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Effect of additions on the self-compacting concrete's absorption

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Abstract
Self-compacting concretes (SCC) are unique concretes that have been developed over the past 30 years. They have the distinct property of being very fluid. Even though they have a great deal of potential for growth, they are still classified as "new concretes" today because of their modest use. SCC differs from conventional vibrated concrete (OVC) in that it is extremely flexible and does not involve the use of vibration. They can be cast in places where there is a high reinforcement density because they compact under the weight of their own mass. In order to reduce the amount of cement caused by the increase in paste volume required to allow the concrete to flow, a large volume of mineral addition is required for the formulation of self-compacting concretes. The main goal of this research was to use the capillary absorption test to determine the impact of various cementitious additions (limestone filler (Lf), brick waste powder (Br), and crushed dune sand (Sd)) by partially substituting a specific amount of Portland cement on the SCC. The findings indicate that, with the exception of brick, all self-compacting concretes produce intriguing results in terms of compressive strength and water absorption.
Keywords: Self-compacting concrete. Additions. Limestone filler. Brick waste powder. Crushed dune sand. Absorption. Uniaxial compression.

1. Introduction

The simplicity of manufacture and use of concrete and its installation, its low cost, its mechanical performance and its durability, have contributed to increasing its use to carry out the most diverse works. After the search for an improvement in the strength and durability of concrete with high workability, a further step was taken with self-compacting concrete (SCC) in the 90s in Japan (Okamura *et al*., 2003; Okamura *et al*., 2000; Okamura *et al*., 1999). The (SCC) are very fluid special concretes, their specification is to be put in place under the effect of their own weight without contribution of external or internal vibration (Okamura *et al*., 1999).

On the one hand, the formulation of SCCs is relatively expensive compared to ordinary concrete because of their relatively high demand for chemical binder and adjuvant. This implies an increasing exploitation of non-renewable natural resources. For this, the use of a large volume of cementitious additions so as to reduce the quantity of cement induced by the increase in the volume of paste necessary to allow the flow of the SCC. On the other hand, the problem of the introduction of mineral additions leads to a modification of the porosity of the cementitious matrix and influences the mechanical and self-compacting characteristics of the concrete, and also on the absorption of water.

The present work aims to understand the influence of different cement additives used (limestone filler (Lf) – brick waste powder (Br) – crushed dune sand (Sd)) on the behavior of self-compacting concretes in the fresh state and in the hardened state.

2. Materials and methods

The materials used are local and natural available on the Algerian market. All the concretes are made with the same materials.

2.1 Materials used

To accomplish our objectives, we used local materials that were easily accessible on the Algerian market. All forms of self-compacting concrete are made with the same components. Materials used include:

Cement: The Portland cement used for our study is a CPA CEM I / 52.5 type cement from the M'sila factory. Physical Properties of cement are given in Table 1. The chemical and mineralogical analysis of cement is indicated in Table 2.

Table 1 – Physical properties of cement used.

Properties	CEM I/B
Specific density (kg/m^3)	3096
Apparent density (kg/m^3)	1026
Fineness (cm^2/g)	3912

Table 2 – Chemical and mineralogical composition of cement used (%).

Mineralogical composition (%)								
C_3S	C_2S		C_3A			C_4AF		
62,35	14,84		7,05			12,15		
Chemical composition (%)								
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	LOI
20,87	62,36	5,1	3,42	1,88	2,92	0,11	0,68	1,8

Sand: The sand used is alluvial sand (0/5) from the Oued M'zi region located north of the town of Laghouat. Its fineness modulus is Mf = 2.29.

Gravel: The gravel is of calcareous origin, crushed, composed of two fractions 3/8, 8/16 from the "Zaccar" quarry located south of the town of Djelfa. The physical-mechanical properties of gravel are indicated in Table 3.

Table 3 – Physical-mechanical properties of gravel used.

Physical - mechanical property	Absolute density mass (g/cm^3)	Apparent density mass (g/cm^3)	Degree of absorption (%)	Los Angeles Coefficient (%)
(3/8)	2,66	1,37	2.3	23
(8/16)	2,66	1,36	2.2	23.5

Mixing water: The water used is potable tap water.

Adjuvant (Superplasticizer): the high water-reducing superplasticizer makes it possible to obtain high quality concretes and mortars in terms of resistance and fluidity, MEDAPLAST SP30 from GRANITEX of Algiers was used.

Mineral additions:

Limestone filler (Lf): This is waste from the crushing of limestone rocks composed essentially of calcite $CaCO_3$.

Brick Powder (Br): Brick waste is a by-product of the red goods industry. They are found in large quantities at the national level because of the high number of brickyards.

Finely ground dune sand (Sd): Finely ground dune sand for use as an addition to cement comes from the Biskra region.

Table 4 – Mineral additions used

Type of addition	Abbreviation	Color	Absolute density mass (g/cm^3)	Apparent density mass (g/cm^3)
Limestone filler	(Lf)	White	2,45	0,86
Powder of the Brick	(Br)	Red brick	2,51	1,08
Crushed dune Sand	(Sd)	Gray clear	2,77	1,3

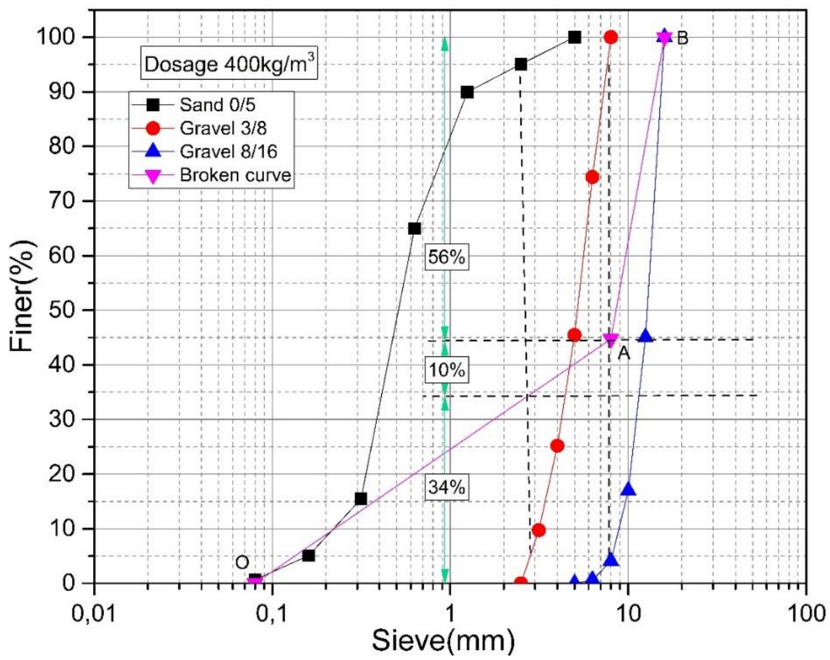

Figure 1 – Grading curves of the three classes of aggregates, the broken curve, with the dividing lines.

2.2 Formulation of self-compacting concretes

We have complied with the necessary conditions, making it possible to guarantee self-compacting while basing ourselves on compositions proposed in the specialized literature (Su et al., 2003). It is a question of choosing the proportions of the constituents in 1m ^{3} of concrete having as data the following parameters (Brouwers et al., 2005):

Gravel (G) + Sand (S) + Cement (C) + Air (A) + Water (E) + super plasticizer (Sp) = 1000 liters

♦ A G/S ratio = 1. ♦ A W/C ratio =0.5
♦ A dosage of cement C = 400 kg/m ^{3} ♦ A percentage of 20% additions.
♦ A percentage of 03% super plasticizer (Sp).

Five (05) mixtures were made, four SCC and one ordinary concrete (OC). The different concrete compositions are summarized in Table 2.
As regards the formulation of the corresponding ordinary vibrated concrete (OVC), its composition was obtained using the Dreux- Gorisse method while maintaining the same water to cement (W/C) ratio as that of the SCCs.

The concretes were made according to the current recommendations of the French-Association of Civil-Engineering (FACE, 2000).

The symbols of the various concretes produced are summarized in Table 1. All the compositions studied are presented in Tables 2.

Table 1 – The symbols of the various concretes produced.

Notation	Designation
OVC	Ordinary vibrated concrete with 100 % cement.
SCC	SCC with 100 % cement.
SCC_{Lf}	SCC with 20 % limestone filler + 80 % cement.
SCC_{Br}	SCC with 20 % brick powder + 80 % cement.
SCC_{Sd}	SCC with 20 % finely ground dune sand + 80 % cement.

Table 2 – Composition of different concretes for 1m^3.

	Concretes (kg/m^3)				
Composition	**(OVC)**	**(SCC)**	**$(SCC)_{Lf}$**	**$(SCC)_{Br}$**	**$(SCC)_{Sd}$**
Cement	400	400	320	320	320
Limestone filler	-	-	80	-	-
Brick powder	-	-	-	80	-
Sand dune	-	-	-	-	80
Sand 0/5	607.82	855.78	846.97	847.97	851.80
Gravel 3/8	184.09	295.26	292.20	292.55	293.88
Gravel 8/16	1030.26	590.49	584.43	585.12	587.75
Water	200	200	200	200	200
Sp	12	12	12	12	12
W/L	0.5	0.5	0.5	0.5	0.5

3. Test results and discussion

3.1 SCC characteristics in a fresh state

The characteristic tests on fresh SCC concrete were carried out just after mixing. These are those recommended by the French Association (FACE, 2000): spreading with the Abrams cone, flow with the L box and stability with the sieve. Their purpose is to estimate the fluidity, the static and dynamic segregation of the manufactured SCCs. Table 3 summarizes the characteristics obtained for ordinary concrete OC and the various SCCs tested in the fresh state.

Table 3 – Table summarizing the results of tests in the fresh state of SCC and OC concretes.

Concrete	**(OC)**	**(SCC)**	**$(SCC)_{Lf}$**	**$(SCC)_{Br}$**	**$(SCC)_{Sd}$**
Subsidence (cm)	7,5	-	-	-	-
Spreading out (cm)	-	67	66	65	68
Time T_{50} (s)	-	3,54	3,61	3,86	3,77
Limps in L (%), (capacity of filling)	-	81	83	80	86
Weight of milt Π (%), (stability with the sieve)	-	7,5	6,5	4,9	7
Visual appreciation, wafer of spreading out	-	Good	Good	Good	Good

It is noted that the characteristics in the fresh state of the self-compacting concretes are satisfactory.

3.2 Characteristics of the (SCC) in a hardened state:

The formulations of the studied concretes were made in cubic specimens (10×10×10) cm. We follow the following steps:

The specimens were stored in the open air under laboratory conditions (T=20 ±2°C and HR= 45±10%), for: (7 days, 14 days, 28 days, 60 days, and 90 days), and a cure in water for 28 days for water absorption test.

<u>Uniaxial compression test:</u> The compression test is carried out in accordance with the standard (NF P 18-406). It consists of subjecting the concrete specimen to crushing by axial compression. Loading must be carried out continuously until the specimen breaks (see Figure 2).

Figure 2 – (a) Specimens before crushing, (b) Specimen after crushing (breaking).

The results of the direct compression crush test at 7, 14, 28, 60 and 90 days of age are shown in Figure 3.

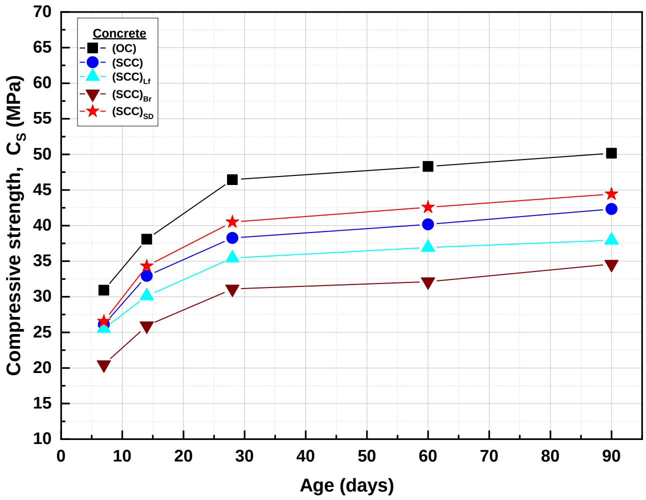

Figure 3 – Evolution of the compressive strength of concrete as a function of age.

The results represented in Figure 3 show, on the one hand, a clear evolution and increase in the compressive strength of different concretes prepared as a function of age.

We were able to conclude that the SCC_{Sd} based on the addition of dune sand has better compressive strength compared to other concretes: SCC, SCC_{Lf}, and SCC_{Br}. These results can be explained by the nature of the additions used and their consequences on the increase in the compactness of the solid skeleton.

The water absorption test (Initial absorption by capillarity): The transfer of liquid in a porous material, due to surface tensions in the capillaries, is called water absorption. The absorption of water inside the dry concrete by capillary rise depends on the open porosity and the porous networks of the concrete.

This test is intended to measure the rate of water absorption by capillary suction of concrete specimens at 28, 60 and 90 days, unsaturated afterwards, placed in contact with water without hydraulic pressure.

Sorptivity measurements, specimens will be pre-conditioned in the oven at approximately 105°C to constant mass.

On the day of the test, the prepared concrete specimens are weighed with a precision balance of 0.1 g, to determine their masses before and after the absorption of water for (1 hour):

$$A_{bi} = [(M_{C2} - M_{C1}) / S\ (t)^{0.5}] \qquad (1)$$

Where M_{C1} is specimen mass before water absorption; M_{C2} is mass of specimens after absorption of water (1 hour); S is area of the base of the specimen (10x10); and t is time (*1 hour*).

The quantity of water absorbed after one hour per surface unit is retained as a quantity representative of the volume of the largest capillaries present in the skin zone (Rabehi et al., 2012; Balayssac et al., 1993)**,** these capillaries being the most efficient.

A plastic film (an adhesive) is used to waterproof the side faces, forcing the water to take a uniaxial path and prevent evaporation through the same faces. The specimens are successively weighed to determine the mass of water absorbed.

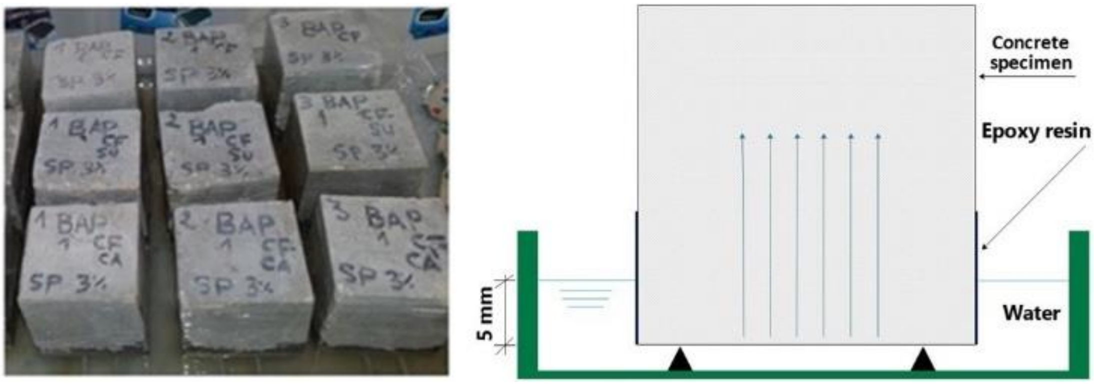

Figure 4 – Concrete water absorption test.

The initial water absorption coefficients obtained after a suction time of one hour (1h) will be noted A_{bi} ($kg.m^{-2}.h^{-1/2}$), all the concretes are represented with the rate of gain in Table 4 and are shown in Figure 5.

$$\text{Win rate of } A_{bi} = \left| \frac{A_{bi_{j\,(sans\ cure)}} - A_{bi_{j\,(cure)}}}{A_{bi_{j\,(sans\ cure)}}} \right| \quad (2)$$

Table 4 – Initial water absorption coefficients A_{bi} of all concretes at different ages.

Age (days)	Mode	(OC)	(SCC)	$(SCC)_{Lf}$	$(SCC)_{Br}$	$(SCC)_{Sd}$
	Without cure	2,78	2,67	3,58	4,90	2,00
28	With cure	1,75	1,76	2,60	37,40	1,50
	Rate in A_{bi} (%)	37,05	34,08	27,37	16,67	25,00
	Without cure	2,67	2,56	3,10	4,32	1,75
60	With cure	1,58	1,58	2,35	3,38	1,20
	Rate in A_{bi} (%)	41,01	38,20	24,19	21,88	31,43
	Without cure	2,33	2,03	2,95	3,78	1,70
90	With cure	1,49	1,50	2,20	3,19	1,25
	Rate in A_{bi} (%)	36,16	26,31	25,42	15,67	26,47

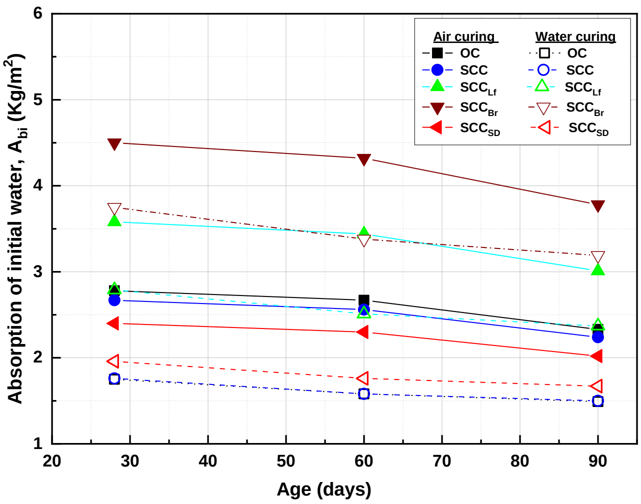

Figure 5 – Initial water absorption (A_{bi}) of the various concretes at 28, 60 and 90 days.

Figures 5 present the results of the initial water absorption (A_{bi}) of the prepared concretes, we note that the absorption decreases with age (28, 60 and 90 days) and according to the type of additions. The results shown in Figure 5 show a decrease over time of (A_{bi}) for all the self-compacting concretes prepared and for ordinary concrete (Oc). We note that with the substitution of 20% of cement by the addition of crushed dune sand (SCC_{Sd}), we obtain an A_{bi} lower compared to SCC without additions and also compared to SCC with other additions (limestone filler and brick powder). This means that SCC_{Sd} are less porous and their transport properties are improved compared to other concretes (Figure 6). This can be explained in two ways: first, by a decrease in the porous network; second, by the greater compactness offered by these additions, whose exceptional finesse produces a filler effect in terms of physical filling (Benmerioul et al., 2017; Zaouai et al., 2020; Agha et al., 2023).

On the other hand, the improvement is due to the pozzolanic reaction by transformation of part of the calcium hydroxide into CSH (hydrated calcium silicates), which gives a very dense microstructure that has made it possible to close the pores already existing in the structure by decreasing the number of large pores and increasing that of small pores (Logbi et al., 2023).

For ordinary concrete (oc), the initial water absorption A_{bi} is relatively higher than the A_{bi} of different elaborated self-compacting concretes except for SCC_{Br} and SCC_{Lf}.

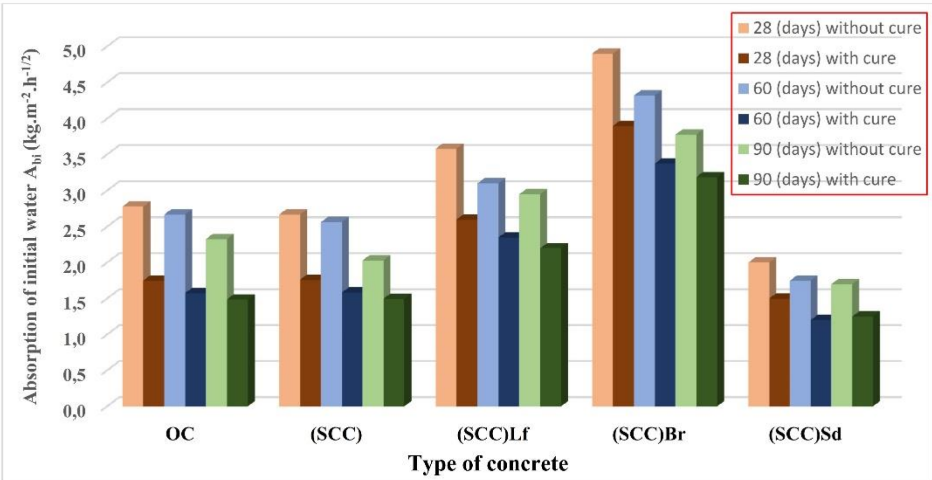

Figure 6 – Initial water absorption Abi at 28, 60 and 90 days for concrete (with and without curing).

4. Conclusions

The objective of this work was to experimentally study the behavior of self-compacting concretes in the fresh state and in the hardened state with different additions.

The results obtained can be summarized in the following points:

- The self-compacting concretes (SCC) studied have characteristics that comply with the requirements of the French Association of Civil Engineering;
- The additions chosen for the development of our study can have beneficial effects on SCC, in particular by improving its fluidity, its stability on the sieve and reducing the risk of segregation.
- The compressive strength (C_S) of all the self-compacting concretes tested increases with age and shows no drop. This resistance is greater for SCC_{Sd} than for SCC, SCC_{Lf}, and SCC_{Br}. For the latter, the compressive strength is even lower compared to ordinary concrete (OC) because of the nature of the addition used;
- The compressive strength (C_S) of ordinary concrete OC is greater compared to that of self-compacting concretes SCC_{Sd}, SCC_{Lf}, and SCC_{Br};
- Additions such as dune sand make it possible to obtain a more compact and homogeneous granular skeleton. The introduction of additions leads to a modification of the open porosity and influences the physical-mechanical characteristics of the concrete.

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