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Durability of high performance sandcretes (HPS) in aggressive environment

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Abstract. High performance sandcretes (HPS) are new concretes characterized by particles having a diameter less than 5 mm, as well as very high mechanical strength and durability. This work consists in finding solutions to make sandcretes with good physico-mechanical and durability properties for this new generation of micro-concrete. However, upgrading ordinary sandcrete into high performance sandcrete (HPS) requires a thorough study of formulation parameters (equivalent water/binder ratio, type of cement and its dosage, kind and amount of super plasticizer, and gravel/sand ratio). This research study concerns the formulation, characterization and durability, in a sulphate environment, of a high performance sandcrete (HPS), made from local materials. The obtained results show that the rheological properties of fresh concrete and mechanical strength differ with the mineralogy, density and grain size distribution of sands and silica fume used.

Keywords: HPS; additive; sulphate environment; mechanical strength; durability

1. Introduction

The mechanical performances of concrete are not the sole criteria for judging its quality. Therefore, a number of specific properties of sandcretes make them preferential for some usages. However, their classification according to their mechanical performance, in particular their compressive strength at 28 days, remains a determining factor for their use. In general, the mechanical performances of sandcrete are lower than those of ordinary concrete. In particular, the kinetics of strength increase is generally slower for sandcretes, and this can eliminate their use as fast-setting concretes. This is due to the large amount of water used in the mixture, the amount of small elements, as well as the great number of micro-pores in the hardened structure of sandcrete (Sablocrete 1994). However, today with the development of materials technology, particularly with the emergence of superplasticizers, sandcrete can be of high performance, with a very high strength (up to 90 MPa), in order to meet specific mechanical requirements; its high resistance is an inverse function of its total void content (Aïtcin 2001, Guettela *et al.* 2002).

The incorporation of the active fillers like granulated slag or silica fume in sandcrete, has permitted to get 50% of strength gains in compressions. Furthermore the microscopic observations are done by an electronic microscope on samples show a more compact microstructure, more homogeneous and a supplementary pozzolanic effect. This allows improving the strength in long term and particularly the durability (Achoura and Redjel 2005).

Tebbal *et al*. investigated the combined effect of granulated slag and silica fume on the characteristics of high performance concrete. They formulated a high performance concrete (HPC) with cementitious addition and one as a control mixture. The curing mode of conservation was the gypsum water which was used as an aggressive environment for the concrete specimens. The results showed that the concrete containing a dosage of 10 % granulated slag and 5% silica fume; present a higher physico - mechanical properties than the concrete without blending addition. Also, the results of XRD revealed that the peak of $Ca(OH)_2$ showed a high intensity in the reference concrete and completely disappeared in the sample with silica fume and slag content. In addition, the intensity peaks of C_4AH_{13} sharply increased with granulated slag and silica fume (Tebbal *et al.* 2016).

High performance sandcrete (HPS) is not a revolutionary material as it contains exactly the same constituents as sandcrete. The components of this new material are sand (preferably river sand), with continuous grain size, ordinary Portland cement (Portland cement with high initial strength) when high *strengths* at early *age* are required for an important dosage (400 to 600 kg/m^3), fumed silica (typically 5 to 25% of the total mass of the binder), and sometimes some other mineral additives such as fly ash or ground and granulated blast furnace slag, in order to improve compactness, workability and mechanical strength. HPS may also contain a superplasticizer to reduce water (≥ 1.5%), with a very low W/C ratio, lower than 0.35 (Bederina *et al.* 2007, Bederina *et al*. 2009, Gadri *et al*. 2012).

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Table 1 The chemical properties of cement , dune sand powder and silica fume

	Cement (%)	Dune sand powder (%)	Silica fume (%)	
SiO_2	22.31	89.51		93,17
Al_2O_3	4.39	1.64		0.6
Fe_2O_3	5.52	0.72		1.25
CaO	63.89	5.94		1.4
MgO	0.8	0.07		1.02
SO_3	1.11	0.03		2.3
Cl	-	-		-
K_2O	0.41	0.20		1.0
Na_2O	0.09	0.06		-
Mineralogical composition of cement				
Phase content (%)	C_3S	C_2S	C_3A	C_4AF
	60	25.55	2	12.45

Tebbal *et al.* (2016) presented the addition of crushed sand (CS) in the composition of a concrete and studies the effect of its gradual replacement by the dune sand (DS) on sustainability of high performance concrete (HPC) in aggressive environments. The experimental study shows that the parameters of workability of HPC are improved when the CS is partially replaced by the DS (<2/3). The mechanical strengths decrease by adding the DS to CS, but they reach acceptable values with CS in moderate dosages. The HPC performances are significantly better than the control concrete made up with the same aggregates. The tests of durability show that the water absorbing coefficients by capillarity increase after substitution DS to the CS.

According to Aitcin, the strength and durability are two essential factors which define performance of a concrete (Aïtcin 2001). The structures constructed in nuclear waste storage units, chemical industries, marine environment, sewer carriers often face the problem of deterioration of concrete, corrosion of reinforcement, loss in strength, etc. The improved mechanical properties are obtained by lessening the water / binder ratio and often using silica fume and superplasticizers. The reduction of the water/binder ratio and addition of ultrafine particles contribute to improve the life of concrete (Santosh and Khadiranaikar 2014).

The use of high performance sandcrete (HPS) has expanded the scope of use of concrete in areas rich in various types of sand. The use of HPS has significantly increased due to its limited porosity, durability, rheological qualities and outstanding mechanical properties. Many years of research were required to produce this special type of concrete (Aïtcin 2001, Sadok *et al.* 2014).

In north Africa, the aggregates for concretes are made up entirely of rolled sands and crushed gravels. These countries suffer from an important lack of aggregates and mainly of suitable sands. Also, these countries contain inexhaustible quantities of desert sands which were never seriously used in constructions (Rmili *et al.* 2009).

It would be interesting to try to improve some little-known characteristics for this sand and eliminate its drawbacks, in order to provide it with a better economic value and to obtain a better performance, especially in regions rich in sand, such as southern Algeria.

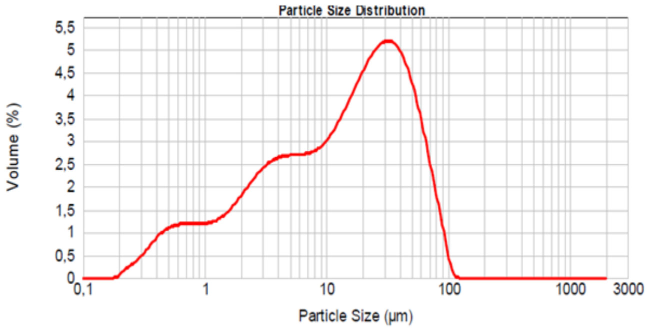


Fig. 1 Particle size distributions of cement

The improvements made in this study are:

- The incorporation of a small percentage of aggregates;
- The addition of a high efficiency superplasticizer (water reducer);
- The incorporation of active and inert cement additives.

2. Materials and methods

2.1 Materials

The Portland cement: Type CEM I 42.5 HRS (Portland cement with a high resistance to sulfates) from Hammam Dalâa local factory was used in this experimental study. The chemical composition and particle size determined by laser granulometer (Master-sizer 2000) of cement are shown in Table 1 and Fig. 1.

Dune sand powder: The dune sand powder used exhibited absolute density and Blaine specific surface values of 2650 kg/m^3 and 6300 cm^2/g, respectively. Properties of sand dune powder are mentioned in the Table 1.

The silica fume: Is obtained from GRANITEX (Algeria region). It results from melting in the silicon and ferro-silicon industry. The reduction of high purity quartz to silicon at temperature up to 2000°C produces SiO_2 vapors, which oxidize and con-dense in the low-temperature zone to tiny particles consisting of non-crystalline silica (Tebbal *et al.* 2017). Its density and Blaine specific surface values of 2194 kg/m^3 and greater than 15 000 cm²/g respectively. The physical properties of silica fume are shown in Table 1.

The natural fine aggregates used were dune sand with specific gravity, fineness values and a moisture content of **2.7**, 3.2 and 0.3%, respectively. This natural sand was taken from the region of Boussâada, (250 km east of Algiers). The sieve analysis is performed according to the European standard NF EN 933-1. After the treatment, process allows eliminating a significant portion of clay minerals impurities. As for gravel, it is of class 3/8, with a specific gravity of 2.65 and a Los Angeles value of 18%.

The adjuvant used is a super plasticizer high water reducing. It is a solution of pH=8.2 and a density of 1.22, with 40% of solids. Its normal use scale is fixed by the manufacturer’s recommendation which is between 0.6 and 2.5% of the cement weight.

The tap water used all through the study for mixing was taken from the laboratory of civil engineering.

Table 2 Granular skeleton adopted for 1 m^3 of sandcrete

Cement (kg/m^3)	Sand (kg/m^3)	Water (l)	Water/ Cement	CS 07 days (MPa)	CS 28 days (MPa)
450	1335	315	0.70	15.2	19.9

CS 07 days: Compressive strength at 7days, CS 28 days: Compressive strength at 28days.

2.2 Mix design

The concrete mix design was proposed according to an experimental approach, adopted from the SABLOCRETE method (Sablocrete 1994). The first phase consists in determining the reference sandcrete (cement, water and sand). This experimental approach requires the preparation of several successive batches, and is characterized by the measurements of both workability (maniabillimeter) and bulk density. The optimum granular skeleton is reached when the theoretical apparent density is close to the real density, for a normal workability.

- Formulation steps:

I. Determination of a basic formula without fillers: *Choosing cement content***:** Cement dosage is given by the following equation as a function of $D_{\max}$ of aggregates: C_{opt}=(550 or 700)/$D_{\max}$ (Sablocrete 1994). When the value of $D_{\max}$ is equal to 5 mm, which is the case of sandcrete, the cement content lies between 380 and 480 kg/m^3; for high performance sandcrete (HPS), a cement dosage of 450 kg/m^3 was chosen.

Fixing water content: At this stage of the method, an approximate water dosage W (l/m^3) is sufficient to estimate that dose. Based on experience, practitioners take a rough water amount of 315 l for 450 kg of cement.

$$V_C + V_W + V_S = 1000 \text{ (volumes in liters)} \quad (1)$$

Determination of sand content: The quantities of cement and water are known, and the mixture needs to be completed with sand so as to obtain a total volume of one cubic meter of concrete. The following relation is thus obtained:

Let:

$$\frac{\text{Mass of cement}}{\text{Density of cement}} + \frac{\text{Mass of water}}{\text{Density of water}} + \frac{\text{Mass of sand}}{\text{Density of sand}} = 1000$$

$$\text{Mass of sand} = 1000 - \left(\frac{\text{Mass of cement}}{\text{Density of cement}} + \frac{\text{Mass of water}}{\text{Density of water}} \right) \times (\text{ density of sand })$$

Adjusting the workability and efficiency of the formulation: The composition of the control sandcrete used is given in Table 2.

According to SABLOCRETE, in the second stage, sandcrete may contain a certain percentage of gravel and still retain its name of reinforced sandcrete. Four proportions of gravel (3/8) were used in this research to strengthen sandcrete, by substituting a part of sand (A/S: 0%-0.15%-0.25%-0.35%), with a fixed *W/B* ratio. These are percentages of the total sandcrete volume. The various compositions are shown in Table 3.

It is easy to observe that the compressive strength increases with the dosages of the aggregates. This is due to the quality and shape of the crushed aggregates used; it gives better aggregates/matrix adhesion.

Table 3 Final compositions of used reinforced sandcrete

Constituents \ Batches	N° 01	N° 02	N° 03	N° 04
Water/binder	0.70	0.7	0.7	0.7
Cement (kg/m^3)	450	450	450	450
Sand (kg/m^3)	1335	1135	1035	935
Aggregate (kg/m^3)	0	170.25	258.75	327.25
A/S (%)	0	0.15	0.25	0.35
CS 07 days (MPa)	15.2	17.3	19	21.3
CS 28 days (MPa)	19.9	20.8	23.2	27.1

A/S: Aggregate/Sand

II. Determining the dosage in cementitious additives: The optimal formulation of reinforced sandcrete was found; it gave the maximum strength for each proportion. In the third phase, the fourth composition was taken. The Mineral additives is added at dosages of 5%,10%, 15% and 20% of cement weight and the super plasticizer at 0.5%, 1%, 1.5% and 2% respectively. After several preliminary tests, the final compositions were recorded and reported in Table 4.

III. Optimization for maximum compressive strength: The fourth phase consists of measuring the compressive strength of each composition. Then, the optimal formulations are selected, as they give the maximum strength, depending on the type of additive, with a good workability (fairly good fluidity). The compressive strength of various compositions of concrete (with and without additives) is shown in Table 5.

It is easy to see from the results that it is possible to obtain a high-strength sandcrete, i.e., SC6 (15% SF)=57.8 MPa and SC4 (10% DS+5% SF)=54.3 MPa. The following conclusions can therefore be drawn:

- The superplasticizer used its role of densifying agent for the skeleton of concrete, and this allowed the dispersion of cement particles as well as the hydration of all cement grains. It helped to achieve maximum water reduction and a satisfactory rheology of concrete during implementation. Strength increased by 42.15% with respect to that of control sandcrete.
- Ground dune sand gave an optimum of 10%, and the compressive strength decreases with the percentage of dune sand added. This is due to the fact that the pozzolanic reaction did not occur at early ages, so the addition of dune sand (incorporation) led to a decrease in the active part.
- At 28 days, the compressive strength becomes greater than that of reinforced concrete, when the ratio *W/B*=0.4, with a dosage of 10% of dune sand, which means that the fixation of lime in the form of CSH improves strength (Sadok *et al.* 2014).
- For sandcrete with silica fume, the optimal content is 15%. This composition showed a compressive strength of 57.8 MPa at 28 days, an increase of **65.57%** compared to SC1. The compressive strength at 7 days is close to that of reinforced concrete, but it becomes higher in the long run.

Moreover, it remains higher than that of sandcrete made of finely ground sand dune; this explains the fixation of

Table 4 Final compositions of concrete

Concretes Constituents	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10
Dune sand powder (%)	-	-	-	5	-	-		5	10	20
Silica fume (%)	-	-	-	10	10	15	20	-	-	-
Superplasticiser (%)	-	-	1.5	1.5	1	1.5	2	0.5	1	1.5
Water/binder	0.70	0.7	0.5	0.35	0.5	0.4	0.35	0.6	0.40	0.35
Cement (kg/cm^3)	450									
Sand (kg/m^3)	1335	935	935	935	935	935	935	935	935	935
A/S=0.35	-	360	360	360	360	360	360	360	360	360
Slump (cm)	6	5	10	9.5	11	9	8	11	13	15
CS 07 days (MPa)	**15.2**	21.3	**27.7**	**26.9**	27.9	**28.3**	28.8	26.6	**25**	23
CS 28 days (MPa)	**19.9**	27.1	**34.7**	**54.3**	48	**57.8**	51	37.9	**41**	38

SC: sandcrete, HPS: high performance sandcrete; CS: compressive strength; A/S: aggregate/sand, SF: silica Fume; DSP: Dune sand Powder; SC1: control sandcrete; SC2: reinforced sandcrete; SC3: reinforced sandcrete with superplasticizer; SC4: reinforced sandcrete with (superplasticizer + silica fume + dune sand powder); SC5-SC6-SC7: reinforced sandcrete with (superplasticizer+silica fume); SC8- SC9- SC10: reinforced sandcrete with (superplasticizer+dune sand powder).

lime in the presence of CSF (pozzolanic reaction), which occurs before the 7th day of treatment, unlike that of ground sand which takes place at a later time. Increasing the silica fume content beyond 15% does not increase the strength of concrete. It is also obvious that silica fume content greater than 15% is not really more efficient, as any SF excess cannot attach to the surface of the aggregates (Gadri *et al.* 2012).

The incorporation of cement by 5% of dune sand, with 10% of silica fume, increased the mechanical performances to 54.3 MPa. This combination gave concretes which ought to be classified among high strength sandcretes. Thus, one can minimize the use of silica fume for sandcrete of compressive strength equal to 55 MPa, as silica fume is the most expensive ingredient in the composition of concrete. The optimum formulation that gave maximum strength with acceptable workability is given in Table 5.

2.3 Characterization of sandcrete

Workability: For all the concrete made, workability was measured by the Abrams cone slump test in accordance with NF EN 12350-2.

Compressive strength: For the compression strength test, three cubes of size (10×10×10) cm^3 were used for each mixture, and the average strength values of these samples were determined as compressive strengths for the mixtures.

The test was performed in accordance with NF EN 12390-4.

The shrinkage tests: The measurement of shrinkage was carried out on prismatic specimens of dimensions (7×7×28) cm^3, according to the standard NF P-15-433. These specimens are provided with metal pads on each end and

Table 5 Compressive strengths of concretes used at 7 and 28 days

Concretes / Strengths	SC1	SC3	SC4	SC6	SC9
CS07	15.2	27.7	26.9	28.3	25
CS28	19.9	34.7	54.3	57.8	41

placed vertically in the deformeter which allows monitoring the change in the sample length. Shrinkage of concrete is measured, on a daily basis, after unmolding.

The water absorption by *capillarity*: Measuring the water absorption by capillarity was performed on specimens (7×7×28) cm^3. The test consists in placing the specimens in a tank containing water-saturated sand on one face of the sample. The lateral faces are waterproofed with a plastic film (adhesive plastic tape), which forces water to follow an uniaxial course and prevents evaporation from these same faces (Arliguie and Hormain 2007).

$$CA = 100.W/S\sqrt{t} \tag{2}$$

W: weight of water absorbed (g),
S: surface of the face sawn (cm^2),
t: time in hours (*t*=72 h).

Ripening type on the compressive strength: Samples of size (10×10×10) cm^3 were cured in water, at 20°C for 28 days. However, other concrete blocks underwent the following curing: 3 days in water at 90°C, then stored in water at 20°C, until the end of the test time. The tests were performed in accordance with standard ASTM CL09 (Test Method for Compressive Strength of Hydraulic Cement Mortars).

Resistance of concrete to sulphates: Fresh concrete mixes were prepared in a modified laboratory mixer. The concrete specimens were preserved in their moulds in a wet place at a temperature of 20°C and 95% relative humidity (RH) during 24 hours. After demoulding, they were immersed in a 5% Na_2SO_4 solution and water at 20°C.

Analysis by X-ray diffraction: Phase compositions of these concretes were investigated on the fine powders using X-ray diffraction method. X-ray diffraction analysis was performed on an X-ray diffractometer (X'Pert) coupled to a computer system. The essential purpose of this analysis is to identify different crystalline phases present in a sample.

3. Results and discussion

3.1 Shrinkage measurement

The shrinkage tests were carried out on prismatic test tubes, stored in open air; at ambient laboratory temperature (20±2°C). The obtained results are shown in Fig. 2, which shows the evolution of shrinkage with the age of the specimen.

The shrinkage phenomenon is very complex as it is influenced by many unquantifiable parameters, such as fineness, chemical composition of the binder used, temperature, ambient humidity, hydration heat of the binder,

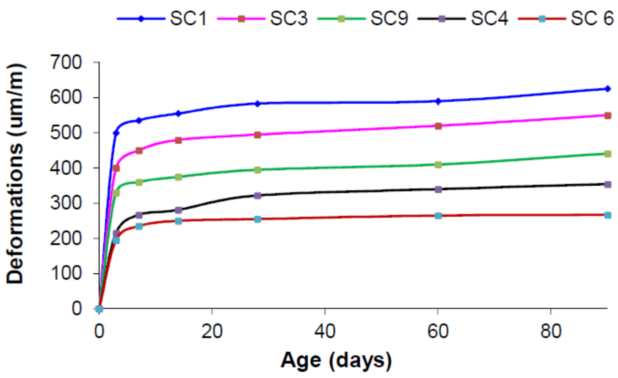


Fig. 2 Evolution of shrinkage related to age

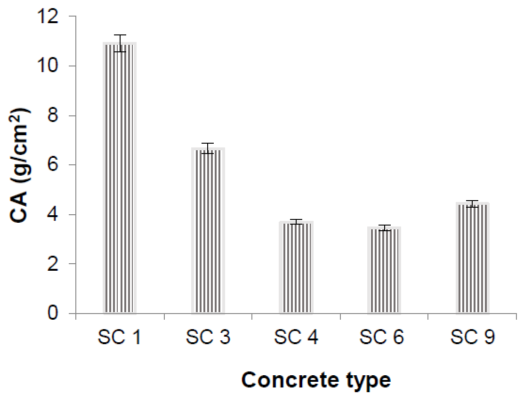


Fig. 3 Capillary absorption for different compositions

the *W/C* ratio. The shape of the test tubes has an effect on shrinkage, as well.

Results clearly indicate that concrete shrinkage depends on the amount of water used in the mix. Indeed, shrinkage increases with the W/B ratio, because drying becomes important, due to the big quantity of water, and thus the large number of pores, present in concrete.

Fig. 2 shows that introducing 10% of dune sand leads to a decrease in shrinkage. This shrinkage reduction is even more pronounced for SC6 and SC4. This is due to the formation of additional C-S-H, from the pozzolanic reaction, which makes the concrete matrix denser, henceforth preventing its contraction (Chadli *et al.* 2018). This C-S-H also fills the capillary pores and reduces their free volumes. This prevents migration of water and drying as well. However, the specific area being very large (>15 m^2/g), the spherical, smooth and very small silica fume particles just fill the interstices between cement grains. This granular effect, which leads to a significant reduction in shrinkage, can be achieved with a deflocculating product. The pozzolanic effect of amorphous silica fume, rich in silica, can combine with lime, during cement hydration, to give additional hydrates.

3.2 Measurement of Water Absorption by Capillarity

Fig. 3 shows the results of water absorption by capillarity for different compositions.

From these results, it is easily noted that the absorption by capillarity (ca) decreases with the *w/b* ratio. For concretes with additives, the absorption by capillarity decreases as the percentage of dune sand increases (5% and 10%). Beside the partial pozzolanic role of DSP, this fact is also attributed to the dune sand filling role. In addition to the fineness of SDP, which is greater than that of cement, DSP grains fit between those of cement, thus causing a decrease in size and percentage of capillary pores.

Silica fume behaves the same way as dune sand, but its influence on the compactness of concrete is more pronounced, because of these significant finesse and their glassy state which provide them with an important pozzolanic reactivity, and hence a significant decrease in the absorption by capillarity (Tebbal and Rahmouni 2016). In accordance with Belouadah's studies (2018), the pozzolanic reaction of the silica fume and dune sand powder with the released lime tends to produce CSH, so that the amount of binder is increased. Twice the effects increase the compressive strength and give the dense structure (Belouadah *et al.* 2018). On the other hand, the use of the water-reducing admixture decreases the void ratio, because the lubricate facilitates the rearrangement of particles and thus the HPS becomes less porous and more compact. The incorporation of dune sand with a silica fume in concretes leads to increase in the compactness related to the increase of the rheological properties.

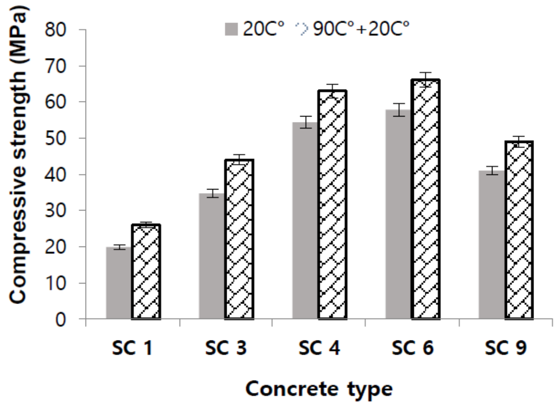


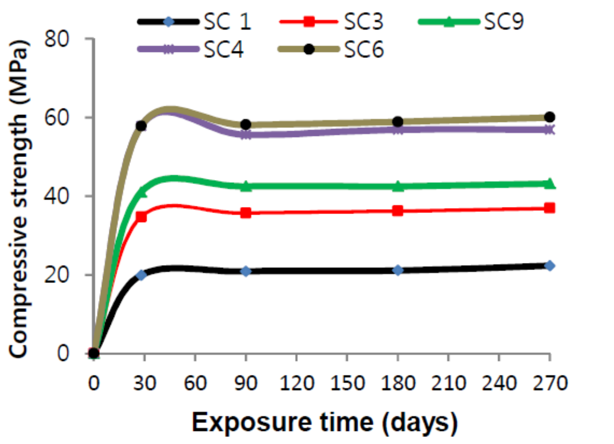
Fig. 4 Compressive strength of the different concretes as a function of curing

3.3 Effect of ripening type on the compressive strength

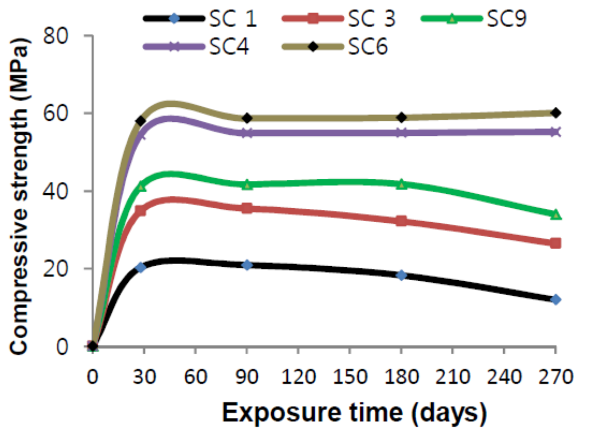
The compressive strength of the different concretes as a function of their curing is given in Fig. 4.

Fig. 4 shows a compressive strength increase for the different concrete compositions, which have been through a three-day-heat treatment, in water at 90°C. In all the effects resulting from heat treatment, sandcretes containing silica fume or ground sand dune, exhibit a strong pozzolanic reaction for temperatures between 65°C and 90°C; this changes the structure of the hydrates formed.

Just like most exothermic reactions, hydration of cement is accelerated by heat. Thus, when one considers the evolution of concrete strength with time, it is seen from the beginning that the phenomenon evolves at various speeds,



(a) Compressive strength as a function of immersion time in potable tap water



(b) Compressive strength as a function of time of exposure to sulfates

Fig. 5 Compressive strength as a function of immersion time

depending on the temperature of treatment applied (Bederina *et al.* 2007, Rmili and Ben Ouezdou 2012).

Water dosage of heat-treated concretes is important because water is one of the constituents of high strength sandcretes, which expands the most. Alexanderson studied the causes of loss of strength at 28 days on heat-treated specimens (all concretes that were heat-treated gave lower strengths in the long term than those of concretes that hardened naturally (Rmili and Ben Ouezdou 2012, Bumanis *et al.* 2015). These losses are mainly due to the increase in porosity and cracking, which suggests that air pressure inside the pores, is responsible for these degradations.

Now, this phenomenon can be prevented using a super plasticizer (a very low *W/C* ratio) and silica fume. Furthermore, removing large aggregates from sandcrete increases its homogeneity and makes it closer to a ceramic material than to a conventional concrete. On the other hand, it is essential that the rate of temperature rise and fall be slow to avoid cracking which results from thermal shock.

Finally, heat treatment is a way to improve the mechanical performance of sandcrete. The process occurs after the end of curing in moist environment, at atmospheric pressure.

3.4 Resistance of concrete to sulphates

To assess the sustainability of concrete vis-à-vis chemical attack, the compressive strength was determined as a function of immersion time, using a series of test tubes in a sulfate solution (5%). Figs. 5(a) and 5(b) depict the variation of compressive strength, for different types of concrete, as a function of exposure time.

One finds that the compressive strength of sandcretes, immersed in potable tap water, increases steadily with age and shows no drop during 9 months (Fig. 5(a)). However, a small gain in strength is noted for the specimens placed in the aggressive solution until the age of 90 days. This increase in resistance seems to result from the continuous hydration of anhydrous cement products as well as from the reaction of Na_2SO_4 with Ca $(OH)_2$, to form primary gypsum and primary ettringite; this complements the micropores and therefore leads to a denser structure which positively affects the mechanical strength. Beyond this point, a strength decrease was observed for the control sandcrete and the reinforced concrete placed in the aggressive solution (Fig. 5(b)). The decrease in strength is attributed to the reaction of Portlandite, which comes from cement hydration, with sulfates to form gypsum and expansive secondary ettringite, causing micro-cracks that lead to reduced strength (Yusuf and Hamza 2011).

For SC9, the decrease in strength is delayed up to 180 days of immersion, because the finely ground sand dune leads to the formation of additional hydrosilicates which result from the fixing of portlandite by ultrafine silica particles, which fill the pores. This process has a direct effect on the skeleton of cement paste and concrete; it reduces the probability of penetration of external aggressive agents, allowing to obtain more durable and more compact concrete (Guettela and Mezghiche 2011).

Concretes SC4 and SC6 show a stable strength up to nearly 270 days, which means that the resistance to sodium sulphate attack is proportional to the incorporation rate of additives into cement. This is mainly due to the reduction of portlandite into concrete, proportionally to the rate of incorporated silica fume; this delays and prevents the formation of gypsum and secondary ettringite.

However, the time factor plays an important role in the ultimate value of expansion. The more the expansion is delayed, the lower its ultimate value is, because a long time is needed for ettringite to move in the vacant space of capillary pores within sandcrete with partial substitution of silica fume. Besides, the pozzolanic reaction leads to the formation of secondary CSH gels, which in turn form an envelope on aluminates and other reactive phases; this hinders the formation of ettringite. Incorporate part of the silica fume with cement also reduces-the amount of C_3A in the binder. Silica fume, which is amorphous and silica-rich, can combine with lime, during cement hydration, to give additional hydrates. This mixture will provide much better performance than the ones generated by SDP.

3.5 Analysis by X-ray diffraction

The *X*-ray diffraction technique was used to identify the products formed in the hardened sandcretes kept in the 5%

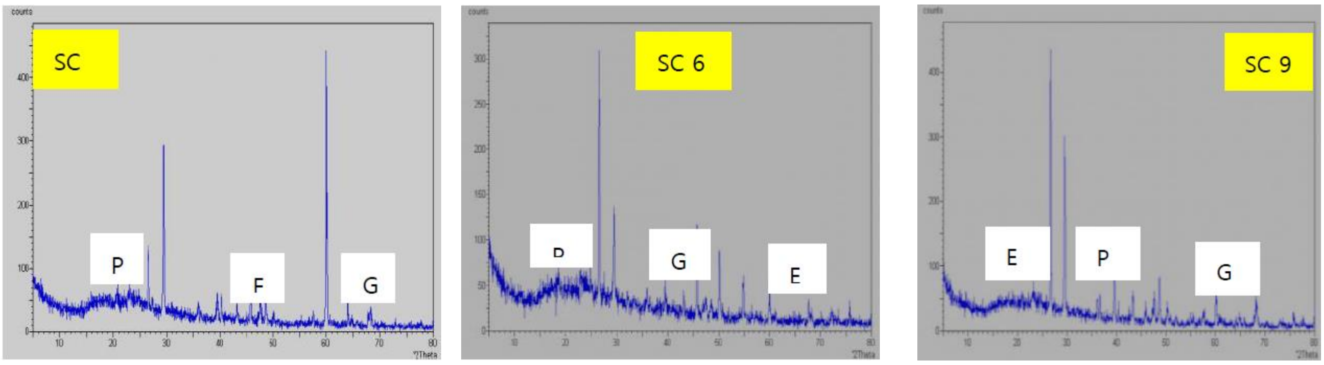


Fig. 6 Sandcrete immersed in water, after 270 days

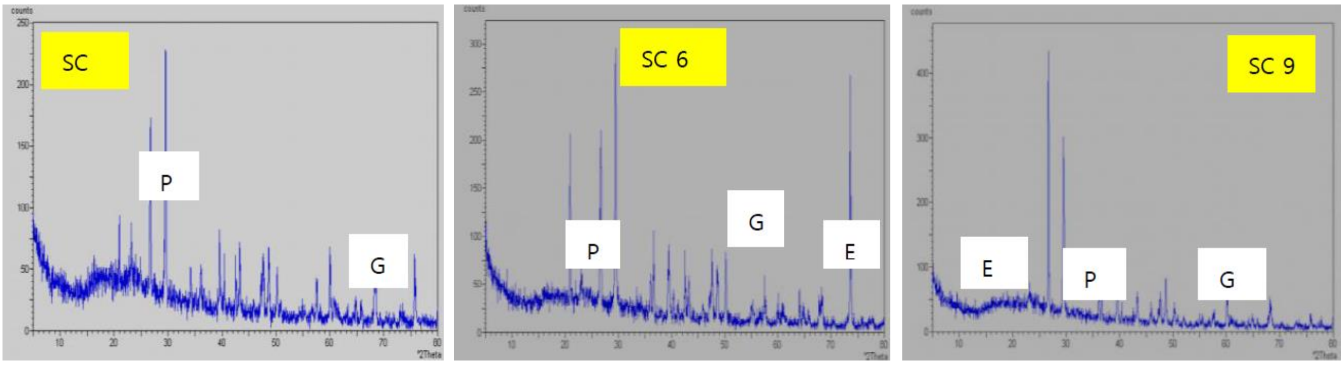


Fig. 7 Sandcrete immersed in Na_2SO_4 (5%), after 270 days

sodium sulfate solution. This method was used to confirm and refine the results obtained in the tests on concretes. The diffractometer (X'Pert) used was connected to a computer system.

For different types of concretes, powder samples were taken from the surface of the test tubes that reached the age of 270 days.

The analysis of spectra in Figs. 6 and 7, is used to report the following findings:

- Presence of traces of Portlandite [P] Ca $(OH)_2$
- Presence of gypsum [G] ($CaSO_4.2H_2O$).
- Presence of ettringite [E] ($C_3A.3CaSO_4.32H_2O$).

Note that for sandcrete specimens, with or without additives in the control medium (potable tap water), the peak intensity of portlandite is low, which explains the absence of attack (Fig. 6), while in the aggressive medium (Fig. 7), peaks which characterize gypsum (g), ettringite (e) and portlandite are more visible and more intense in the control concrete than in sc with additives. Portlandite in the control concrete is responsible for the formation of gypsum and secondary ettringite. These two crystalline phases originate from sulphatic reactions and are destructive agents for concrete, as they are expansive and may cause concrete spalling, following its reaction with sulfates. By cons, in concrete with additives, the peak intensity of Portlandite in the aggressive environment is very low. This explains its consumption by the pozzolanic reaction, according to the equation

$$CH + S \longrightarrow C\text{-}S\text{-}H \qquad (3)$$

This result confirms that the ultrafine additive reduces the effect of chemical attacks by decreasing the permeability of the material, the pore size and the percentage of $Ca(OH)_2$. However, finely ground dune sand is not inert and is involved in the formation of new C-S-H that make sandcrete denser and more compact.

5. Conclusions

The objective of this work was to study the possibilities of obtaining hydraulic high performance sandcretes by reducing the interstitial porosity of cement paste and filling the intergranular spaces of cement with finely ground additives.

In light of the tests performed, this study allowed us to extract a certain number of key points which are worth noting:

- Today, the formulation and manufacture of sandcretes with a compressive strength at 28 days, of more than 58 MPa is possible in Algeria.
- The partial replacement of sand by a certain amount of gravel can result in a 25% increase in strength. This increase is due to the quality and form of crushed aggregates used; this gives a better aggregates-matrix adherence. The high fineness modulus of sand used (FM=3.2) and the optimal composition of SC6 and SC4 enable to gain some more MPa.
- The combination of silica fume and dune sand in mixtures resulted in a very dense microstructure and low porosity which produce a concrete with lowed permeability compared to the control concrete and thus very resistant to the penetration of aggressive agents. This combination enables to obtain an *economical high*

performance concrete.

- Heat treatment is for sandcretes a way to improve their mechanical performance.
- Note that, even after 270 days of storage in an aggressive environment, the characteristics of sandcrete, with partial incorporation of cement by silica fume, do not degrade probably because of the very low porosity that prevents the penetration of aggressive agents and the exit of cations.

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