Properties of Self-Consolidating Concrete Produced Using Local Algerian Materials

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Abstract: This paper describes an experimental investigation of the effects of the Water/Cement ratio on the behaviour of self-consolidating concrete in the fresh and hardened states, using local Algerian materials. Several tests were carried out to characterise the properties of these concretes: spread flow, L-box test, stability assessment with sieve, bleeding, mechanical strength, shrinkage and microstructural studies that encompassed both mineralogical characterisation and porometric distributions. The results offer important insight into the optimisation of the rheological characteristics of self-consolidating concrete. They also permit the development of a variety of formulations that meet rheological requirements such as good deformability, reduced bleeding and the absence of segregation.

Keywords: Self-consolidating concrete, Local materials, Superplasticisers, Limestone fines, Fresh and hardened concrete

INTRODUCTION

In the past two decades, studies related to high-performance concrete have helped to show the harmful impact of the presence of excess water. Reduction of the water quantity by the use of dispersants and the correction of the granular distribution with ultrafines addition have enhanced strength and durability. Moreover, the significantly improved workability of these new concretes has led researchers to develop and increase the reliability of highly workable concrete. Today, alongside high-performance concrete, self-consolidating concrete (SCC) suggests a change of objectives constituting a true cultural revolution: the study of a material is no longer solely controlled by the improvement of resistance and durability. These properties, though, have remained equivalent to or better than those of normal concretes (NC). The control of all concrete mixture variables enables very highly flowable mixes with good handling, placing and finishing properties.

However, in spite of the interesting aspects of SCC, in particular in a fresh state, its long-term behaviour can reduce its utility. Indeed, the inherent physico-chemical phenomena governing the shrinkage of self-consolidating concrete are still far from being clearly

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defined (Proust, 2002). It is recognised that the present component formulation gives a suitable fluidity by preserving homogeneity and mechanical strength, but the problem of deformations still remains.

The research described in this paper was undertaken in an attempt to answer several questions, some of which relate to the evolution of the physical and mechanical properties of concrete over time. Our objective is to provide an explanation of the behaviour of SCC with respect to shrinkage according to the variation of its components (in particular the Water/Cement (W/C) ratio), using locally produced materials. The present study will help future researchers get more information about the shrinkage values of SCC the advantages of using SCC instead of NC.

EXPERIMENTAL WORK

Materials

Cement
The physical properties and average chemical analyses of the cement and limestone fines used in the mix are given in Table 1. The cement used was CPJ CEM II/A 32.5 obtained from the manufacturer, located in Zahana (western Algeria). The cement has an average 28-day strength of 33 MPa, a figure obtained in accordance with standard NF INTO 196-1.2 (1995).

Table 1. Physical Properties and Chemical Analysis of Cement and Limestone Fines

	Cement	Limestone Fines
Physical properties		
Apparent volumetric mass (g/cm^3)	1.09	0.87
Absolute volumetric mass (g/cm^3)	3.00	2.66
Blaine specific surface area (cm^2/g)	3100	2880
Chemical analyses		
SiO_2	21.93	10.81
CaO	63.87	47.51
MgO	0.21	0.21
Fe_2O_3	4.26	0.76
Al_2O_3	6.81	0.31
SO_3	1.31	-
Ignition loss	1.83	40.69
Free CaO	0.13	-
Carbonates	-	85.45
CO_2	-	37.60
H_2O	-	3.09

Limestone fines

The limestone fines used in the concrete mix were obtained from the Kristel quarry, also located in Western Algeria. Chemical analysis revealed that the limestone sample consisted primarily of $CaCO_3$ (85.45% wt.) and contained a considerable quantity of silica, up to 10.81% wt. The remaining constituents of the limestone, such as magnesia, alumina and iron oxide, make up very little of the material by weight percent. There are no sulphates, chlorides or other soluble salts, nor any organic components.

Aggregates

Coarse aggregates included in the formulations were natural crushed limestone gravel with continuous grading curves from the Kristel quarry and siliceous sea sand and crushed sand from the Sid Lakhdar quarry (in the area of Mostaganem, west of Algiers). The physical characteristics of the aggregates used in this study are listed in Table 2.

Superplasticisers

A non-chlorinated superplasticiser containing an acrylic copolymer ("Viscocrete 20" HE; Sika-France), and conforming to the standard NF INTO 934-2 (2001) was used for all SCC mixes. This highly water-reducing additive is available as a yellow liquid with a dry solid content of 40% wt. and a density of 1.085. For NC, a water-reducing plasticiser (Plastiment BV 40) was used.

Table 2. Physical Properties of Aggregates

	Sea sand (Sm)	Crushed sand (Sc)	Gravel (G)	
Class	0/2	0/3	3/8	8/15
Nature	Siliceous	Limestone	Limestone	Limestone
Absolute volumetric mass (g/cm3)	2.64	2.66	2.67	2.67
Absorption (%)	-	-	1.28	0.93

This additive is a dark brown liquid with 36.6% to 40.4% wt. of dry solid content and a density of 1.185.

Concrete Mixes

Three SCC mixes and one NC mix (used as the control mix) were prepared for this study. For the self-consolidating mixes, the paste volume (V_{paste}), fines/cement (F/C) ratio and superplasticiser (S_p) dosage were kept constant (F/C = 0.25, V_{paste} = 37.5% and S_p = 1%). The quantities of the NC mix components were determined by the Dreux-Gorisse method (Neville, 2000), by considering the same W/C as that of the SCC mix. Concrete mix details are given in Table 3.

Table 3. Concrete Mix Proportions

Designation	W/C	Mixture proportion (kg/m3)								
		Cement	Limestone fillers	Efficious water	Viscocrete 20 HE	Plastiment BV 40	Sm	Sc	G (3/8)	G (8/15)
SCC1	0.4	448	112	179	4.48	-	578	249	333	499
SCC2	0.5	400	100	200	4	-	578	249	333	499
SCC3	0.6	361	90	217	3.61	-	578	249	333	499
NC	0.5	350	-	175	-	5,25	129	576	204	947

Fresh State Tests

The characterisation of concrete in the fresh state was limited to tests recommended by the AFGC (2000) and included the following: the slump flow cone, L-box set-up flow, sieve stability and bleeding tests.

Slump flow test

In the slump flow test, freshly mixed concrete is removed from a standardised DIN cone, and the diameter of concrete spread is measured. It should be noted that SCC forms a spread with a diameter ranging between 60 and 75 centimetres. In the case of normal concrete, a traditional slump test was performed according to the NF P 18-451 standard (2000).

L Box set-up test

The L-Box set-up test evaluates concrete flow in confined surroundings and helps to verify that the placement of a particular mix will not be impeded by any obstructions that may block the flow. In this test, 13 litres of concrete are poured into the opening at the top of the vertical part of the L Box, and the concrete, filling this part of the box, rests for 1 minute. A trap door at the base of the box is then raised, and the concrete then flows along the horizontal part of the box and through steel reinforcements. At the end of the flow period, heights H_1 and H_2 are measured, and the result is expressed in terms of the filling ratio of H_2/H_1 (see Figure 1).
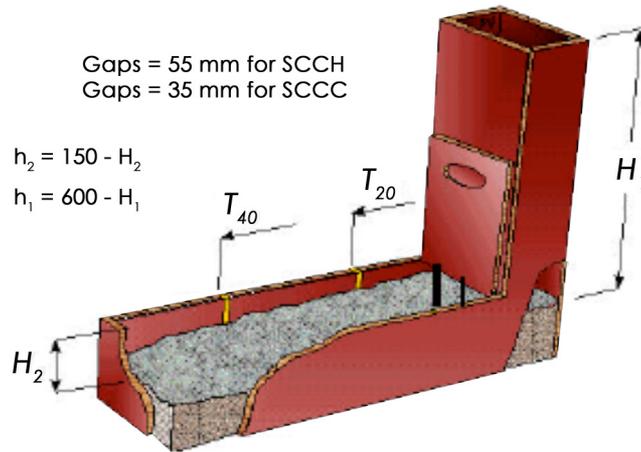
Figure 1. Measurement Parameters after Stabilisation (NF EN 196-1, 1995) Drawing not in scale, adapted by Sonebi et al. (2000)

Sieve stability test

This test is performed to measure the proportion of concrete fine elements (laitance) passing through a 5-mm sieve to determine the risk of segregation and degree of concrete stability. Criteria for determining the acceptability of a mix are divided into three classes:

- $0\% < \varpi_{Laitance} < 15\%$: good stability,

- $15\% < \varpi_{Laitance} < 30\%$: critical stability,

- $\varpi_{Laitance} > 30\%$: bad stability (segregation, unusable concrete).

Bleeding test

The purpose of the bleeding test is to measure the quantity of liquid that rises to the surface of a 15 by 30-cm test specimen after 3 hours. Evidence of a significant degree of bleeding reduces the aesthetic quality of concrete facings and may also affect the long-term durability of the component. The bleeding value must be less than or equal to 3% in volume (AFGC, 2000).

Tests on Hardened Concrete

Three samples were tested for each concrete mix and each test.

Mechanical strength

The compressive strength of the concrete mixes was determined from tests on cylindrical samples 110 mm in diameter and 220 mm in height. All concrete specimens were demolded 24 hours after casting and then stored in a water tank at $20 \pm 2°C$ until the tests were undertaken at 1 day, 7 days, 28 days and 90 days of curing. The tensile strength was also measured on the same size cylindrical specimens (i.e., 110 by 220 mm) using the splitting test in accordance with the NF P 18-408 standard (1981).

Free shrinkage

Deformation due to shrinkage was measured with a retractometer on prismatic specimens (7x7x28 cm). The

specimens had been stored in a temperature-controlled room at 20±1°C and 50±5% relative humidity in two conditions:

1) with environmental hydrous exchange, for which the total shrinkage was measured, and

2) without hydrous exchange with the environment [by wrapping the samples in one (or two) sheet(s) of self-adhesive aluminium foil], for which the endogenous shrinkage was measured.

After 24 hours, the specimens were demolded, and shrinkage measurements were performed within a short period of time (< 10 minutes).

Mineralogical characterisation using a Scanning Electron Microscope (SEM)

Complementary tests were performed to identify and quantify the structural elements and to visualise their arrangement. This test was done by observations using an SEM (JEOL JSM-T330A model) on hardened SCC fractures at 90 days.

RESULTS AND DISCUSSION

Concrete in the Fresh State

Effect of W/C ratio

In addition to its major contribution to the hydration process, water is one of the most important factors influencing concrete workability. Increasing the water content increases the concrete fluidity and reduces the concentration of solids; at the rheological level, the yield stress and viscosity decrease. However, the use of excessive water will lead to a decrease in the mechanical strength of the hardened concrete, as well as segregation in the fresh state (Oh et al., 1999).

The cement content in concrete influences its mechanical properties and its durability. Concrete flow and workability are related to W/C, making it a significant factor. Indeed, the concrete mixture formulation is strongly related to this parameter.

Figure 2 and Figure 3 represent the effect of W/C on the spread diameter and dynamic segregation, respectively. Figure 2 shows that the reduction in W/C ratio directly influences the flow of the SCC. The SCC1 displays a spread diameter that is 12.90% less than that of SCC2 and 16.13% less than that of SCC3. This reduction is due to the reduced quantity of water incorporated at mixing. It should be noted here that the results agree
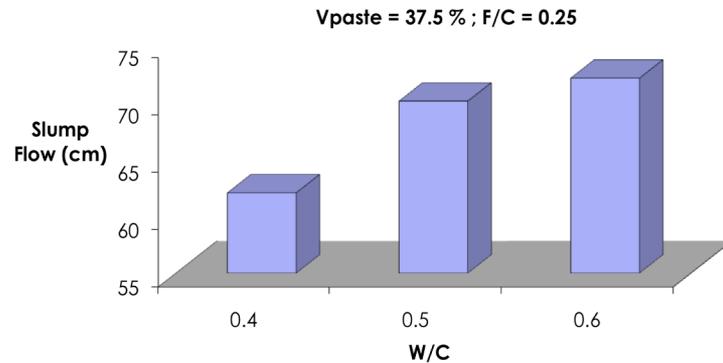
Vpaste = 37.5 % ; F/C = 0.25

Figure 2. Effect of W/C on Slump Flow Diameter of the SCC

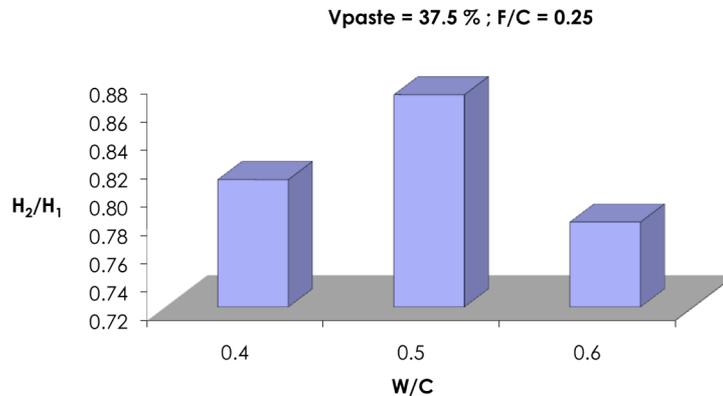**Vpaste = 37.5 % ; F/C = 0.25**

Figure 3. W/C Effect on Dynamic Segregation (H_2/H_1)

with those obtained by Leemann and Winnefeld (2007). However, this reduction positively effects stability and the resistance to dynamic segregation for the SCC with W/C = 0.4 and W/C = 0.5 (Figure 3). The mix with a W/C = 0.6 is the only one that does not fulfil the conditions set forth for stability and segregation resistance.

Table 4 summarises the resistance to static segregation and the bleeding of the SCC. The SCCs corresponding to W/C = 0.4 and 0.5 have a rate of segregation lower than 15% and bleeding less than 3%, demonstrating an acceptable stability.

The SCC3 (W/C = 0.6) material has poor flow stability, which conforms to expectations, as it contains a greater quantity of water.

Segregation verification

There is another method to examine the segregation of SCCs that consists of sawing hardened concrete samples in the transverse direction and observing the

Table 4. W/C Effect on Static Segregation Resistance and Bleeding

	W/C = 0.4	W/C = 0.5	W/C = 0.6
Stability on sieve ϖ (%)	7.45	7.68	15.98
Bleeding (‰)	1.09	1.15	3.25

distribution of aggregates in three parts of the sample: the top, the middle and the bottom (Figure 4). This picture illustrates the fact that the concrete mix presented here (SCC with W/C = 0.6) is prone to segregation (static and dynamic). The aggregates are not regularly distributed over the height of the sawn samples (vertically cast from the top).

Hardened State

Mechanical strength evolution

Compressive strength is an essential characteristic of hardened concrete, and one of the fundamental parameters of our study. Consequently, its initial value and its progression over time were determined for all the mixes studied in this project.

Figure 4. Observation of Aggregate Distribution in Three Sections of the Sample (SCC with W/C = 0.6)

The progression of concrete tensile strength is difficult to determine experimentally. It is appreciably influenced by the same factors as those that influence the evolution of the compressive strength. It is therefore important to assess the tensile strength of the SCC as a function of the compressive strength and to compare it with that of the equivalent normal concrete.

W/C effect

The most commonly used parameter to predict the compressive strength is the W/C ratio. The resistance of a well-compacted concrete seems to be inversely proportional to its W/C ratio. This relation is in fact an established rule, described by Duff Abrams (Neville, 2000). Figure 5 shows the variation of the mechanical strength with respect to W/C changes.

This figure shows that the reduction of W/C significantly influences the compressive strength. It can be seen that the SCC1 (W/C = 0.4) sample shows mechanical strength improvements of 8% and 29% compared to those of the SCC2 (W/C = 0.5) and SCC3 (W/C = 0.6), respectively, at one day.

At 28 days, the SCC with W/C = 0.4 shows differences of 4% and 23% in strength compared to those of the SCC with W/C of 0.5 and 0.6, respectively.
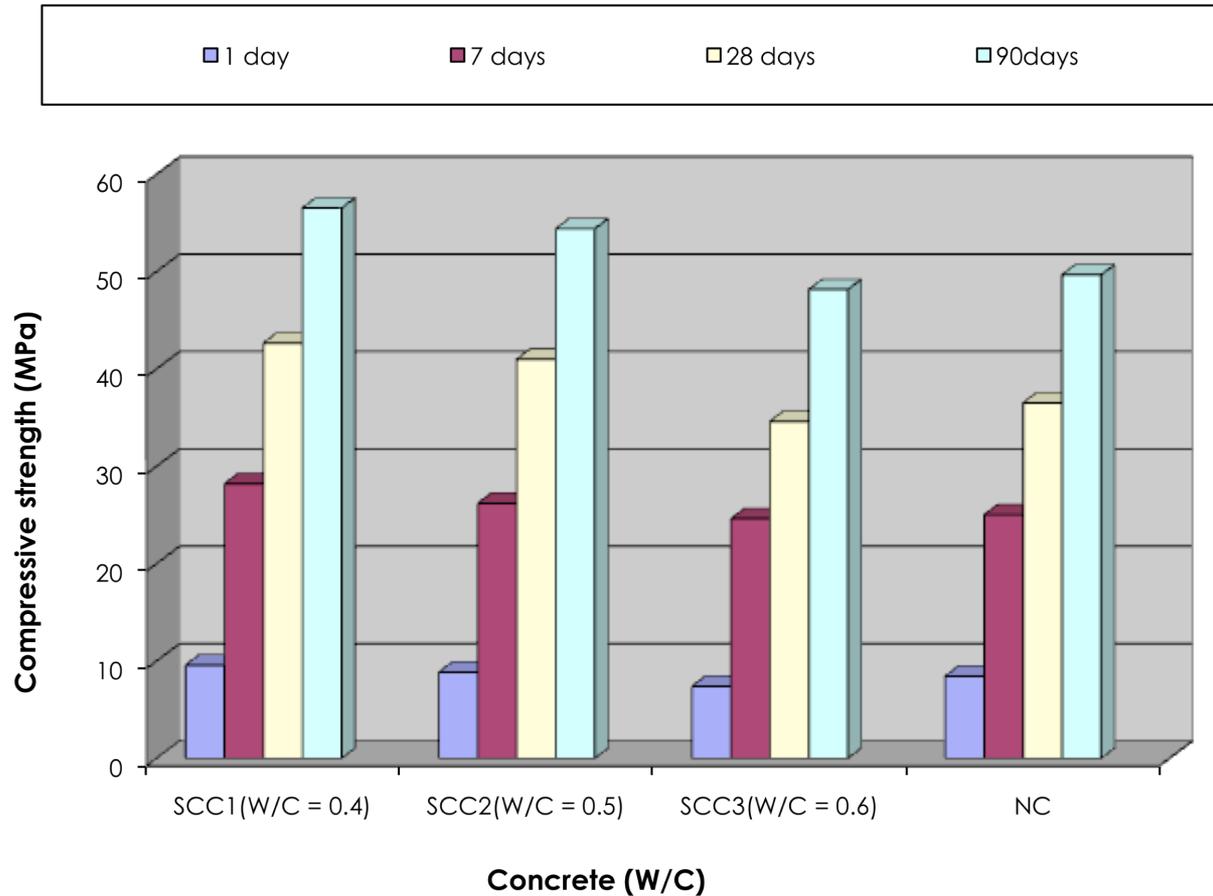
Figure 5. Compressive Strength Histograms as a Function of W/C at Different Ages

The measurements carried out at 90 days provide a higher strength for the SCC1 (56.53 MPa) compared to those of the SCC2 (54.40 MPa) and SCC3 (48.17 MPa).

This improvement of resistance is mainly due to the reduction in the quantity of interstitial water. Indeed, a self-consolidating behaviour is reached at high superplaticiser dosage. However, that did not result in significant modification of the kinetics of hardening.

The strength progression of the SCC with W/C = 0.5 compared to that of normal concrete with the same W/C implies much faster kinetics; the volume of hydrates obtained is higher than that developed in the normal concrete, resulting in a greater thickening of the gel. Moreover the presence of limestone fines in the SCC allows a better arrangement of the granular structure, permitting greater compactness compared to that of normal concrete. It is easy in these conditions to understand the superiority of the SCC compressive strength over the normal concrete at 28 days and 90 days. The strength at these times is greater by approximately 12% and 9.50% than those of the NC at 28 days and 90 days, respectively.

The time dependence of the evolution of the tensile strength is not of considerable interest, as in practice it is evaluated based on the compressive strength.

Nevertheless, the curves of the tensile strengths at 28 days versus W/C were plotted (see Figure 6) to show that the reduction in W/C does not significantly influence the tensile strength. It can be noted that SCC with W/C = 0.4 gives an increase of 5% and 20% in strength compared to those of the SCC of W/C of 0.5 and 0.6, respectively, at 28 days.

Free shrinkage

Concrete undergoes dimensional deformations as soon as it is placed in the formwork. These dimensional changes are governed by various physical and chemical phenomena. They take place in the free material, but occur more strongly for a material under load.

To reach the size necessary for the examination of free deformations, two series of samples were necessary to consider different modes of conservation (i.e., endogenous and in desiccation).

Effect of W/C ratio

Endogenous shrinkage begins before the concrete first sets, but the part of this deformation that occurs at the plastic stage does not have a mechanical consequence on the hardened state. The development of endogenous shrinkage occurs rapidly, but typically stabilises after a few months. This phenomenon is of course related to auto-desiccation, i.e., a reduction in internal moisture content following water consumption because of the hydration process.
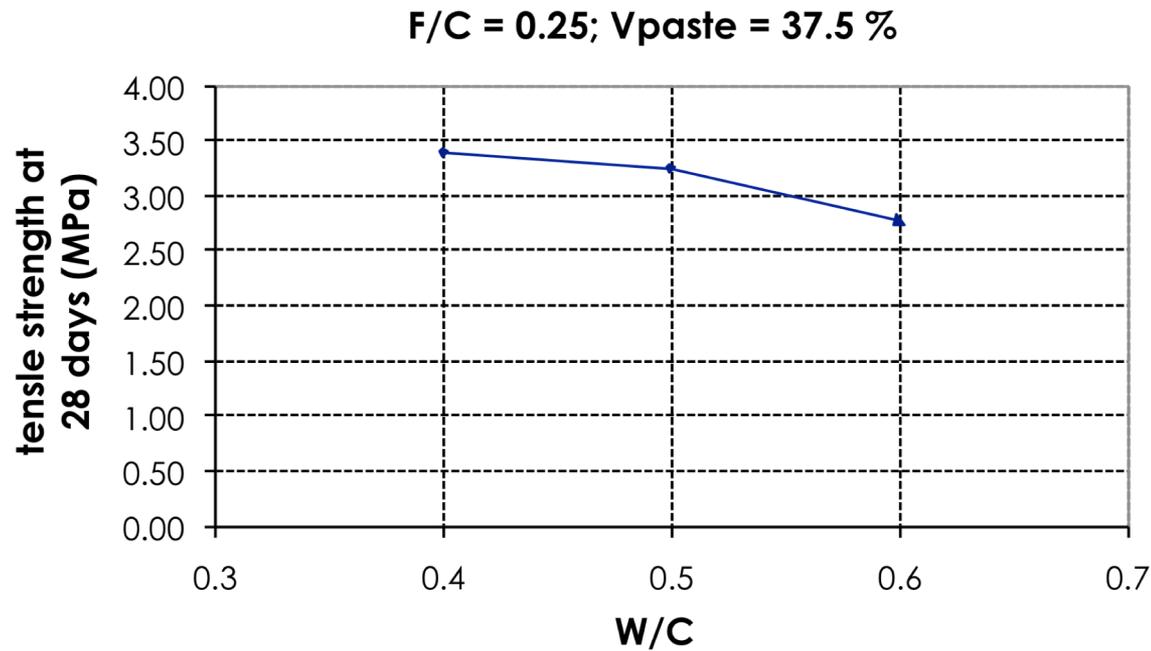
F/C = 0.25; Vpaste = 37.5 %

Figure 6. Impact of W/C on Tensile Strength at 28 Days

Endogenous shrinkage

When the W/C ratio is low (e.g., 0.4), the process of hydration very quickly reduces the water content in the capillary pores. Self-desiccation thus has a marked effect, and the degree of endogenous shrinkage is then higher. The results presented in Figure 7 agree with this assumption regarding the effect of the W/C ratio on endogenous shrinkage.

It is observed that for values of the W/C ratio ranging between 0.4 and 0.6, the shrinkage curves are roughly the same as those observed in the first 50 hours.
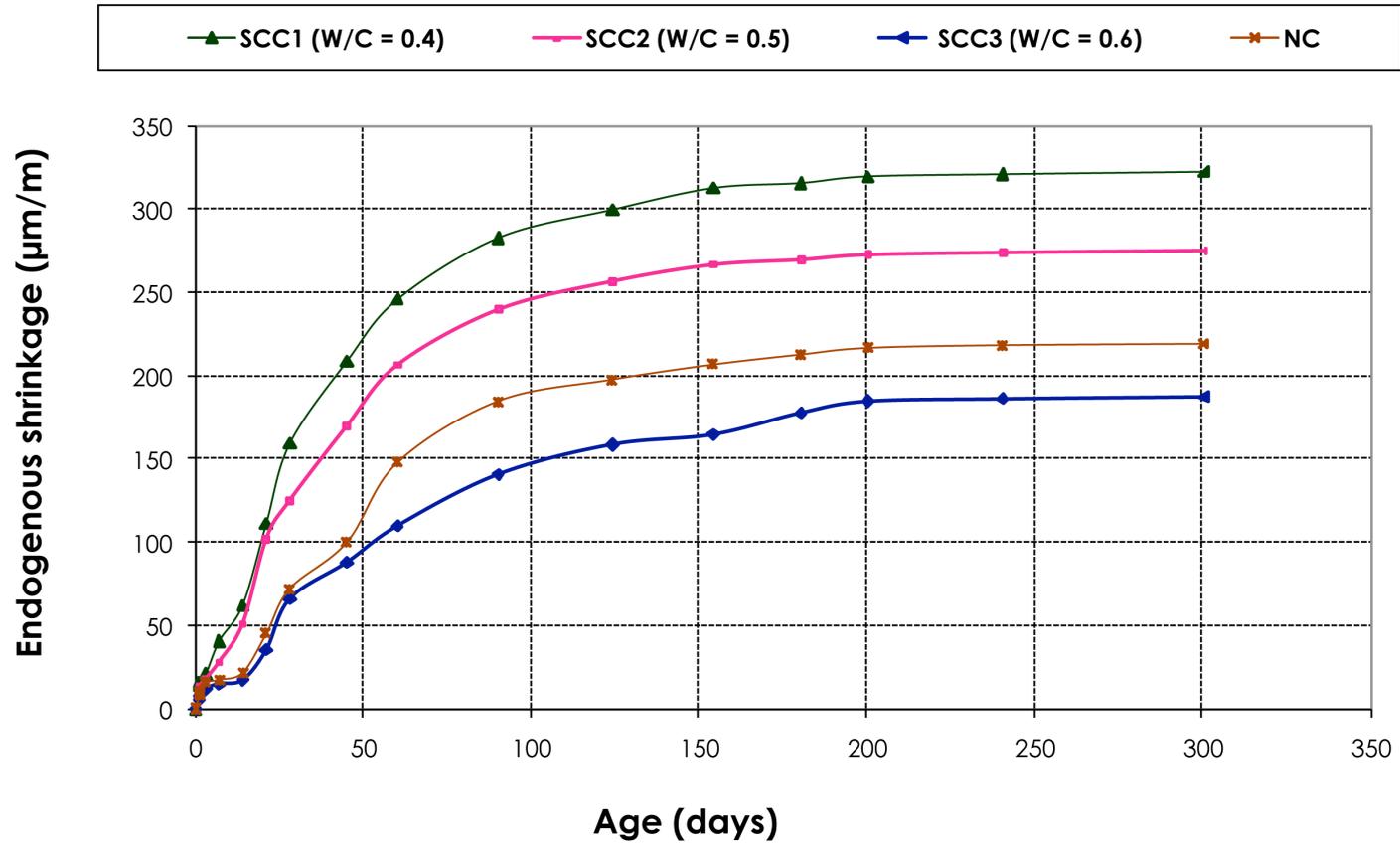
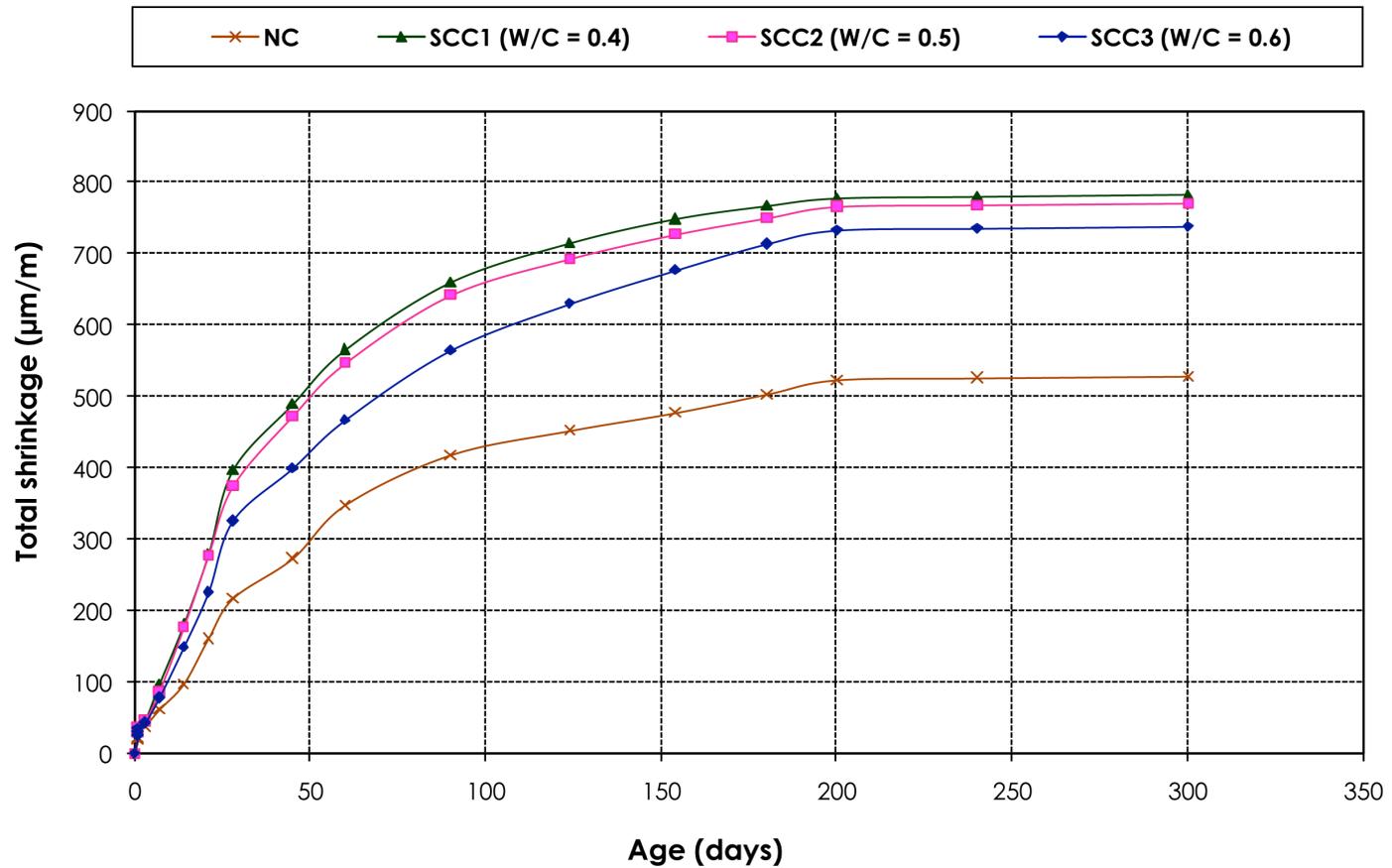Figure 7. Effect of W/C Ratio on Endogenous Shrinkage of SCC

Figure 8. Effect of W/C Ratio on Total Shrinkage of SCC

The comparison of the deformation amplitudes of the SCC shows that, for the formulations with low W/C (lower than 0.5), a significant part of the change due to endogenous shrinkage occurs after 150 days. This effect is explained by the fact that the hydration reaction stops when the water content in the porous network drops below a certain threshold (Tazawa and Miyazawa, 1998; Turcry, 2004). As represented in Figure 9, at 200 days of age, the SCC1 (W/C = 0.4) material develops a self-desiccation shrinkage 1.2 and 1.8 times greater, respectively, than those of the SCC2 (W/C = 0.5) and SCC3 (W/C = 0.6) materials. According to Brooks et al. (1998), the difference in ionic concentration between the water contained in the pores and the adsorbed water would generate a water movement that would increase the shrinkage, in particular when W/C was low; this is why the endogenous shrinkage is important for SCC.

Based on the fact that lower hygrometry results in lower endogenous shrinkage (Proust, 2002), the endogenous shrinkage of the SCC with W/C = 0.5 should be appreciably equal to that of the NC because they have same W/C ratio. In our case, the SCC develops self-desiccation shrinkage (Figure 7) about 1.3 to 1.7 times larger than that of the NC. The variations of amplitude constitute a surprising result that calls into question the above-mentioned relation between the hygrometry and the endogenous shrinkage. This is explained by the fact that limestone fines, in the presence of a superplasticiser,

activate the hydration reactions, densifying the gel to result in a markedly higher volume of hydrates in the SCC compared to the NC.

Total shrinkage

The total shrinkage is defined as the sum of shrinkages due to endogenous and desiccation effects. The total shrinkage is measured on samples preserved in open-air conditions (i.e., specimens not coated).

The difference in total shrinkage noted in Figure 8 is the consequence of the endogenous shrinkage that decreases with the W/C ratio. The curves obtained for the SCC appear in a cluster. W/C has very little effect on the total shrinkage of the SCC and remains higher than that of the NC.

Desiccation shrinkage and mass loss

In Figure 9, the desiccation shrinkage is directly proportional to the W/C ratio because the W/C ratio determines the quantity of water that can evaporate in the cement paste and the rate at which this water can reach the surface of the test specimen. Brooks (1989) obtained the same result for W/C ratios ranging between 0.20 and 0.60. For higher W/C ratios, additional water disappears with drying without causing shrinkage.

Figure 9 shows that for all SCC mixes tested, the greatest part of the desiccation shrinkage takes place
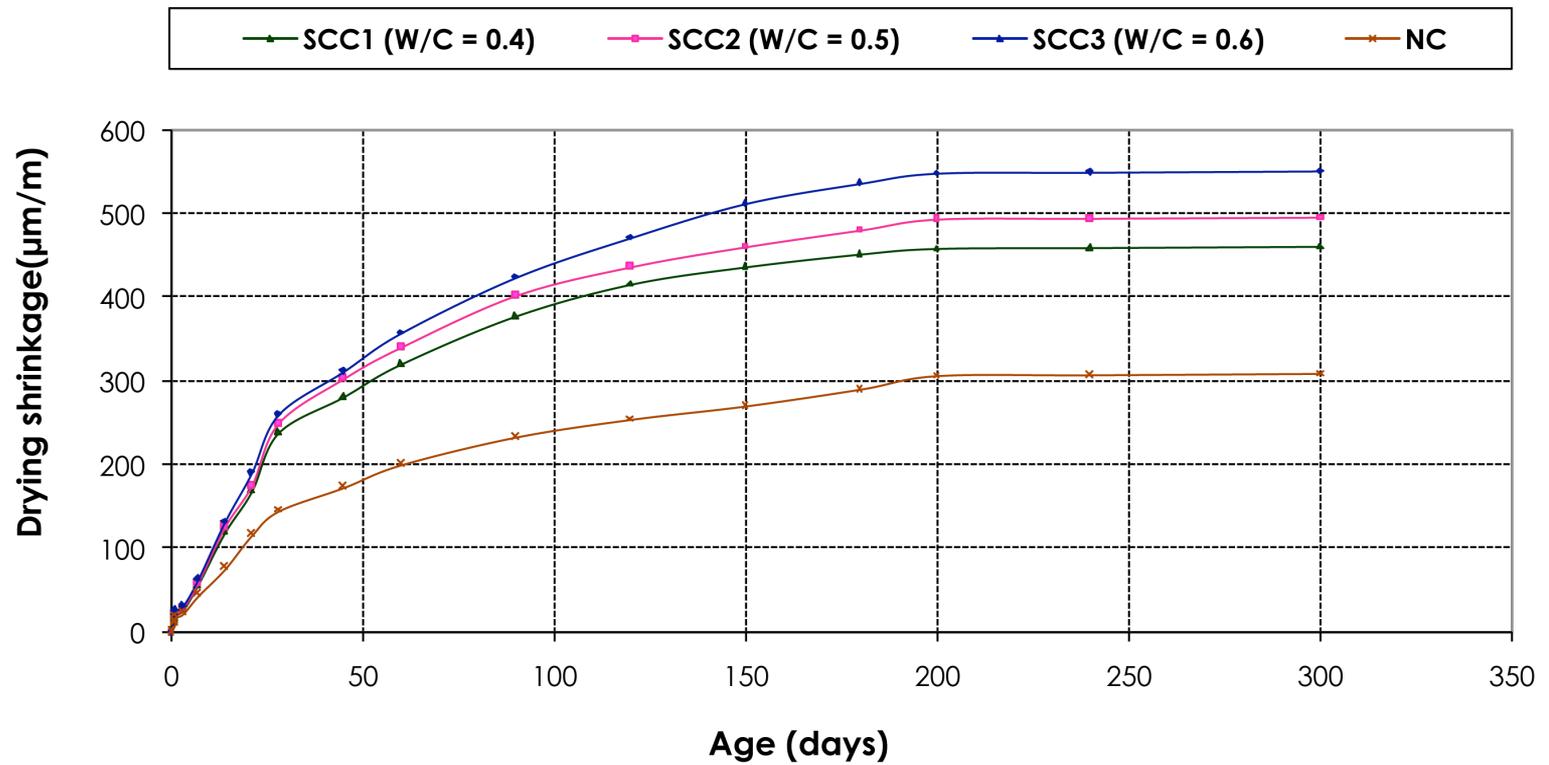
Figure 9. W/C Effect on the Desiccation Shrinkage of the SCC

before approximately 180 days. The shrinkage of the SCC1 mix is lower than that of the other two mixes (i.e., SCC2 and SCC3); in six months, the reduction in desiccation shrinkage is 29µm/m for mix SCC2 and 85 µm/m for mix SCC3. This difference corresponds to reductions of 6% and 16% for SCC2 and SCC3, respectively. Such reductions are nonetheless appreciable.

It can be observed that the kinetics of SCC are entirely similar to those of NC: 5 to 7% of the final deformation, measured at 300 days, is reached after three days, whereas around 50% of the final deformation is reached at 28 days.

The amplitude of deformation of SCC is 1.49 to 1.78 times the deformation in NC. In respect to the amplitude of deformation, Chopin et al (2003) found a difference of only 20%, whereas Rols et al. (1997) showed that the desiccation shrinkage of SCC is 50% higher as compared to a normal concrete. Tanaka et al. (1993), however, does not indicate a significant difference in desiccation shrinkage when comparing SCC and NC. This suggests that results from previous studies do not converge towards the same amplitudes.

Beyond the first days of curing and hardening of the concrete, the two types of concrete demonstrate different behaviour. Desiccation shrinkage quickly stabilises for NCs, whereas it continues to progress for SCC until stabilisation begins at about 200 days.

Typically, three phases can be identified with respect to the loss of mass from shrinkage curves (see Figure 10):

Phase I: The loss of mass generates negligible shrinkage. This phase, occurring over a short period of time, is due to water evaporation from the broadest pores at the periphery of the test specimen (Khelidj et al., 2001). Granger (1995) showed, on the contrary, that there is a cracking of the skin due to the intense moisture gradient of between the surface and centre of the concrete. This cracking decreases the amplitude of the measured shrinkage considerably.

Phase 2: The shrinkage evolves linearly with the loss of mass. The drying shrinkage is the response of the skeleton to the departure of water; it depends on the mechanical properties of the concrete and also on the transfer properties. The gradient of moisture and the shrinkage become uniform in the test specimen section. Its shortening tends to close the cracks that occurred during the first phase.

It is noted that the loss of mass at the beginning of the second phase does not depend on the concrete's nature, but rather, it depends on the concrete's strength. An important difference in the upward trend shown in Figure 10, indicates a difference in drying behaviour.
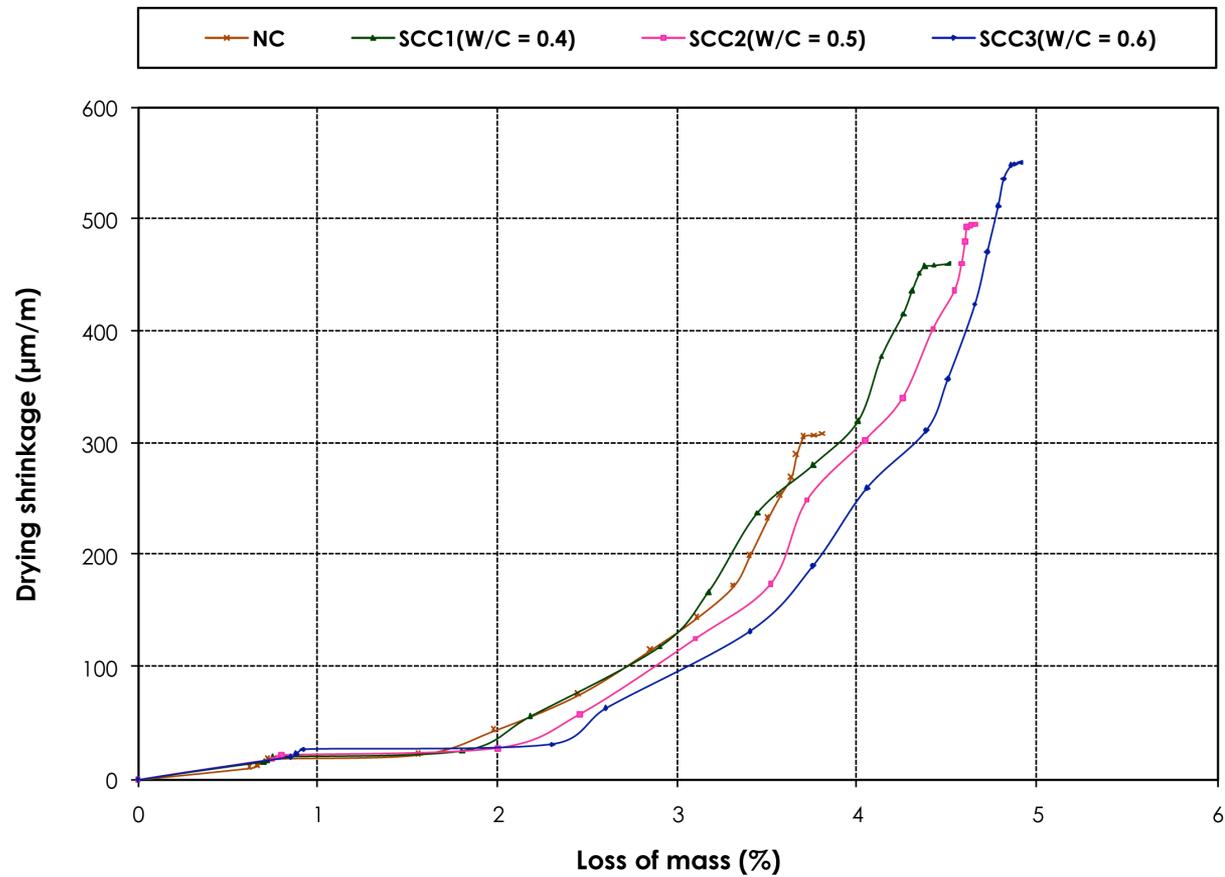
Figure 10. Drying Shrinkage as a Function of Loss of Mass

Phase 3: The loss of mass does not generate any shrinkage. Granger (1995) explains this phenomenon by stating that the cracks at the periphery cannot be completely closed because of the frictions of the edges of the cracks against each other. It is difficult to interpret the phenomenon completely because the shrinkage of calculated drying is not the shrinkage of real drying.

Desiccation shrinkage increases with W/C. It should be added that there is a linear relationship between the desiccation shrinkage and the rate of drying (Figure 10), this last being taken as the ratio of the loss of mass to the initial water mass.

The variation of W/C from 0.5 to 0.6 changes the experimental behaviour of the SCC with respect to the drying shrinkage, but in the field [0.4–0.5], W/C does not significantly modify the mechanism of the SCC shrinkage.

The study of drying does not reveal any difference between SCC and NC with the same W/C ratio.

Shrinkage and segregation

The interpretation of measurements using the mix formulation proves to be difficult. This is why, apart from the parameters of formulation, it is interesting to use concrete homogeneity to analyse shrinkage.

Table 5 shows that SCC3 (W/C = 0.6), which has a considerably higher drying shrinkage than the two other materials, is also the one that presents a higher laitance in the sieve test of stability, within the critical range (15% to 30%) according to AFGC'S (2000). This concrete has a significant drying shrinkage in the short term. A concrete with a homogeneity defect would have reduced transfer properties.

Mineralogical characterisation under Scanning Electron Microscope (SEM)

The microstructural study focused on the hydrates HSC, $Ca(OH)_2$ and ettringite formation. Also of interest was the paste-aggregate contact (mainly the influence of the variation of the parameters on the contact aureole phenomenon).

Table 5. Percentage of Laitance Obtained in the Sieve Stability Test and Drying Shrinkage of the SCC

	SCC1 (W/C = 0.4)	SCC2 (W/C = 0.5)	SCC3 (W/C = 0.6)
Sieve laitance (%)	7.45	7.68	15.98
Drying shrinkage at 90 days (µm/m)	377	402	424

Effect of W/C ratio

The SCC with a high W/C ratio (0.6) contains more water, which results in well-formed crystals. In Figure 11, it can be seen that drying results in an increase of porosity and a decrease of strength due to drying. The structure is notably less dense than that of the SCC1 sample shown in Figure 12 (note that Figure 12 shows twice the area of Figure 11).

The microstructure of the SCC1 (W/C = 0.4) sample appears extremely dense and homogeneous, presenting a cementing matrix rich in HSC and ettringite (see Figure 13), with visible portlandite formation and better developed calcite than that of the SCC2 (W/C = 0.5) (Figure 14) and SCC3 (W/C = 0.6) samples, justifying its mechanical performances in terms of compressive and tensile strengths.

Effect of porosity

The exchange of moisture between a concrete and the external medium is related to the porous structure. If the concrete porosity is known, it enables consideration of the relative differences of the SCC microstructure formulation, which are likely to explain the results obtained for the mixture proportion-dependent shrinkage of this type of concrete. Accordingly, the porosity of the various mixes of the SCC was characterised (at approximately 300 days, the last measurement age of shrinkage). Measurements were carried out at the Laboratory of Civil
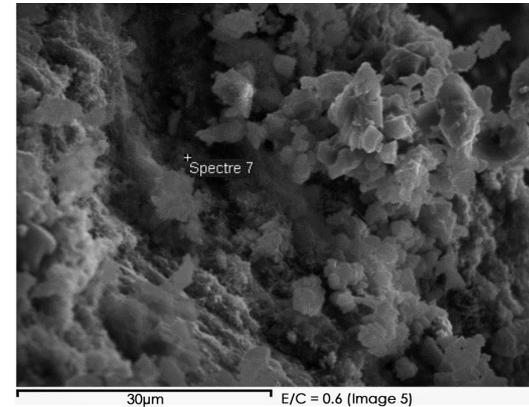

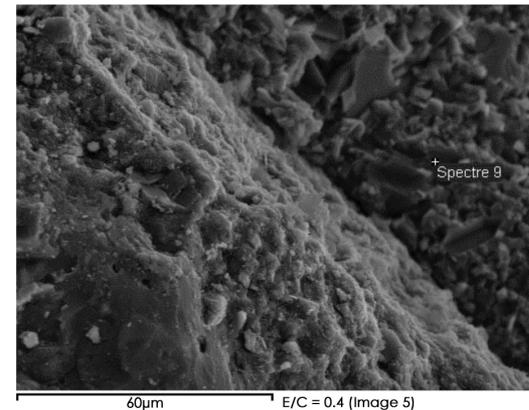Figure 11. Loose Structure of SCC3 (W/C = 0.4)

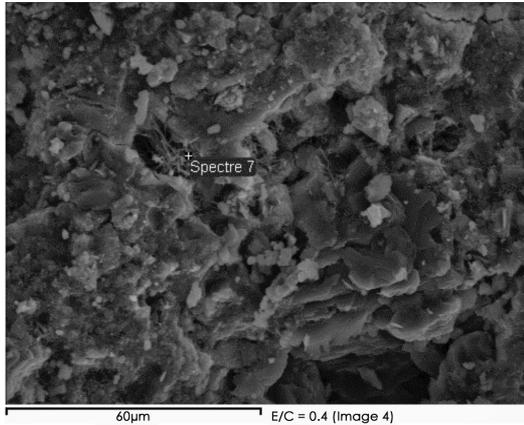Figure 12. Dense Structure of SCC1 (W/C = 0.4)

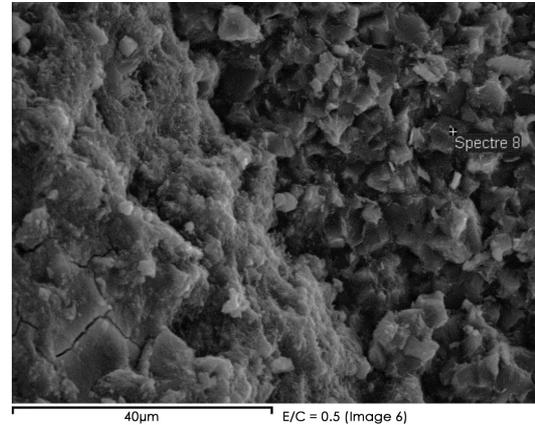Figure 13. Cement Matrix Rich with CSH and Ettringite of SCC1 (W/C = 0.4)

Figure 14. CSH and Ettringite Less Developed in SCC2 (W/C = 0.5)

Engineering of La Rochelle (France) using an "Autopore III" mercury porosimeter from Micrometrics. The range of measurement was from 200µm to 3nm.

Effect of W/C ratio

Table 6 gives the proportion of the mesopores (pores diameter <1 µm) and the macropores (pores diameter >1 µm) estimated from the experimental results of the mercury porosimeter for each W/C ratio.

Figure 15 shows the evolution of the cumulated porosity with the pore diameter (curves are averaged over two tests). On the curves, two distinct slopes are observed. Their intersection characterises a threshold of porosity, which decreases towards the narrow pores.

In addition, a significant increase in the number of small pores (mesopores) of the SCC with W/C = 0.4 can be noted in comparison to the SCC with W/C = 0.5 and W/C = 0.6. However, the SCC with W/C = 0.6 has both broader pores and higher numbers of pores than the two other SCCs. The difference between the SCC (W/C

Table 6. Mesopores and Macropores Rates for Different W/C Ratios

W/C	Mesopores rate (%)	Macropores rate (%)
0.4	15.03	1.28
0.5	11.12	1.62
0.6	9.81	3.00

= 0.4) and the SCC (W/C = 0.5) curves tends to decrease with increasing pore diameter; in the macropore region of the plot, the curves are almost superimposed.

Figure 16 shows the porosity distribution as function of the pore diameter and W/C of the SCC. This representation has the advantage of revealing the dominant pore size. For each SCC, there is one peak that corresponds to the abundance of capillary pores. The device used does not make it possible to go below a pore size of 50 A°. On the graphs, the existence of two families of pores can be seen. One small family with a peak located towards 50µm for the SCC with W/C = 0.6 and disappear for the other SCCs (W/C = 0.4 and 0.5).

The other family of pores is more important; its peak is located between 0.05 and 0.1µm for all SCCs. This peak corresponds to the family of pure cement paste pores. These pores are an intrinsic characteristic of the porous distribution in the cement pastes.

The SCC with W/C = 0.4 shows a maximum mesopore content of 15.03%, as compared to the other SCCs. This corresponds to the appearance of ettringite, as observed, using the SEM, in the SCC with W/C = 0.4 at 300 days. Indeed, this hydrate does not have sufficient space to properly hydrate, given the high compactness of the mix that exerts a crystalline "push", in turn causing structural swelling, which creates additional capillary porosity (Chaouch, 1996).

These observations suggest that, in the case of endogenous shrinkage, the self-desiccation of an SCC mix with W/C = 0.4 generated a greater proportion of capillary pores (size < 0.1µm), leading to a higher degree of endogenous shrinkage for that mix as compared to SCC mixes having W/C of 0.5 or 0.6. Experimental results do indeed reflect this observation.

With regard to the desiccation shrinkage, the pores of interest are the hydrate pores smaller than the capillary pores, specifically those smaller than 0.01 µm. However, for this family of pores, it can be noted that there is a significant difference between the SCCs. It seems paradoxical that the porosity of the SCC (W/C = 0.4) is higher than the SCC with W/C = 0.5 and W/C = 0.6 although its drying is reduced. The cause could be a micro-cracking of the samples as they come from the splitting test.
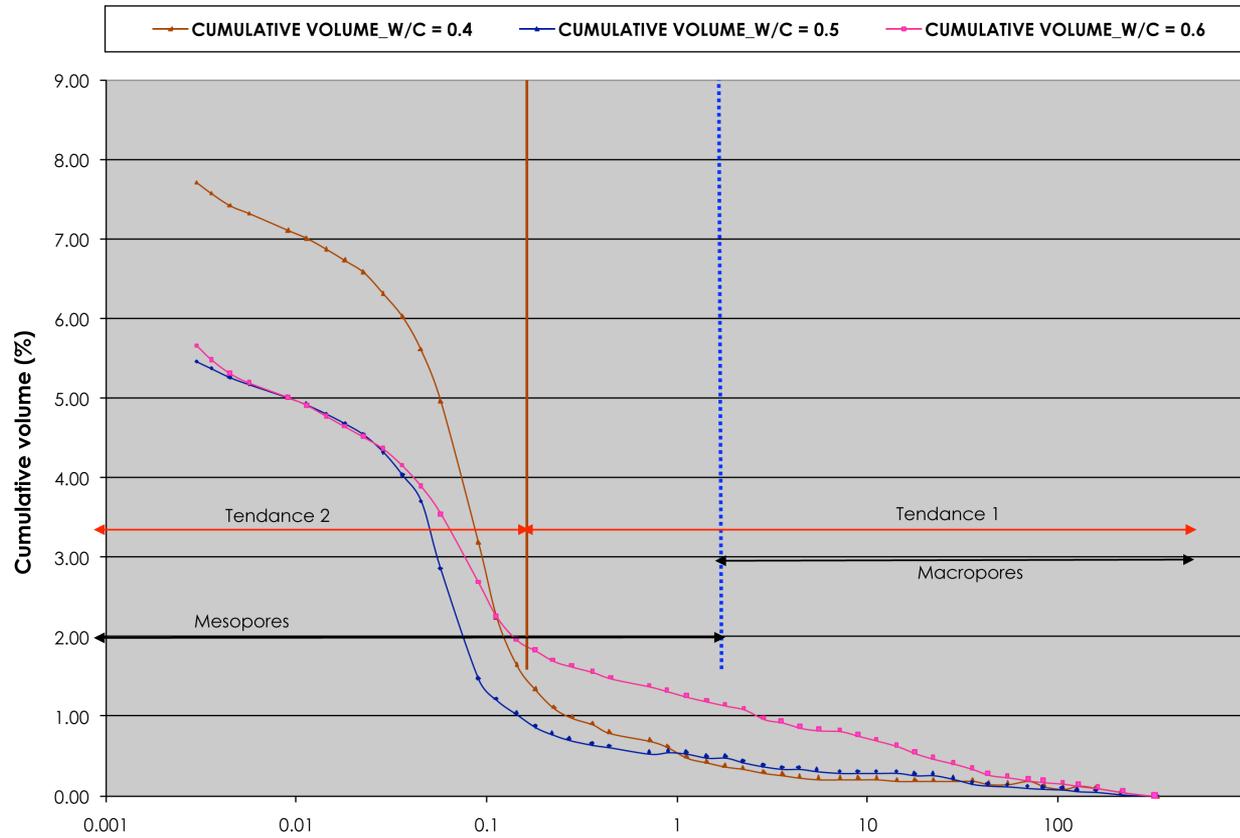
Figure 15. Mercury Porosimetry: Cumulative Volume of Hg Introduced into the Sample as Function of Pore Diameter for Different W/C Ratios
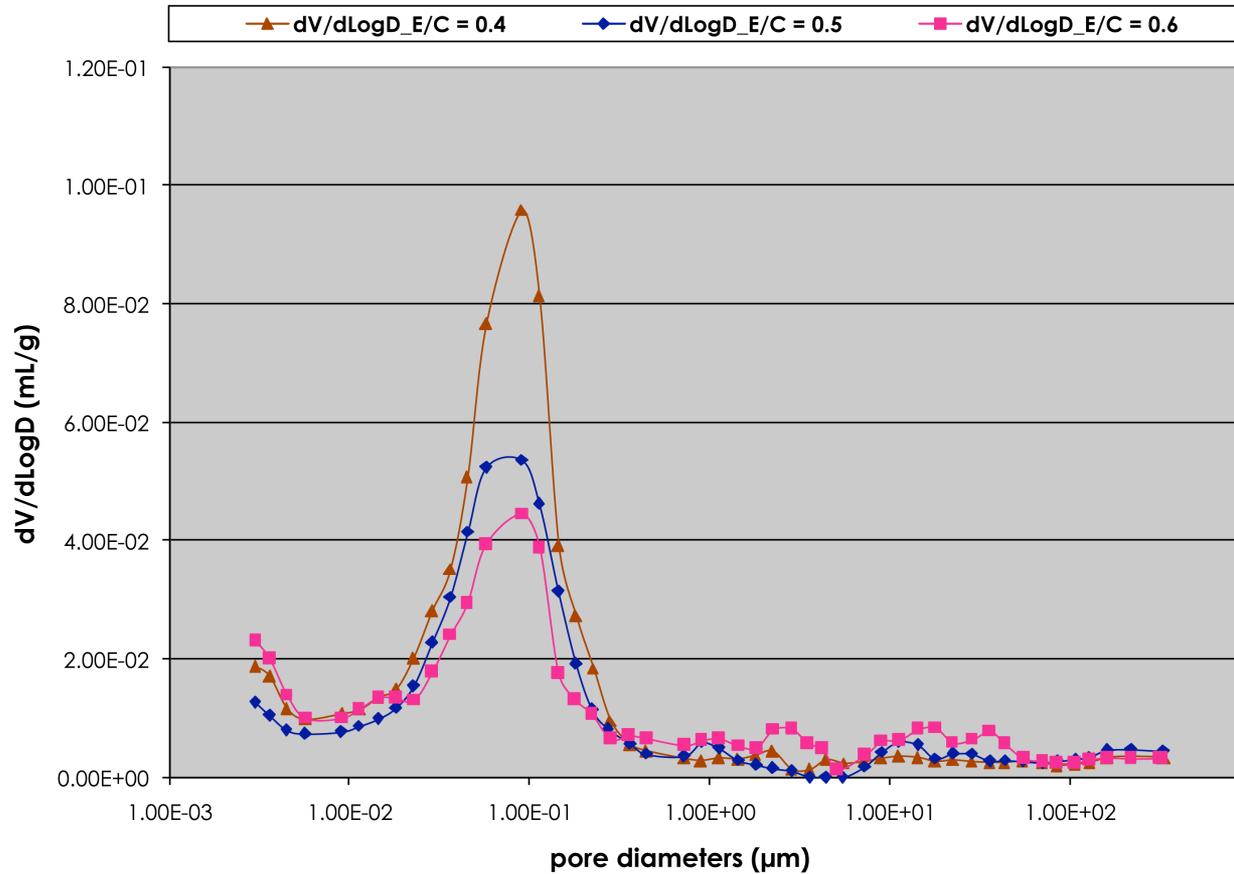
Figure 16. Mercury Porosimetry: Differential Volume of Hg Introduced into the Sample as Function of Pore Diameter for Different W/C Ratios

The minimum rate noted for pores larger than 1 µm in the SCC with W/C = 0.4 (1.28%) seems to explain why it develops strength faster than the SCCs with W/C = 0.5 and W/C = 0.6.

CONCLUSIONS

Producing SCCs containing local Algerian materials having the same characteristics as those typically obtained in an international context is straightforward. However, it is advisable to properly proportion the mix and to consider those parameters that most influence the workability and long-term performance, in particular the W/C ratio.

In the fresh state, mixes with W/C = 0.4 and W/C = 0.5 have positively influenced both the stability of the SCC and its resistance to segregation. Poor stability with respect to flow can be expected for SCC mixes having W/C = 0.6.

A reduction in W/C ratio in the SCC significantly influences the compressive strength. A SCC mix with W/C = 0.4 provides the best mechanical performance in terms of strength.

The W/C ratio does not affect the total shrinkage of the SCC. Note that the reduction in W/C ratio causes a marked effect on of the self-desiccation shrinkage, whereby the endogenous shrinkage of the SCC is higher. The formulation of the SCC corresponding to W/C = 0.5, F/C = 25% shows a very compact and dense structure. For other compositions (i.e., SCC1, SCC3), the paste appears very loose. The capillary pores are more numerous in the SCC having a W/C = 0.4, and the self-desiccation that occurs inside these pores results in a higher shrinkage for this SCC than for the SCC with W/C = 0.5 and W/C = 0.6.

The proportion of pore sizes of hydrates (<0.01µm) of SCC mixes with W/C = 0.4 is significantly different than the SCC mixes with W/C = 0.5 and W/C = 0.6, indicating a higher degree of endogenous shrinkage for the SCC having W/C = 0.4 as compared to the SCC with W/C = 0.5 or W/C = 0.6.

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