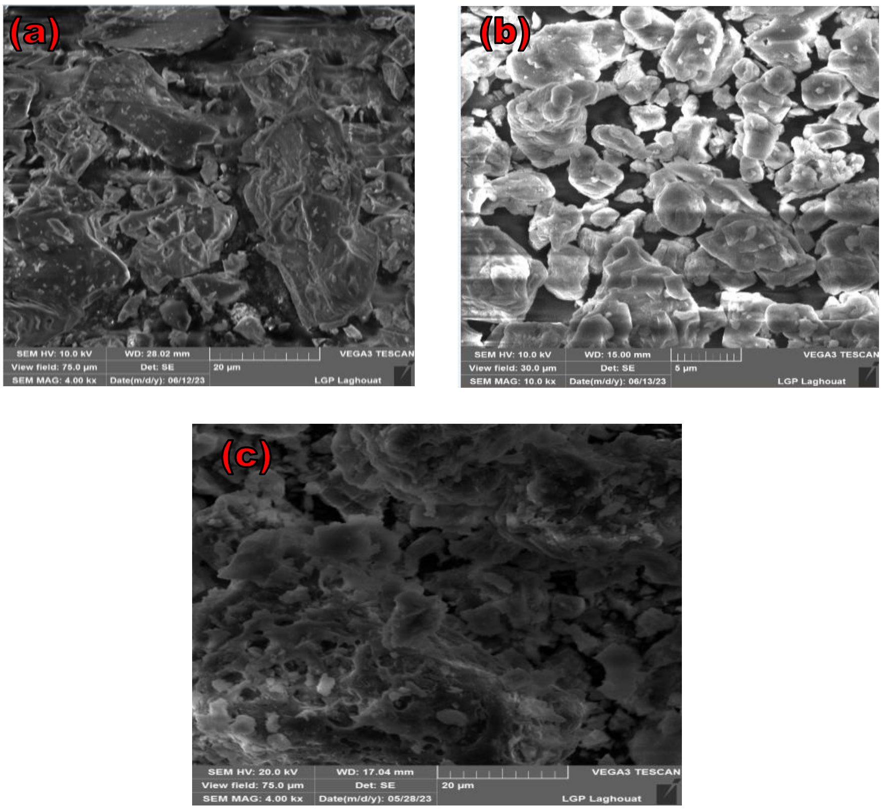


Fig. 3. Particle shape of mineral additives, (a) SEM MAG (500X) Ceramic powder, (b) SEM MAG (500X) Limestone filler and (c) SEM MAG (500X) Brick powder

Formulation of the center composition

The crucial step of formulating self-compacting sand concrete (SCSC) was performed using the "Sablocrete" method. The composition of SCSC consists of a mixture of sand with a maximum diameter of 5 mm, CEM II/B -CPJ 42.5-ES NA443 cement to achieve a strength of 44 MPa, and fine materials evaluated at 164 l/m3. The minimum porosity was set at 207 l/m3, with a trapped air volume of 25 l/m3. The cement dosage was determined to be 350 kg/m3, and the sand mixture was composed of alluvial and dune sands, with 15% dune sand to maximize density. The superplasticizer dosage was set at 1.3% to achieve an optimal spread of 26-30 cm.

COMPOSITION OF THE FORMULATIONS

The results of the experiments carried out in the first phase of our study allowed us to find a formulation that greatly helps to study the influence of the combination of the three different types of mineral additions on the characteristics of the SCSCs under study, according to the recommendations established by the EFNARC [32].

Note that the total sand dosage was kept constant (AS+DS = 1498 g/m3) for all the compositions. The cement dosage was also kept constant (472 kg/m3). The quantity of water to be added was calculated according to the ratios (W/B) given, with a correction of the quantity of water and a constant dosage of the superplasticizer.

The different SCSC compositions obtained using the three types of mineral additions are presented in Table 4.

Table 4. *Composition of the formulations studied*

Mix. N°	mineral additions used			Alluvial sand (kg/m^3)	Dune sand kg/m^3)	Cement (kg/m^3)	W/B	Mixing water (kg /m^3)	SP (kg/m^3)
	LF	BP	CP						
1	1	0	0						
2	0.8	0.2	0						
3	0.6	0.4	0						
4	0.4	0.6	0						
5	0.2	0.8	0						
6	0	1	0						
7	0.8	0	0.2						
8	0.6	0.2	0.2						
9	0.4	0.4	0.2						
10	0.2	0.6	0.2						
11	0	0.8	0.2	1217	281	472	0.29	180	6.28
12	0.6	0	0.4						
13	0.4	0.2	0.4						
14	0.2	0.4	0.4						
15	0	0.6	0.4						
16	0.4	0	0.6						
17	0.2	0.2	0.6						
18	0	0.4	0.6						
19	0.2	0	0.8						
20	0	0.2	0.8						
21	0	0	1						

Aggregates

Two types of local sands, namely alluvial sand (AS) and dune sand (DS) from the region of Laghouat, were used for the formulation of the SCSC compositions under study.

Table 5. *Main properties of the sands used*

Sand	Alluvial Sand(AS)	Dune SandDS)
Size (mm)	0/5	0/0.63
Density	2.65	2.67
Absorption coefficient (%)	1.79	5.18
Finenessmodulus	3.0	0.9
Sand Equivalent	87.70	91

Table 5 summarizes the main characteristics of these two types of sand. This same table clearly shows that DS is characterized by higher water absorption capacity, higher fineness, and better cleanliness than those of AS. It is also observed that DS is a finer sand (Dmax = 0.63 mm) than AS (Dmax= 5 mm).

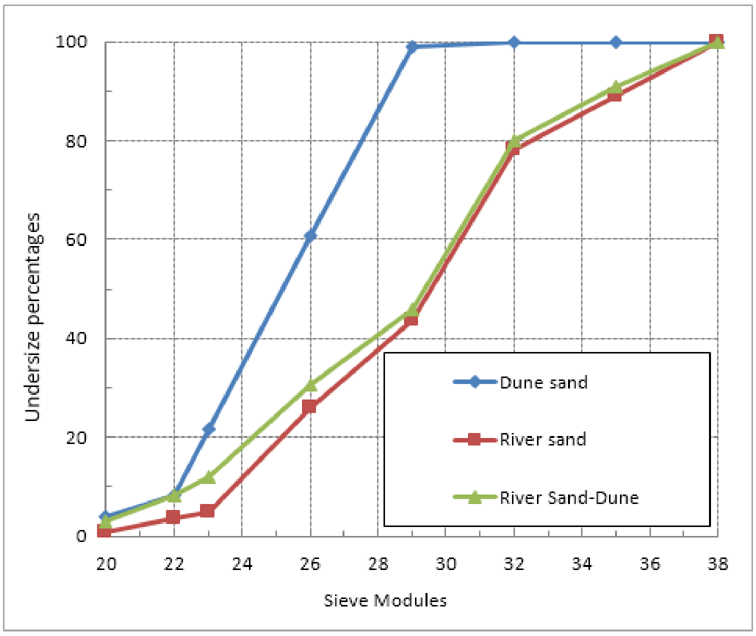


Fig. 4. Particle size curves

Figure 4 above depicts the particle size curves of the sands used in this study. It is worth mentioning that dune sand is widely available in the south of Algeria comparing to river sand .

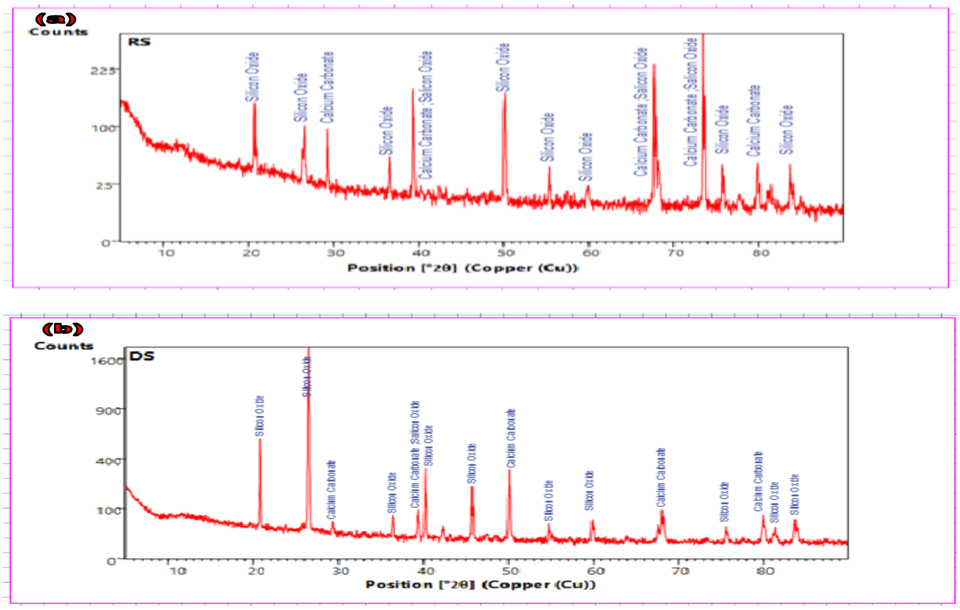


Fig. 5. X-ray diffraction of the two types of sand used, (a) RS; (b) DS

Figure 5 illustrates the X-ray diffraction of the two types of sand used. DRX analysis of both alluvial and dune sands shows their siliceous nature (quartz (SiO2)) by the presence of calcite (CaCO3) in accordance with Belferrag [33]. The absence of fragments of active carbonate rocks such as dolomite means that the sands studied have a chemically stable composition, and can produce mortars without alkali-aggregate reaction [34].

Superplasticizer

The superplasticizer used is MEDAFLOW-RE25 which was developed by the GRANITEX Company (Algeria). It is a third generation high water-reducing superplasticizer, in the form of liquid and of a yellowish color. It was designed based on polycarboxylates and complies quite well with Standard EN 934-2 [AFNOR, 2002]. The density, pH value and dry extract of this superplasticizer are respectively equal to (1.06+0.01), 7 and 25%.

MEDAFLOW-RE25 reduces the water-to-cement ratio (W/C=0.38), but at the same time, it considerably improves the fluidity of concrete. It also has the ability to increase the early and long-term mechanical strength of concrete.

It is worth emphasizing that the recommended dosage range for MEDAFLOW-RE25 is between 1.0 and 2.5%. However, the optimal dosage must be identified as it depends on the type of concrete to be prepared as well as on the desired properties by conducting some laboratory batch experiments.

Influence of the types of mineral additions used

The results of the different tests conducted on the 21 SCSC compositions under study in the fresh state are given in Table 4. However, Tables and 7 present the coefficients and the parameters of the models found in the fresh state and in the hardened state of the SCSCs under study. It can easily be noted that the correlation coefficients of the models considered are good in general (from 0.71 to 0.95).

Table 6. *Coefficients and parameters of models of empirical tests and static stability*

Terms	Spread (cm)		J-Ring (cm)		V-Funnel(s)		T500 (s)		L-Box (%)		Sieve stability (%)	
	R^2=0.70 P<0,0014		R^2=0.75 P<0,0004		R^2=0.70 P<0,0014		R^2=0.88 P<0,0001		R^2=0.76 P<0,0003		R^2=0.70 P<0,0014	
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
LF	83.51	<0.0001	2.78	<0.0001	8.61	<0.0001	2.10	<0.0001	89.0	<0.0001	83.51	<0.0001
BP	48.10	<0.0001	0.19	0.5872	4.62	<0.0001	5.66	<0.0001	100.7	<0.0001	48.10	<0.0001
CP	71.23	<0.0001	2.26	<0.0001	7.39	<0.0001	5.71	<0.0001	76.73	<0.0001	71.23	<0.0001
LF*BP	-48.69	0.0579	-1.62	0.2880	-4.30	0.1053	-6.87	0.0009	12.64	0.4832	-48.69	0.0579
LF*CP	-20.75	0.3951	-2.38	0.1256	-3.62	0.1678	0.81	0.6291	-16.07	0.3754	-20.75	0.3951
BP*CP	35.16	0.1587	0.020	0.9889	-4.10	0.1213	-8.71	<0.0001	-29.91	0.1098	35.16	0.1587

Table 7. *Results of mechanical tests in the hardened state - Compression and flexural tensile strengths*

N°	Combination of additives			Rc-3d (MPa)	Rc-28d (MPa)	Rc-180d (MPa)	Rt-3d (MPa)	Rt-28d (MPa)	Rt-180d (MPa)
	LF	BP	CP						
1	1	0	0	24.1	53.0	64.0	2.53	5.16	6.82
2	0.8	0.2	0	20.1	43.1	53.5	1.85	4.14	5.86
3	0.6	0.4	0	1.3	39.6	45.3	1.72	3.75	4.45
4	0.4	0.6	0	10.8	30.6	38.4	0.73	3.99	4.36
5	0.2	0.8	0	8.1	18.4	27.0	0.51	2.56	3.66
6	0	1	0	4.1	13.0	20.12	0.44	2.08	2.45
7	0.8	0	0.2	19.4	51.6	55.1	2.83	4.64	5.74
8	0.6	0.2	0.2	13.68	36.9	43.4	1.8	3.75	4.15
9	0.4	0.4	0.2	18	34	37.5	1.5	3.5	3.99
10	0.2	0.6	0.2	11.8	26.7	32.0	1.2	3.2	4.1
11	0	0.8	0.2	9.6	19.5	28.7	0.52	2.7	3.1
12	0.6	0	0.4	19.1	45.6	52.0	1.65	2.64	4.67
13	0.4	0.2	0.4	20	30.4	45.6	1.37	3.26	4.99
14	0.2	0.4	0.4	9.8	31.6	35.0	1.92	3.94	4.23
15	0	0.6	0.4	12.3	33.3	38.0	1.6	3.8	4.8
16	0.4	0	0.6	19.5	48.7	53.0	1.47	4.11	5.81
17	0.2	0.2	0.6	12.25	44.25	47.31	1.98	4.2	4.95
18	0	0.4	0.6	10.1	25.3	39.8	1.66	3.35	4.88
19	0.2	0	0.8	11.81	49.2	55.0	1.91	4.6	6.2
20	0	0.2	0.8	13.37	48.31	52.0	1.3	3.64	5.14
21	0	0	1	15.6	52.4	60.1	1.7	4.61	6.3

Table 8. *Coefficients and parameters of rheological tests and models in the hardened state – Compressive strength (MPa) and Flexural tensile strength (MPa)*

Terms	Rc-3d(MPa)		Rc-28d(MPa)		Rc-180d(MPa)		Rt-3d(MPa)		Rt-28d(MPa)		Rt-180d(MPa)	
	R^2=0.79 P<0,0001		R^2=0.92 P<0,0001		R^2=0.97 P<0,0001		R^2=0.79 P<0,0001		R^2=0.67 P<0,0028		R^2=0.86 P<0,0001	
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
LF	23.35	<0.0001	52.94	<0.0001	63.75	<0.0001	2.65	<0.0001	4.88	<0.0001	6.57	<0.0001
BP	5.24	0.0252	13.27	0.0006	21.63	<0.0001	0.24	0.3651	2.195	<0.0001	2.78	<0.0001
CP	13.50	<0.0001	53.76	<0.0001	61.46	<0.0001	1.59	<0.0001	4.66	<0.0001	6.50	<0.0001
LF*BP	-	-	-1.99	0.8789	-13.18	0.1080	-	-	0.58	0.7375	-1.34	0.4072
LF*CP	-2.24	0.8015	-25.15	0.0696	-40.36	<0.0001	-1.04	0.3500	-4.29	0.0248	-5.43	0.0037
BP*CP	-	-	-11.73	0.3764	-14.56	0.0784	2.54	0.0327	0.43	0.822	-0.68	0.6716

Mathematical models

The model coefficients, correlation coefficients (R^2), t-ratios, probabilities, and p-values of the responses are summarized in Table 8. According to this table, the models adopted for the responses are the spread,Vf, Rc-28days, and Rt-28days. An example of calculations is given below:

$$Spread(cm) = 83{,}51 \times LF + 48{,}10 \times BP + 71{,}23 \times CP - 48(LF.BP) - 20{,}75(LF.CP) + 35{,}16(BP.CP) \quad (3)$$

$$V_f\,(\text{sec}) = 8{,}61 \times LF + 4{,}62 \times BP - 4{,}30(LF.BP) - 3{,}62(LF.CP) + 4{,}10(BP.CP) \quad (4)$$

$$Rc_{28}(MPa) = 52{,}94 \times LF + 13{,}27 \times BP + 53{,}76 \times CP - 1{,}99(LF.BP) - 25{,}15(LF.CP) + 11{,}73(BP.CP) \quad (5)$$

$$Rt_{28}(MPa) = 4{,}88 \times LF + 2{,}195 \times BP + 4{,}66 \times CP + 0{,}58(LF.BP) - 4{,}29(LF.CP) + 0{,}43(BP.CP) \quad (6)$$

These calculations play a crucial role in translating the models from coded units into real-world units. Negative coefficient signs indicate that an increase in the value of the corresponding variable results in a decrease in the response, while positive coefficient signs indicate that an increase in the value of the related variable leads to an increase in the response. For example, if the dosage of PB, the W/B ratio, and SP is increased, that will lead to a decrease in the flow time, as measured by the v-funnel (Vf). On the other hand, increasing the dosage of (AS+DS)+LF increases Eta and Spread (cm).

The constructed models were developed using the least squares method, which involves minimizing the sum of squares of the residuals. The plots depicting the predicted-to-observed relationship, as illustrated in Figure 6 reveal that the data points appear to be distributed within the limits of the confidence curves.

Analysis of Variance (ANOVA)

Experimental data were utilized to perform an Analysis of Variance (ANOVA) and formulate a multiple regression model to assess the properties based on three different mineral additions. The primary objective was to compare and test input quantities as a mixture of one specific component, two specific components, or all three specific components while maintaining a total quantity equal to 1.

This approach serves as an essential tool for determining the significance of an effect or mathematical model. The significance of all terms present in the polynomial was statistically assessed by calculating the F-value, with probabilities (P) of 0.0001, 0.0004, 0.0014, or 0.0028. Models with P-values less than 0.05 are considered significant.

The analyses of variance for each of the modeled responses are presented in Table 9 :

Table 9. *ANOVA Results for Response Variance*

Response	Source	Degrees of freedom	Sum of Squares	Mean Square	F Ratio
Spread (cm)	Model	5	1783.89	356.77	7.08
	Errors	15	755.51	50.367	
	Total	20	2539.40	*p-value*<0.0014	
J-Ring (cm)	Model	5	8.82	1.76	9.11
	Errors	15	2.90	0.19	
	Total	20	11.72	p-value<0.0004	
Rc-28d(MPa)	Model	5	2640.01	528.00	35.57
	Errors	15	222.60	14.84	
	Total	20	2862.62	*p-value*<0.0001	
Rt-28d(MPa)	Model	5	8.09	1.61	6.09
	Errors	15	3.98	0.26	
	Total	20	12.07	*p-value*<0.0028	

According to Table 9, it is noticeable that the Fisher's F-ratios for the responses, specifically compressive strength at 28 days (Rc-28) and the J-Ring test, are significantly high (35.57 and 9.11, respectively). On the other hand, the responses for workability (Eta), flexural tensile strength at 28 days (Rt-28), and 6.09. are relatively low compared to the previous ones but are still acceptable. All of these ratios are greater than 1, which is further confirmed by the low p-values.

Therefore, it can be concluded that the proposed models not only represent the mean measurements but also adequately capture the variations in the responses due to variations in the factors.

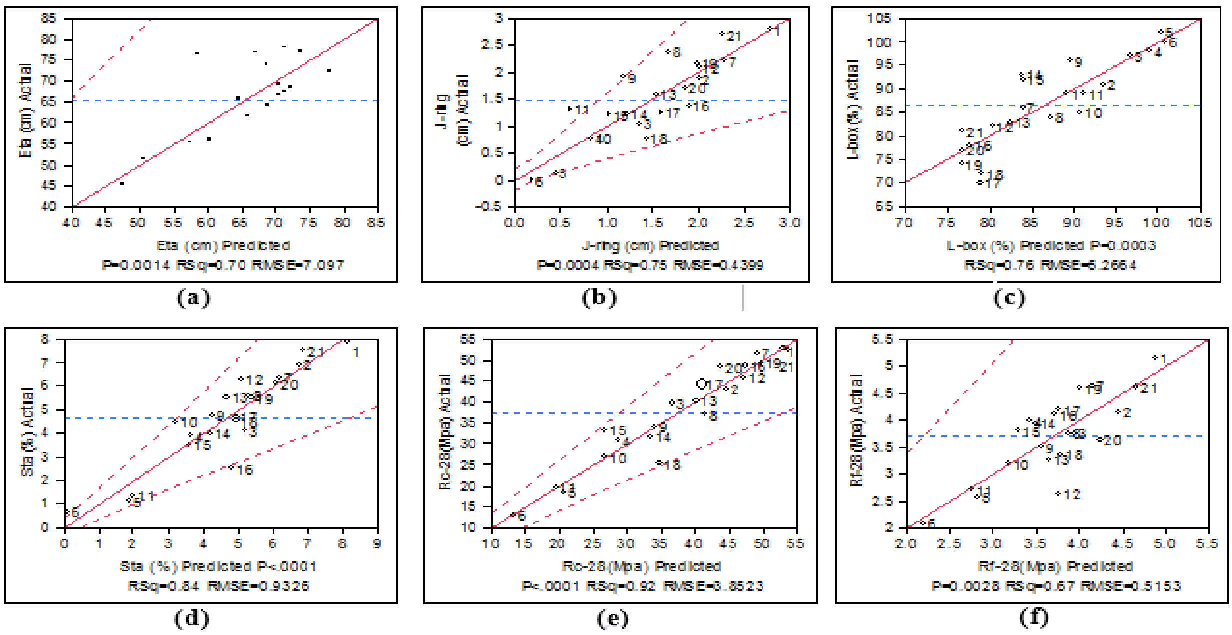


Fig. 6. Observed-to-predicted plots for: (a) SPD, (b) J-ring, (c) L-box, (d) Sta, (e) Rc-28 days, (f) Rt-28 days

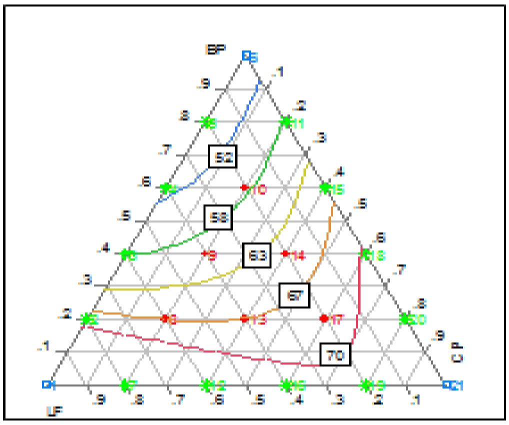
Figure 6 shows that the results were statistically significant, judging from the different values of R^2 obtained. With the exception of (f), where R^2 stood at 0.67, the results can be said to be satisfying.

The correlation coefficient (R^2) is significantly high, signifying a strong correlation between the experimental and predicted responses. Additionally, it is clear that the flow time distribution in the fresh state, as well as the outcomes of compressive and flexural strength tests for the mixtures, have a notable impact on the lowest correlation coefficient [35] in Figure 6 (0.70, 0.88, 0.92, and 0.67), along with the highest standard deviation value for these property results.

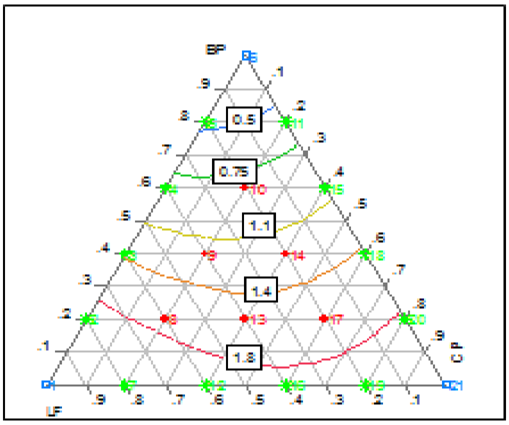
RESULTS AND ANALYSIS

Influence of mineral addition on spreading

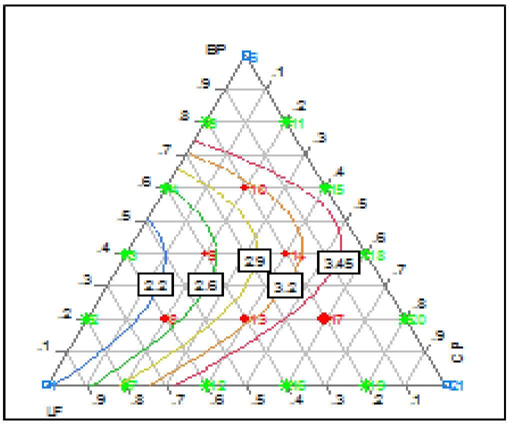
The results, as depicted in Figure 7-(a), show that the concrete spread test is indicating an increase in the percentage of LF addition, making it possible to have a better concrete spread. Similarly, it was found that the addition of up to 35% of CP in ternary systems (FC, PB, PC) contributes to improving the workability of self-compacting sand concretes (SCSCs).



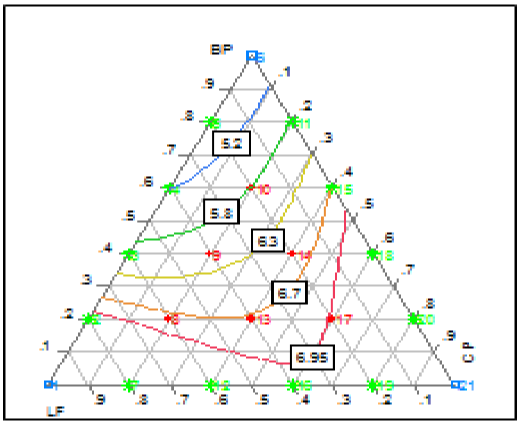
(a) Ternary diagram of spreading (cm) according to the type of mineral addition used



(b) Ternary diagram of modified J-Ring spread according to the type of mineral addition used.



(c) Ternary diagram of T500 (s) as a function of type of mineral addition.



(d) Ternary diagram of V-funnel flow time as a function of the type of mineral addition.

Fig. 7. Ternary diagram of SCSC in the fresh stats

Furthermore, the highest spread value (70 cm) was obtained for the proportions of 50% LF, 40% CP, and 10% BP.

These same results also indicated that the spread decreased as the BP percentage increased. This was particularly noticed for the formulation (F6-100% BP), as the amount of water is kept constant.

On the other hand, the improvement in workability can be explained by the presence of a denser stacking of the added particles, which generates an excess of paste that can serve to lubricate the solid grains in the mixture. The same observation can be made in the case of a percentage of 100% of LF.

Incorporating ceramic waste powder as a substitute for up to 15% of the cement content has been found to enhance the flowability of self-compacting sand concretes. However, when the combination consists of 50 % LF and CP, bleeding becomes noticeable. In summary, replacing a portion of the cement with ceramic powders and limestone filler typically improves the flowability and homogeneity of the concrete, except in cases where 50% LF and PC are used. These findings align with the results reported in reference [36].

Influence of mineral addition on the J-ring slump flow time T500J

In the context of concrete testing, discusses the results of the J-ring test and its comparison to the spread test for different types of Self-Compacting Sand Concrete (SCSC) mixtures.

The J-ring test assesses how well concrete can fill voids. The flow time (T500J) of the various SCSC mixtures is represented in Figure 7-(b). It shows that the flow time (T500) of 1.25 to 2.40 seconds, in the presence of the J-Ring, is acceptable when compared to tests conducted without the J-Ring, regardless of the SCSC type [37].

These results indicate that the behavior of SCSC in the J-Ring test closely resembles its behavior in the spread test. This similarity is also observed in a specific ternary system (comprising LF, BP, and CP) with a spread time of 1.8 seconds. It's worth noting that these results were obtained for a mixture consisting of 20% LF, 10% BP, and 70% CP. These findings suggest that SCSC has excellent flowability through reinforcements and confinement, primarily because it lacks large aggregates, which would otherwise cause blockages when encountering obstacles. Figure 8 below shows the spreading (cm) of SCSC in the fresh state.

Fig. 8. Example (b) of spreading (cm) of SCSC in the fresh state (formulation F1) and Example (a) of J-ring spread (formulation F21)

Influence of mineral additions on the flow time

Figure 7-(c), represents the variation in T500 for different groups with different percentages of mineral additions. It is allowed to point out that the diffusion behavior of SCSC practically does not change. In this case, the maximum T500 value for the mixture is obtained at 3.45 s, for the percentages 30% LF, 50% CP, and 20% BP. It should also be noted that the total amount of mineral additives represents 23% of the total amount of sand used, which led to poor compaction. This is mainly due to the homogeneous nature of this type of sand [38].

Furthermore, dune sand has a low fineness coefficient, which means that a large amount of water is needed [28, 39]. It is also noted that the use of CP and BP leads to an increase in flow time, because these two components require larger amounts of water. It is worth noting that the flow times at T500 for all SCSCs are lower than those suggested by Domone et Chai [40]. This is probably due to high viscosity mixtures. The lowest flow time was found in F3 mixture (60% FL + 40% BP), and this can be justified by the large and high slope (533 mm) and minimum T500 value equal to 1.91 s.

Influence of mineral additions on the flow time of SCSC through the V-funnel

One method for determining the viscosity and resistance to segregation of SCSC is to test the flow through the V-funnel. According to Domone and Jin [41], the flow time values range between 2-10 s. Based on the obtained results, it can be concluded that all SCSC mixtures produce good results with flow time ranging between (3.76, 8.55) s.

Figure 7 -(d), depicts the variation of the V-funnel flow time of the compositions under study as a function of the dune sand (SD) and limestone filler (LF) dosages. The results obtained show that LF has a greater influence on the flow time as compared to BP. In addition, the maximum time required for the passage of the ternary SCSC is 6.95 s. This corresponds to a mixture containing the percentages 50% LF, 40% CP, and 10% BP

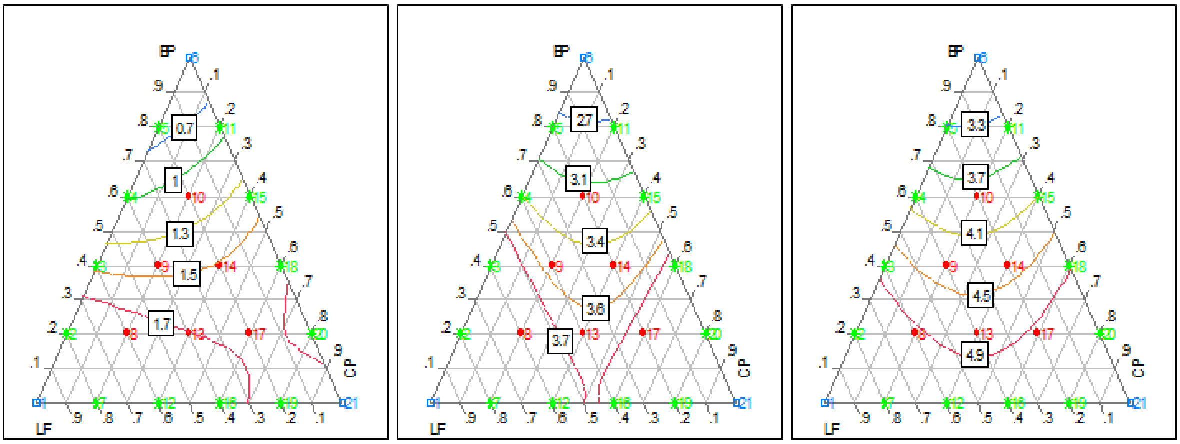
Likewise, the results show that the V-funnel flow times (between 8 and 12 s) of all the compositions under study are lower than the values recommended for the SCCs [37], except for the two compositions F1 (100 % LF) and F21 (100% CP), owing to enhanced pozzolanic activity. Figure 9 represents an example of the flexural tensile strength of the SCSC used in the experiment.

Fig. 9. Example of V-funnel flow time for fresh SCSC (formulation F1)

Mechanical strengths

Mechanical strength tests, encompassing both compressive and flexural strength measurements, were systematically conducted at varying ages—specifically at 3 days, 28 days, and 180 days—in strict adherence to the NF EN 12390-2 and NF EN 12390-3 standards. These comprehensive tests were executed utilizing prismatic specimens exclusively for self-compacting sand concrete (SCSC), all meticulously prepared in full accordance with the prescribed standards.

In the preparation process for the SCSC specimens, the concrete was carefully poured into molds sized at 4x4x16 cm^3. Subsequently, the specimens underwent a vibration process on a shaker table, a step taken to eliminate any entrapped air bubbles and ensure a consistent, uniform composition. The ensuing test results have been documented and are presented in Table 7.



(a) Ternary diagram of Rt-3days (MPa) (b) Ternary diagram of Rt-28days (MPa) (c) Ternary diagram of of Rt-6 months (MPa)

Fig. 10. Ternary diagram of flexural stress according to the type of mineral addition

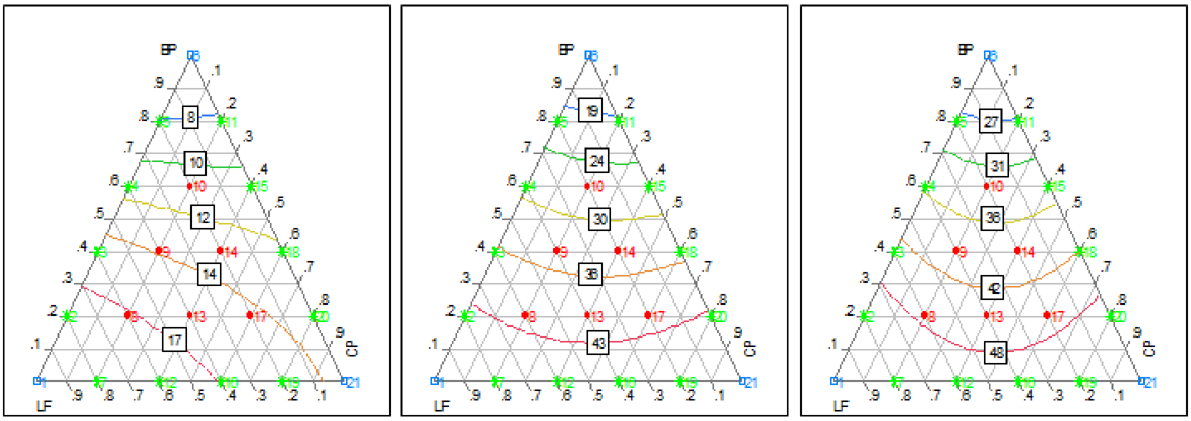
Influence of mineral additions on Flexural strength

The ternary diagrams presented in Figures 10 depict the test results. These figures illustrate that the flexural tensile strength increases as the proportions of LF (Limestone Filler) and CP (Ceramic Powder) increase. Interestingly, BP (Brick Powder) was found to have no significant influence on this strength parameter. Furthermore, at the 28-day mark, when the flexural tensile strength reaches its peak, it attains a value of 3.7 MPa. It is noteworthy that a substantial amount of fines in the mix leads to the entanglement of LF grains [39, 42].

Incorporating ceramic waste powder at a substitution rate of 60% led to an increase in the splitting tensile strength. This enhancement can be attributed to the higher levels of silica and alumina present in both the brick and ceramic powders, which promote the formation of sodium alumino-silicate compounds and calcium hydroxide, crucial for the geopolymerization process [42].

Observations showed that the flexural strength increases with longer curing times. Additionally, the inclusion of brick powder (BP) resulted in a reduction in flexural strength, with a more pronounced decrease as the BP content increased [43]. Our findings corroborate these observations, with the lowest recorded value occurring in the triple combination (PB 80% + LF 10% + CP 10%) Fig. 10-b, measuring 2.7 MPa at the 28-day mark. Similar trends were observed in other test results.

The presence of limestone filler and ceramic powders, either individually or combined at levels exceeding 20%, led to a significant decrease in flexural strength. Notably, at the 28-day point, the strength was 2.7 MPa, and at 180 days Fig. 10-c, it reached 3.3 MPa. This decrease was more pronounced in mixtures containing 60% brick powder.



(a) Ternary diagram of Rc-3days (MPa). (b) Ternary diagram of Rc-28days (MPa). (c) Ternary diagram of of Rc-6 months (MPa).

Fig. 11. Ternary diagram of the compressive strength according to the type of mineral addition

Influence of mineral additions on the compressive strength

The effect of ceramic powder, limestone filler and brick powder on compressive strength at 3, 28 and 180 days can be observed in Fig. 11. Note that the LF and CP ratios in the binary and ternary systems result in better tensile strength, where we recorded a pressure value of 43 MPa at an age of 28 days for the mixtures in the binary system with the following ratios (60% LF +40% CP) Fig. 11-b. Similarly, for ternary mixtures at an age of 180 days, the pressure was equal to 48 MPa with ratios (50% LF +40% CP+10% BP) Fig. 11-c.The same results were observed at 3 days (Fig. 11-a).

Enhancing the compressive strength of mixtures containing less than 20% BP and more than 60% CP over a period of 180 days has demonstrated a positive response to the ternary composition of mineral additives. By incorporating fine pozzolanic powders, we achieved a peak pressure value of approximately 48 MPa within the ternary blend (60% CP + 20% BP + 10% LF). This phenomenon contributes to the densification of voids and pores, ultimately increasing their overall density. The pozzolanic reaction between SiO_2 (from the powders) and calcium hydroxide results in the formation of novel compounds (calcium hydroxide silicates) and fills the fine voids, leading to a higher compression-to-strength ratio. These findings align seamlessly with the outcomes presented in study [36, 42].

On the other hand, it is also observed that the mixture with high LF content offers better compressive strength. In addition, the inclusion of CP provides the same effect on compressive strength due to the shape of the particles that make up each composition and the interaction of the compositions with the cement used.

Moreover, the hydrated cement paste mix was prepared with a mixture of alluvial sand (SA and dune sand (DS), and the addition of LF gave a rough texture, although the alluvial and dune sand particles have rounded shapes [44]. Figure 12 below depicts an example of the compressive strength of SCSC.

Incorporating ceramic powder significantly boosts compressive strength over time, especially beyond the 28-day curing period due to increased pozzolanic activity. Limestone filler, rich in CaCO3, enhances concrete performance, positively affecting both compressive strength, thanks to its synergistic interaction with cement and sand composition.

The incorporation of brick powder yielded favorable outcomes in terms of both compressive and flexural strength, particularly when it constituted a component of a ternary mixture at lower percentages, usually below 20%. Nevertheless, when the proportion of brick powder surpassed this threshold, its impact on mechanical properties diminished compared to the findings associated with other mineral additives examined in this study.

Fig. 12. Example of the process of measuring the compressive strength of SCSC (formulation F1)

CONCLUSIONS

This article investigates the impact of certain mineral additions on the properties of Self-Compacting Sand Concrete (SCSCs). The results were obtained

- The concrete spread test showed that increasing the percentage of limestone filler (LF) improved the workability of SCSCs.
- The greatest spread value of 70 cm was obtained when using a mixture comprising 50 % LF, 40 % CP, and 10 % brick powder (BP). However, an excessive amount of BP resulted in a reduction in spread.
- The enhanced workability was attributed to the more compact arrangement of the additional particles, which in turn supplied extra paste for lubrication, as indicated by the J-Ring Slump Flow Time (T500J).
- The V-funnel flow time showed positive outcomes for all SCSCs mixtures, ranging from 3.76 to 8.55 seconds. Among the components, LF had the most pronounced impact on flow time. Both CP and BP contributed to an increase in flow time due to their higher water demand.
- Mechanical strength tests were carried out at three different time intervals: 3 days, 28 days, and 180 days. The flexural tensile strength exhibited an upward trend with increased proportions of LF and CP in the mixture.
- The tensile strength showed improvement when ceramic waste powder was incorporated at a substitution rate of 60 %.
- The addition of brick powder (BP) resulted in a reduction in flexural strength, with the most notable decrease occurring in the case of the triple combination (80 % PB +10 % LF+10 % CP).

- The compressive strength at 28 days reached 43 MPa for binary mixtures consisting of 60% LF and 40 % CP, and it increased to 48 MPa for ternary mixtures containing 50 % LF, 40% CP, and 10 % BP.
- These results suggest that the addition of mineral powders, especially LF and CP, can enhance the workability and mechanical properties of (SCSCs).

This article highlighted the importance of mineral additions in improving the performance of self-compacting sand concrete, offering potential benefits in construction and infrastructure projects.

REFERENCES

1. Nehdi M., Rahman M.: Why some arbonate fillers cause rapid increases of viscosity in dispersed cement-based materials. Cement and Concrete Research, 30 (2000) 1663-1669.
2. El Barak M.: Contribution à l'étude de l'aptitude à l'écoulement des BAP à l'état frais, thèse de doctorat, Université Toulouse III, 2005.
3. Billberg P.: Fine mortar rheology in mix design of SCC. Proceedings of 1st inter Rilem Conference on SCC, Cachan cedex, (1999) 47-58.
4. Zhang X., Han J.: The effect of ultra-fine admixture on the rheological property of cement paste. Cement and Concrete Research, 30 (2000) 827-830.
5. Alsanusi S.: Influence of silica fume of self compacting concrete. International Journal of Civil and Envirenment al Engineering, (2013) 7.07.
6. Mohammadi Y., Sajjad Mousavi S.: The effect of silica fume on the properties of self compacted lightweight Concrete. Current World Environment, 10 (2015) 381-388.
7. Akhtar P., Paliwal M.C., Singh V.K.: Experimental Investigation and Cost Analysis of Self Compacting Concrete by using Red Mud. International Journal of Engineering Development and Research, 5 (2017) 3.
8. Arivalagan S.: Experimental Analysis of Self Compacting Concrete Incorporating Different Range of High Volumes of Class F Fly Ash. Scholars Journal of Enginering and Technology, 3 (2013) 104-111.
9. Shah U.N., Modheda C.D.: Study on fresh of self compacting concrete with process fly ash. International Journal of Research in Engineering et Technology, 2 (2014) 2321-8843.
10. Jalal M., Pouladkhan A.: Comparative study on effects of class F fly ash , nano silica and silica fume on properties of high performance self compacting concrete. Construction and Building Materials, 94 (2015) 90-104.
11. Boel V., Audenaert K., De Schutter G., Heirman G., Vandewalle L., Desmet B., Vantomme J.: Transport properties of self compacting concrete with limestone filler or fly ash. Materials and Structures , 40 (2007) 507–516.
12. Chaid R., Jauberthie R., Zeghiche J.: Impact de la poudre de marbre conjuguée au calcaire du CEMII sur la durabilité du béton. European Journal of Environmental and Civil Engineering, 15 (2011) 427-445.
13. Kumar A. D.: Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth. Journal of Building Engineering, 15 (2018) 236-242.
14. Cagin U. G., Bilir T., Artir R.: Durability Properties of Concrete Produced by Marble Waste as Aggregate or Mineral Additives. Procedia Engineering, 161 (2016) 543 – 548.

15. Ricardo P., Roberto P. Jr L., Lima A.E, Pelisser F., Jean Paul G.P.: Use of porcelain polishing residue as a supplementary cimentitious material in self-compacting concrete. Construction and Building Materials, 193 (2018) 623–630.
16. Lavanya G., Karuppasamy R.: Experimental study on concrete using glass powder and granite powder. International Journal of Advanced Engineering Research and Technology, 4 (2016) 97-101.
17. Kim S., Choi S., Yang E.: Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate. Construction and Building Materials, 184 (2018) 269–277.
18. Senthamarai, R.M., Manoharan P.D: Concrete with ceramic waste aggregate. Cement and Concrete Composites, 27.9-10 (2005) 910-913.
19. Gonzalez-Corominas A., Etxeberria M.: Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates. Construction and Building Materials, 68 (2014) 618-626.
20. El-Dieb, A.S., Kanaan, D.M.: Ceramic waste powder an alternative cement replacement–characterization and evaluation. Sustainable Materials Technologies, 17 (2018) e00063.
21. Subaşı, S., Öztürk H., Emiroğlu M.: Utilizing of waste ceramic powders as filler material in selfconsolidating concrete. Construction and Building Materials, 149 (2018) 567-574.
22. Kannan, D.M., Aboubakr A.H., EL-Dieb A.S., Taha M.M.R.: High performance concrete incorporating ceramic waste powder as large partialreplacement of Portland cement. Construction and Building Materials, 144 (2017) 35-41.
23. Lasseuguette E., Burns, S., Simmons D., Francis, E., Huang Y.: Chemical, microstructural and mechanical properties of ceramic waste blended cementitious systems. Cleaner Production, 211 (2019) 1228-1238.
24. Khayat K. H., Ghezal A., Hadriche M. S.: Factorial design model for proportioning self-consolidating concrete. Materials and Structures, 32 (1999) 679-686.
25. Sonebi M., Svermova L., Bartos PJM.: Statistical modelling of cement slurries for self-compacting SIFCON containing silica fume. Materials and Structures, 38 (2005) 79-86.
26. Yahia A., Khayat K.H.: Experiment design to evaluate interaction of high-range water-reducer and antiwashout admixture in high-performance cement grout. Cement Concrete Research, 31.5 (2001) 749–57.
27. Bayramov F., Taşdemir C., Taşdemir M. A.: Optimisation of steel fibre reinforced concretes by means of statistical response surface method. Cement Concrete Composites, 26.6 (2004) 665–675.
28. Bouziani T.: Formulation d'un béton de sable autoplaçant: rôle de la granularité et de dosages des constituants sur le comportement rhéologique, PhD thesis, Université M'Hamed Bougara de Boumerdès, 2012.
29. Bouziani, T.: Assessment of fresh properties and compressive strength of self-compacting concrete made with different sand types by mixture design modelling approach. Construction and Building Materials, 49 (2013) 308-314.
30. Goupy J., Creighton L.: Introduction to design of experiments with JMP examples, 3rd ed. Cary, NC SAS Institute, (2018) 11-240.
31. R'mili, A., Ben Ouezdou B.: Incorporation du sable de concassage et du sable du désert dans la composition des bétons autoplaçants, Séminaire international, Innovation et Valorisation en Génie Civil et Matériaux de Construction, 81 (2009) 10: 271.
32. EFNARC S.: Guidelines for Self-Compacting Concrete, European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk, UK, English ed, February, 2002.

33. Leila Z., Azzeddine Z. B.: Contribution à l'étude des caractéristiques du sable de dune et de son effet sur le comportement des bétons autoplaçants, ACMA. 9-12 May 2012.
34. Belferrag A.: Contribution à l'amélioration des propriéts mécaniques et rhéologiques des bétons de sable de dunes, PhD thesis, Biskra Algérie: s.n., (2016) 125-526.
35. Ghrieb A., Abadou Y.: Physical and Mechanical Properties of Dune Sand Mortar Reinforced with Recycled Pet Fiber: An Experimental Study. Advances in Materials Science, 24.1 (2022) 41-56.
36. Aboubakeur B., Abderramane H., Belkacem S.: Some engineering properties of sustainable self-compacting mortar made with ceramic and glass powders. Építőanyag: Journal of Silicate Based & Composite Materials, 74.1 (2022).
37. Saad C., Lakhdar A., Benchaa B.: Use of recycled aggregates from different sources in the production of SCC Part I: Mix design and fresh properties, Építöanyag (Online) , 6, (2022): 210-217.
38. Taha-Honice D., Guettala S.: Effets de divers types de sables sur les propriétés d'un béton autoplaçant. Journée nationale du béton (JNB), Troisième conférence du génie civil et de la planification urbaine, 2017.
39. Benabed B.: Influence de la qualité et de la nature des sables sur les performances et la durabilité des bétons autoplaçants, PhD thesis, Université de Laghouat-Amar Telidji, 2014.
40. Domone P.L., Jin J., Chai WH.: Optimum mix proportioning of self-compacting concrete. Innovation in Concrete Structures: Design and Construction, Thomas Telford Publishing, (1999) 277-285.
41. Domone P., Jin J.: Properties of mortar for self-compacting concrete. Self-compacting concrete, Stockholm, 13-14 September 1999.
42. Mucteba U., Yurdakul A.O.: Investigation of using waste marble powder, brick powder, ceramic powder, glass powder, and rice husk ash as eco-friendly aggregate in sustainable red mud-metakaolin based geopolymer composites. Construction and Building Materials, 361 (2022) 29718.
43. Aboubakeur B., Benchaa B.: Fresh and hardened properties of self-compacting repair mortar made with a new reduced carbon blended cement. Journal of Silicate Based & Composite Materials, 71.4 ,(2019).
44. Aïssoun B. M., Soo-Duck H., Kamal H.Kh.: Influence of aggregate characteristics on workability of superworkable concrete. Materials and Structures ,49 (2016) 597-609.