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Effects of Cement Additions on Self-compacting Concrete Durability Indicators

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Abstract

This study highlights the effect of initial curing time on sustainability indicators such as sorptivity (S), water absorption (WA) and total porosity (P) of self- compacting concretes (SCC) containing the blended cement such as limestone cement (CEMIIA-L42.5) and pozzolanic cement (CEMII-A-P42.5). The durability test (acid and sulfate attack) of SCCs is also studied in this researcher. For this purpose, three water/binder (W/B) ratios were used, Six SCC mixtures were prepared and tested in the fresh state (slump follow, flow time, J-Ring, L-Box, V-Funnel and sieve segregation), the main properties in the hardened state compressive strength (Sc), S, WA and P of the SCC mixtures were studied and evaluated each in its different curing. Furthermore, the results of the Sc and transfer properties are globally significantly affected by the hot climate during the design and maturation phase. On the other hand, the values of S to SCC for pozzolanic cement are lower compared to limestone cement and this regardless of W/B ratio and the cure mode. The difference between the mixtures SCC-L32, SCC-L38 and SCC-L44 at the 28 day is between 2.45%, 87.57% depending on the cure mode and the W/B ratio. In addition, WA was observed to range from 5.8 to 7.1%. On the other hand, a good correlation was found between sustainability indicators and Sc. Durability has also been improved for pozzolanic cement compared to that of limestone cement as compressive strength against sulfate and acid attack have been improved.

Keywords

SCC, porosity, hot climate, sorptivity, curing method, sulfate attack, acid attack

1 Introduction

Self-compacting concretes is a porous material. In other words, it has pores or voids. These pores are critical for the mechanical strength and durability of concrete [1]. Low porosity is the best characteristic for concrete against all aggressive agents. Porosity is the natural consequence of the amount of water that is required for hydration and with cement bonding aggregates. This porosity inconvenience is in two domains on the mechanical resistance and on the concrete durability [2, 3]. The amount of water that can be chemically bound by Portland cement is about 25% of the cement mass. Also, a quantity of water, approximately equal to 15% of the cement mass is physically linked. The porosity of a material represents the volume of all the accumulated capillaries. It is important to distinguish between porosity and permeability. This is how a material can be very porous and at the same time very permeable (by example a concrete with a semi-cavernous structure). On the contrary, it can be relatively porous but do not let the slightest drop through your water [4]. According to el Mahdi Safhi et al. [5] an average total porosity of 9 ± 0.4% was found for the mixtures studied. However, the incorporation of treated marine sediments (TMS) increased the volume of micropores (16%), decreased the volume of mesopores (44%) and decreased the volume of macropores (90%) compared to the reference mixture. This has been attributed to the pozzolanic reaction.

On the other hand, the absorption of water by immersion is the result of capillary movements in the pores of the concrete that are open on the ambient medium. It is determined by immersing a specimen of concrete in the water up to constant mass and measuring the increase in mass. It is expressed as a percentage of the dry mass

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of the test specimen. Being an image of porosity, water absorption is used as an indicator of concrete quality. Sorptivity is an index of moisture transport into unsaturated specimens, and recently it has also been recognized as an important index of concrete durability Dias [6]. The water absorption by immersion is also considered to be a relevant parameter about the performance of concrete. Several investigations have shown that the capillary permeability is substantially affected by the curing condition Tasdemir [7]. According to the results of Nematollahzade et al. [8] have decreased the W/C ratio, the amount of capillary absorption decreases. The use of plastic curing (pc) and wet burlap curing (wbc) conditions cause capillary water absorption coefficient decreased 46–56% and 28–49%, respectively, compared to water curing (wc). Other researcher [9] indicated that as the content of fly ash (FA) and silica fume (SF) increased, the sorptivity coefficient values of SCM with (FA) increased while the sorptivity coefficient of SCM with (SF) decreased. It was observed that temperature modified the reaction speed and the evolution of early age (EA) properties while relative humidity affected evaporation and shrinkage at (EA) and hardened porosity and stiffness [10]. In the hardened state, silica-based additions (SBA) improved the mechanical performance of the material and the pore network formation and vapor permeability. Although the strength was lower and the open porosity was larger at 7 days, the pozzolanic effect of SBA improved the material performance at 28 days [11]. According to Stephan Assié et al. [12] the results of chloride diffusion and water absorption revealed that the transport properties of both concretes (SCC and vibrated concrete) were equivalent. Khatib [13] studied the SCC containing fly ash (FA) from 0 to 80% of cement replacement at a water/binder ratio of 0.36. According to the test results, a systematic increase in water absorption with increasing (FA) content was found for SCC with 1, 28 and 56 days of hardening. Dinakar et al. [14] conducted the durability tests which include water absorption test, on SCCs with (FA) percentage from 0% to 85%. Higher water absorption in (FA) SCCs than normal concretes at the same strengths was concluded. According to Sasanipour and Aslani [15] the substituting up to 30% copper slag in SCC significantly lowered the water absorption.

However, the absorption value was lowest for SCC mixes with 20% slag replacement. At the age of 28, 90 and 365 days, there was a reduction in the rate of absorption by 9.4, 11.42 and 13.15% for SCC with 20% copper slag. Water absorption of SCC containing beyond 30% slag was not more than that of control concrete. According to Nematollahzade et al. [8] the water absorption test shows that the SCC45, SCC40 and SCC35 concretes have a lower water absorption in plastic hardening methods of plastic curing (PC), wet burlap curing (WBC), water curing (WC), room- air-curing compound (RACC), out-air curing (OACC), room-air curing (RAC) and out-air curing (OAC), respectively. Amount of water absorption of SCCs in different curing conditions has lower than 9% at 28 days. Of course, in different curing conditions, water absorption decreases with decreasing water/cement (W/C) ratio. In all ages and with W/C ratio from 0.45, 0.40 to 0.35, the difference between the results of methods (PC), (WBC) and (WC) is more evident and clearer.

It is possible to state that SCC produced with limestone filler (LF) has lower total porosity but larger pores, while the reverse is true of SCC with fly ash (FA), i.e., higher porosity but pores smaller [16]. The incorporation of high-volume of slag (HVS) in the matrix decreased drying shrinkage, permeability, water absorption and porosity [17]. The objective of this study was to evaluate the effect of both curing environment and the initial water curing period on the durability indicators of SCC based at two blended cement and three W/B ratios. The properties of SCC cured under different initial periods of water hardening are: compressive strength (Sc), sorptivity (S), total porosity (P) and water absorption (WA). Based on the different types result founded at 28 and 90 days, on the performance durability indicators. Different types of correlation are proposed such as the relationship of the (S) depending the Sc, the WA between the Sc and the P between the Sc.

2 Materials and methods

2.1 Materials used

In this study, the SCC was made by using the limestone cement (16% limestone) and pozzolanic cement (18% pozzolan). The chemical composition and physical properties of the blended cement used are presented in Table 1. The fine aggregate was of 0–3 mm, its sand equivalent equals to 80. The coarse aggregate was granular class 8/15 mm. Their main properties are summarized in Table 2. The admixture used in this study was a superplasticizer with a density of 1.06, a content of chloride ions less than 0.1% and dry extracts between 28 and 31%. The dosage can vary from 0.2 to 3% according to the fluidity and the desired performance.

Table 1 Chemical and mineralogical analysis of cement

Constituent	Weight (%)	
	CEMII-A-L- 42.5	CEMII-A-P- 42.5
SiO_2	18.25	23.44
Al_2O_3	4.48	5.47
Fe_2O_3	3.28	2.83
CaO	62.38	60.49
MgO	0.94	0.39
CaOlibre	0.70	0.66
SO_3	2.00	2.46
Fire loss 950°C	7.38	2,94
C_2S	18.68	11.97
C_3S	58.20	67.19
C_3A	7.55	8.13
C_4AF	11.43	9.30
Finesse Blain (cm^2/g)	3500	3700

Table 2 Properties of sand and gravel

Property	Sand	Gravel
Density	2.4	2.5
Finesse module	1.6	/
Absorption (%)	0.7	1.2

2.2 Mix proportion design

A total of six mixtures were prepared and tested. The mixture of specimens was made of two blended cements CEMIIA-L42.5 and CEMIIA-P42.5. In all of the mixtures, gravel/sand ratio (G/S) was approximately equal to 1. The total content of binder and water binder ratio (W/B) varied between 0.32 and 0.44 for providing the desired fluidity. The proportions of SCC mixes are summarized in Table 3.

2.3 Test method

Six self-compacting concretes, with three W/B ratios of 0.32, 0.38 and 0.44, have been used in this research. The choice of the three W/B ratios aims to obtain the three classes of compressive strength of the cement. The compositions of the SCC adopted in this study were estimated by using Japanese method [18]. The coarse aggregate was limited to 15 mm. The content of the binder was between 527 and 624 kg/m^3 following the W/B ratio. The total quantity of aggregates varies from 1414 to 1427 kg/m^3. The quantity of superplasticizer was used to improve the mix workability and the SCC mix proportions are shown in Table 3.

Hot climate is characterized by high temperatures, low humidity and high solar radiation. The temperature in Chlef a town located in North-West of Algeria often rises to 48°C in inland and even more than the coastal areas during June, July and August being the hottest months of the year (Fig. 1).

2.3.1 Compressive strength

The mechanical strengths of concrete were determined in accordance with the European standard EN 196-1 [19]. The concrete are cast in 15 × 15 × 15 cm cubic steel molds and then covered with a plastic sheet. After 24 h, the concrete specimens is demolded and then immersed in water saturated with lime at 20 °C until the age of testing (3, 7, 28 and 90 days).

2.3.2 Sorptivity, porosity and water absorption

The sorptivity was determined according to the procedure described by [20], by using three cubic molds 10 × 10 × 10 cm at 28 and 90 days. The test of the total porosity was carried out according to the procedure recommended by

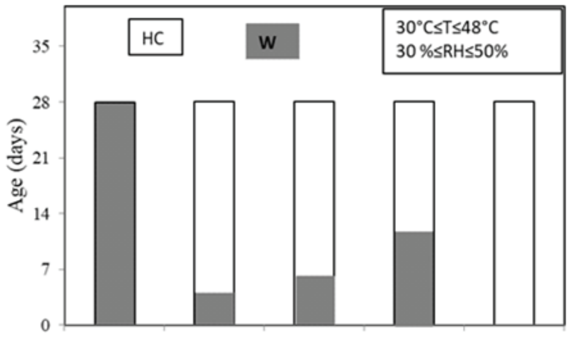


Fig. 1 Curing method

Table 3 Mix designs of SCC mixtures

Materials (kg/m^3)	SCC-L32	SCC-L38	SCC-L44	SCC-P32	SCC-P38	SCC-P44
W/B	0.32	0.38	0.44	0.32	0.38	0.44
Cement (C)	624.4	572.2	527.8	624.4	572.2	527.8
Sand 0/4	757.7	722.2	694.5	757.7	722.2	694.5
Gravel (6/14)	770.0	700.0	722.2	770.0	700.0	722.2
Water	199.8	215.7	232.2	199.8	215.7	232.2
SP (%)	2.2	1.4	1.0	2.2	1.4	1.0

standard ASTM C642 [21]. The water absorption test consists of measuring the mass of water absorbed by a concrete test piece according to ASTM C 1585 [22].

2.3.3 Durability test

For the sulfate attack tests, concrete specimens 15 × 15 × 15 cm was prepared with the same mixture proportions. After 28 days of their hardening in lime water, the specimens have been conserved in different solutions up to 270 days. The SCC specimens were immersed in 5% sodium sulfate (5% Na_2SO_4). According to ASTM C1012 [23], the pH of the sulfate solution must be between 6 and 8 and the solution must be renewed weekly. The acid attack was determined by concrete specimens 15 × 15 × 15 cm, these were cured in water at 20 °C for 28 days before being subjected to acid attack. Three specimens of each concrete mix were immersed in sulfuric acid solution (5% H_2SO_4). The specimens of SCCs that were subjected to sulfate and acid attacks will be tested for compressive strength at 30, 90, 180 and 270 days.

The concrete specimens 10 × 10 × 10 cm was used for the determination of Sc, S, P and WA. After mixing, slump flow test, T_{500} test, V-funnel test, L-Box, J-Ring test and sieve stability were conducted to characterize the workability of fresh concrete. After having obtained an SCC, the concrete turns into molds, for 24 hours covered with plastic, and then kept in five groups to study the effect of the curing methods on the properties of the SCC.

The curing methods were mentioned in Fig. 1. Before, the hardened properties have been tested. All series have been exposed to these curing conditions during summer months. In this period, highest atmospheric air temperatures are observed in Algeria. Thus, these conditions can be clearly said as hot climate. After the hardening periods, the tests on hardened concrete were carried out.

3 Results and discussion

3.1 Fresh properties

Table 4 summarizes the results of the various characterization tests of SCCs. Each rheological test was carried out three times for a given composition and the result represents the average of three values. The results through the spreading tests show that the spreading of the concretes incorporating the limestone cement for the three SCCs (SCC-32L-SCC-38L-SCC-44L) meets the class SF2 (660–750 mm) according to EFNARC [24].

As for pozzolan cement, the two SCCs (SCC-P32 and SCC-P38) conform to class SF2 (660–750 mm). On the other hand, SCC (SCC-P44) meets class SF1. It is noted that all the mixtures of SCC incorporating the pozzolan cement have a slightly higher spread than the mixtures of SCC based on a limestone cement, while, the opposite has been observed for the mixture SCC-P44.

According to Uysal and Sumer [25] the water demand and the workability are controlled by the shape of the particles, the particle size and the smoothness of the surface texture of the particles, the results of spreading tests (Slump Flow) of mixtures containing limestone filler (LF), marble powder (MP) and Basalt powder (BP). According to [25] with a constant amount of water for all mixtures, an optimal content of 20% of LF lead to a higher spreading than that of the other mineral additions such as MP and BP. This could be explained by the larger specific surface of the particles of BP and MP which requires a significant amount of water compared to that of LF [26]. Thus, the LF needs less water and results in a higher spread. Generally, mixtures that contain mineral additions have shown better performance than the mixture without addition in terms of spreading with Abrams cone. The use of mineral additions in SCCs aims to increase the distribution of powder skeleton particles, and thus reduce friction between

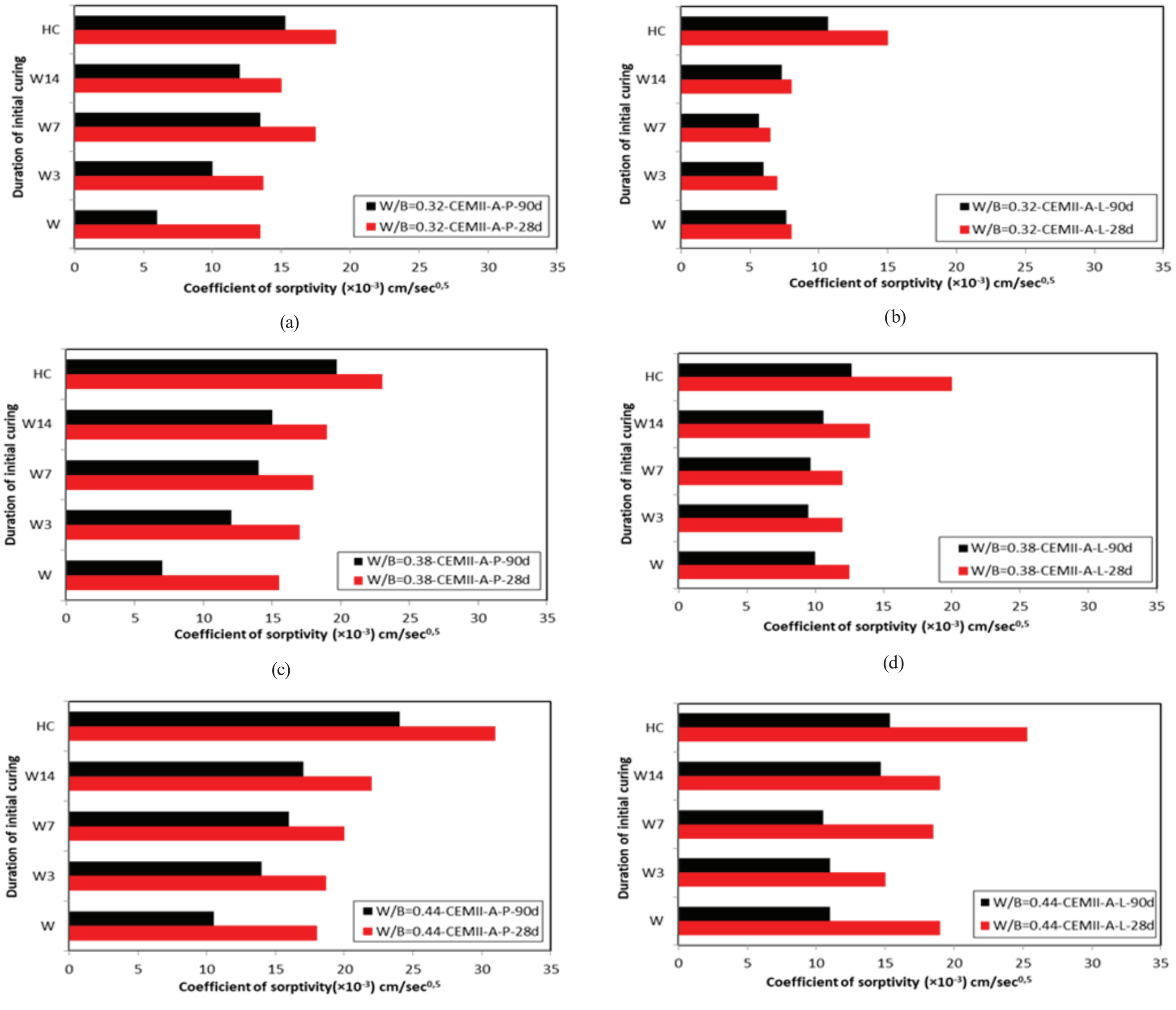
Table 4 Properties of SCC fresh just after mixing

Properties in the fresh state		Cement type					
		CEMII-A-L			CEMII-A-P		
		SCC-L32	SCC-L38	SCC-L44	SCC-P32	SCC-P38	SCC-P44
Slump Flow	Diameter (mm)	750	710	730	76.5	74.5	63
	T_{500}(s)	3.1	2.4	1.6	3.98	1.83	1.37
J-Ring	$d_{\text{J-Ring}}$ (mm)	725	710	710	79.5	81	64.5
	(d_{slump}–d_{JRing}) (mm)	25	0	20	-30	-65	-15
L-Box	H_2/H_1(%)	94.4	91.6	80	94.4	93.4	81.5
V-Funnel	T_v (sec)	11	7	4	7.9	4.8	2.75
Sieve segregation	%	14	11	20	19	18	16.4
Density	Kg/m^3	2375	2327	2223	2420	2410	3990

the particles. Belaidi et al. [27] studied the effect of pozzolan (PZ) and marble powder (MP) on the rheological properties of binary and ternary self-compacting mortars (SCM). The results show that up to 15% PZ, there was no effect on the slump flow as compared to control concrete. However, at 20% and 25% PZ, slump flow of concrete reduced to 342 mm and 269 mm, respectively; a reduction of 55% and 65% indicating that substituted the high content of the pozzzolan in MAP reduced the slump flow.

According to Boukendakdji et al. [28] with a W/B ratio and constant superplasticizer content, an increase in slump flow was observed up to 20% of slag with an optimum at 15%, but with slag from the content in isolation and l increase in viscosity. On the other hand, with high substitution content (dairy), segregation and viscosity increase. Other researcher [29] studied the effect of slag on the rheology of SCC, they found that the incorporation of slag improves the workability of SCC and causes a reduction in the shear threshold, in addition, the plastic viscosity decreased with increasing milk content.

According to the recommendations established by EFNARC [20] the viscosity can be evaluated by the time $_{500}$ of the flow time test or the V-Funnel time test. In addition, the results of T_{500} presented in Fig. 2 are included in the categories (VS2/VF2) for SCC-L32, SCC-L38 and SCC-P32 but (VS1/VF1) for SCC-L44, SCC-P38 and SCC-P44. In addition, the T_{500} time values are higher for SCC mixtures with a lower W/B ratio 0.32 indicating a higher plastic viscosity. This result was confirmed by other researchers [27, 30, 31] and they have shown that the flow time increases with increasing the content of pozzolan, indicating an increase in viscosity.



(a) (b)

(c) (d)

(e) (f)

Fig. 2 Sorptivity of SCCs as a function of the initial curing time

The capacity of passage of SCC mixtures is tested with the J-Ring test in accordance with standard ASTM C1621 [32]. The values of the slump flow measurements in the presence of J-Ring are presented in Table 2. It can be observed that slump flow in the presence of J-Ring for mixtures of pozzolanic cement is greater than that without J-Ring. According to ASTM C1621 [32] the risk of blockage is estimated through the difference between spreads obtained with the dmoy cone and at the $d_{\text{J-Ring}}$. Thus a SCC does not present a risk of blockage if $d_{\text{moy cone}}–d_{\text{J-Ring}} \leq$ 50 mm. All the manufactured SCCs meet the criteria of standard ASTM C162 [32]; the concrete is also visually inspected to assess segregation and blockage.

In addition, The V-Funnel time was in the 2.75–11 s range mainly depends on the W/B ratio and the type of cement used, the minimum value of the measured flow time is 2.75 s for SCC-P44 concrete while the maximum value is recorded for the SCC-L32 mixture. The incorporation of PZ or LF in the binary system generally made more viscous concretes; this tendency is in agreement with the works of Doğan et al. [33]. In addition, V-Funnel time decreases with the increase in the W/B ratio and this regardless of the type of cement. The mixtures of pozzolanic cement have slightly lower times than those of mixtures of limestone cement.

In all cases of the tested concretes, the values of H_2/H_1 are greater than or equal to 0.8, taking into account the dispersions, which classifies the concretes in the category PL2 within the meaning of the standard EFNARC [24]. In addition, the capacity to change to the L-Box is retained. The mixtures of pozzolanic cement have slightly higher H_2/H_1 ratios than limestone cement. According to Topcu et al. [34] the increase in limestone filler (LF), marble powder (MP) and Basalt powder (BP) in SCC mixtures, the blocking ratio is not negatively affected due to the simultaneous decrease in viscosity.

The SCC mixtures for limestone cement with the W/B ratios equal to 0.32 and 0.38 have lower percentage of sieve segregation than SCC mixtures for pozzolanic cement with the same ratios, while for SCC-P44 this trend is reversed. According to EFNARC [24] the mixtures SCC-L32 and SCC-L38 respect the class SR2 (milk ≤15%), while the other SCCs (SCC-L44, SCC-P32, SCC-P38 and SCC-P44) belong to the class SR1.

3.2 Effect of the initial cure time on the compressive strength of SCC

Tables 5 and 6 summarize the average values of Sc of concrete at different ages. It is clearly observed that the curing methods play a very important role in the development of Sc. The compressive strength of SCC stored in water is higher than that of concrete exposed to hot climate (HC) at all ages, regardless of the W/B ratio and the type of binder. In addition, the initial wet cure time also contributes to the development of compressive strength. The optimal initial wet cure time, to develop better compressive strengths, is 7 days, compared to other cure modes. It should be noted that the same result was obtained by [35, 36, 37].

Table 5 Values of the compressive strength in (MPa) of the limestone cement

W/B	0.32	0.38	0.44									
Day	3d	7d	28d	90d	3d	7d	28d	90d	3d	7d	28d	90d
W	58	58.8	68.6	70	44.5	49.8	52.5	61.2	32.8	39.8	42	44
W3	–	64.2	66	68	–	52.5	54	58	–	40.3	42	43
W7	–	–	71.8	74	–	–	60	64	–	–	44	45
W14	–	–	70.8	72.3	–	–	58.8	62.8	–	–	40.5	43.5
HC	42.5	47.2	55.5	60.7	42.2	43.2	44.5	51.3	31.8	35.3	36.5	37.8

Table 6 Values of the compressive strength in (MPa) of the pozzolanic cement

W/B	0.32	0.38	0.44									
Day	3d	7d	28d	90d	3d	7d	28d	90d	3d	7d	28d	90d
W	52.7	64	71.3	72.3	48.2	52	54	64	41.8	47	50	52
W3	–	65.5	69	70	–	53	54	57	–	45	46	47.8
W7	–	–	73	74.3	–	–	56	64	–	–	48	53
W14	–	–	70.2	71	–	–	55.8	63	–	–	50	51.5
HC	47.9	50.2	55.2	59.2	43	45	47.2	48.7	38	40.3	41.8	44.5

3.3 Transport properties and durability

3.3.1 Effect of the initial cure time on the sorptivity coefficient of SCC

The sorptivity (S) test is used to measure the rate of water absorption by capillary suction of unsaturated concrete specimens, placed in contact with water without hydraulic pressure. The higher the capillary absorption, the more likely the material is to be rapidly invaded by the liquid in contact. It is also a property that characterizes the arrangement of the pores of the material that absorb and transmit water by capillarity. The S in the form of a histogram, for the two retention periods (28 and 90 days), are shown in Fig. 2 for the two blended cements. The S increases with the increase of the W/B ratio which is in agreement with the results of Nagaratnam et al. [38]. The S of the SCCs at 28 days is systematically higher than that of SCCs at 90 days regardless of the W/B ratio and the type of cement. This is probably due to the confinement of the pores. The results show that SCCs immersed in water have a low coefficient of sorptivity. The initial cure time substantially reduces the capillary absorption of the SCC. On the other hand, independently of the W/B ratios and the type of cement, the S of the test specimens kept in the hot climate (HC) is higher compared to specimens tested in the other modes of conservation. This was probably related to the low degree of hydration of the cement caused by a shorter period of hardening in the water and also related to microcracks formed on the concrete surface resulting from the early dissipation of moisture from the concrete [39]. According to Nagaratnam et al. [38] the low amount of hydration produced and the poor microstructure in the concrete matrix were responsible for the high values of S at 28 days. The sorptivity decreased sharply with age, while the effect of W/B was pronounced. With a W/B ratio of 0.32, the sorptivity of SCC specimens partially cured in water is similar to that which has been completely cured in water for 28 and 90 days. For comparison, the greatest decrease was obtained for SCC samples made with a W/B ratio equal to 0.44.

The large decrease is noticed for the formulations of SCC-L44. Between 28 and 90 days of treatment, the decrease is 41%, 41%, 43%, 36% and 39% for the cure methods W, W3, W7, W14, and HC, respectively. For SCC-L38, the decrease is between 13.8% and 36.7%. Also, this decrease is between 11% and 29% for SCC-L32.

Regarding the formulations of SCC-P44, the reduction of their S between 28 and 90 days of cure is 41.7%, 24.3%, 20%, 22.7% and 22.6% for the treatment methods W, W3, W7, W14, and HC respectively. For SCC-P38, the decrease is between 15.4% and 54.8%. Comparison between the two types of cement, the values of S of SCC for limestone cement are lower than that of the cement with pozzolanic cement, and this regardless of W/B ratio and the cure mode. This deference is probably due to the physical effect of limestone in the short term.

The presence of limestone substantially reduces the capillary pores. The introduction of finely ground limestone filler leads to a densification of the cement matrix. The limestone filler grains are inserted into the pores created by the hydration of the cement between the aggregates and the hydration products. Also, the presence of natural pozzolan reduces the sorptivity, but this reduction is less pronounced compared to that of limestone, despite the filling of capillary pores by the second-generation C-S-H gel formed from the reaction pozzolanic with Portlandite resulting from the hydration reaction of the cement [20].

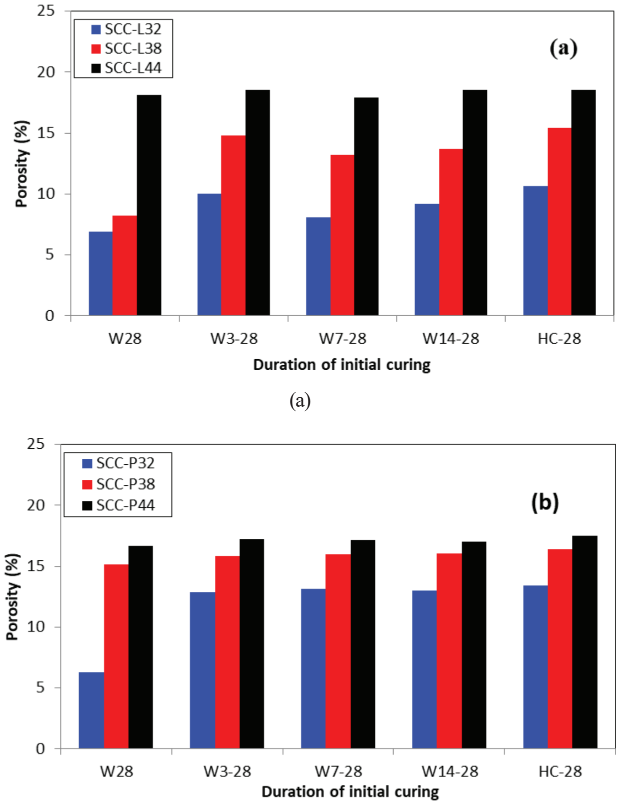
Sawicz and Heng [40] showed that limestone not only changes the pore structure of concrete but the chemical structure of the cement paste. Some researchers [41] have concluded that the hydrocarboaluminate ($C_3A.CaCO_3.11H_2O$) is formed between the limestone aggregate and C_3A in the cement as a result of chemical reactions. As a result, the interface is reinforced and the strength of the concrete increases.

3.3.2 Effect of wet cure time on porosity of SCCs

The total porosity (P) translates the open void volume to the total volume of the concrete. This quantity indicates the ability of the material to be penetrated by aggressive agents (open porosity). The results obtained in this study are presented in Fig. 3.

Fig. 3 present the P values for the six SCCs matured according to the five cure modes. The graphical illustration of the results shown in Figs. 4 and 5 shows that the porosity increases with the W/B ratio and the growth rate decreases as a function of the curing time. In addition, it is noted that the porosity of cement-based SCC CEMII-A-L is lower than that of cement-based concrete CEMII-A-P, and this is due to the fineness of limestone addition. The finer addition has two effects: it first results in a denser package.

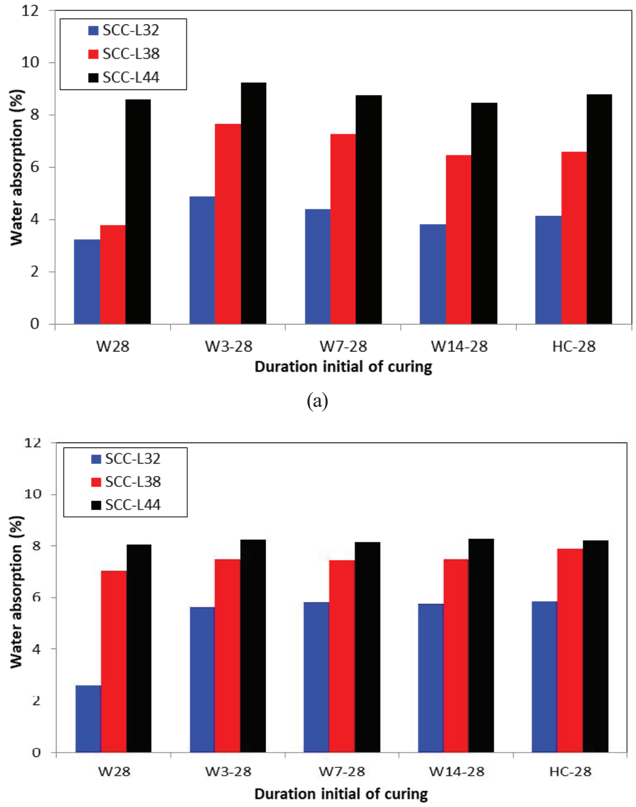
A larger surface area of CEMII-A-L cement also causes a larger precipitation area for hydration products, and thus an improved and denser microstructure [42]. In addition, the specimens of SCC preserved in water have minimum porosity values at 28 days in comparison with that conserved in the other curing methods. For



(a)

(b)

Fig. 3 Total porosity at 28 days depending on initial wet cure time, a) CEMII-A-L, b) CEMII-A-P



(a)

(b)

Fig. 4 Water absorption of SCC as a function of initial cure time, a) (CEMII-A-L), b) CEMII-A-P

example, the difference between the mixtures SCC-L32, SCC-L38 and SCC-L44 at 28 days is between 2.45% and 87.57% depending on the cure mode and the W/B ratio considering the specimens kept entirely in water as reference. In addition, this difference is between 1.79% and 112.36% for the mixtures SCC-P32, SCC-P38 and SCC-P44 is whatever the W/B ratio.

From Fig. 3, two trends seem to emerge. The first concerns concretes incorporating limestone filler (SCC- L32, SCC-L38 and SCC-L44); the concreting in hot weather seems to modify significantly the porosity compared to the materials preserved entirely in water at 20°C. On the other hand, with an increase of superplasticizer, the fermented concretes tempered at high temperature exhibit a decrease in porosity. This result can be explained by a double effect generated by the deflocculation of the cement grains and by a decrease in the W/B ratio due to the evaporation of the water during mixing. The second trend is observed on materials made with the pozzolanic matrix (SCC-P). For a pozzolan-based binder phase, a rise in manufacturing and maturation temperatures seems to significantly affect this durability indicator, because the difference in porosity between the SCCs seems to be maximum for the low W/B ratios.

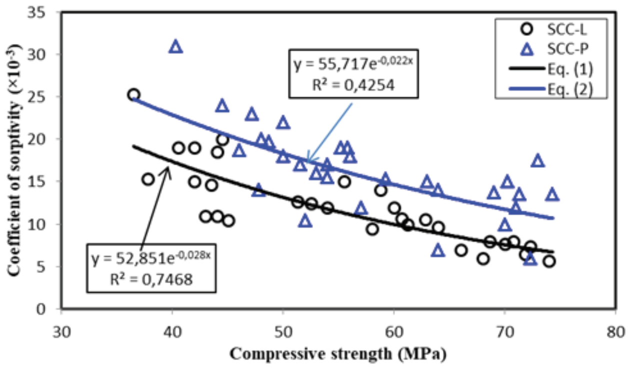


Fig. 5 Correlation between sorptivity coefficient and compressive strength at 90 days

3.3.3 Effect of wet cure time on water absorption

The water absorption reflects the ability of concrete to be penetrated by water during a phase of total immersion. According to normative texts (EN 206-1 [43] and ASTM C1585 [22]), which essentially assess the porosity of concrete. This test has certain limits. One being that it only measures the accessible pore volume, generally called open porosity. However, this value does not represent the absolute porosity of the concrete since it does not take into account the volume closed pores.

The Fig. 4 shows that the W/B ratio has a significant influence on the variation of WA (total volume of penetrable pores).

Also, WA has been observed to range from 5.8 to 7.1%. It should be noted that all SCC mixtures have a low WA characteristic (less than 10%). This is in agreement with the results reported by [44]. Similarly, Assié [45] mentions that the open porosity of concrete, evaluated by the absorption of water by immersion, is a parameter directly related to its mechanical strength and necessarily to its W/C ratio. The influence mentioned can be associated with the fact that the porosity of the concrete increases with the W/B ratio, that is to say the higher the W/C ratio is larger the pore volume of the cement matrix is important, thus increasing the volume of accessible pores.

3.3.4 Correlations between compressive strength and durability indicators

The Fig. 5 shows the relationship between the sorptivity coefficients and compressive strength at 90-day for all SCC samples. However, it can be seen from Fig. 5 that the S decreases with increasing the Sc.

For all SCC samples, exponential relationships between S and Sc at 90 days hardening can be adopted. According to Siad et al. [46] the decrease is greater for 90-day to SCC specimens. Based on the results obtained, the relationships between the S and Sc at 90-day for the two types of blended cement are given in Eqs. (1) and (2), respectively.

$$S = 52.85 \times e^{-0.022 \times S_C};\ (R^2 = 0.7468) SCC - L \tag{1}$$

$$S = 60.55 \times e^{-0.024 \times S_C}; \left(R^2 = 0.7038\right) SCC - P \tag{2}$$

On the other hand Leung et al. [47] reported that no obvious correlation between S and compressive strength of *SCC* cubes at 28-day. The behavior of surface water absorption of SCC and its *Sc* depends on the proportion of mineral admixtures and other environmental factors. Also, the concrete strength at a longer time period may serve as a better indicator of concrete durability [47].

According to Assié [45] the first characteristic that should be represented as a function of compressive strength is porosity. This parameter is directly related to the compressive strength of concrete.

The results obtained show that there is a linear correlation between the compressive strength and the porosity at 28 days whatever the type of binder, the correlation coefficients are R^2 = 0.782, R^2 =0.652 for SCC-L and SCC-P respectively (Eq. (3) and Eq. (4)).

$$P = -0.321 \times S_C + 30.75; \left(R^2 = 0.782\right) SCC - L \tag{3}$$

$$P = -0.229 \times S_C + 2773; \left(R^2 = 0.652\right) SCC - P \tag{4}$$

With *P* porosity and *Sc* compressive strength at 28 day. Fig. 6 shows the variation of the porosity depending of the compressive strength on the 28 day. The porosity decreases when the compressive strength increases which is in agreement with the literature.

The correlation results between absorption and compressive strength obtained at 28 days are shown in Fig. 7. The results obtained, show that there is a linear correlation between the compressive strength and the absorption, the correlation coefficients are R^2 = 0.656, R^2 = 0.694 for SCC-L and SCC-P respectively (Eq. (5) and Eq. (6)).

$$WA = -0.174 \times S_C + 14.34; \left(R^2 = 0.65\right) SCC - L \tag{5}$$

$$WA = -0.127 \times S_C + 14.03; \left(R^2 = 0.69\right) SCC - P \tag{6}$$

With WA water absorption and *Sc* compressive strength at 28 days.

Fig. 7 shows the variation of absorption versus compressive strength at the 28 day. It is found that absorption decreases markedly when the compressive strength increases which are in agreement with the results obtained by other researchers [13].

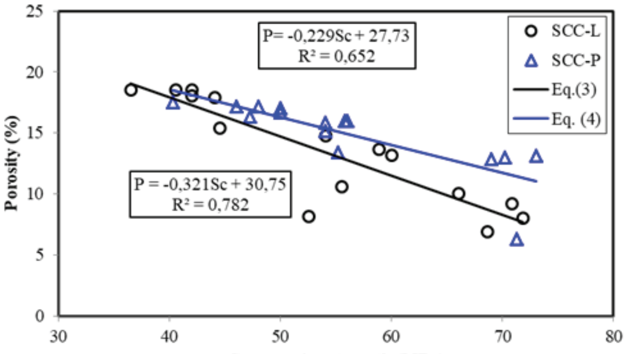


Fig. 6 Correlation between porosity and compressive strength

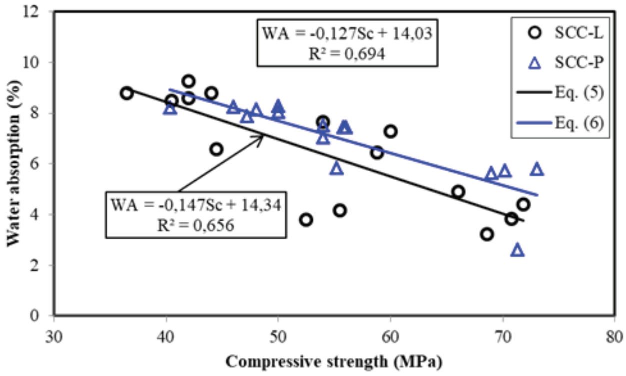


Fig. 7 Correlation between water absorption and compressive strength

3.3.5 Sulfate attack

The compressive strength reaches its peak during the first 90 days of exposure to 5% Na_2SO_4 solution then it starts to decrease. The compressive strength for specimen SCC-L44 and SCC-P44 increases by 9% and 10%, respectively.

This variation mainly depends on the continuous salt crystallization and generation of gypsum and ettringite in the pores or micro-cracks of concrete [48, 49]. At the initial stage, the expansion induced by crystallization and new products (gypsum and ettringite) can fill the pores and micro-cracks, and increase the compactness of concrete, which leads to an increase in compressive strength at macro level [50].

At the advanced stage, at the 270 days the compressive strength for specimens SCC-L44 and SCC-P44 decreases by 18% and 9%, respectively, as shown in Fig. 8(b), however, with further salt crystallization and formation of gypsum and ettringite, the pores or micro-cracks in concrete cannot accommodate further expansion. New cracks start to appear and develop when the expanding stress exceeds the tensile strength [51].

In addition, it should be noted that the compressive strength of SCC-L44 concrete is lower than that of SCC-P44 concrete, regardless of the duration of immersion. On the other hand, it can be seen in Fig. 8(a) that the compressive strength of specimens stored in water increases with age.

3.3.6 Acid attack

For SCCs specimens, after immersion in H_2SO_4 solution for 30, 90, 180 and 270 days. Fig. 8(c) shows the evolution of compressive strength of mixtures of SCCs on the basis of two binders (Limestone cement, pozzolanic cement) with water to binder ratio (W/B = 0.44) immersed in the sulfuric acid (5% H_2SO_4). By contrast, the cubes SCCs test pieces weathered in the acid solution show a decrease in the compressive strength with the age and this regardless of the type of binder.

After 270days the compressive strength for specimens SCC-L44 and SCC-P44 decreases by 76% and 66%, respectively, as shown in Fig. 8(c). It is recognized that the beneficial effect of the pozzolanic reaction occurs in the long term compared with that of limestone cement. When acid reacts with concrete, the interlocking between the cement matrix and aggregate as C-S-H gel was broken down. The specimens kept under acid curing exhibited white patches on their surfaces. Honeycombing was also noticed on their surfaces due to acid attack. The conversion of the portlandite $Ca(OH)_2$ in gel C-S-H as a result of the pozzolanic reaction contributes to an increase in the resistance and the reduction of the porosity [52].

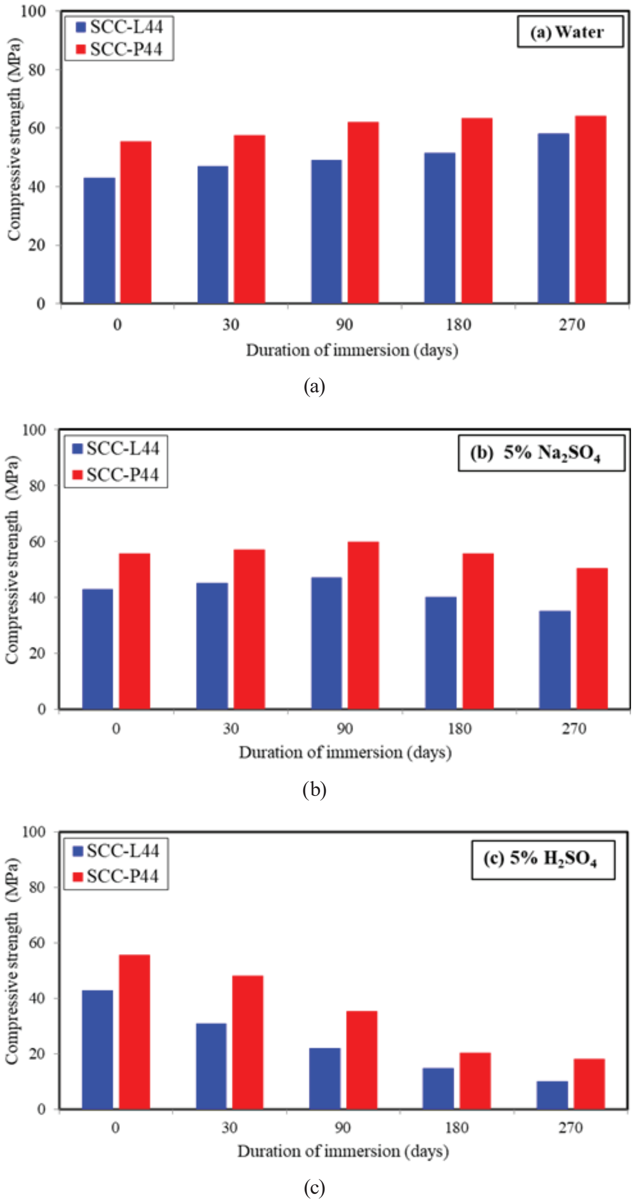


Fig. 8 compressive strength of SCC in attack solution, a) immersion in water, b) Immersion in 5% Na_2SO_4, c) Immersion in 5% H_2SO_4

4 Conclusions

Concerning the transfer properties, they are globally significantly affected by the hot climate during the design and maturation phase (initial cure time). The properties of sorptivity, porosity, and water absorption are generally strongly modified, thus inducing modifications of the porous network (total pore volume, pore size, connectivity, the capacity of a species ionic to penetrate the material). The strong modification of the porous network can be explained by the increase in the heterogeneity of the hydrated phases which can be encountered for matrices having undergone temperature rises. The following conclusions are made:

The sorptivity coefficient of SCC decreases with age regardless the W/B ratio. However, regardless of the W/B ratio and the type of cement the S of SCC at the 28 day is higher than this coefficient of SCC at the 90 day.

- The initial cure time substantially reduces the sorptivity of the SCC. On the other hand, independently of the W/B ratios and the type of cement, the sorptivity coefficient of the test specimens kept in the hot climate (HC) is higher, compared to specimens tested in the other modes of conservation.
- The high decrease in sorptivity is noticed for the formulations of SCC-L44 between 28 and 90 days of treatment. The decrease is 41%, 41%, 43%, 36% and 39% for the cure methods W, W3, W7, W14, and HC respectively.
- Comparison between the two types of cement, the values of coefficients of sorptivity (S) of SCC containing the limestone cement are lower than that the SCC with pozzolanic cement, this regardless of W/B ratio and the cure mode.
- The porosity increases with the W/B ratio. However, it is noted that the porosity of cement with limestone is lower than that of with pozzolanic cement.
- The specimens of SCC preserved in water have minimum porosity values tested on the 28 days in comparison with that conserved in the other curing methods. For example, the difference between the mixtures SCC-L32, SCC-L38 and SCC-L44 at 28 day is between 2.45% and 87.57% depending on the cure mode and the W/B ratio considering the specimens kept entirely in water as reference.
- The variation of water absorption is strongly influenced by the W/B ratio. Also, water absorption has been observed to range from 5.8 to 7.1%. It should be noted that all SCC mixtures have a low water absorption characteristic (less than 10%).
- The relationships between sorptivity depending on the compressive strength at 90-day and water absorption depending the porosity presents a good correlation, which confirms the reliability of the experimental results found.
- The specimen exposed to the hot climate appears to have a significant influence on the porosity compared to the specimens cured entirely in water at 20°C.
- For all SCCs studied the values of compressive strength increases in the initial stage up to 90 days of immersion in Na_2SO_4 solution and reaches a peak value, then tends to decrease.
- The SCCs specimens immersed in the acid solution show a decrease in compressive strength with age.

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