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EFFECT OF THE VISCOSITY MODIFYING AGENT AND THE DIFFERENT MINERAL ADDITIONS ON RHEOLOGY AND COMPRESSIVE STRENGTH OF SELF-COMPACTING CONCRETE

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ABSTRACT

This paper presents an experimental study of the influence of the viscosity modifying agent and the different mineral additions (limestone filler, natural pozzolana and slag) on the rheological properties (fluidity, deformability and stability) and compressive strength of self-compacting concrete (SCC). The workability of fresh SCC was measured using slump test, L-Box and sieve stability test. The compressive strength was determined on samples (160×320 mm) at the ages of 28 days.

The results have allowed us to develop a range of SCC that can fill the formwork heavily armed without vibrations and have of the compressive strengths acceptable. The incorporation of superplasticizer (SP) increases the fluidity and deformability but reduces slightly the stability and compressive strength. For cons, adding a viscosity modifying agent (VA) is quite contrary. Loss of fluidity and deformability caused by adding a VA can be recovered by adding a SP without affecting the stability and compressive strength. However, high dosages of VA, the effect of SP is limited, or in other words, it is mainly related to dosage used of VA. The use of a dosage (VA = 0.03%) is sufficient to assure the best properties and with this dosage, SCC require reasonable quantities of SP.

Keywords: Self-compacting concrete (SCC); mineral additions; viscosity modifying agent; rheological properties; compressive strength.

1. INTRODUCTION

The vibrations of concrete can lead to white finger syndrome (a disease) amongst workers and there is a significant environmental noise loading imposed on both the work place and around

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the site [1-4]. Research has also shown that even the perceived full compaction does not actually produce homogeneous and uniform concrete [5, 6]. Besides, conventional concrete tends to present a problem with regard to adequate compaction in thin sections or areas of congested reinforcement, which leads to a large volume of entrapped air voids and reduces the compressive strength and durability of concrete [7]. Self-compacting concrete (SCC) is a recently developed concept in which the ingredients of the concrete mix are proportioned in such a way that the concrete is compacted by its own mass, assuring complete filling of formwork. Originally developed in Japan in the late 1980s, the SCC has now been taken up with enthusiasm throughout the world for both site and precast work [8,9]. On the other hand, as the concrete flowability increases, its stability decreases. This is due the reduction in viscosity of the fresh concrete. There are two ways of increasing the viscosity of concrete; first by increasing the powder content, second by incorporating a viscosity modifying chemical admixture [10-14].

The recent studies [15-26] have investigated the behaviour of SCC with several types of pozzolanic materials; blast furnace slag and silica fume to replace part of the Portland cement. Limestone powder has also been used to control the segregation potential and deformability in the fresh state of SCC [27-30]. Uysal and Yilmaz [31] have shown that it is possible to successfully utilize waste limestone powder, basalt powder and marble powder as mineral additions in producing SCC. Due to its observed mechanical advantages, the employment of waste mineral additions improved the economical feasibility of SCC production on a unit strength basis. SCC mixes generally have a much higher content of fine fillers. The use of supplementary cementitious materials is well accepted because of the improvement in concrete properties and also for environmental and economical reasons. An optimum slag content of 15% seems to give a good SCC mixture with workability retention of about 60 min. A decrease in compressive strength with increase of slag content was obtained, but this decrease in compressive strength is less important at late ages (56 and 90 days after mixing) [32]. An improvement in the workability of SCC with the use of pozzolana and marble powder. Compressive strength of binary and ternary SCC decreased with the increase in natural pozzolana and marble dust content, but strength at 28 and 90 days indicate that even with 40% (natural pozzolana + marble powder), suitable strength could be achieved [33]. Several studies [34-41] have shown that natural pozzolana have been widely used as a substitute for Portland cement in many applications because of its advantageous properties which include cost-reduction, reduction in heat evolution, decreased permeability and increased chemical resistance. Methods of formulating the SCC current are all relatively complex and relatively imprecise mainly based on empirical results. They generally provide SCC with the desired mechanical properties but they do not always achieve desired workability [42]. This is why the researchers, optimized SCC by their experience. It is obvious that the SCC made in the world is very rich in cement quantity. Therefore, the important cement content causes an increase in the temperature of SCC due to the heat of hydration and generates more increased cost [43]. It is therefore reasonable to replace a portion of cement by mineral addition. In more, SCC must contain a high dosage of superplasticizer to ensure its high workability. Other, chemical admixture such as viscosity agent may be introduced to reduce segregation and better stability [44].

This study is to determine the effect of the nature and dosage of mineral additions (limestone filler, natural pozzolana and slag) as well as the viscosity modifying agent on the rheological properties and compressive strength of SCC. It is also to find the optimal proportions of each type of addition mineral and admixture that provide good flow properties while maintaining

acceptable a compressive strength.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Cement

The cement that was used is a compound cement (CEM II/B) class 42.5 MPa; it is composed of 70% clinker, 25% limestone filler and 5% gypsum, for the regularization of the setting. The clinker is from the cement factory of Ain-Touta (Batna). Apparent density = 1120 kg/m^3, specific density = 3100 kg/m^3 and fineness Blaine = 3000 cm^2/g. The chemical analysis of cement shows that it is in conformity with standard NFP 15-301. Chemical and mineralogical compositions of cement are presented in Tables 1 and 2, respectively. The potential mineralogical composition is calculated according to the empirical formula of Bogue [45].

Table1: Chemical composition of cement (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
17.38	4.69	2.72	61.53	1.55	2.44	0.20	0.95	8.20

Table 2: Mineralogical composition of cement (%)

C_3S	C_2S	C_3A	C_4AF
59.00	16.00	9.00	10.00

2.1.2 Water

The water is drinking water that contains little sulphate and having a temperature of 20 ± 2°C. Its quality conforms to the requirements of standard NFP 18-404.

2.1.3 Sand

The sand used (0/5 mm) is from the Biskra region (River Oued-Djedi). Apparent density = 1680 kg/m^3, specific density = 2540 kg/m^3, fineness modulus = 2.06 (preferential), sand equivalent = 77 (slightly argillaceous sand of acceptable cleanliness for concrete). The grading curve of sand is given in Fig.1.

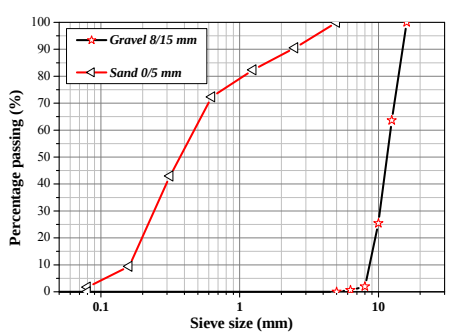

Figure 1. Grading curves of sand and gravel

2.1.4 Gravel

We used fraction of crushed stone (8/15 mm) the Ain-Touta region (Batna). Apparent density = 1390 kg/m^3, specific density = 2620 kg/m^3 and Los Angeles coefficient = 23% (hard). The grading curve of gravel is given in Fig.1.

2.1.5 Mineral additions

Chemical compositions of mineral additions are presented in Table 3.

Table 3: Chemical compositions of mineral additions (%)

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
Limestone filler	-	-	0.03	55.50	0.80	-	-	-	43.60
Natural pozzolana	44.85	17.20	10.50	10.10	3.40	1.50	4.05	1.60	4.10
Slag	42.20	5.85	1.90	42.20	4.72	1.54	0.12	0.43	0.80

Limestone filler (LF): crushed limestone, available in most careers in the Biskra region. It has the following characteristics (Apparent density = 1090 kg/m^3, specific density = 2500 kg/m^3 and fineness = 3200 cm^2/g).

Natural pozzolana (NP): the pozzolana additions are obtained by crushing a natural accumulation of volcanic origin extracted from deposit Bouhamdi located 2500 m south of Beni-Saf west Algeria. It has the following characteristics (Apparent density = 1150 kg/m^3, specific density = 2730 kg/m^3 and fineness = 3000 cm^2/g).

Slag (S): the addition of granulated blast furnace slag from El-Hadjar (Annaba region). It has the following characteristics (Apparent density = 1080 kg/m^3, specific density = 2730 kg/m^3 and fineness = 3070 cm^2/g).

2.1.6 Admixtures

Superplasticizer (SP): superplasticizer based on polycarboxylate of from the company Granitex Algeria liquid form and is referred to (Medaflow 30). It has a specific density of 1.07 and the concentration of solid particle is 30%.

Viscosity agent (VA): it is in the form of soluble in water powder known by the name (Medacolbse). It has a specific density of 0.5.

2.2 Tests conducted

In the fresh state, many different test methods have been developed to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Hence, each mix design should be tested by more than one test method for the different workability parameters.

To evaluate its properties, AFGC [46] recommended three tests; in the present study slump flow by Abrams Cone test (Fig. 2.a), L-Box test (Fig. 2.b) and sieve stability test (Fig. 2.c) were used to determine the filling ability, passing segregation index of SCC respectively.

a. Slump flow test b. L-Box test c. Sieve stability test

Figure 2. Characterization tests of SCC in the fresh state

a. Slump flow test

At first, the base plate and inside of slump cone were moistened. Then the base plate was placed on a level stable ground and the slump cone was placed centrally on the base plate where it was held down firmly. The cone was then filled with concrete. No tamping was done. Any surplus concrete from around the base of the cone was removed. After this the cone was raised vertically and the concrete was allowed to flow out freely. The diameter of the concrete in two perpendicular directions was measured. The average of the two measured diameters was calculated. This was recorded as the slump flow.

b. L-Box test

The L-Box test apparatus with three bars of 12 mm diameter with a gap of 41 mm was set on a levelled firm ground, ensuring that the sliding gate can be opened and closed freely. The inside surface of the apparatus was moistened. The vertical section of the apparatus was filled with concrete and it was allowed to rest for 1 min. Then the sliding gate was lifted and the concrete was allowed to flow out into the horizontal section. When the concrete stopped flowing, the distance (H_1) and (H_2) were measured. The (H_2/H_1) was the blocking ratio. The whole test was completed in 5 min.

c. Sieve stability test

It consists in depositing 4.8 kg of concrete on a 5 mm sieve. After two minutes of sieving, we weigh the quantity of mortar (milt) having passed through the sieve. The percentage milt π with respect to the initial mass provides the segregation index, ($\pi \leq 15\%$).

In the hardened state, the compressive strength is expressed by the power of concrete to resist destruction by the action of stresses due to the compression load. The compression test at 28 days on the samples of concrete (160×320 mm) was conducted in accordance with standard NF P 18-406, each set includes three samples. The compressive strength is the ratio of breaking load per the transversal section of the sample. The hardening was under natural conditions, the samples are subjected to a curing in drinking water at 20 ± 1°C [47].

2.3 Testing method and concretes compositions

This part is to formulate various SCC which differs only by the kind of binder. This binder comprises, first, (cement + limestone filler), in continuation, (cement + natural pozzolana) and finally (cement + slag). Mineral additions are introduced in proportions various by mass of 0-50%. Based on some parameters of previous studies [48,49]; our SCC include in $1m^3$,

gravel volume of 290 l, 304 l sand and 406 l paste. The mass ratio (W/B = 0.35) and the dosage of the superplasticizer was 1.3% by binder mass. The compositions of SCC studied are detailed in Table 4.

To investigate the influence of dosages in SP and VA on the rheological properties and compression strength, we combined the SP and VA dosages (0.5 to 2.5% by mass of binder, not 0.5%) and (0 to 0.15 by mass of binder, not 0.05%) respective. Twenty combinations considered are introduced separately, in a concrete with the same dosages of the first formulation of Table 4. For improve even more the performance of SCC by using appropriate combinations of SP and VA. To this effect, we modified the SP dosages, for each dosage VA (0 to 0.05% by binder mass, not 0.01%), in order to adjust the fluidity a slump flow 80 cm. In continuation, Authors have measured other properties of SCC. Note that the five combinations considered are introduced in three SCC optimized with dosages of the mineral additions (30% LF, 30% NP and 40% S).

Table 4: Compositions of the self-compacting concrete studied

N°	Nature of binder (%)	Cement kg/m^3	MA kg/m^3	Water kg/m^3	SP kg/m^3	W/C
1	100 C	593.3	000.0	207.7	7.71	0.35
2	90 C + 10 LF	527.4	058.6	205.1	7.62	0.39
3	80 C + 20 LF	463.2	115.8	202.6	7.53	0.44
4	70 C + 30 LF	400.4	171.6	200.2	7.44	0.50
5	60 C + 40 LF	339.2	226.1	197.9	7.35	0.58
6	50 C + 50 LF	279.4	279.4	195.6	7.26	0.70
7	90 C + 10 NP	530.1	058.9	206.1	7.66	0.39
8	80 C + 20 NP	467.8	116.9	204.7	7.60	0.44
9	70 C + 30 NP	406.4	174.2	203.2	7.55	0.50
10	60 C + 40 NP	345.9	230.6	201.7	7.49	0.58
11	50 C + 50 NP	286.2	286.2	200.3	7.44	0.70
12	90 C + 10 S	530.1	058.9	206.1	7.66	0.39
13	80 C + 20 S	467.8	116.9	204.7	7.60	0.44
14	70 C + 30 S	406.4	174.2	203.2	7.55	0.50
15	60 C + 40 S	345.9	230.6	201.7	7.49	0.58
16	50 C + 50 S	286.2	286.2	200.3	7.44	0.70
Gravel = 759.8 kg/m^3 Sand = 772.9 kg/m^3			W/B = 0.35			

3. RESULTS AND DISCUSSIONS

3.1 Optimization of the nature and dosage of mineral additions

It is possible to notice on Figs 3, 4 and 5, the beneficial effect of the introduction of mineral additions on the rheological properties (fluidity, deformability and stability) of SCC.

From Figs 3 and 4, we observe an increase in fluidity and deformability with dosing mineral additions to the mass proportions (30% LF, 30% NP and 40% S). Beyond, a slight

decrease of fluidity and deformability was recorded with the excess of these additions. We can also see that the SCC made with LF have the best fluidity and deformability, and they are followed by the SCC-based slag. This improvement due to the presence of mineral additions is usually attributed, on the one hand, their finest particles that can fill the voids between the coarse grains of the cement and water release captive there between, and on the other hand, their morphology which has a low water adsorption and low hydration. The fineness of LF and the no reactivity during hydration tend to improve fluidity.

However, any excess of mineral additions compared to the quantity required to fill the intergranular voids may affect the fluidity and deformability. In Fig. 5 shows that the stability of the SCC is systematically improved with the introduction of mineral additions. We also note that the most important improvement is obtained with the use of LF. Indeed, for each type of additions (LF, NP and S), the growth of its dosage from 0 to 50% resulted in a decrease of the segregation index, respectively (49, 33 and 27%) approx. This result is explained by the fact that the grains of mineral additions improve granulometry and compactness of the SCC, which can give increased stability. Also, these grains can increase cohesion and viscosity of the SCC, which makes it very difficult to separate the components from each other.

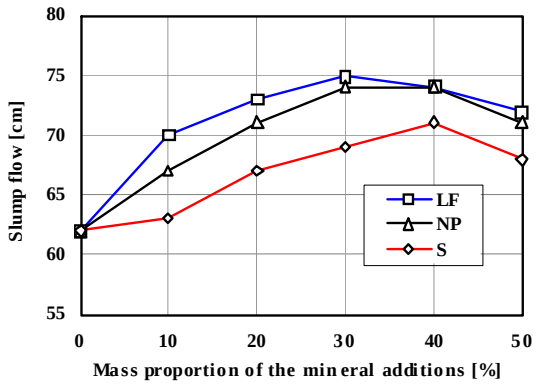

Figure 3. Effect of mineral additions on the fluidity

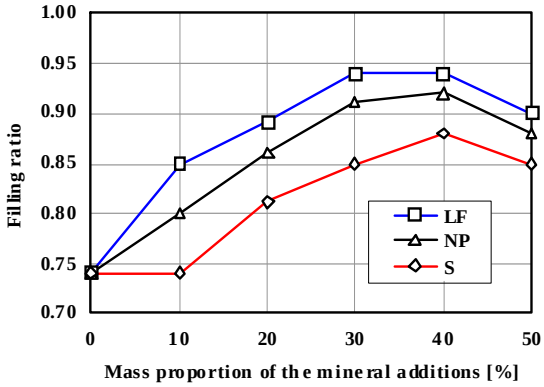

Figure 4. Effect of mineral additions on the deformability

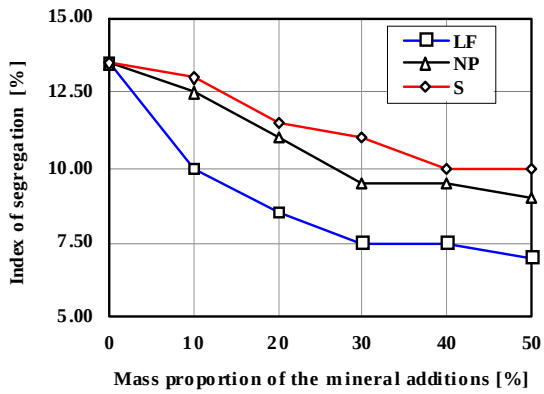

Figure 5. Effect of mineral additions on the stability

We see in Fig. 6 that the compressive strength is inversely proportional to the dosage mineral additions, whatever the type of addition used. Indeed, SCC made a loss of acquired strength (36, 37 and 28%) due to some increased (LF, NP and S), respectively, from 0 to 50%. This result is explained by the fact that the introduction of a mass of mineral additions greater is accompanied by a decrease in the quantity of cement and, therefore, leads to a W/C ratio higher. This modification is also reflected in a reduction in volume of hydrates formed where lower strength. Moreover, we can notice that the SCC-based slag are more resistant that the slag hydrates faster than other additions (LF and NP). In more, although the LF is considered an inert addition, his SCC have higher strengths than those of SCC containing NP. This is explained by a finesse of LF, which can improve of compactness and the adhesion of the hydrated cement paste with aggregates.

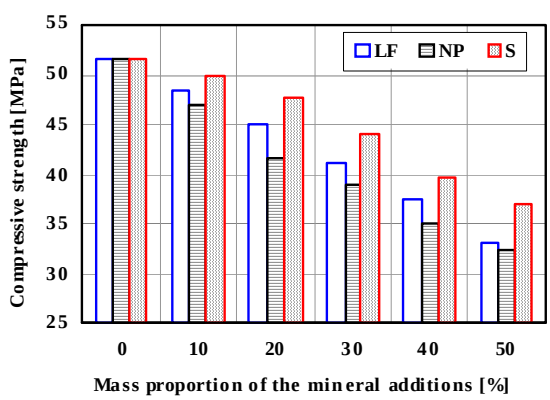

Figure 6. Effect of mineral additions on the compressive strength

3.2 Optimization of superplasticizer dosages and viscosity agent

According to Fig. 7, it is clear that adding the SP significantly improves fluidity. Indeed, for dosages VA (0, 0.05, 0.1 and 0.15%), the growth of SP content of 0.5 to 2.5% resulted in a progressive increase slump of (174, 204, 160 and 105%) respectively about. This

improvement is due to the action of the molecules of SP. These molecules can be rolled around the grains of the cement and to impart a negative charge, so that they repel each other, resulting in deflocculating and dispersion of the grains of cement. This action will release a important quantity of water, where the fluidity is increased [50]. Also, we note that for mixtures no VA, improving the fluidity is limited to a dosage (SP = 2%). Beyond, the fluidity does not change practically. One can think, therefore, the dosage (SP = 2%) is the maximum dosage used (saturation point).

On the other hand, it seems that adding a VA causes loss of fluidity and especially when VA changes from 0.05 to 0.1% in mixtures considered fluids (SP ≥ 1%). E.g., a dosage (SP = 1.5%), the increase is VA from 0.05 to 0.1%, 42.62% fluidity decreases about. This decrease is due to the action of VA which can increase the viscosity and shear threshold of concrete [51].

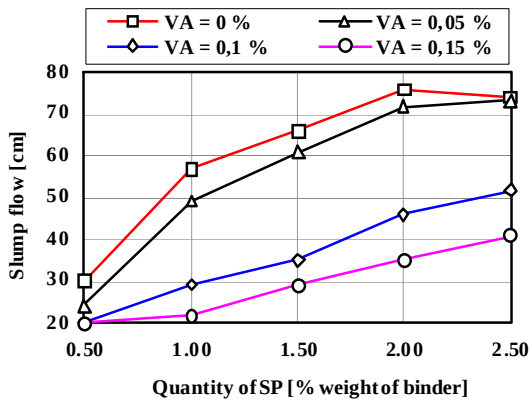

Figure 7. Effect of SP dosages and VA on the fluidity

It is possible to observe in Fig. 8, the variation of the filling rate based dosages in SP and VA takes almost the same appearance of fluidity. We can say in this case that the deformability depends heavily on the flow.

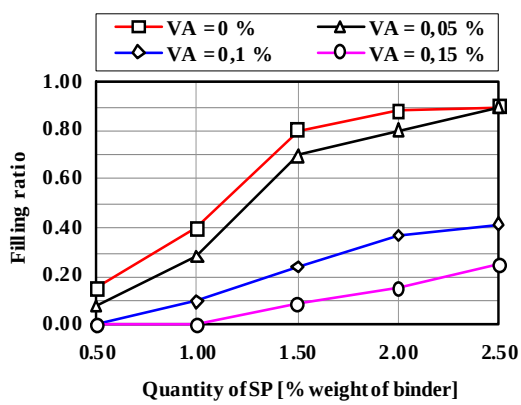

Figure 8. Effect of SP dosages and VA on the deformability

The variation of the stability of concretes containing different dosages of SP and VA is illustrated in Fig. 9; we observe that the incorporation of VA resulted in a great improvement in stability. Indeed, it is evident that for different dosages in SP considered, the concretes made with dosages in VA of 0.1 and 0.15% providing the best stability, which is estimated by a segregation index not exceeding 4%.

This improvement is due to the increase in viscosity of mixtures. By cons, we note that, for VA dosages in of 0 and 0.05%, an increase of SP causes a great loss of stability. E.g., for concrete without VA, the segregation index progressively increases of 277% according to the increase in SP content from 0.5 to 0.25%. However, the adding of SP does not affect stability if VA equal dosages in 0.1 and 0.15%, which can prevent segregation.

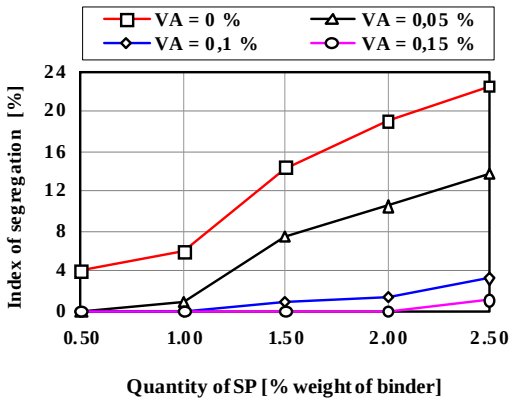

Figure 9. Effect of SP dosages and VA on the stability

Fig. 10 shows the evolution of compressive strength based dosages of SP and VA. Firstly, it is very evident that all the mixtures (SP = 0.5%) and those of (SP = 0.1% with VA = 0.1 or 0.15%) have very low strengths, not exceeding 11.5 MPa about. These strengths are generated due to the presence of very large volume of voids in the samples, which is caused by the lack of fluidity and absence of vibration during casting. Beyond these dosages unusable, adding VA contributes to the improvement of strength. Indeed, blends made with (SP = 1.5, 2 and 2.5%) increase in the strength gain respectively (9.62, 11.76 and 12.87%) approximately when the VA increases from (0 to 0.15%). For cons, the adding of SP caused a slight decrease strength which can be limited with a dosage (VA = 0.1%). It is believed that the increase or decrease of the compression strength is directly related to changes in stability.

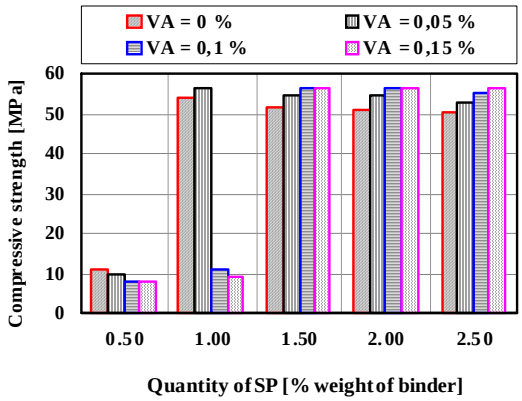

Figure 10. Effect of SP dosages and VA on the compressive strength

It is possible to see in Fig. 11 that the incorporation of VA in the SCC requires more SP to ensure fluidity given. Indeed, when the dosage of VA increases from 0 to 0.05%, we must add a supplementary quantity of SP (3.1, 3.42 and 3.96 kg/m3) respective in the SCC (30% LF, 30% NP and 40% S). The increase in SP dosage is due to the loss of fluidity caused by the adding of VA.

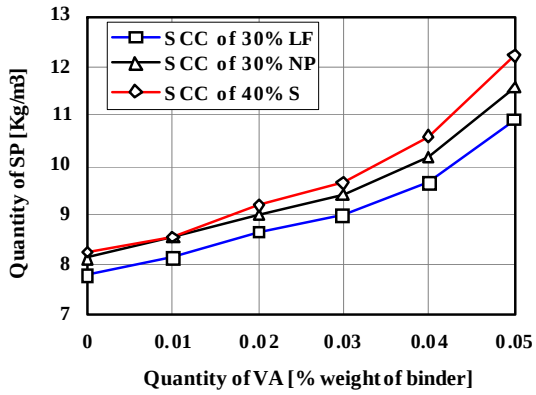

Figure 11. Dosage of SP necessary to achieve a slump flow of 80 cm as a function to the dosage in VA

According to Fig. 12 It may be noted that, for a constant fluidity guaranteed by adding the SP, increasing the dosage in VA improves deformability. The filling rate of all SCC is optimum with (VA = 0.03%).

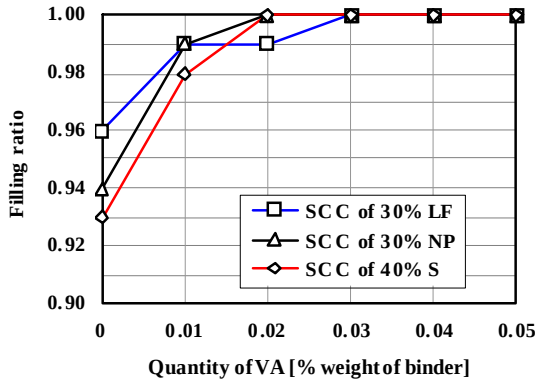

Figure 12. Effect of dosage in VA on the deformability of SCC with a slump flow of 80 cm

The authors also note in Fig. 13 that at the same fluidity, it is possible to obtain increased stability by adding the VA. The increase in dosage VA (0 to 0.05%) reduces the segregation index of 90% for three SCC studied. However, the improved stability is all the more significant when the dosage of VA does not exceed 0.03%.

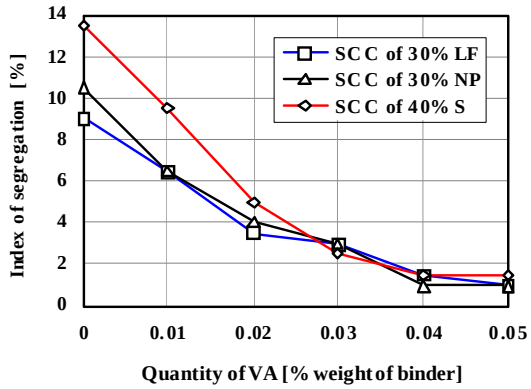

Figure 13. Effect of dosage in VA on the stability of SCC with a slump flow of 80 cm

In Fig. 14, it is evident that, for a fluidity equal the incorporation of VA slightly improves the compressive strength of SCC. However, this improvement is limited to dosage of (VA = 0.03%) because the stability of the SCC does not vary beyond this dosage. Note that adding of VA increases the compressive strength by improving stability.

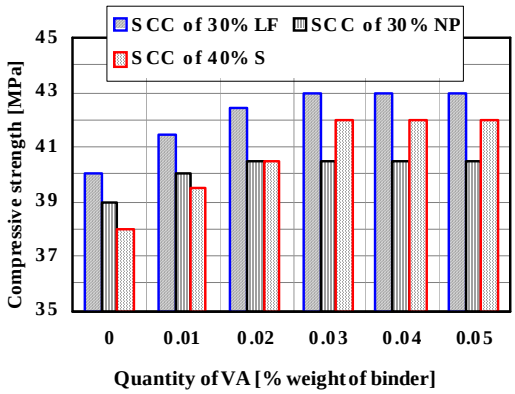

Figure 14. Effect of dosage in VA on the compressive strength of SCC with a slump flow of 80 cm

4. CONCLUSION

The main objective of this paper aimed to determine the effect of the nature and dosage of mineral additions (limestone filler, natural pozzolana and slag) as well as the viscosity modifying agent on the rheological properties and compressive strength of self-compacting concrete. Based on the results of this experimental study, the following conclusions could be drawn:

Introduction of mineral additions such as (LF, NP and S) in well-defined proportions significantly improves the rheological properties of SCC. However, this operation is to the detriment of the compressive strength. Mass proportions of the mineral additions (30% to 40% by binder mass) offer formulations the SCC that meet the criteria required by AFGC [46], while ensuring acceptable a compressive strength.

Incorporation of SP increases the fluidity and deformability but reduces slightly the stability and compressive strength. For cons, adding a VA is quite contrary. Loss of fluidity and deformability caused by adding a VA can be recovered by adding a SP without affecting the stability and compressive strength. However, high dosages of VA, the effect of SP is limited, or in other words, it is mainly related to dosage used of VA. Dosage in SP adequate to guarantee a fluidity given depends on the use of viscosity modifying agent. In more, the incorporation of VA for fluidity equal, improves much deformability, stability and compressive strength. The use of a dosage VA = 0.03% is sufficient to assure the best properties and with this dosage, SCC require reasonable quantities of SP.

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