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Investigating the Performance of Self-compacting Concrete Exposed to Hot Weather

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Abstract

This study investigates the behavior of concrete in a real environment with a temperature exceeding 35 °C in the shade. It focuses on the rheological behavior of self-compacting concrete (SCC) and its ability to maintain its self-compacting aspect over time, compared to ordinary concrete (C3). The research also examines the impact of limestone fillers on SCC's fluidity in hot climates. In the hardened state, the study emphasizes concrete durability against sulfate and acid attacks and their effects on its microstructure. Three types of concrete were studied such as SCC without addition (C1), SCC with 15% of limestone fillers (C2), and (C3), were tested in terms of fresh and hardened states, along with durability against acid and sulfate attacks. Results showed that SCC in a hot climate maintained its self-compacting properties up to 25 minutes after mixing. However, over time, the fluidity of SCC with limestone fillers decreased noticeably and faster. The aging of concrete exposed to sulfuric acid in a hot and dry climate for six months was more intense than with sodium sulfate.

Keywords

self-compacting concrete, compressive strength, durability, porosity

1 Introduction

Concrete is the most widely used construction material in in the world. The casting of ordinary concrete requires compaction to ensure satisfactory strength and durability. Improper concrete compaction will cause voids to form, resulting in poor-quality concrete. The development of self-compacting concrete (SCC) has considerably changed the traditional compaction process [1]. Self-Compacting Concrete (SCC) is utilized even in the most complex shapes and dense reinforcement without requiring vibration, making it recommended for use in large construction sites.

Several effects are associated with the production of concrete in hot climatic conditions. Factors such as high temperature, wind speeds, low relative humidity, and solar radiation cause rapid evaporation of water. This has a detrimental effect on the properties of fresh and hardened concrete [2–5].

The analysis of climate data from the Algerian Sahara region, as an example of an arid zone with a hot and dry climate, shows that the summer period is the hottest, with temperatures exceeding 48 °C in July [6].

2 Literature review

The exposure of concrete to high temperature results in decreased compressive strength and pulse velocity. The compressive strength of concrete specimens cast and exposed at 30 °C was higher than those cast at 45 °C. The exposure conditions also influence durability properties. Coarse pores were noted in concrete specimens cast at 45 °C tan those cast at 30 °C. The coarse pore volume in the concrete specimens cast at 45 °C was greater than that of the specimens cast at 30 °C [7].

Early drying shrinkage is a major problem, especially for slabs, where a large area is exposed to drying immediately after casting [8–10]. According to da Nóbrega [11], variations in compressive strength following the maturity and compactness of the fresh concrete matrix highlighted the positive effect of incorporating lime plaster and superplasticizer on the development of the compressive strength of Self-Compacting Concrete (SCC) under high mixing and curing temperatures, particularly for a highly fillerized matrix.

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The durability of concrete is directly associated with the ease of penetration of aggressive agents in to the material and the behavior of concrete to deteriorate. Permeability and porosity refer to the size and distribution of pores and are important factors in determining a concrete's resistance to aggressive agents [12]. According to Rizzuto et al. [13] the use of waste tire extracts as a partial replacement for fine aggregates in concrete is viable, economical, and environmentally friendly. The addition of rubber crumbs and steel fibers improves certain mechanical properties such as tensile and flexural strength, although it may increase air permeability. Research supports the use of this green concrete for interior and exterior applications, helping to reduce the carbon footprint and environmental impact of used tires. Shaaban et al. [14] studied the impact of the self-curing admixture polyethylene glycol (PEG 400) on concrete properties in hot climates. It finds that self-curing concrete (SC) outperforms normal concrete (NC) in workability, compressive strength, tensile strength, and flexural strength. PEG 400 is shown to be effective in improving concrete properties in hot weather, offering a viable alternative to traditional curing methods. Montaser et al.'s [15] study on reinforced self-compacted concrete (SCC) beams has shown mixed results on reinforcement bond behavior in good bond zones as per Eurocode 2. This study compares the bond behavior in normally vibrated concrete (NVC) and SCC in poor condition zones, examining four parameters: concrete type, SCC strength, lap splice length, and concrete cover depth. Results indicated that increasing splice length improved energy absorption and changed the failure mode to a more ductile manner, with SCC beams showing higher steel strains and bond stress values than NVC beams.

External sulfate attacks are among the causes of deterioration that affect the durability of concrete structures [16, 17]. The interaction between external sulfates and cement hydrates leads to the formation of expansive products such as ettringite, gypsum [18–20], and thaumasite [21]. However, the attack of sulfates can lead to a progressive reduction in resistance and a loss of mass [22].

3 Research significance

This research work involves studying the behavior of concrete under hot and dry climatic conditions. The objective is to investigate the effect of a high temperature above 40 °C on the characteristics of self-compacting concretes in both fresh and hardened states, including aspects such as spreading, deformability, stability, and slump for ordinary concretes. Additionally, it examines compressive strength, dynamic modulus of elasticity, ultrasonic pulse velocity (UPV), porosity, and durability. This study is relevant to construction sites in southern Algeria, raising many questions, particularly concerning concreting during the summer period and durability in an aggressive environment prone to sulfate attacks. This is assessed by subjecting samples to an accelerated attack through immersion in a solution containing acid and sulfate. Furthermore, Scanning Electron Microscopic (SEM) analysis was conducted on Self-Compacting Concrete (SCC) samples preserved in various aggressive environments.

4 Materials and methods

4.1 Materials used

Ordinary cement (CEM I) widely produced and replaced by 15% of limestone powder, having 28-day compressive strength of 42.5 MPa. The physical, chemical and mineralogical properties communicated by the manufacturer of GICA Group (Algerian Cement Industrial Group) are shown in the Tables 1 and 2. The crushed limestone is available in the quarries of Ain-Touta. According to our laboratory analysis, the crushed limestone of the following properties: Absolute density = 2.75, bulk density = 1.09 and specific surface area of 307 m^2/kg. The sand used is a local siliceous sand of granular class 0/4 mm. Table 3, presents the physical properties of this sand. There is only one type of gravel (7/15) was used to prepared self-compacting concrete. Whereas the types of (7/15) and (15/25) were used for the preparation of C3. Crushed gravel and limestone in nature were brought from Ain Tuta sediments. Polycarboxylate superplasticizer was used to maintain the same workability for all tested mixtures, the

Table 1 Chemical and mineralogical properties of the cement used

Chemical compositions (%)									
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	Loss on fire	Insoluble residue
61.37	22.28	4.56	3.88	1.40	1.72	0.06	0.33	3.71	3.29

Mineralogical compositions (%)			
C_3S	C_2S	C_3A	C_4AF
59.2	14.1	6.1	11.4

Table 2 Physical properties of the cement used

Physical properties	Values
Absolute density	3.1
Apparent density	1.09
Blaine specific surface area (cm^2/g)	3775
Normal consistency (%H_2O)	25.6
Start of setting	171
End of setting	232
Hot expansion (mm)	1.80

Table 3 Physical properties of the sand used

Physical properties	Values
Absolute density	2.56
Apparent density	1.54
Fineness modulus	2.54
Visual sand equivalent	78.32
Sand equivalent per piston	73

physical properties of the superplasticizer are shown in Table 4. We used tap water with quality.

4.2 Preparation and testing procedure

The properties of the fresh composite SCC were tested in accordance with EFNARC guideline [23]. These guidelines are summarized in the mass ratio *G*/*S* close to 1 unity, to the volume of the paste which must be from 330-400 l/m^3. The total quantity of varies from 350 to 465 kg/m^3. Furthermore, with the dosage of the superplasticizer which must not exceed its saturation. On the basis of these directives, we proceeded to several preliminary formulations in order to optimize and characterize the SCC which meets the criteria and recommendations in the fresh state of the AFGC [24]. Dreux-Gorisse method is used to determine the best proportion of materials used to obtain a compact mixture [25].

The compositions of the three concrete types are given in Table 5. The slump flow diameter and L-Box ratio were used to measure the workability. The flow times were measured to indicate the viscosities of the composite SCC.

Table 4 Physical properties of the superplasticizer used

Physical properties	Values
Aspect	Liquid
Color	Light brown
PH	6–6.5
Density	1.07
Chlorine content	Less than 0.1 g/l
Dry extract	30%

The properties of the hardened composite SCC were established, cubes for testing of dimensions 10 × 10 × 10 cm^3, were made in molds previously oiled and covered with a plastic film in order to avoid any type of evaporation.

These samples were kept under shelter at an ambient temperature over 35 °C and relative humidity between 11 and 28% until demolding after 24 hours. The cube specimens were cured the middle of the open air of the hot and dry climate under the sun's rays, up to the crushing age of 2, 7, 14, 28 and 150 days to study the compressive strength.

The durability part, specimens were kept in sodium sulfate (5% Na_2SO_4) and sulfuric acid (5% H_2SO_4) solutions and fresh water as a control.

To maintain the pH of the sulfate solution between 6 and 8, the method of Mehta [26] was adopted which recommended the correction of the solution already used by adding a daily quantity (0.1% H_2SO_4) of sulfuric acid during the first weeks of the test, then it became weekly. The solutions were renewed every month.

5 Results and discussion

5.1 Fresh state properties of SCC in hot climate

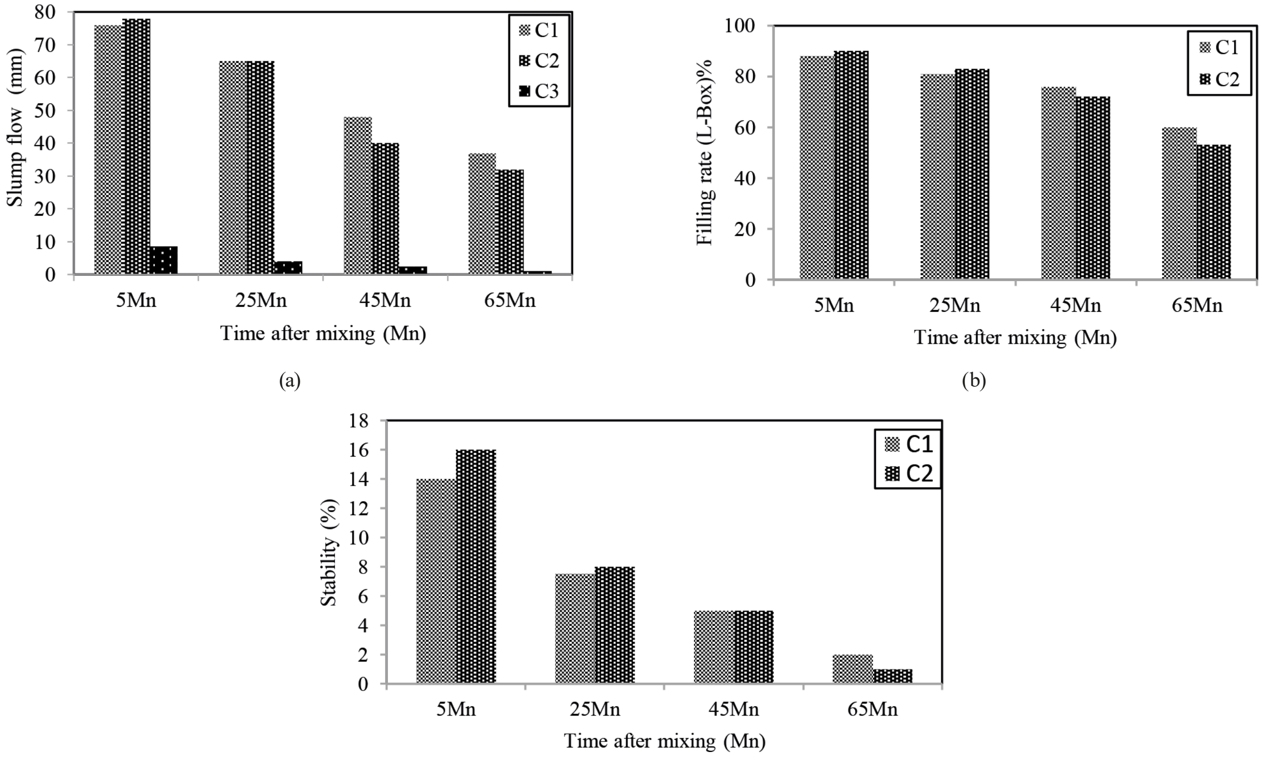
Fig. 1 shows the effect of temperature on the workability of self-compacting concrete. It is clear to observe that the high ambient temperature causes an excessive loss of slump, stops after 65 minutes from mixing.

It is found that up to 25 minutes, the SCC at an ambient temperature above 35 °C and relative humidity between 11 and 28% retains its self-compaction. It can be seen that the spread decreases from 76 cm after 5 minutes to 65 cm after 25 minutes of mixing, and a reduced filling rate from 0.88 after 5 minutes to 0.81 after 25 minutes of mixing. At the same time, the stability rate becomes 7.5% at 25 minutes after mixing. These results are in concordance with others research results.

These studies reported that up to 30 minutes after mixing, the flow properties are not strongly altered with the increase of the initial temperature, especially for the mixture with a *G*/*S* ratio close to 1. Fig. 1 shows the effect of temperature on the workability of self-compacting concrete. It is clear to observe that the high ambient temperature causes an excessive loss of slump, stops after 65 minutes from mixing. This loss is due to a rapid acceleration of hydration and evaporation of water which is consistent with previous studies [26]. In these investigations, it was found that raising the temperature from 22 °C to 32 °C causes loss of slump. The effect of limestone fillers on the rheology of SCC is very significant.

Table 5 Composition of the synthesized concretes

Type of concrete	*W*/*B*	Cement kg/m³	Limestone fillers kg/m³	Sand 0/5 kg/m³	Gravel 7/15 kg/m³	Gravel 15/25 kg/m³	Water kg	SP kg/m³	*G*/*S*
C1	0.46	465	00	741.46	804	00	214	4.65	1.08
C2	0.46	350	115	741.46	804	00	214	4.65	1.08
C3	0.52	350	00	697	395	757	182	00	1.65



(a)

(b)

(c)

Fig. 1 Effect of the temperature on the workability of self-compacting concrete: (a) spread/sag, (b) deformability and (c) stability

Benzaid and Benmarce [27] report that due to the presence of limestone easily participates in obtaining a self-compacting concrete. Immediately after mixing, workability tests showed the positive and beneficial effect of limestone fillers on the fluidity and rheology of SCC [27]. The spreading test records a slight increase for C2 containing limestone fillers compared to C1 (78 cm for C2 against 76 cm for C1); the same for the tests of deformability and sieve stability, the results are consistent with several studies [27, 28]. However, at 25 minutes after mixing, the loss of fluidity of C2 containing limestone fillers becomes more noticeable and very rapid as shown in Fig. 1.

This loss of fluidity may be due to the calcareous nature of the fillers, which requires a request for water or super plasticizer to maintain its fluidity. Moreover, the effect of limestone fillers which improves the rheological properties of SCC and increases their stability depends on several factors such as fineness which strongly influences the flow [29] as well as the nature and quantity [30].

5.2 Compressive strength of SCC in hot climate

Fig. 2, shows that all the concretes developed very high compressive strengths such as C1. At seven days, its strength reached 87% of the strength at 28 days; C2 reached 80% of the compressive strength at 28 days while the C3 registered 82% of the compressive strength at 28-day.

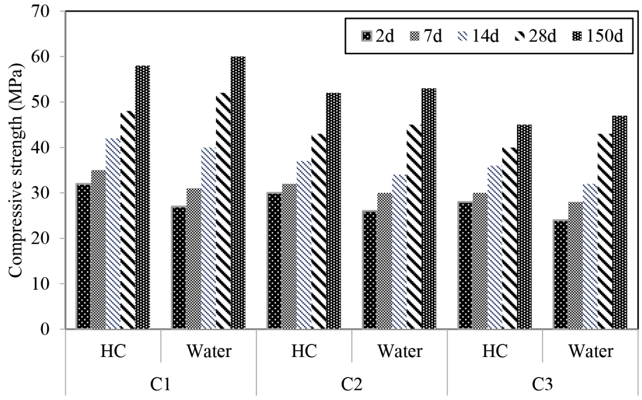


Fig. 2 Effect of the temperature on compressive strength of SCC

These results explain the effect of high temperature in the early days on the hydration reaction which leads to a rapid change in compressive strength.

It can be concluded that the mechanical properties of concrete exposed to a hot climate can be significantly affected, especially in a very short time. On the other hand, at a later age, the compressive strength increases slowly. These results are similar to those found by Boubekeur et al. [31]. For example, at 150 days we recorded a drop of 9% in the 28-day strength of C1, 5% for C2 and 7.5% for C3. This is due to a coarser microstructural development, the hydrates (in particular the C-S-H) being dense at high temperature and distributed in a more heterogeneous manner; thus, allowing the development of a larger porous network at the origin of the loss of resistance. Also, Boubekeur et al. [31] are confirmed that the temperature of cure has a positive effect on the heat of hydration under a temperature of 50 °C; the mortar containing the ordinary cement has the higher values of heat of hydration compared than other mortars containing blended cement. This explains that at very early age the increasing in temperature accelerates the dissolution of the anhydrous clinker in cement paste.

It is clear that in all the concretes, one notices the favoring of C1 concrete, which has shown good compressive strength values comparable to C2 and C3 concrete, it is due to the effect of the composition, which plays a primary role in the development of mechanical strength. The C2 recorded poor strengths and lower than those of C1 cement, and closer to that of C3 in all ages, perhaps it is the fineness of limestone (less than that of cement) and the quantity substituted (10%) of the fillers used which are the reason of these resistant results.

Bellifa et al. [32] reported that the substitution of part of the Portland cement by limestone fillers is the origin of a decreasing of compressive strengths.

Whereas Beeralingegowda and Gundakalle [33] found that the tests of the compressive strength on cubic specimens show an increase until a replacement of 20% after which the resistance begins to decrease. Zainal Abidin et al. [34] found that the compressive strength of high-performance SCC decreases by 20% of cement substitution. Achour et al. [35] disclosed that for superplasticized concrete (SCC), a quantity of 60 to 80 kg/m^3 makes it possible to increase the compactness and significantly improve the mechanical performance of the concrete. Limestone powder added to Portland cement (PC) leads to an increase of hydration at early ages, inducing a high early strength, however it can reduce the later strength due to the dilution effect. According to Elfakhrany et al. [36], using proprietary rapid-hardening concrete with a 2% polycarboxylate ether admixture can achieve 50 MPa compressive strength within 3 days. On the other hand, the compressive strength of concrete mixes cast in summer is significantly higher than those cast in winter, with increases of approximately 25% for normal concrete and 92% for rapid-hardening concrete. While polycarboxylate ether performs better in hot weather, the impact on shrinkage cracks needs to be evaluated [36].

5.3 Dynamic modulus of elasticity of SCC according to the mode of cure

From the results shown in Fig. 3; self-compacting concretes without substitutions C1 expressed the highest elastic modulus, this rise may be due to their higher strengths, while the elastic modulus of ordinary concretes is closer to those of self-compacting concretes incorporating limestone fillers. For the ripening mode, it was not found any big differences between the modulus of elasticity of the same concrete in the two different curing modes. In such a way, 39.41 and 41.38 GPa were recorded for the C1 conserved in hot climate and water respectively, that is to say with a difference of 1.07 GPa. On the other hand, 26.17 and 27.90 GPa were recorded for the C2 conserved in hot climate and water respectively, that is 1.73 GPa of difference. At the end 31.17 and 34.04 GPa for the C3 conserved in hot climate and water respectively, that is to say of 3.87 GPa of difference. These results are in agreement with the results of same researchers and in disagreement with others. When comparing self-compacting concrete to ordinary concrete, it was found that there is no obvious difference between the elastic modulus of SCC and that of C3. Vieira and Bettencourt [37] mentioned that with equivalent mechanical strength: the two types of concrete do not seem to present any significant difference with regard to

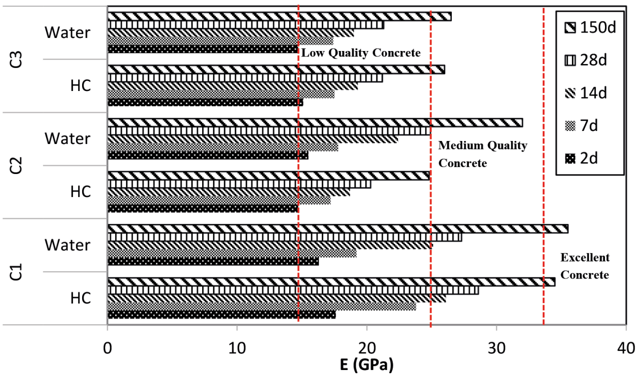


Fig. 3 Dynamic modulus of elasticity of SCC according to the mode of cure

this instantaneous mechanical property. To this end Pons et al. [38] have found that the elastic modulus of SCCs is very close to those of C3 on tests in a room at 20 °C and 55% RH [39]. On the other hand, Boubekeur et al. [40] have found no significant difference in the EM between the SCC and OC. This is the case of certain researchers who presented identical behaviors between C3 and SCC for the elastic modulus (35.5 and 35.6 GPa respectively) for similar resistances (45.1 and 44.5 MPa), but with different volumes of dough (270 liters for the C3 against 370 liters for the SCC) and a *G*/*S* ratio of 1.78 for the C3 and 1 for the SCC [37]. While the obvious claim is that since cement paste is in a higher proportion in a SCC and generally has a lower modulus than aggregates, then the elastic modulus of SCC is about 10% less than that of a C3 of identical strength and produced with aggregates of the same type [39]. In a hot climate, Le [41] found that the values of the elastic modulus of SCC oscillate without much variation around 30 GPa, and without any significant difference for specimens tested according to the parameters of the initial temperature and the means of maintaining self-compacting concrete on the one hand, and the storage mode (20 °C and 35 °C) and at the end of 28 days, even, the storage mode during the first 24 hours does not induce any remarkable change on the modules elasticity [42].

5.4 Ultrasonic pulse velocity (UPV) of SCC according to the mode of cure

Ultrasonic pulse velocity is a non-destructive test to check the quality control of the structure and concrete elements. Concrete with higher velocity is considered to contain fewer defects and imperfections in the concrete microstructure. The ultrasonic pulse velocity results of all concrete mixes used at different hardening ages and regardless of the cure mode (hot climate or water) are shown in Fig. 4. The control concrete showed a speed of the order of 3900 to 4640 m/s at the hardening age of 2 to 150 days for the specimens stored in water and of the order of 4050 to 4570 m/s for specimens exposed to hot climate. The ultrasonic speed for the C2 mixture incorporating limestone filler is of the order of 3800 to 4400 m/s and from 3700 to 3880 m/s for the mixtures preserved in water and in a lime climate respectively. In addition, the UPV of ordinary concrete is of the order of 3700 to 4010 m/s, and of the order of 3750 to 3970 m/s for concretes stored in water and exposed to the hot climate respectively. The UPV for all mixtures kept in water increased with the ascending hardening period as the hydration mechanism progressed; in contrast, the rates of the mixtures exposed to the hot climate increased up to 28 days. However, the UPV values have decreased the latter is more pronounced for ordinary concrete compared to self-compacting concrete. During an early curing period of 7 days in the hot climate all mixtures demonstrated excellent concrete quality compared to mixtures kept in water. Ultrasonic pulse velocity is a non-destructive test to check the quality control of structure and concrete elements. Concrete with a higher velocity is considered to contain fewer defects and imperfections in the microstructure of the concrete.

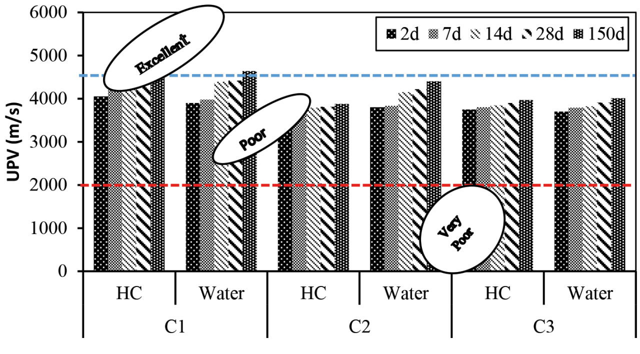


Fig. 4 Ultrasonic pulse velocity of SCC specimens

5.5 Correlation between the compressive strength and the UPV

In cementitious materials, UPV mainly depends on its elastic modulus, and since this is closely related to compressive strength, it is natural to believe that UPV may also be correlated with compressive strength [37]. Several researchers have worked on the relationship between UPV and compressive strength, Demirboğa et al. [43] have found an exponential relationship between compressive strength and UPV for concrete based on mineral additions. Salhi et al. [44] found a good correlation between the measured compressive strength and the value obtained by the relation between the resistance and the ultrasonic pulse velocity for different concretes with three *W*/*B* ratios (0.32; 0.38, and 0.44) and the correlation coefficient R^2 is equal to 0.93840. According to Hammat et al. [45], a correlation coefficient (R^2) close to 0.841 was found for heat-treated SCCs. In our study and according to Fig. 5 the coefficient of correlation R^2 equal to 0.636. Equation (1) explains that there is a correlation but not so clear:

$$S_c = 4.405 \times e^{0.526 \times V}, \tag{1}$$

where S_c: compressive strength, V: ultrasonic pulse velocity (UPV).

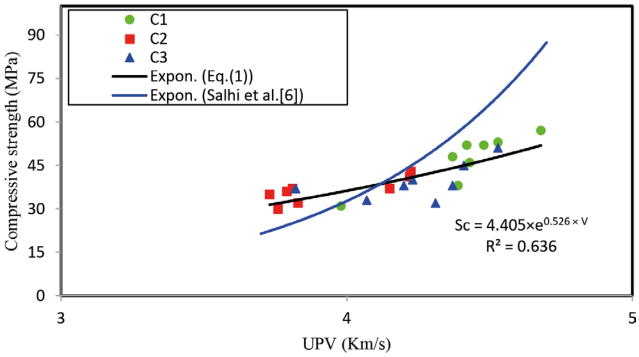


Fig. 5 Correlation between compressive strength and UPV at 150 days

6 Microstructure and durability performance of concrete

6.1 Porosity

The water-accessible porosity reflects the intrinsic characteristics of the concrete material, stemming from its composition. This indicator, which measures the volume of open voids relative to the total volume of the concrete, is a key factor in assessing durability and demonstrates the porous nature of concrete. It provides insights into the material's susceptibility to penetration by aggressive agents. Fig. 6 presents the water-accessible porosity values for different concretes in various modes. The emerging trends from the results shown in Fig. 6 are:

- The porosity accessible to water decreases over time, whatever the ripening method, but not as much with C3 as with self-consolidating concrete. In a hot, dry and arid climate, the porosity accessible to water in self-compacting concrete is higher than that of C3. A result which is in agreement with Elfakhrany et al.'s work [36]. In an ambient temperature which found 10.5% for a SCC against 8.9% for C3.

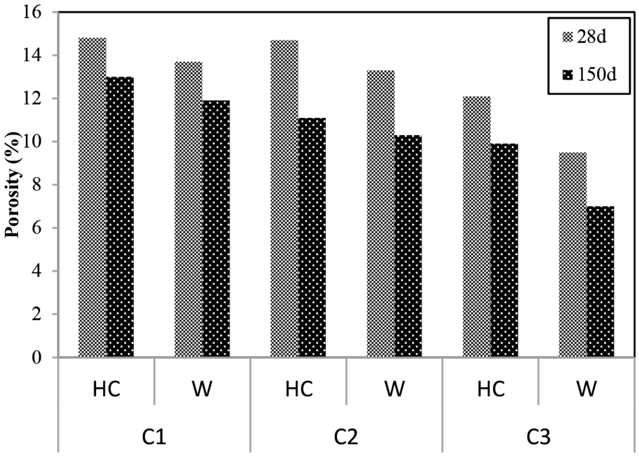


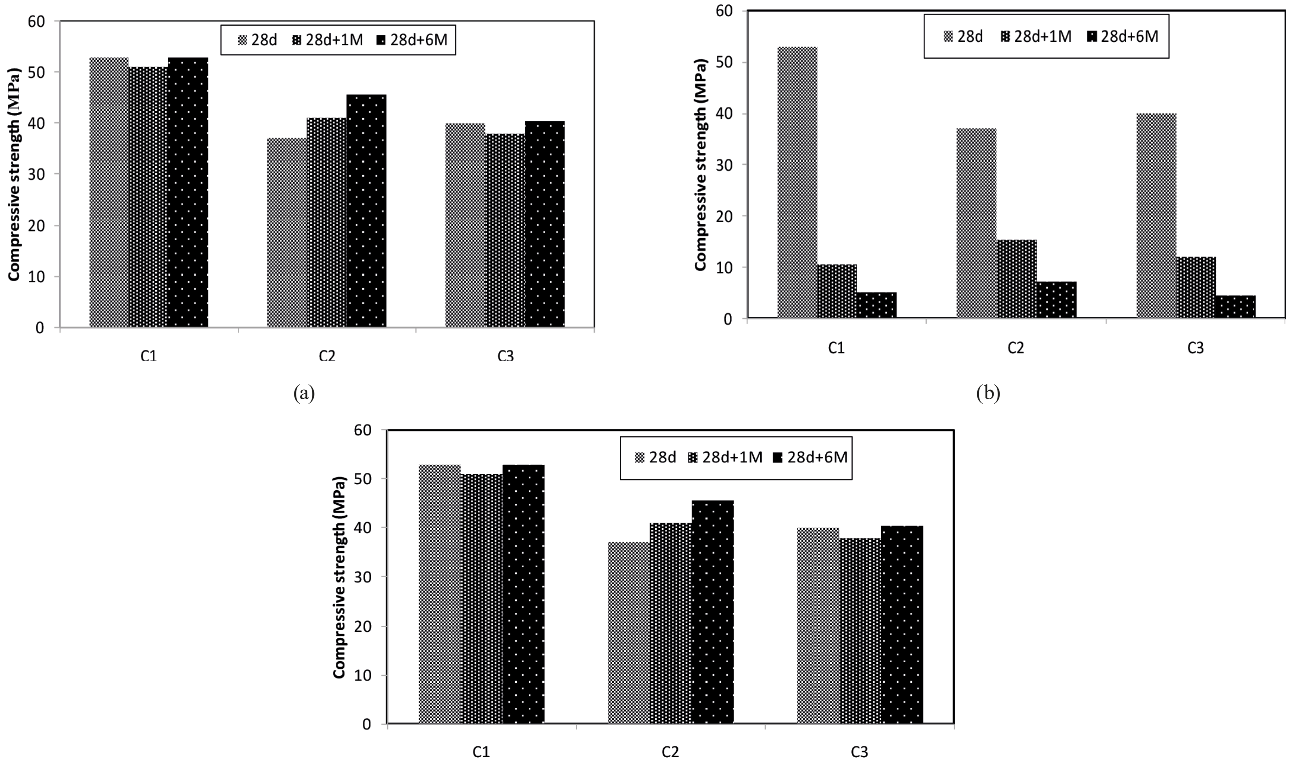
Fig. 6 Porosity of concretes according to the mode of treatment at 28 and 150 days

- Self-compacting concretes incorporating limestone filler (C2) in a hot climate have a decrease in porosity compared to self-compacting concretes without substitution (C1), this result is explained by the effect generated by the deflocculating of the cement grains [41–46]. All concretes cured in water exhibit a decrease in open porosity compared to concretes exposed to open air which explains the impact of the hot climate, that slightly modify the porosity of the concrete. This result agrees on the one hand with Vieira and Bettencourt [37] and on the other hand contradicts [47], who found that the rise in temperature does not significantly modify the total porosity.

6.2 Acid and sulfate attack

After 150 days of immersing of the samples in the various environments, the visual inspection reveals the following:

- In fresh water, there are no changes or degradation on the samples.
- In the Na_2SO_4 solution, a slight yellowish layer is formed on the surface of the specimens.
- In the H_2SO_4 solution, there are formation of a white layer on the surface and deterioration of the corners and edges of the specimens. The monitoring of the compressive strength of the samples made and cured in a hot and dry climate with an ambient temperature exceeding 35 °C, showed that, on the contrary to the mixtures (C1, C2 and C3) immersed for five months in the fresh water where we have recorded changes in compressive strength. All concrete samples immersed in 5% Na_2SO_4 and 5% H_2SO_4 aggressive media have undergone external sulfate attack. For the 5% of Na_2SO_4 solution is shown in Fig. 7 (a), a drop-in resistance (45.0%) for C1 was recorded after a six-month immersion, comparable to the compressive strength at 28 days before immersion, and of 52.35% for C3, against 34.29% for the C2. Concerning the 5% of H_2SO_4 solution which is shown in Fig. 7 (b), the drop in resistance is very dramatic, around 90.56% for C1, 88.75% for C3 and 80.54% for C2. Of course, these results show that concretes subjected to sulfuric acid degrade drastically because during their immersion, the samples develop phases which predispose materials capable of embrittlement, particularly gypsum, to turn into ettringite. These results show that the aging of concretes by the sulfuric acid solution is more intense compared to the sodium sulfate solution [45], as well



(a) (b) (c)

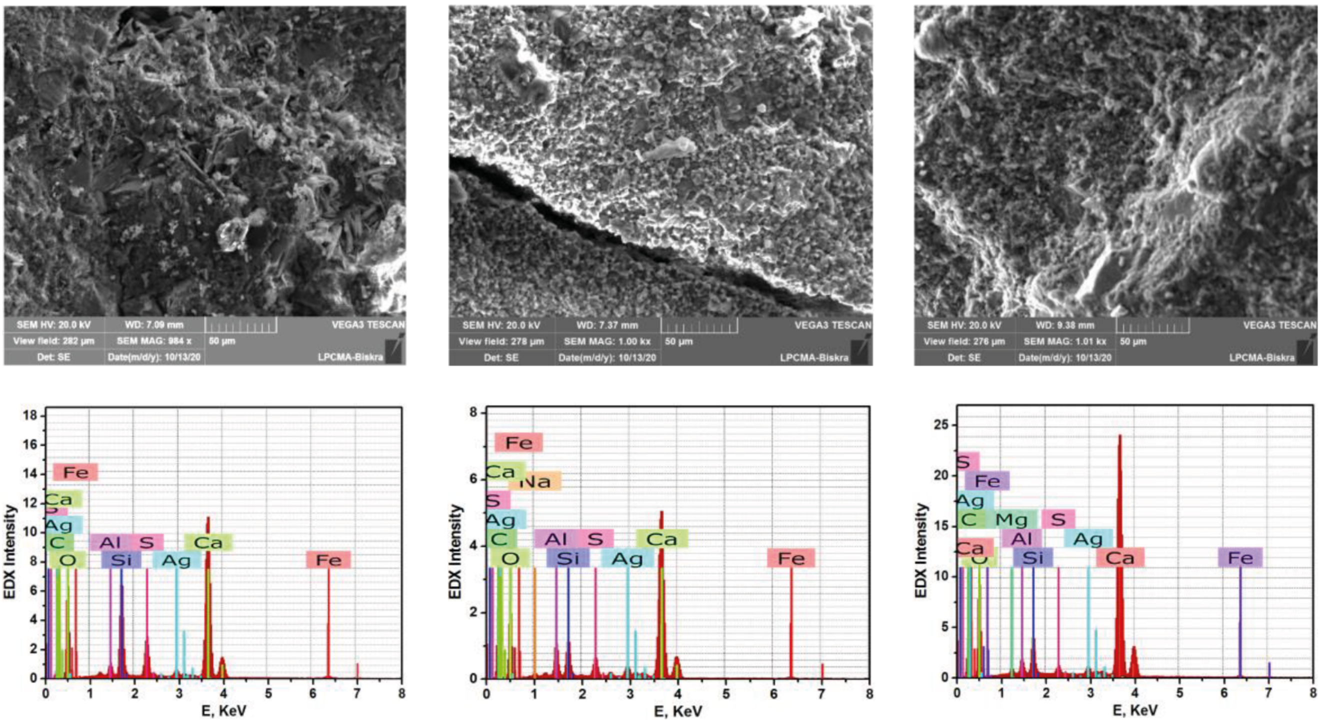
Fig. 7 Variation of the compressive strength: (a) 5% Na_2SO_4, (b) 5% H_2SO_4, (c) water

as the substitution of limestone fillers is beneficial to maintain the best resistance in a sulfate environment 25, 44 and even to its increase vis-à-vis the attack of 5% H_2SO_4 [48]. Boubekeur et al. [49] conducted a study involving visual inspections of hardened mortar samples stored in acidic solutions for 180 days. They found that mortars containing limestone powder showed significant weight loss.

6.3 Scanning Microscope Analysis (SEM)

The SEM observations make it possible to account for the microstructure of concrete, the defects included, micro cracks, and porosities. When these observations are coupled with chemical analyzes by EDX, we can recognize the phases present and go back to their influence on the durability of these materials. The SEM observations of the various concretes and of the materials used were carried out. The SEM images, and the corresponding EDX analyzes are shown in Figs. 8, 9 and 10. Observations were conducted on the various concretes that were characterized, observed, and mechanically tested to establish a connection between the different components constituting the samples and the obtained performances. It is important to note that in all analyses, the presence of silver (Ag) is a result of the preliminary step of preparing the samples through metallization, enabling them to become conductors and optimizing the quality of the images obtained. The SEM images corresponding to the different concretes (C1, C2, and C3) immersed in fresh water for six months, show that these concretes have homogeneous structures and good grain distribution, and the corresponding EDX analyzes reveal the presence of Ca, Si, Al, Fe, Mg, and S. This analysis thus confirms the presence of calcite ($CaCO_3$), silicates and silicas (CSH-SiO_2), and possibly a weak presence of sulfates. For the samples immersed in the 5% Na_2SO_4 solution, the SEM images show reliefs with heterogeneities and porosities. Analysis of these samples reveals a significant amount of sulfur, also the immersion of concrete in the 5% Na_2SO_4 solution makes it possible to make the aspects of the concrete very heterogeneous, by presenting micro-cracks, and cavities linked to the repairs of the concrete with its sulfates.

The degradation of the samples immersed in the 5% H_2SO_4 solution is more serious, the corresponding SEM images reveal more heterogeneous facies, containing grains of very diverse geometries, presenting very uneven and cracked surfaces. EDX analysis of these samples shows a significant presence of *S*, responsible for the formation of gypsum and ettringite.

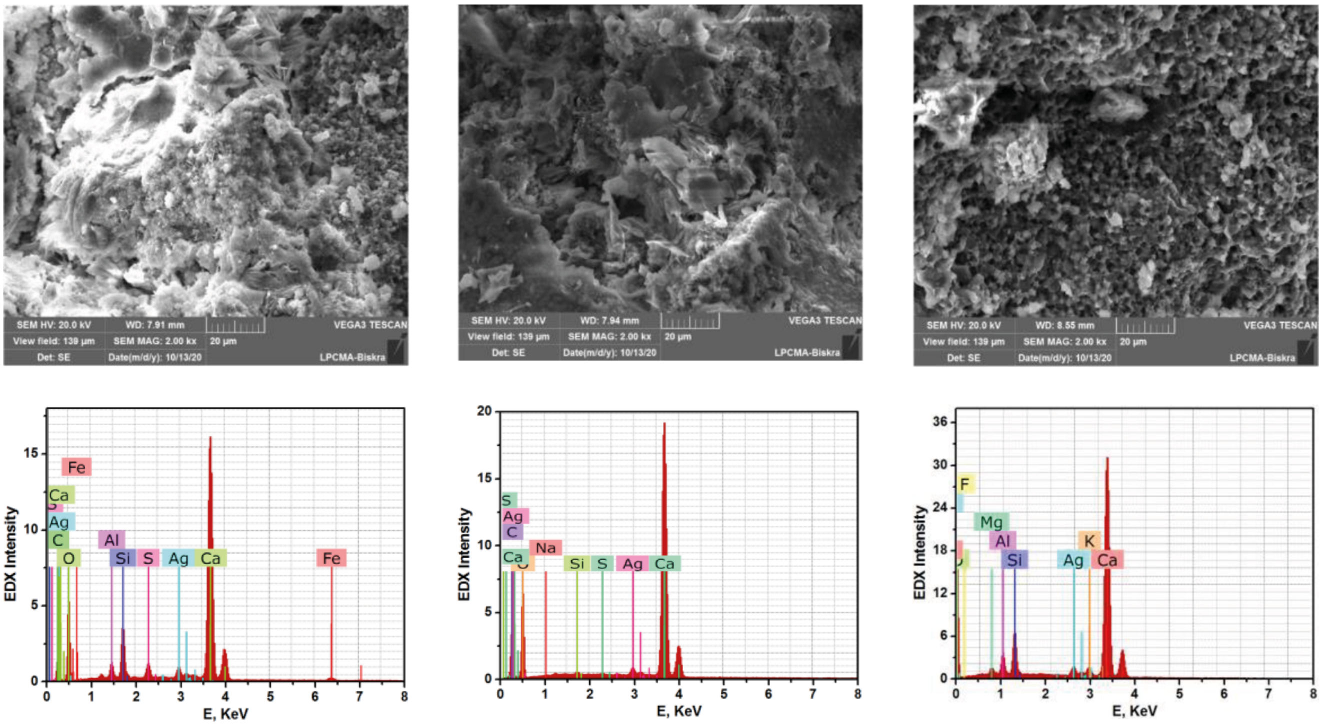


C1-(5%) H_2SO_4

C1- (5%) Na_2SO_4

C1- Water

Fig. 8 Micrographs of selected self-compacting concrete C1 immersed in different media



C2- (5%) H_2SO_4

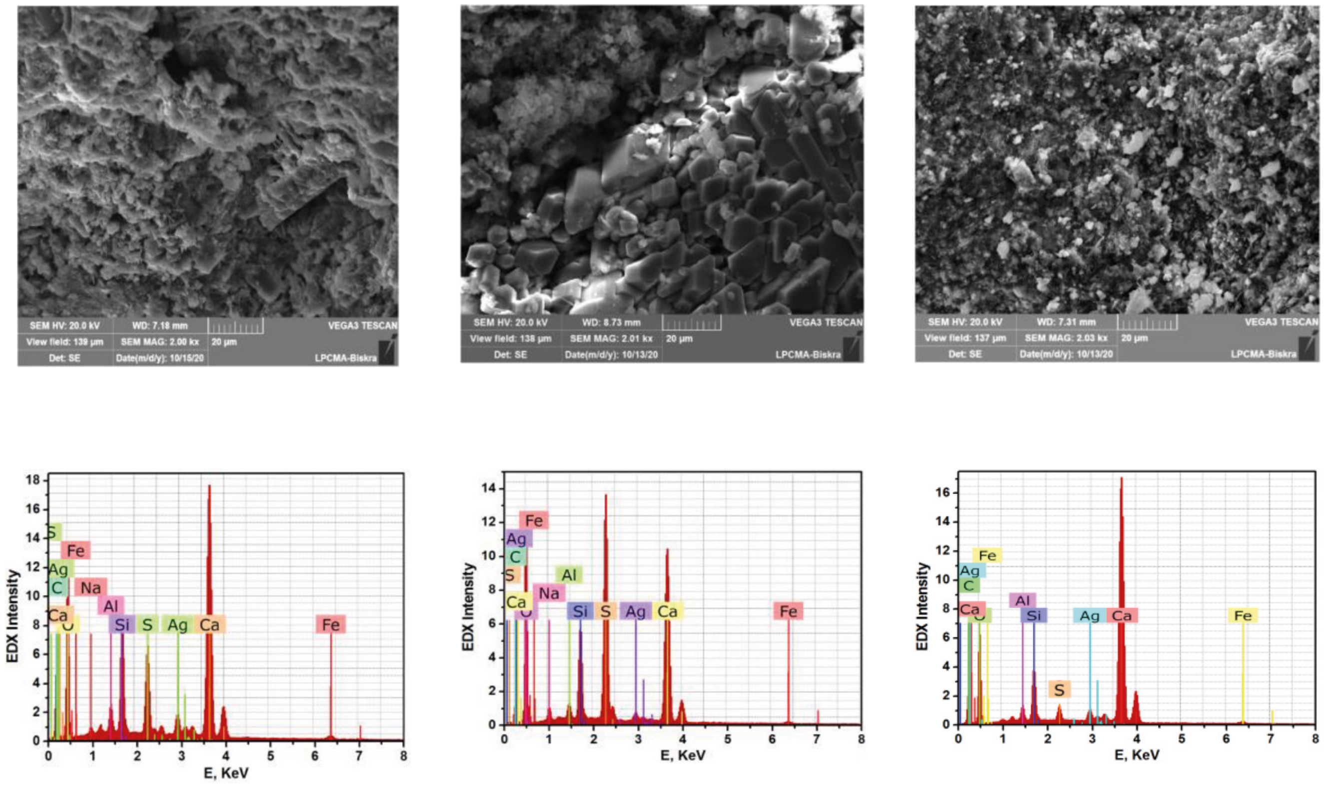
C2- (5%) Na_2SO_4

C2-Water

Fig. 9 Micrographs of selected self-compacting concrete C2 immersed in different media

7 Conclusions

This study was conducted to investigate the effect of high ambient temperature over 35 °C on the fresh state characteristics of self-compacting concrete (spreading, deformability, stability) and slump for vibrated concrete. The following conclusions were drawn:



C3- (5%)-H_2SO_4

C3-(5%)-Na_2SO_4

C3-Water

Fig. 10 Micrographs of selected self-compacting concrete C3 immersed in different media

- The high ambient temperature caused an excessive loss of slump, due to a rapid acceleration of hydration and evaporation of water.
- All the concretes developed very high compressive strengths. These results explained the effect of high temperature in the early days on the hydration reaction, leading to a rapid change in compressive strength.
- Self-compacting concretes without substitutions (C1) expressed the highest elastic modulus, which may be attributed to their higher strengths, while the elastic modulus of C3 was closer to those of self-compacting concretes incorporating limestone fillers.
- In a hot, dry, and arid climate, the porosity accessible to water in self-compacting concrete was higher than that of C3. The C2 in a hot climate exhibited a reduction in porosity compared to C1.
- The concretes subjected to sulfuric acid degraded drastically because during their immersion, the samples developed phases which predisposed materials capable of embrittlement, particularly gypsum, to turn into ettringite.

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