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Characterizations of self-consolidating concrete (SCC) from a physical-mechanical perspective with various additions

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Abstract – Self-consolidating concretes (SCC) are special concretes that have the particularity of being very fluid and have been developed over the past thirty years. They are still qualified today as "new concretes" because their use remains modest, although they have strong development potential. The specificity of SCC compared to ordinary vibrated concrete (OC) lies in the fact that it is extremely fluid and does not require vibration to be implemented. Compacting under the effect of their own weight, they can be poured in areas with a high density of reinforcement. For the formulation of self-consolidating concretes, a large volume of mineral addition is necessary so as to reduce the quantity of cement induced by the increase in the volume of paste necessary to allow the flow of the concrete. The main objective of this work was to determine the effect of different cement additions (Filler limestone (Fc), crushed dune sand (Sd), and silica fume (Fs)) by partial substitution of a certain quantity of Portland cement on the physical-mechanical properties of SCC using the capillary absorption test. The results obtained demonstrate that all self-consolidating concretes give interesting results in terms of compressive strength and water absorption.

Keywords – Addition, Self-consolidating Concrete (SCC), Absorption of Water, Compressive Strength.

I. Introduction

The ease of manufacture, use, and placement of concrete, its low cost, its physical-mechanical performance, as well as its durability, have contributed to increasing its use as a plus for carrying out civil engineering and public works with time. Much research on concrete has been carried out since its discovery. In order to seek better strength, durability, and workability, in 1990, in Japan, work began with self-consolidating concrete (SCC) [1–3].

The SCC are very fluid concretes; they are put in place under the effect of their own weight without any contribution from external or internal vibration [1–3]. On the one hand, the formulation of SCC is relatively expensive compared to ordinary concrete (OC) due to its relatively high demand for chemical admixtures and binders.

This means increased exploitation of non-renewable natural resources. For this reason, it is preferable to use large quantities of additives for cement in order to reduce the quantity of cement resulting from the increase in the volume of paste necessary to allow the flow of the SCC [4–6].

On the other hand, the introduction of mineral additions causes a modification of the porosity of the cement matrix and influences the self-placing of the concrete and its physical-mechanical characteristics, in particular water absorption [7].

This paper investigates the beneficial effects of different cement additions on the behavior of SCC by checking the self-placing concrete in the fresh state and the compressive strength and water absorption in the hardened state.

II. Materials and experimental program

II. Materials used

In order to achieve our objectives, we used natural and local materials available on the Algerian market. All the concrete that has been produced is made with the same materials. Table 1 gives the materials that were used, and Table 2 summarizes the physical-mechanical properties of the aggregates.

Table 1. Local materials used.

Materials used	Nature	Type
Cement	Portland	CPA CEM I / 52,5
Sand	Alluvial	(0/5)
Gravel	Limestone	(3/8) and (8/16)
Water	Potable water	---
Superplasticizer	Water reducer	MEDAPLAST SP30

Table 2. Physical-mechanical properties of the aggregates.

Physical property	Size range		
	0 / 5	3 / 8	8 / 16
Apparent volume mass (g/cm^3)	1,55	1,37	1,36
Absolute density mass (g/cm^3)	2,58	2,66	2,66
Porosity e (%)	40,00	48,50	48,87
Degree of absorption (%)	0,32	0,238	0,096
Fineness modulus	2,29	-	-
Sand equivalent (%)	93	-	-
Water content (%)	-	0,158	0,096
Coefficient Los Angeles (%)	-	23	23,5

II. Mineral additions used

Three (03) additions were used with diameters less than 80 µm. Table 3 summarizes the properties of all the additions that have been used.

Table 3. Mineral additions used.

Type of addition	Calcareous Filler (Fc)	Crushed dune Sand (Sd)	Silica smoke (Fs)
Color	White	Gray clear	Gray
Absolute density mass (g/cm^3)	2,45	2,77	2,24
Apparent density mass (g/cm^3)	0,86	1,3	0,5
Remarks	They are waste of crushing of the rocks limestones primarily.	The dune is finely crushed intended to use as addition with cement.	It is about a silica smoke, containing micro silica in the form of gray powder.

III. Formulation of self-consolidating concrete and ordinary concrete

The vibrated ordinary concrete (OC) is formulated by the Dreux-Gorisse method, but this method is not applicable and not suitable for self-consolidating concretes (SCC) because it does not take into account the admixtures or additions, which are essential components of a SCC [8]. Most SCC formulas are currently designed empirically.

The formulation is therefore based on the experience acquired in recent years.

We observed the requirements allowing us to guarantee the self-consolidating all while basing ourselves on compositions suggested in the specialized literature. It is a question of choosing the proportions of the components in 1 m^3 of concrete by having like data for the following parameters [9]:

Without additions:

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

With additions:

Cement (C) + Gravel (G) + Sand (S) + Water (E) + Additions + Air (A) = 1000 liters.

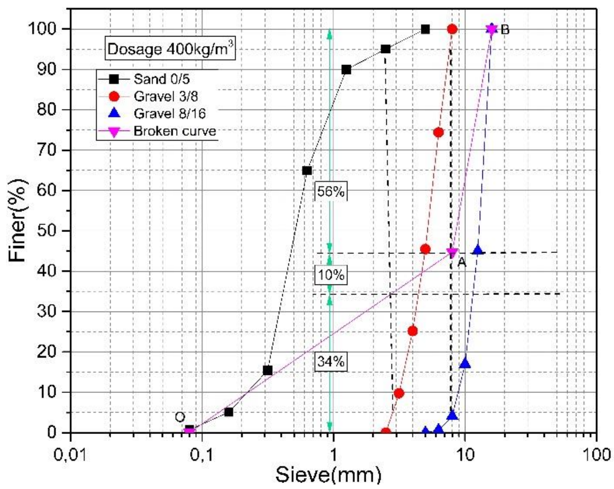

Fig. 1. Grading curves of the three aggregate classes, the broken curve, with the dividing lines.

To be able to compare the performances, the water absorption by capillary, and find a relation between the compressive strength and the water absorption of the studied concretes and self-consolidating concrete (SCC) with different additions with the same materials, we have set some parameters for all the concretes tested as follows:

- ♦ a ratio G/S = 1;
- ♦ a ratio W/L (W/C) = 0.5;

♦ a cement dosage C= 400 kg /m^3;

♦ a percentage of 20 % additions;

♦ a percentage of 03 % of s superplasticizer.

Five (05) mixtures were made : ordinary concrete and seven SCC. The different concrete compositions are summarized in Table 4. The SCC was made according to the current recommendations of the French Association of Civil Engineering [10].

Table 4. Composition of the different concretes in kg per m^3

Composition	Concrete				
	(OC)	(SCC)	$(SCC)_{Fc}$	$(SCC)_{Sd}$	$(SCC)_{Fs}$
Cement	400	400	320	320	320
Limestone filler	-	-	80	-	-
Sand dune	-	-	-	80	-
Silica smoke	-	-	-	-	80
Sand 0/5	607.82	855.78	846.97	851.80	843.04
Gravel 3/8	184.09	295.26	292.20	293.88	290.84
Gravel 8/16	1030.26	590.49	584.43	587.75	581.72
Water	200	200	200	200	200
Sp	12	12	12	12	12
W/L	0.5	0.5	0.5	0.5	0.5

IV. TEST RESULTS AND DISCUSSION

IV.1. CHARACTERISTICS OF THE (SCC) AND (OC) IN A FRESH STATE

The characteristic tests on freshly-mixed concrete was carried out just after the mixing. They are those recommended by the French Association of Civil Engineering [10] : spreading out with the slump test, the flow with the box in L and stability with the sieve. The purpose of they are to estimate fluidity, the static and dynamic segregation of the made (SCC). Table 5 summarizes the characteristics obtained for the various SCC and OC tested in the fresh state.

Table 5. Summary table of the test results in a fresh state.

Concrete	(OC)	(SCC)	$(SCC)_{Fc}$	$(SCC)_{Sd}$	$(SCC)_{Fs}$
Subsidence (cm)	7,5	-	-	-	-
Spreading out (cm)	-	67	66	68	69
Time T_{50} (s)	-	3,54	3,61	3,77	3,5
L-box (%) (Capacity of filling)	-	81	83	86	90
Weight of milt Π (%) (Stability with the sieve)	-	7,5	6,5	7	8,2

It is noticed that the characteristics in a fresh state of the self-consolidating concrete are satisfactory, and the visual assessment of the spreading wafer for all self- consolidating concrete is good.

IV.2. CHARACTERISTICS OF THE (SCC) AND (OC) IN A HARDENED STATE

The formulations of the studied concretes were made out of cubic testtubes (10×10×10) cm^3. We follow the following steps:

The specimens were stored under two types of curing regimes: in the open air under laboratory conditions (T=20 ±2°C and HR= 45±10%), and in water for 28 days.

IV.2.1. TEST OF ABSORPTION OF WATER

The transfer of liquid in a porous material, due to surface stresses in the capillaries, is called the absorption of water. The absorption of water inside the no-slump concrete by capillary increase depends on open porosity and the porous networks of the concrete. This test comes to measure the rate of absorption of water by capillary suctions of the concrete test-tubes with 28, 60 and 90 days, unsaturated afterwards, put in contact with water without water pressure. Before measurements of the sorptivity, the specimens will be packaged in the drying oven with approximately 105 °C until a constant mass. The day of the test, the elaborate concrete test-tubes are weighed with a balance of precision of 0.1 G, to determine their masses before and after the absorption of water during (1 hour) that is to say:

$$A_{bi} = [(M_2 - M_1) / S\ (t)^{0.5}] \qquad (1)$$

M_1: mass before absorption of water;
M_2: mass after absorption of water (1h);
S: surface of the base of the test piece (10x10) cm^2;
t: time (1 hour).

Quantity of water absorptive at the end of one hour per unit of area east retained like size representative of volume of the largest capillaries present in the zone of skin [11,12], these capillaries being most effective. The side faces are waterproofed using a plastic film (an adhesive ribbon plastic) which forces water to adopt a uniaxial advance and to avoid evaporation by these same faces. The absorptive water mass is determined by successive weighings of the test-tubes (see Fig.2).

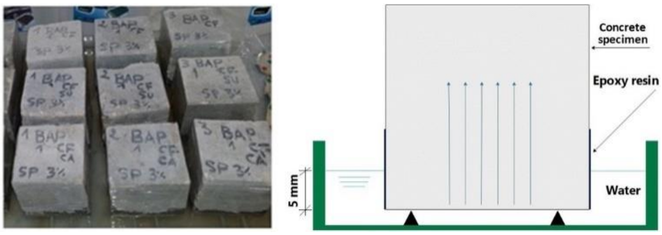

Fig. 2. Test of absorption of water by capillary of the concretes.

The absorption coefficients of initial water obtained after a time of one-hour suctions (1h) will be noted A_{bi} (kg.m-2.h-1/2), the totality of the concretes are represented with the rate of gain in Table 6 and are illustrated in Fig.3.

Rate of gain:

$$A_{bi} = \left| \frac{A_{bi_{j\,(without\ cure)}} - A_{bi_{j\,(cure)}}}{A_{bi_{j\,(without\ cure)}}} \right| \quad (2)$$

Table 6. Coefficients of initial water absorption A_{bi}

Age (days)	Curing	Concrete (OC)	(SCC)	$(SCC)_{Fc}$	$(SCC)_{Sd}$	$(SCC)_{Fs}$
28	Air	2,78	2,67	3,58	2,00	1,71
	Water	1,75	1,76	2,60	1,50	0,63
	Rate in A_{bi} (%)	37,05	34,08	27,37	25,00	63,16
60	Air	2,67	2,56	3,10	1,75	1,54
	Water	1,58	1,58	2,35	1,20	0,52
	Rate in A_{bi} (%)	41,01	38,20	24,19	31,43	66,23
90	Air	2,33	2,03	2,95	1,70	0,98
	Water	1,49	1,50	2,20	1,25	0,50
	Rate in A_{bi} (%)	36,16	26,31	25,42	26,47	48,98

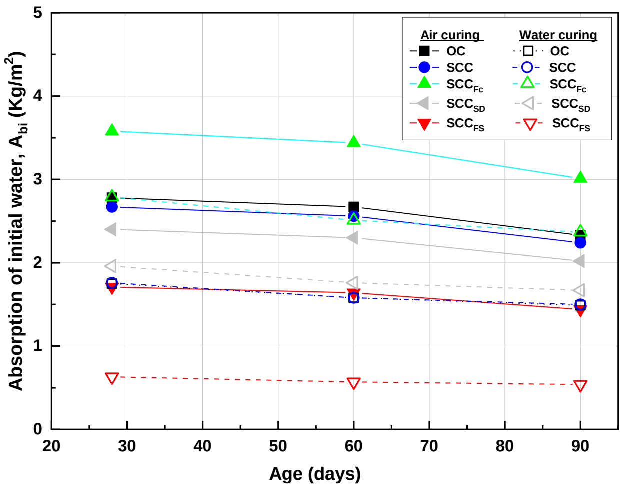

Fig. 3. Absorption of initial water (A_{bi}) of the various concretes

Fig. 3 shows the results of the absorption of initial water (A_{bi}) of the worked-out concretes. We note that absorption decreases with age (28, 60, and 90 days) and according to the type of additions. The results represented in figure 5 show a decrease with time of (A_{bi}) for the whole of the elaborate self-consolidating concrete and for the ordinary concrete (OC). We notice that by substituting 20% of the cement with one of the additions, either silica smoke ($(SCC)_{Fs}$) or sand of dune crushed ($(SCC)_{Sd}$), we obtain less A_{bi} compared to the (SCC) without additions and, by ratio, also with the (SCC) with other additions of limestone filler. That means that $(SCC)_{Fs}$ and $(SCC)_{Sd}$ are less porous, and the properties of transport are improved compared to the other concretes. This can be explained, on the one hand, by a reduction in the porous network; the greatest compactness brought by these additions, its large smoothness, gets a physical effect of filling (filler effect) [13]. In addition, the improvement is due to the pozzolanic reaction by transformation of part of the calcium hydroxide into HSC (calcium silicate hydrates), which gives a very dense microstructure, which made it possible to close the pores already existing in the structure while decreasing the number of large pores and increasing that of the small pores [14]. For ordinary concrete, the absorption of initial water A_{bi} is relatively higher than A_{bi} of various elaborate self-consolidating concretes except for $(SCC)_{Fc}$.

IV.2.2. TEST OF UNIAXIAL PRESSING

The test of compression is carried out in accordance with the standard (NF P 18-406) [15]. It consists of subjecting the concrete test tube to crushing by axial compression. Loading must be done in a continuous way until the test tube ruptures.

The test results of crushing by direct compression at the ages of 7, 14, 28, 60, and 90 days are represented in Fig. 4.

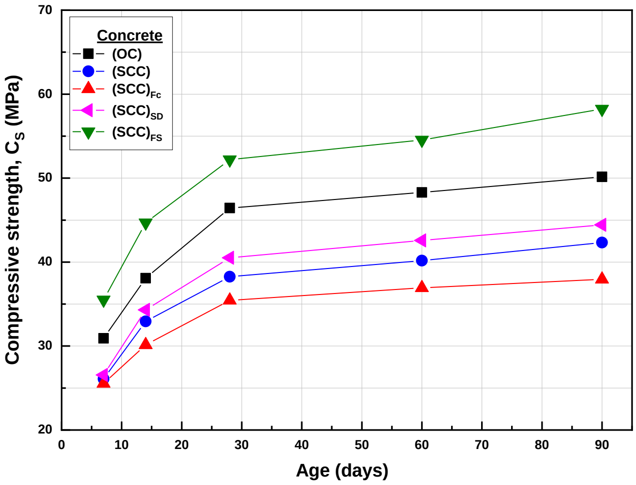

Fig. 4. Evolution of the compressive strength Rc of the concretes according to the age.

The results represented in Fig. 4 show, on the one hand, a clear evolution and increase in the compressive strength of various types of concrete worked out according to age. We could conclude that $(SCC)_{Fs}$ and $(SCC)_{Sd}$, respectively, containing the addition of silica smoke and crushed dune sand, have a better compressive strength compared to the other concretes: (SCC) and $(SCC)_{Fc}$. 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.

V. CONCLUSION

The article presents the results for the SCC with different additions. The main important findings are as follows:

- The studied self-consolidating concrete has characteristics in conformity with the requirements of the French Association of Civil Engineering (AFGC).
- The additions chosen for the development of our study can have beneficial effects on the SCC in particular by improving its fluidity, its stability with the sieve, and and reducing the risk of segregation.
- The compressive strength R_c of all the self-consolidating concrete tested increases with age and does not fall. This resistance is more important for $(SCC)_{Fs}$ and $(SCC)_{Sd}$ that for (SCC), $(SCC)_{Fc}$. For these last, the compressive strength is even lower compared to ordinary concrete because of the nature of the addition used.
- The compressive strength R_c of ordinary concrete (OC) is larger compared to that of the self-consolidating concrete $(SCC)_{Sd}$ and $(SCC)_{Fc}$.
- The additions, such as the silica smoke and the sand of the dunes, make it possible to obtain a more compact and homogeneous granular skeleton. The introduction of the additions involves a modification of open porosity and influences the physical and mechanical characteristics of the concrete.

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