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Research Paper

Durability of self-compacting concretes made with the natural pozzolan and siliceous fines

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ABSTRACT

The effect of natural pozzolan and local waste siliceous fines on the durability of SCC was studied in this paper. Three self-compacting concretes were made with the following three additions, namely limestone fillers (SCC LF), pozzolanic fillers (SCC NP) and siliceous fillers (SCC SF). Durability tests, such as the porosity accessible to water, capillarity, carbonation, permeability to oxygen gas and diffusion of chloride ions, were carried out on these concretes in order to study the influence of these fillers on the transfer properties and durability of SCCs. The results obtained indicate that the SCC LF and SCC NP generally have the same transfer properties; these properties are significantly influenced by porosity and carbonation. In addition, the capillarity is nearly similar for all three SCCs. Moreover, it is worth noting that SCC NP gives permeability and diffusion coefficients of chloride ions slightly lower in comparison with those of the other SCCs. These finding suggest that the incorporation of Algerian natural fines and industrial waste as mineral additions into the SCC may have a positive environmental impact and can promote the development of local materials that are available in large quantities and whose production cost is low.

1 Introduction

This study is part of the policy of promoting and valorising natural and industrial materials in Algeria. Self-compacting concretes (SCCs) are easy to use, without vibration; this significantly reduces noise nuisance on site or in precast plants. SCCs exhibit excellent pumping characteristics. As they are very fluid, they can be used to cover areas that are difficult to access or have a complex geometry with heavily reinforced concrete. SCCs are also very useful for repairing damaged

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structures. Moreover, when these fluid concretes are properly formulated and implemented, they can give concrete an attractive surface finish. Because of their technical advantages over vibrated concretes (VCs) and the economy they can bring, SCCs are very fast growing materials around the world [1, 2]. This new generation of concretes, which is characterized by large amounts of mineral additions and also an important volume of paste, may prove to be a relevant industrial application for local mineral fines, both economically and ecologically.

The natural pozzolan (NP) that comes from the region of Beni-Saf, a western town in Algeria, which has huge deposits of pozzolan, is currently used in the manufacturing of the cement compound (CPJ-CEMII). Natural pozzolan is not fully exploited in our country because it is used only in the cement industry, with a percentage of replacement of cement that does not exceed 10%, according to the Algerian standard NA 442 [3]. Using cement combined with mineral additions is an approach that aims to reduce the amount of cement to be used; this certainly induces a substantial reduction in carbon dioxide emissions in the atmosphere [4, 5].

The costs associated with the elimination of wastes when washing silica sand, brought from the quarry of the small western town of Sig, represent significant expenditures for glass manufacturing. Today, better waste management is a great economic and ecological challenge in our country as well as in the whole world. In this study, an attempt is made to use natural pozzolan and by-products wastes, such as siliceous fines, as mineral additions in the formulation of self-compacting concretes (SCCs). The development of these additions for the production of concrete, such as SCC, offers great opportunities in valorising and recycling these fines [6, 7]. It is well known that over 330 000 tons of these fines are produced each year in Algeria and more than two million tons are still awaiting a solution to their disposal problem [8]. So far, studies that deal with the influence of natural pozzolan and siliceous fillers on the durability of SCCs, especially the transfer properties, are not numerous compared to SCCs formulated with limestone fillers, fly ash or silica fume [9-13].

The approaches used in these studies were based on the comparison of durability indicators of SCCs with those of vibrated concretes (VCs). This research deals with the possibility of using natural resources and industrial by-products, such as natural pozzolan and siliceous fines that are available in Algeria, for manufacturing self-compacting concretes. A third SCC was also formulated with limestone fillers, just for the sake of comparison. The present study has multiple objectives. The first one is the ability to produce SCCs with natural pozzolan and siliceous fines, in the fresh state, according to the European recommendations [14]. The instantaneous mechanical behaviour (compressive strength) was also studied. The second objective is to study the durability of the two SCCs made with natural pozzolan and siliceous fines, which are then compared with the SCCs that were made with previously prepared limestone fillers. Next, general durability indicators were also studied in order to address the sustainability issue of concretes SCC NP and SCC SF, and compare them with other SCCs found in the literature. In the end, a comparative analysis of the results was carried out to help identify the impact of various types of mineral additions on the durability of concrete.

2 Materials and methods

2.1 Materials

Cement CEM I 52.5 N was used in all formulations. It has an average compressive strength of 63 MPa, a Blaine surface of 3800 cm^2/g and a density of 3130 kg/m^3. The limestone filler used in the formulation of the concrete SCC LF is the BETOCARB P2, manufactured in France, in accordance with the French standard [15]. The pozzolan particles used in this study are finely ground pozzolans from Bou Hamidi, in the western town of Beni-Saf, in Algeria. Wastes of siliceous fillers were obtained from the silica sand washing plant at ENAVA, in the western city of Oran. The chemical compositions and physical characteristics of cement and additions are listed in Table 1.

Note that limestone fillers are mainly composed of calcite, and the principal components of natural pozzolan are silica (56.25%) and alumina (16.98%). All the elements used are in the typical range for natural pozzolans. However, the content of SiO_2, which is essentially responsible for the pozzolanic activity, is close to the lower limit. According to [16], pozzolans are little rocks composed of volcanic glass and crystallized minerals, mainly quartz, feldspars and pyroxenes. Siliceous fillers are essentially composed of silica (95.82%). Sand and aggregates of different granular classes were used in our formulations. The physical characteristics of fillers and aggregates are reported in Table 2. Two types of adjuvant were used, namely a Cimfluid Adagio 2019 superplasticizer and a Collaxim L10 viscosity agent.

Table 1 - Chemical characteristics of cement and mineral additions

Chemical composition	Cement (%)	LF (%)	NP (%)	SF (%)
CaO	63.93	55.8	9.83	1.86
SiO_2	20.40	0.9	56.25	95.82
Al_2O_3	4.53	0.5	16.98	0.45
SO_3	3.2	-	-	-
Fe_2O_3	2.31	0.2	8.57	0.39
MgO	2.39	0.2	1.81	0.02
Na_2O	0.18	0.2	-	0.03
K_2O	0.87	-	-	-
P.A.F	0.94	2.2	6.54	-
TiO_2	-	-	-	0.08
LIO	0.16	-	-	-

LF: limestone fillers, NP: natural pozzolan, SF: siliceous fillers

Table 2 - Physical characteristics of aggregates and fillers

Physical characteristics		Density (kg/m^3)	specific surface area (Blaine) (cm^2/g)	Fineness modulus
LF		2710	4060	/
NP		2750	5000	/
SF		2660	4100	/
Fine sand (D ≤ 75µm)		3000	115	/
Sand Rolled	0/0.315	2630	/	0.58
	0.315/1	2630	/	1.22
	1/4	2600	/	2.45
Coarse Aggregate	4/8	2610	/	/
	8/12	2620	/	/

2.2 Formulations

Formulations of the self-compacting concretes, investigated in this study, are based on that of an SCC of strength class 40 MPa, containing limestone filler, and studied by Assié using an empirical method [10]. Three SCC types were considered, i.e.SCC LF, SCC NP, and SCC SF. These concretes were made with the same compositions, but with different fillers. The three different kinds of mineral additions, i.e. Algerian siliceous fines (FS), Algerian natural pozzolan (NP), and French limestone filler (LF), were incorporated with the same proportions (140 kg/m3).

The different formulations are summarized in Table 3. Only the spreading test was carried out at the end of mixing. This test was performed in order to characterize the behaviour of fresh concrete. All the results obtained are presented in Table 4. All fresh concretes could be spread in accordance with standard [14]. The absence of laitance was also checked for hardened concrete. Cylindrical specimens (11x22 cm) were made and stored in a room at controlled temperature and humidity (T = 20 °C, RH = 95%). The test specimens, for durability testing, were conserved for 9 months, the required period of time for concrete to mature and develop the maximum possible pozzolanic reactions.

Table 3 - Formulations of different SCCs and mechanical results (kg/m³).

Components (kg/m³)		SCC LF	SCC NP	SCC SF
Cement CEM I 52.5N		350	350	350
Minerals additions	Limestone	140	/	/
	Pozzolana	/	140	/
	siliceous	/	/	140
Fine sand		32.8	32.8	32.8
Sand (0/0.315)		227	227	227
Sand (0.315/1)		304	304	304
Sand (1/4)		323	323	323
Coarseaggregate (4/8)		204	204	204
Coarseaggregate (8/12)		587	587	587
Adagio 2019		10	10	10
Collaxim L10		0.5	0.5	0.5
Total water		209	209	209
Effective water		196	196	196

3 Testing procedures

The different tests performed on all three SCC formulations, namely SCC LF, SCC NP and SCC SF, are mechanical test to determine the compressive strength at 7 and 28 days, in accordance with standard [17],porosity accessible to water, capillarity for a period of 24 hours, carbonation with CO2 gas for 56 days, the permeability to oxygen gas and diffusion of chloride ions for a testing period of 12 hours.

3.1 Porosity accessible to water

The porosity accessible to water was determined by hydrostatic weighing, after vacuum liquid saturation of the sample of dimensions (Ødiameter = 22 cm x Hthickness = 5 cm) in order to determine the mass of the sample in water (M_{water}); the sample was then weighed in free air to get its wet mass (Mair). The sample was then dried at a temperature of 80 °C. The mass was monitored during several days until it became constant. The difference between the two weighings should be equal to 0.05 %, and this would give the mass of the dry sample (Mdry). The following expression is used to calculate the porosity:

$$\varepsilon = \frac{M_{air} - M_{day}}{M_{air} - M_{water}} \tag{1}$$

3.2 Capillarity

The specimens underwent the following reconditioning:

They were first placed in tight plastic bags and were then put back in the ventilated oven, at a temperature of 80 °C for 10 days, to find the water balance in the sample. The specimens were then taken out of the oven and stored at a temperature of 20 °C in desiccators for a periodof12hours, to have a normal cooling temperature.

The capillarity test was carried out on the dry surface of the cylindrical concrete specimen so dimensions (Ø=22 x H=5 cm). In order to evaluate the water absorption coefficient of concrete, the water flow was controlled at different maturities (0.25, 0.5, 1, 2, 4, 8, 24 hours), and the sample was then weighed.

The capillary coefficient is defined by the following relationship:

$$C_a = \frac{M_x - M_0}{A} \tag{2}$$

With:

M_x: mass of the specimen at a given maturity (kg).

M_0: initial mass of the specimen (kg).

A: section of the test tube (m^2).

Ca: values of capillary absorption coefficient at 1, 4, 8, and 24 hours.

3.3 Permeability

The oxygen permeability test was conducted using a Cembureau permeameter, in accordance with standard AFREM [18]. The flow of oxygen through dried cylindrical concrete samples of dimensions (Ø = 22 x H = 5 cm) was measured, with a constant pressure. A pressure between 2 and 4 bars was applied to evaluate the apparent permeability, using the Klinkenberg approach.

3.4 Carbonation Depth

The accelerated carbonation test was performed on samples of concrete parallelepipeds of dimensions (7 x 7 x 28 cm), stored in specific environmental conditions, according to standard AFREM [18], to promote carbonation. The sample had to undergo a curing to reach 65% of relative humidity. Inside the carbonation chamber, the carbon dioxide level was maintained at 50% ± 1 and the relative humidity was about 65.5%. The carbonation depths were measured at each maturity (7, 14, 21, 28, 56 days). The idea was to split the specimen. The surfaces were wetted and a phenolphthalein solution was applied in order to be able to measure the thickness the carbonated concrete layers. This solution uncovers the interface separating the non-carbonated area from the carbonated area. The measurements correspond to the distances (in mm) between the outer surface of concrete and the colour front.

3.5 Diffusion of chloride ions

The diffusion coefficient of chloride ions in the sample was calculated using the Nord test [19]. A quantity of 10 g of sodium chloride (NaCl) per liter of distilled water was used as the etching solution. A quantity of 12 g of sodium hydroxide (NaOH) per liter of distilled water was used as the support solution, and finally silver nitrate (AgNO3) as the spraying solution. The samples were dried in a ventilated oven, at a temperature of 105 °C, for several days until constant weight was obtained. Then they were cut into 5-cm-thick slices and saturated with lime. The samples were placed in cells filled with the etching solution. The equipment used is a current generator capable of producing an electric field (30 V voltages) and a thermocouple fitted with a thermometer to measure the temperatures during the entire test. A stainless metal grid was used as the anode and cathode.

The non-steady-state diffusion coefficient can be calculated using the following expression (3):

$$Dnssm = \frac{0.0239(273+T)L}{(U-2)\cdot t}\left(Xd - 0.02389\sqrt{\frac{(273+T)LXd}{U-2}}\right) \tag{3}$$

Where:

D_{nssm}: chloride migration coefficient in non-stationary regime ($10^{-12}m^2/s$).
U: absolute value of applied voltage (V).
T: average temperatures of the solution on the side of the anode (°C).
L: thickness of the concrete sample (mm).
Xd: average depth of chloride diffusion in the sample after the test (mm).
t: duration of the test (hours).

4 Results

4.1 Mechanical properties

The results of the tests are presented in Table 4. The average spread values of fresh concrete are given. The average strengths, as well as the elastic modulus of the three SCC samples of hardened concrete are also presented at 7 and 28 days. The results of durability indicators, such as porosity accessible to water, capillarity coefficient, carbonation depth, permeability and diffusion of chloride ions are also presented in the same table.

Table 4 -Results of tests on fresh and hardened concrete.

Properties		SCC LF	SCC NP	SCC SF
Slump flow (cm)		67	68	65
Compressive strength (MPa)	7d	38.3±1.26	46.8±0.14	46.8±0.27
	28d	44.3±3.5	60.6±2.75	50.8±1.2
Durability test				
Water porosity (%)		15.3±0.3	15.6±0.7	14.1±0.3
Capillary absorption coefficient for 24h (kg/m^2)		3.79±1.3	3.72±0.9	3.27±1.2
Depth of carbonation at 28 days (mm)		4.25±0.9	5.25±0.5	8.00±1.8
Intrinsic oxygen permeability (10^{-16} m^2)		1.32±0.4	0.88±0.2	1.07±0.1
Diffusion coefficient (10^{-12} m ^{2}/s)		29±1.14	22±1.7	28±2.5

The spreading of the three concretes was found to lie between 65 and 68 cm. The results obtained were found to be in good agreement with the recommendations of AFGC [20]. The differences between these values are relatively low. It turned out that the type of mineral additions does not have any effect on the behaviour of concrete in the fresh state; that could be due to the shape of their particles or to the amount of water used.

The compressive strengths of concretes, with siliceous and natural pozzolans, reached values 8 MPa greater than that of SCC LF at 7 days. At 28 days, SCC NP showed the highest compressive strength, 60.6 MPa; it is 9.8 and 16.3 MPa greater than those of SCC SF and SCC LF, respectively. Pozzolan uses more portlandite to form more secondary C-S-H. In addition to fineness, the morphology of the particles is another influential parameter on the intensity of the pozzolanic activity [21, 22].

Mnahoncakova et al. [23] found that pozzolana has an effect on the microstructure of concrete; they also revealed that porosity, although generally high, is finer in SCCs containing reactive fly ash than in SCCs containing limestone fillers. In the case of siliceous fines, the high silica content helps to reduce the Ca/Si ratio but causes the amount of C-S-Hs formed to decrease. Natural pozzolans promote the formation of more resistant secondary C-S-Hs [24]. Based on this, the hypothesis of a less porous and especially more resistant paste-aggregate interface, through the formation of a higher quantity of secondary C-S-Hs, could explain the higher compressive strength of SCC NP [25].

4.2 Durability

Porosity is fundamental in all durability tests because it gives us information about the amount of voids existing inside the structure of concrete. The transfer of aggressive chemicals occurs through the porous network. Therefore, porosity can be considered as an important durability indicator [26]. Based on the results given in Table 4, it becomes clear that SCC NP and SCC LF have identical porosities. However, SCC SF exhibits a somewhat lower porosity.

The capillarity test is based on the absorption of water in dry concrete through the large interconnected pores. This test gives a rough idea about the surface pores of concrete.

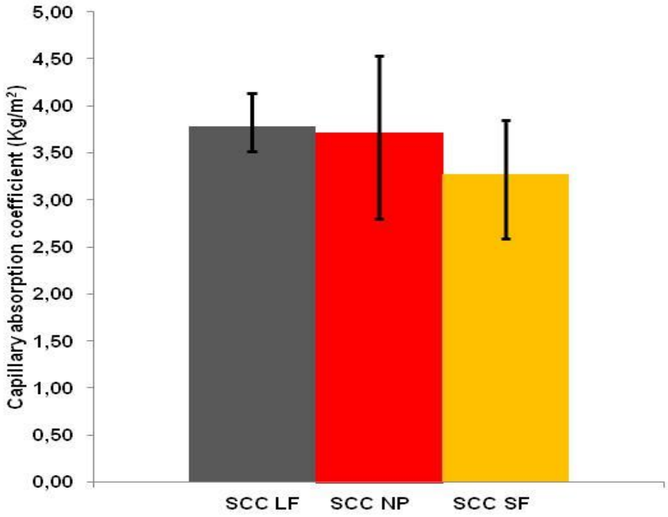


Fig. 1-Capillary absorption coefficient of SCC

SCC LF and SCC NP have the same capillary coefficient but that of SCC SF is smaller; this is consistent with the findings of the porosity test. Comparing the capillary results with those of porosity allows noting that porosity is high and capillarity is low. Therefore, SCC LF and SCC NP have, presumably, a pore network that is finer, denser and more complex than that of SCC SF. Capillarity can be reduced, in the long run, as the pozzolanic reaction develops over time, which is in good agreement with the increasing compressive strength. Moreover, permeability of oxygen gas depends on the inlet pressure and the porous network. It is noted, from Figure 2, that there is no significant difference between SCC LF and SCC SF; however SCC NP has a lower permeability in comparison with the other SCCs. This confirms the results obtained and the assumptions made regarding porosity and capillarity. In general, natural pozzolana helps to reduce the gas permeability of SCCs. This is primarily due to their denser microstructure and to the pozzolanic reaction which was more important in the concrete samples, after 9 months of storage in the wet room.

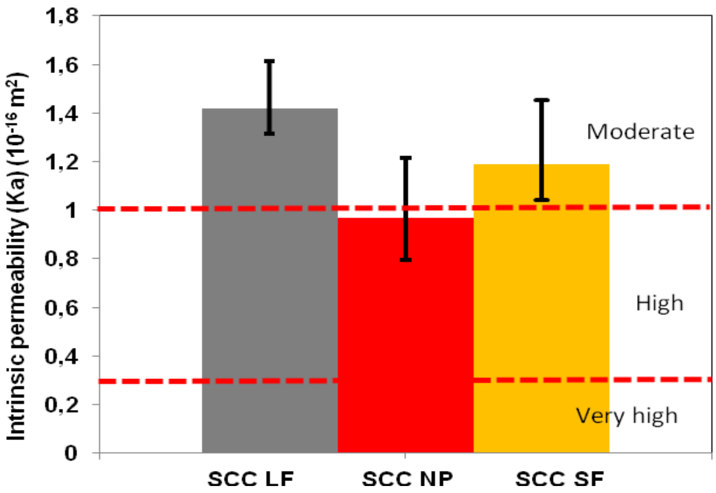


Fig. 2 - Results of gaz permeability.

Fig. 3 illustrates the evolution of the carbonation depth of the different self-compacting concretes (SCCs) as a function of the square root of time. It can be seen from Figure 3 that carbonation is similar for all three SCCs before 28 days. However beyond 28 days, carbonation of SCC LF is lower than that of the other SCCs.

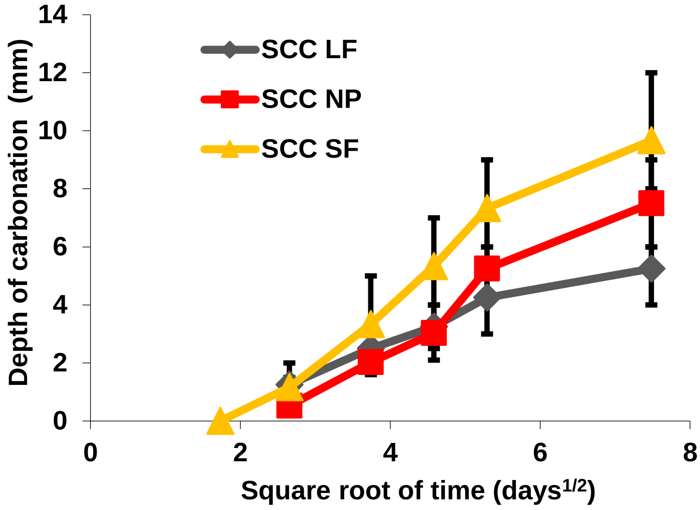


Fig. 3 - Evolution of carbonation depth over time, for the three SCCs, beyond 28 days

The carbonation of SCC NP is significantly lower than that of SCC LF during the first three weeks; beyond that, the percentage of increase in carbonation for SCC LF and SCC SF is 29%, while it is only 19% for SCC NP. Overall, a high percentage of additions into concrete increase the volume of the mix by 40% for SCCs. According to Table 4, this increase gives good mechanical strengths to SCCs. This shows that pozzolan makes the structure of the matrix denser and minimizes the pore size to give a fine porosity [27, 28]. It is easy to note, from Fig. 4, that the SCC NP has an average chloride diffusion coefficient of about 22.10 e-12 m^2/s, which is lower than those of SCC LF and SCC SF. These two SCCs have almost the same diffusion coefficient values which are equal to 29.10 e-12 m^2/s and 31.10 e -12 m^2/s, respectively.

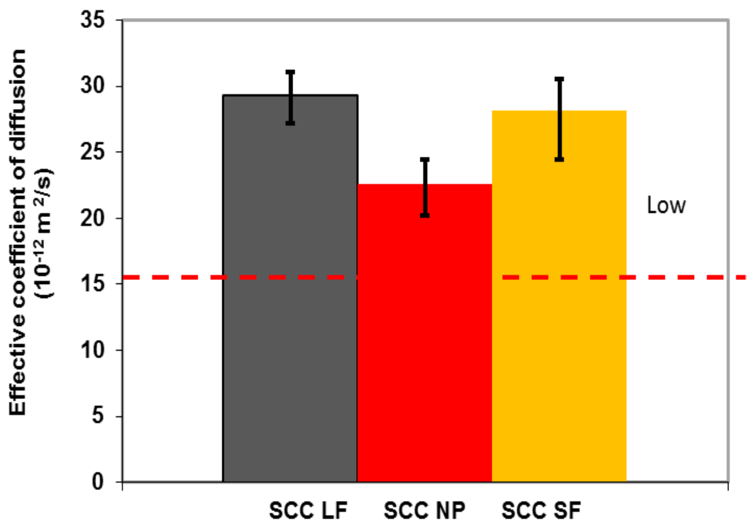


Fig. 4 - Non-steady-state migration coefficient of SCC

The SCC NP has an average migration coefficient 24% lower than that of SCC LF, while SCC SF has an average migration coefficient that is 6% higher than that of SCC LF. The addition of pozzolan gives it a higher diffusion coefficient in comparison with the other concretes. This result is in good agreement with those reported previously by other researchers [9, 28-32] who applied the same method [19] to study the penetration of chloride ions in SCCs.

4.3 Durability indicators (according to the Civil Works French Association (AFGC))

The results of transport properties (permeability and diffusion) given in Table 4 can be analyzed according to the AFGC recommendations [26, 33] in order to assess the durability of concrete subjected to corrosion. According to these recommendations, there are five durability classes, namely very low, low, medium, high and very high. Specific values are given for each durability indicator in each class. It is worth indicating that the overall analysis allows getting an idea about the potential lifetime of the different SCCs.

Table 5–Durability indicators

Compressive strength at 28 days (MPa)	44.3 ± 3.5	60.6 ± 2.75	50.8 ± 1.2
Water porosity (%)	15.3 ± 0.3	15.6 ± 0.7	14.1 ± 0.3
Potential durability [33]	Low	Low	Low
Apparent oxygen permeability (10^{-16} m^2)	1.32 ± 0.4	0.88 ± 0.2	1.07 ± 0.1
Potential durability [33]	average	high	average
Diffusion coefficient (10^{-12} m^2/s)	29 ± 1.14	22 ± 1.7	28 ± 2.5
Potential durability [33]	Low	Low	Low

Results of the durability indicators are all summarized in Table 5. They indicate that the potential lifetime of the three types of concrete changes with its characteristics:

The water porosity and diffusion coefficient indicate that the three SCCs belong to a low durability class. The oxygen permeability reveals that these concretes have different durability values. Both SCC LF and SCC SF are in an average durability class, but SCC NP belongs to a high durability class.

Table 6 displays the chloride diffusion coefficient limits as a function of durability classes, in accordance with standard NT BUITD 492 [19]. These results clearly indicate that all the concretes under study have a low durability potential.

Table 6 - Resistance to penetration of chloride ions based on non-stationary migration tests [34].

Chloride diffusion D (x10^{12} m^2/s)	Concrete strength
> 15	Low
10 – 15	Moderate
5 – 10	High
2.5 – 5	Very high
< 2.5	Extremely high.

4.4 Analysis and discussion

In this section, the durability properties of the SCC specimens under study are compared with those of concretes previously tested by other researchers such as Boel, Auderanert, De Chutter and Sonebi [35, 36, 12]. The authors [35-37] reported a decreasing water to cement (W/C) ratio. They indicated that when the amount of water is reduced, while keeping constant the quantities of cement and mineral additions (C +A), better transfer properties were obtained. Also, when the amount of water increases, the pores become accessible, which results in poor transfer properties. The aim is to keep a (C/P) ratio around 0.60. Decreasing the (W/C) ratio, to maintain a constant (C/P) ratio, by adjusting the amount of additions and cement, can have an effect on the cementitious matrix as well as on the porous network and tortuosity. This allows saying that the concrete properties were improved. Indeed, Boel concluded that the SCC properties are better than those of ordinary concrete, due to the presence of additions. As for Sonebi, he suggested that the ratio of powder to gravel (P/G) affects the homogeneity of concrete. Indeed, a low (P/G) ratio implies more porous concrete and therefore bad transfer properties.

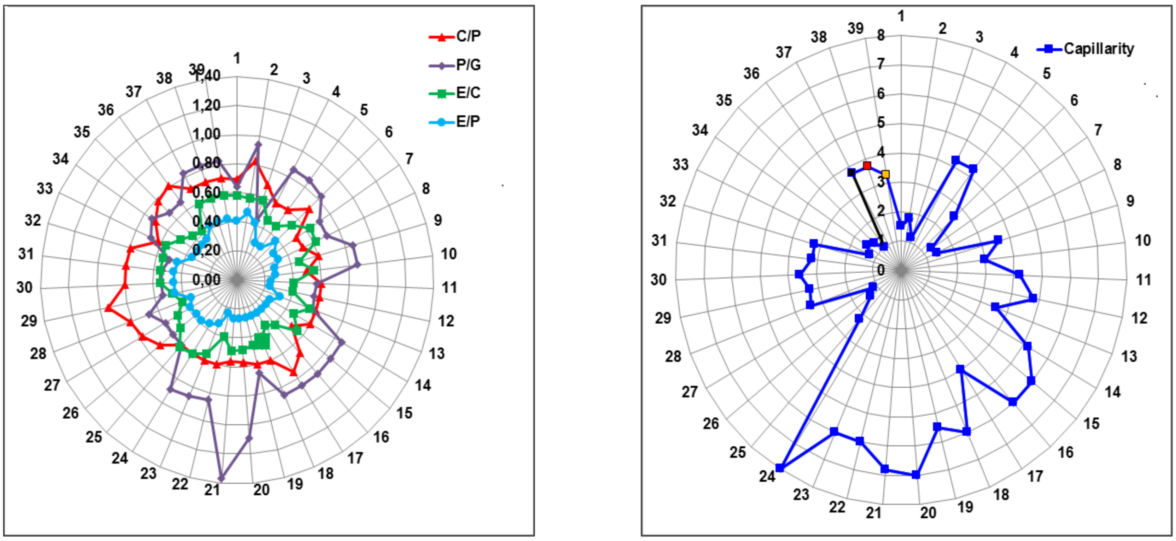
The present comparative study, which is based on these parameters, aims to investigate the durability of the concretes under study. Figs. 5-7 and 8 present the influential ratios (C/P), (P/G), (W/C) and (W/P) (P is the amount of powder, C the quantity of cement, and W the amount of water), the mechanical strengths of our concretes and those found in the literature, in addition to several transfer properties, i.e. capillarity, carbonation, permeability, diffusion of chloride ions.

4.4.1 Capillarity

In Fig.5, Audenaert et al. [35] noted that capillarity does not depend on the ratio (W/C) only, but on the cement powder ratio (C/P) as well. This ratio depends mainly on the amount of fines to be added into concrete. Therefore, when the amount of fines decreases, the ratio (C/P) increases but capillarity decreases. According to [36], this ratio should ideally approach the value of 0.6, with a ratio (W/C) equal to 0.55.

Note that SCCs investigated in this article have higher capillarity values than those reported by Sonebi, Sideris and Zhu. It is worth mentioning that Sonebi used two types of fines, i.e. limestone fillers (LF) with almost equal amount of cement (290/260) kg/m3, and fly ash but with smaller quantities (150/360) kg/m3. In this case, the (C/P) ratio was high. It is important to indicate that in the case of limestone fillers, the proportions of cement and fillers are well balanced. As a result, voids were filled with fines and a low capillarity was obtained. For mixtures with fly ash, a very dense matrix and a high tortuosity porous network were obtained, which resulted in low capillarity. As for Zhu, he prepared SCC mixtures with 20 Kg of silica fume and 100 Kg of limestone fillers. Note that silica fume leads to high compactness and produces more C-S-Hs because it is very fine and very active. Consequently, a quite low capillarity is obtained.

On the other hand, Audenaert and Boel prepared concretes that gave capillarity values higher than those obtained with our SCCs. These two authors used larger amounts of limestone fillers in their preparations and then introduced greater quantities limestone fillers in their concretes, in comparison with those used in the SCCs of this work.



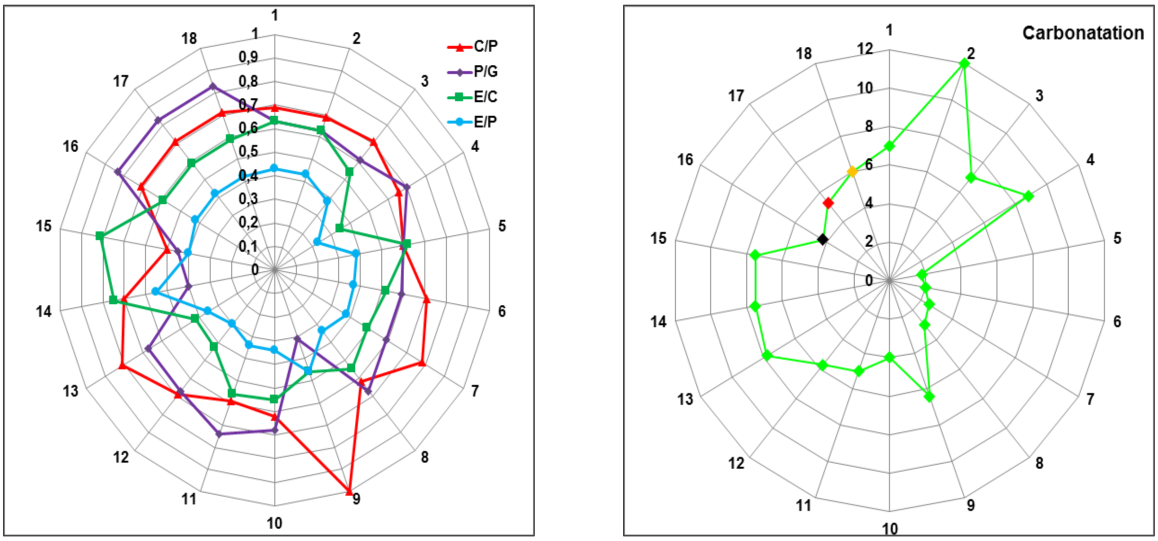
(A) Different influential ratios

(B) Capillarity
1-39 Different capillary-related studies reported in the literature

Fig. 5- Capillarity versus strength, with various ratios

4.4.2 Carbonation

Figure 6 shows that carbonation depends of the ratios (W/C) and (C/P). For Audenaert et al., these ratios are kept constant. Therefore, an increase in the amount of powder requires an increase in the amount of water for hydration. Also, an increase in the quantity of water, while keeping the ratio (W/C) constant, results in using an unnecessary amount of water. This additional free water results in a high porosity. Moreover, when the amount of powder is increased, with a small (C/P) ratio, a larger quantity of mix is obtained for the same amount of concrete. Consequently, high values of porosity are found. The high porosity along with the excessive water encourages the transport of aggressive agents through the material, as is clearly shown in Figs. 6A and 6C (axes 2 to 4 and 13 to 14).



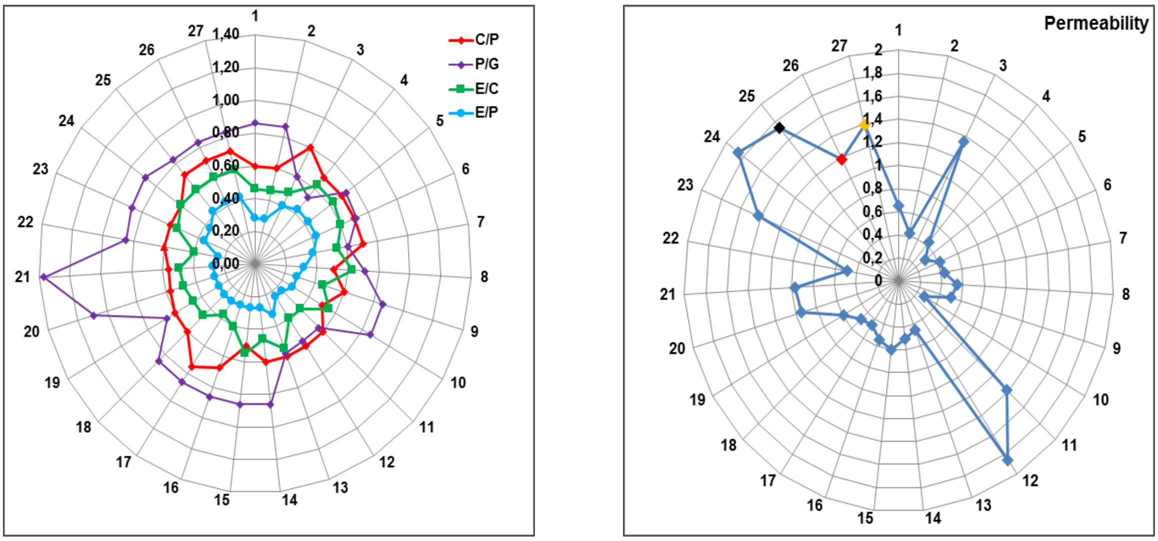
(A) Different influential ratios

(B) Carbonatation
1-18 Different carbonation-related studies reported in the literature

Fig. 6- Carbonation versus strength, with various ratios

4.4.3 Permeability

The permeability values measured for our concretes were found greater than those presented by some researchers, but equal to some others reported in the literature, as is shown in Fig. 7. This may be explained by the difference in the structure and pore size. The various parameters that can have an impact of the physico-chemical characteristics are certainly the nature of the filler, the volume of paste, the values of the ratios (W/C), (P/G) and (C/P) ratios, and the filler's fineness. Sonebi et al. indicated that the ratio (P/G) affects the homogeneity of concrete; indeed, the lower that ratio, the more porous the concrete. This may therefore lead to bad transfer properties, as shown in Fig. 7. It was found that the fines used in our SCCs were responsible for the change in the structure of the cement matrix. Moreover, these fines gave permeability values different from those reported in [35, 36].



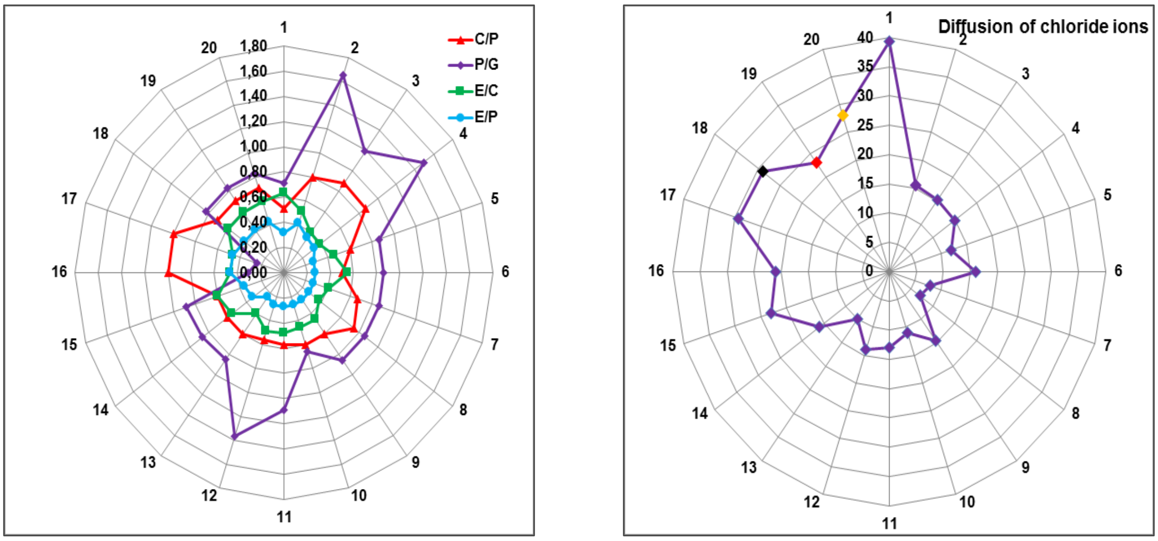
(A) Different influential ratios

(B) Permeability
1-27 Different permeability-related studies reported in the literature

Fig. 7- Permeability versus strength, with various ratios

4.4.4 Diffusion of chloride ions

Fig. 8 shows that the diffusion of chloride ions is inversely proportional to the (P/G) ratio values. Sonebi indicated that the diffusion coefficient of chloride ions is affected by the kind of mineral additions used. These additions improve the matrix and the porous network that becomes denser when minerals are added. Two other parameters are important in determining the diffusion of chloride ions, namely the excess alumina which can bind chloride ions to the matrix, and the secondary C-S-Hs that fill the interstitial spaces. The binding of chloride ions to the matrix as well as the filling of the interstitial spaces result in a reduced flow of chloride ions through the pores. Authors in [37] confirmed that the additional pozzolan reacts with the free portlandite that comes from cement to form silicates which in turn fill the interleaved voids. As a consequence, the interconnectivity of pores decreases and the diffusion of chlorides slow down. Most SCCs give low diffusion coefficients of chloride ions because these concretes are mixed with large amounts of fines, with a (C/A) ratio around 1. This confirms that the nature of mineral additions has an impact on the diffusion of chloride ions, as previously reported by Ghoumari and Sonedi. [12, 37]



(A) Different influential ions

(B) Diffusion of chloride ions
1-20 Different chloride diffusion-related studies reported in the literature

Fig. 8- Diffusion versus strength, with various ratios

5 Conclusion

This study showed that it is possible to formulate self-compacting concretes (SCCs) with local Algerian fillers, which can be natural pozzolan or local siliceous fines whose characteristics are similar to those of limestone fillers, commonly used in SCCs. Moreover, it is worth noting that the concretes containing natural pozzolan are as durable as those containing limestone fillers, commonly used throughout the world.

Our SCCs displayed similar mechanical strengths. However, the SCC NP exhibited a slightly higher value. The durability of these SCCs, found through different tests (capillary, carbonation, permeability and chloride ion diffusion), generally showed the same transfer properties when the three additions were used. Therefore, it is possible to make SCCs with Algerian fines, such as natural pozzolan and siliceous fines.

Note that the transfer properties depend directly on ratios (C/P), (W/C), and (P/G). If the ratios (W/C) and (C/P) are maintained constant, then when the amount of powder is increased, the transport properties are improved. Our SCCs showed transfer properties similar to most SCCs found in the literature.

In the end, it is important to note that the volume of porous paste, porosity and sample preconditioning are not the only factors that affect the transfer properties. These properties are also impacted by the shape of fines, the tortuosity of porous network and the distribution of pore sizes which in turn depend on the ratios (C/P) and (P/G), as well as on the nature of fines.

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