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Valorization of Local Mineral Admixtures in Concretes

Abdelaziz Boudchicha[1] and Jean-Louis Gallias[2]
[1]University of Larbi Ben Mehidi, Department of Civil Engineering, Oum Bouaghi, Algeria
[2]University of Cergy-Pontoise, Laboratories of Mechanical and Civil Engineering Materials, France.

Abstract: This study is an extension of previous researches on mortars with mineral admixtures and super-plasticizers. In this way, the same methodology was applied to concretes and the use of mineral admixture was limited to low cost materials available in Algeria as limestone, pozzolan and blast furnace slag, with current cement and super-plasticizer. The experimental methodology used was based on the volume substitution of the cement by admixtures in mixtures with the absolute volume of the solid phases and workability preserved constant. The main results achieved showed that the super-plasticizer demand of concretes depends on the nature and the quantity of the incorporated admixture. The combined use of admixtures and super-plasticizer has generally a favourable effect on compressive strengths at 07 and 28 days at low rates of cement substitution, which vary significantly with the nature, fineness and quantity of the used admixtures. At 07 days, limestone admixtures give better improvements and reach more than 20 % of gain to the compressive strength of the reference concrete with no admixtures or super-plasticizer, at 10 % of the cement substitution and still better until 30 %. At 28 days, blast furnace slag admixtures give better improvements at 28 days and reach more than 20 % of gain to the compressive strength of the reference concrete at 20 % of the cement substitution and still better until 30 %. This contribution to the compressive strength is explained on the one hand by the reduction of the quantity of water in the mixtures at the same consistency, by the use of the super-plasticizer and on another hand by the activity of Limestone admixtures at early ages and to the latent hydraulic properties of blast furnace slag at 28 days.

I. introduction

Previous released studies showed that the combined use of mineral admixtures and super-plasticizers in mortars can generate certain modifications on the rheological and mechanical behaviors of cementing materials in the fresh and hardened states [1-7]. These modifications depend on several parameters such as, the nature, quantity and fineness of the incorporated admixture, as well as nature of cements and super-plasticizers used [8-14].
In this study, the main objective is to evaluate the benefit of mineral admixtures and super-plasticizers on the fresh and hardened properties of concretes. In this way, we used the same experimental methodology applied to the mortars while carrying out a progressive volume substitution of cement by mineral admixtures in concretes whose the absolute volume of the whole solid constituents and the consistency of mixtures are preserved constant [1-2 and 8-10].
The mineral admixtures retained for this study are those resulting from low costs natural materials or industrial co-products available in Algeria, as limestone, pozzolan and blast furnace slag admixtures.
The study of the mortars with admixtures, showed that the incorporation of mineral admixtures in mortars, produced, a physical effect related to the more or less unfavorable granular behavior, associated with a physicochemical and probably chemical activity of certain admixtures. This behavior is closely related on the nature of the incorporated admixture with the rate of the cement substitution [1-4 and 7-10].
The unfavorable granular effect of the mineral admixtures on mortars could be controlled by the incorporation of super-plasticizers. We could show that the combined use of mineral admixtures with super-plasticizers in mortars could have a positive contribution on compressive strengths. [4, 9-10].
For the used admixtures, the contribution of the mineral admixtures and super-plasticizers, compared to the reference mortar, remained favorable up to 20% of the rate of cement substitution for limestone and pozzolan admixtures with fineness more than 5000 cm²/g. For mortars with blast furnace slag, this contribution remained favorable up to 30% of the rate of cement substitution with fineness about 3000 cm²/g. The contribution to the compressive strengths was explained, by the control of the unfavorable granular effect with the use of super-plasticizers or the chemical activity of certain admixtures [1, 10].

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It results that the use of these admixtures with super-plasticizers has an interest in improving the compressive strengths of mortars at low rates of cement substitution. This interest was even more visible with the use of limestone or pozzolan admixtures with fineness more than 5000 cm²/g or blast furnace slag with fineness about 3000 cm²/g with the cements and super-plasticizers used.
Based on what has been narrated above, we want to confirm the contribution of some local mineral admixtures with low costs from natural deposits or co-products industry, to improve mechanical strengths of concrete. This use could enhance these types of admixtures while helping to reduce the quantities of cement needed to make concretes and to reduce CO2 emissions resulting from the cement industry.

II. Methodology

In this study we prepared reference concretes without mineral admixtures or super-plasticizers with plasticity and compressive strengths at 07 days and 28 days predefined.
On the basis of this reference plasticity, we analyzed the variation of the super-plasticizer demand for concretes with admixtures at the reference consistency depending to the rate of cement substitution by the admixture.
The action of the studied admixtures could cause a decrease or an increase in the consistency of concretes. These favorable or unfavorable effects on the rheological properties of fresh concretes, depended on the nature, quantity and granular characteristics (fineness and morphology) of the admixtures in the mixtures [1, 3-4, 9].
In what follows, we used in the reference concretes a quantity of water lower than that required for mixing concretes with admixtures with a favorable granular effect on the rheological properties. In this way, we have maintained in all formulations of concretes with or without admixtures a constant quantity of water, which required the addition of a certain amount of super-plasticizer needed to ensure the reference consistency which has been chosen equal to a slump of 70 mm. The choice of the amount of water in the different concrete formulations was set at 200 l/m3 to ensure a certain optimization when the dosage of super-plasticizer is maintained around the most optimum efficiency range.
The compressive strengths of concrete with mineral admixtures and super-plasticizers at 07 days and 28 days were analyzed in relation to the reference concretes depending on the rate of cement substitution by the admixture to highlight the contribution of these admixtures on the mechanical strengths of concretes.
Reference concretes were made using the method of Dreux Gorisse. The procedures for the preparation of concretes were conducted in accordance with European standard EN 206-1. The constituents of the concrete were introduced in the mixer in the following order: large elements, sand and binder, the water being added with the optionally super-plasticizer after 01 minute of dry mixing. The mixing of all components is continued for 02 minutes.
The test of plasticity of fresh concrete was conducted in accordance with European standard EN 12350-2, by using the slump test. The test is to observe the collapse of a concrete cone under the effect of its own weight. Concrete collapses is more or less important depending on consistency. After 01 minutes of the release, we measure with the portico, the slump to the highest point of the fresh concrete. Measurement rounded to the centimeter, characterized sagging.
Cubic specimens of 10x10x10 cm^3 were equipped with a system preventing evaporation and stored without being moved for 24 hours in a room with a temperature of 20° C±2°C. After removal, the samples were stored in water at a temperature of 20°C±2 ° C until the time of test. The compressive test on concrete specimens was performed according to European standard EN 206-1. In this case the specimen is examined under increasing load until failure. The compressive strength is the ratio of the breaking load per cross-section of the specimen.
The test was conducted at 07 and 28 days for each formulation, and the strength value is considered the average crushing stress of three specimens.

III. Materials

This study was achieved by using two types of cements currently used for the manufacturing of concretes in the east of Algeria. These cements have comparable fineness and C_3S content, but are different in the C_3A content.
We used current sand and considered three low cost mineral admixtures available in Algeria different by their mineralogical nature and their chemical composition: Limestone (L), Pozzolan (Pz) and Blast furnace slag (BFS) and one super-plasticizer (SP) SIKAFLUID, manufactured and marketed in Algeria.
The principal characteristics of materials used are given in tables1-4.

Table 1. Physical characteristics of materials used

Material	Designation	Specific gravity [Kg/m^3]	Specific Surface Blaine [cm^2/g]
CPJ-CEM II/A 42.5	C1	3100	3200
CPA-CEM I ES 42.5	C2	3150	3020
Limestone	L	2700	5100±270
Pozzolan	Pz	2650	5600±180
Blast-furnace slag	BFS	2800	2900±120

Table 2. Chemical composition of materials used

Designation	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	MnO	Na_2O	SO_3	LOI
C1	64.36	22.0	5.02	2.94	2.07	0.47	-	0.26	1.94	0.64
C2	63.91	21.62	4.49	5.37	1.66	0.25	-	0.08	1.92	0.81
L	55.5	-	-	0.03	0.8	-	-	-	-	43.6
Pz	10,10	44,85	17,20	10,50	3,40	1,60	-	4.05	1.50	4.10
BFS	43.01	40.8	5.2	0.53	6.4	-	3.02	-	-	-

Table 3. Mineralogical composition of the clinker (Bogue)

Minerals (%)	C_3S	C_2S	C_3A	C_4AF
C1	51.28	24.68	8.33	8.94
C2	52.48	22.69	2.82	16.32

IV. Experimental Program and results

IV.1 Making of the reference concrete

The reference concretes without admixtures or super-plasticizer were made by using method of Dreux Gorisse. The composition of the reference concretes B1-0 and B2-0 with cement C1 and C2 respectively were defined for a diameter of the largest aggregate of 25 mm, a slump test of 70 mm and a compressive strength of 25 MPa.
The procedures for the preparation of concrete, the slump test, making of samples, storage, and measurement of compressive strength were carried out according to the procedures described above.
The theoretical compositions of the reference concrete for cements C1 and C2 obtained by Dreux Gorisse method were adjusted to reach the formulations requirements.
The results for the two reference concretes indicated that the water requirement of reference concrete B1-0 is higher compared to B2-0. Compressive strength at 07 days of the reference concrete B1-0 is greater compared to B2-0 and the compressive strength at 28 days of the reference concrete B1-0 is less compared to B2-0.

IV.2 Effect of mineral admixtures on the consistency of concretes.

The cement substitution of cement by mineral admixtures causes a variation of the workability of the fresh mixture. The super-plasticizer demand (A/B in %) of concretes with admixtures needed to ensure the reference consistency for all the mixtures can be represented for the two cements by figure 1. We note that super-plasticizer demand of concretes with mineral admixtures varies significantly with the mineralogical nature, granular characteristics and the amount of the incorporated admixture into the mixture. Concretes with (L), (Pz) and (BFS) admixtures, present a super-plasticizer demand lower than that of the reference concretes for rates of cement substitution less than 10% for both cements used. This behavior confirms the optimization of the granular skeleton of the cementitious matrix for concrete with these mineral admixtures at low rates of cement substitution by admixtures. For highest rates of cement substitution by admixtures, the super-plasticizer demand increases with the increase of the admixture amount in the mixture, but differ from one to another admixture. The super-plasticizer demand is more important for concretes with (BFS) admixture, then with (L) admixture then with (Pz) admixture. This is probably due to the irregular and porous appearance of the (BFS) particles, despite their small fineness. It therefore follows that the reduction of the super-plasticizer demand for concretes with low rates of cement substitutions by admixtures compared to the reference concretes confirms an optimizing of the spatial arrangement of the particles in the mixture. This optimization tends to disappear at higher rates of cement substitution against the inter-granular frictions and surface tensions of the liquid phase, which are more visible for (BFS) admixture. This behavior has been confirmed by previous studies for mortars with fine admixtures [1-4, 9].

Table 4. Results for the studied concretes

Concrete	Rate of cement substitution (%)				Rate of cement substitution (%)				Rate of cement substitution (%)			
	0	10	20	30	0	10	20	30	0	10	20	30
	Super-plasticizer demand (%)				Compressive strengths Rc 07 (Mpa)				Compressive strengths Rc 28 (Mpa)			
B1-0	0	0	0	0	12,09	12,09	12,09	12,09	26,2	26,2	26,2	26,2
B1-SP-L	0,95	0,78	1,02	1,35	13,3	15,03	13,7	12,37	29,08	27,04	27,72	22,68
B1-SP-PZ	0,95	0,65	0,75	1,2	13,3	11,57	12,09	8,91	29,08	28,21	27,04	25,3
B1-SP-BFS	0,95	0,85	1,18	1,45	13,3	13,57	13,43	12,34	29,08	30,53	31,7	28,79
B2-0	0	0	0	0	11,27	11,27	11,27	11,27	27,9	27,9	27,9	27,9
B2-SP-L	0,88	0,61	0,81	1,08	12,42	13,97	12,69	11,43	31,12	28,94	26,08	23,9
B2-SP-PZ	0,88	0,54	0,58	0,91	12,42	11,3	9,63	8,35	31,12	31,59	29,25	26,92
B2-SP-BFS	0,88	0,71	0,98	1,31	12,42	12,87	12,63	11,71	31,12	32,36	34,48	30,68

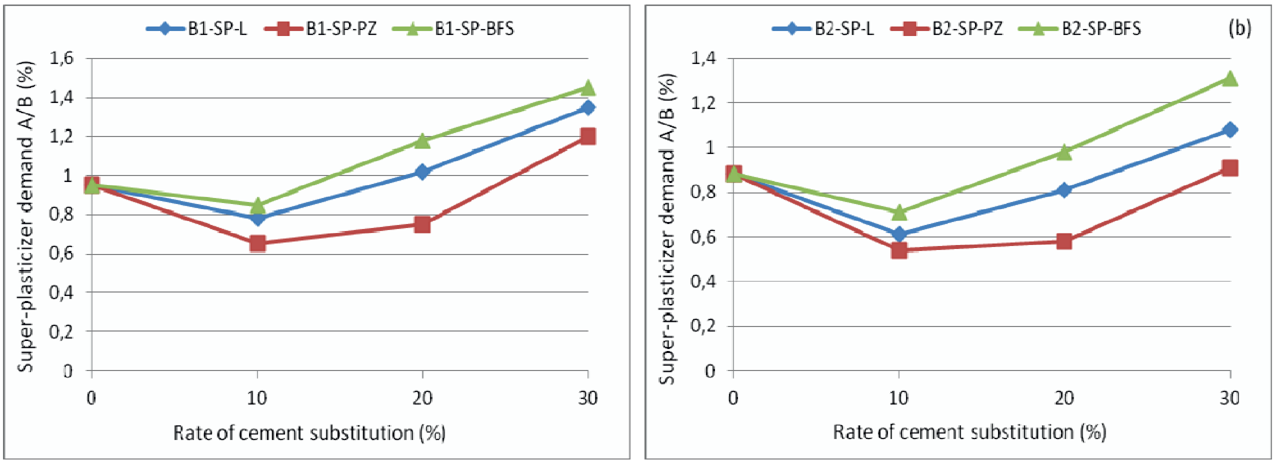

Fig. 1: Variation of the super-plasticizer demand of concretes B1 (a) and B2 (b) with admixtures at the same consistency

IV.3 Contribution of mineral admixtures and super-plasticizer to the compressive strengths of concretes.

The contribution of mineral admixtures and super-plasticizer to the compressive strengths of concretes at 07 days and 28 days can be evaluated by analyzing the variation of compressive strengths of concretes with admixtures and super-plasticizer (B-SP-Ad), compared to the reference concrete without admixtures or super-plasticizers (B-0), depending on the rate of cement substitution by admixtures for both cements used.
The results for the studied concretes can be summarized in table 4. These results confirm the positive contribution of the combined action of admixtures and super-plasticizer on compressive strengths at low rates of cement substitution. This contribution depends on the nature and amount of admixture in the mixture, as well as the nature of the cement used.

IV.3.1 Compressive strengths at 07 days.

The contribution of mineral admixtures and super-plasticizer to the compressive strengths at 07 days can be represented as a function of the rate of cement substitution for concrete B1 (a) and B2 (b) by figure 2.

We can see in Figure 2 that the contribution of super-plasticizer SP to the compressive strengths at 07 days for concrete B1 and B2 without admixtures, can reach up to 10% improvement. For concretes with (L) admixture, the contribution to the compressive strength is maximal at 10% of the rate of cement substitution and remains favorable up to 30% of the rate of cement substitution for both cements used. In this case, the maximum gain of compressive strength can reach 24% for concretes B1 and B2. The contribution of (Pz) admixture to the compressive strength at 07 days is unfavorable, but the addition of super-plasticizer SP keeps these strengths at this level up to 10% of the rate of cement substitution for both cements used. Indeed, the gain of compressive strength at 07 days is maximal for concrete with SP and without admixture. For concretes with (BFS) admixture, the contribution to the compressive strength is maximal at 10% of the rate of cement substitution and remains favorable up to 30% for both cements used. In this case, the maximum gain of compressive strength can reach 12% for concrete B1 and B2 with super-plasticizer SP.
We can therefore confirm that the combined action of mineral admixtures and super-plasticizer on the compressive strengths at 07 days, is conducive at low rates of cement substitution and behavior of admixtures is better with cement C2. The limestone admixture brings the best gain on compressive strengths of concretes at 07 days in the presence of super-plasticizers. The positive contribution of limestone admixture is mainly due to the acceleration of the process of hydration of cement by at youth ages, as well as reducing of the amount of water necessary to the reference consistency by using of super-plasticizer. This behavior of limestone at youth ages has been confirmed by several authors [1, 4, 5, 7, 8] and can be influenced by the nature of cement and the super-plasticizers used [5, 6, 8, 10- 14].

IV.3.2 Compressive strengths at 28 days

The contribution of mineral admixtures and super-plasticizer to the compressive strengths at 28 days can be represented as a function of the rate of cement substitution for concrete B1 (a) and B2 (b) by figure 3.
We can see in Figure 3 that the contribution of super-plasticizer SP to the compressive strengths at 28 days, can reach up to 11 % and 12 % improvement for concretes B1 and B2 without admixtures, respectively.

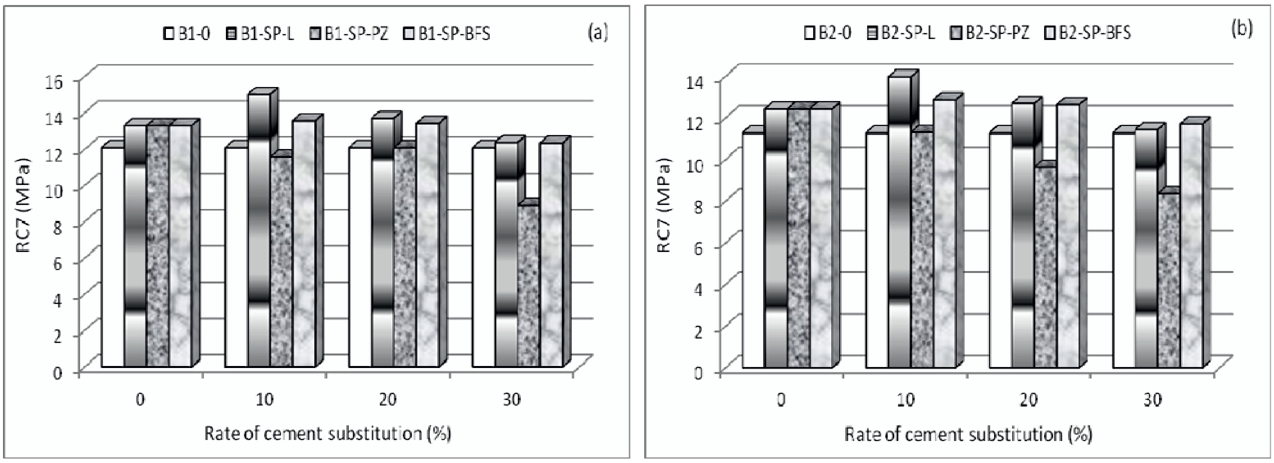

Fig. 2: Contribution of (L), (Pz) and (BFS) admixtures with SP to the compressive strengths of concretes B1(a) and B2 (b) at 07 days

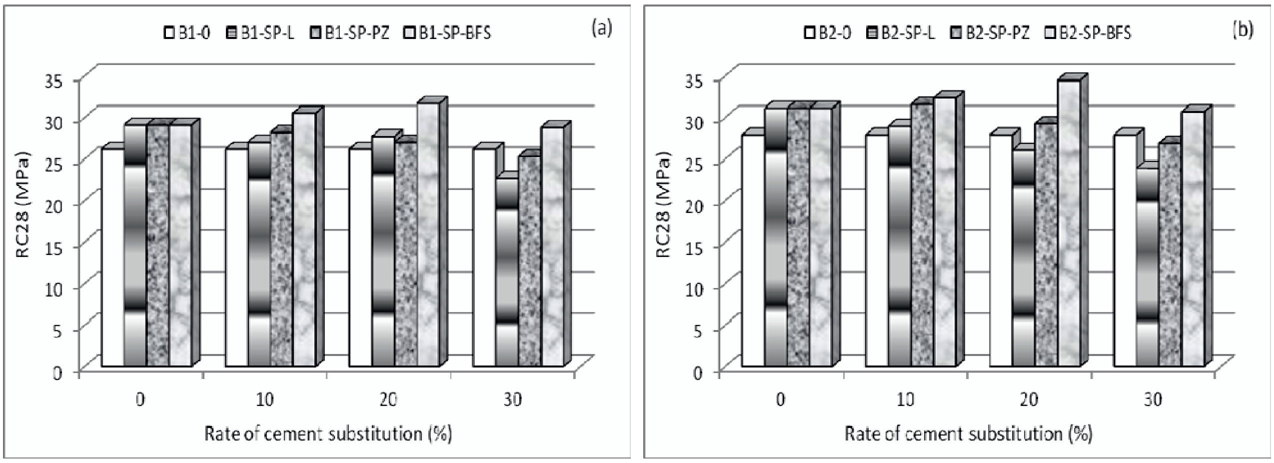

Fig. 3: Contribution of (L), (Pz) and (BFS) admixtures with SP to the compressive strengths of concretes B1(a) and B2 (b) at 28 days

The contribution of limestone admixture to the compressive strengths at 28 days is unfavorable, but the addition of super-plasticizer SP provides greater resistance than that of concrete without admixtures up to 10% of the rate of cement substitution for the two cements used. Indeed, the gain of compressive strength at 28 days is maximal for concrete with super-plasticizer and without admixture. For concretes with Pozzolan admixture, the contribution to the compressive strength is maximal at 10% of the rate of cement substitution and remains favorable up to 20% of the rate of cement substitution for both cements used. The maximum gain of compressive strength can reach 08% and 13% for concretes B1 and B2, respectively.

For concretes with (BFS) admixture, the contribution to the compressive strength at 28 days is maximal at 20% of the rate of cement substitution and remains favorable up to 30% of the rate of cement substitution for both cements used. In this case, the maximal gain of compressive strength can reach 21% and 24% for both concretes B1 and B2, respectively.

We can therefore confirm that the combined action of mineral admixtures and super-plasticizers on compressive strengths of concretes at 28 days is favorable at low rates of cement substitution and behavior of admixtures is better with cement C2. This contribution to the compressive strengths at 28 days is at first due to the reducing of the amount of water in the mixture with the same consistency through the use of super-plasticizer SP [6, 10]. The use of super-plasticizer may also contribute to improving the process of hydration of cement as confirmed by several studies [11-14]. These occurrences could result in a strength gain interest in the image of concrete without admixtures for which improved resistance can reach 12% for concrete B1-SP without admixtures. Second, this contribution to the compressive strength at 28 days is due to the chemical activity of the admixture itself, which in the case of admixtures of type II, provide significant addition to the strength gain [1-4, 7-8], which can reach up to 24% in concrete B2 with cumulative use of (BFS) admixture and super-plasticizer SP at 20% of the rate of cement substitution. The positive contribution of (BFS) is mainly due to its latent hydraulic properties.

So it follows that the results obtained for concretes with admixtures and super-plasticizer, advanced to meet overall mortars results. Phenomena at the origin of mechanical improvements to 07 days and 28 days resistances have been developed and analyzed in the previous studies and can be renewed for concretes [1-4, 7-8].

Conclusions

The main objective of this study was to confirm the contribution of certain of low cost mineral admixtures to mechanical resistance of concretes. The study was limited to limestone, pozzolan and (BFS) admixtures with two cements and super-plasticizer currently used and. In this study, we have maintained in all concrete formulations with or without admixtures a constant quantity of water, which required the addition of a certain amount of super-plasticizer needed to ensure the reference consistency.
The principal conclusions can be summarized as follow:
The cement substitution of cement by mineral admixtures causes a variation of the workability of the fresh mixture, which depend on the mineralogical nature, granular characteristics and the amount of the incorporated admixture into the mixture.
The reduction of the super-plasticizer demand for concretes at low rates of cement substitutions by admixtures compared to the reference concretes confirms an optimizing of the spatial arrangement of the particles in the mixture. This optimization tends to disappear at higher rates of cement substitution against the inter-granular frictions and surface tensions of the liquid phase.
The combined action of mineral admixtures and super-plasticizer on the compressive strengths at 07 days and 28 days is conducive at low rates of cement substitution and behavior of admixtures is better with cement C2.
The limestone admixture brings the best gain on resistances at 07 days in the presence of super-plasticizers. Its positive contribution is mainly due to the acceleration of the process of hydration of cement at youth ages, as well as reducing of the amount of water by using SP.
The contribution of admixtures to compressive strengths at 28 days is at first due to the reducing of the amount of water through the use of super-plasticizer SP which may also contribute to improving the process of hydration of cement. Second, this contribution is due to the chemical activity of the admixture itself, which in the case of admixtures of type II, provide significant addition to the strength gain.

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