Study of Limestone Addition on the Mechanical and Rheological Characteristics in the SCC

F. Ghomari, S.M.A. Boukli Hacene and O. Taleb

Abou Bekr Belkaïd, Tlemcen University, Department of Civil Engineering, Algeria,
ghomarifouad@yahoo.fr, boukli_ma@yahoo.fr, omataleb@yahoo.fr

ABSTRACT

The following research is a contribution to quantify the influence of limestone addition on the properties of the fresh and hardened concrete (SCC). For that purpose, several mixtures of SCC have been formulated and studied in laboratory. Fluidity, blocking and segregation were studied by varying the dosage of mineral additives. Then, the influence of granular skeleton G/S on the behaviour of the SCC was displayed.

The characteristics of concretes made in the laboratory have been identified using tests recommended by the French Association of Civil Engineering (AFGC, 2008). In particular, slump flow test with and without Japanese ring, L box, test of stability to the sieve then the V-funnel test were conducted. In parallel, the cylindrical sample of 16×32cm was tested for each combination in order to follow the evolution of compressive strength at 28 days. The results obtained were treated by the analysis of variance (ANOVA) method using a commercial software (SPSS, ver. 17.0). We carried out this statistical analysis in order to determine the statistically significant factors. Several strong correlations were found.

KEYWORDS: Self compacting concrete (SCC), Formulation, Mineral addition, Segregation, Optimization, Correlation.

INTRODUCTION

Self Compacting Concretes (SCC) are special concretes, which are very fluid. They are set up and tightened under the only effect of gravity, without internal or external contribution of vibration even in the highly reinforced formwork. These concretes are obviously qualified as self-compacting only if the materials have at the same time a sufficient cohesion to be handled without segregation. By testifying the productivity gains and elimination of problems related to vibration, the SCC seem to be among the technical progresses which make the trade of civil engineering more attractive, because they improve the conditions of implementation on building sites (CimBéton, 2003).

The principal disadvantage of SCC is the expensive cost of the raw materials due to using new additives and a great quantity of cement.

The use of mineral additives is an alternative to reduce the cost of SCC. Indeed, the use of these additives could not only increase the fluidity of concrete but they also could reduce the superplasticizer use. Also, the incorporation of these fine materials affects the physical characteristics by improving the particle size distribution and compactness of the mixture, thus ensuring a greater cohesion.

Research Significance

Currently, much scientific research and practices of construction proved that the most effective and most

Accepted for Publication on 15/7/2011.

economic method for the formulation of self-compacting concretes and self-leveling concretes is simultaneously to use superplasticizers and reduce water with the reinforcement of the paste by mineral additives.

The basic function of the superplasticizer in a cementing mixture is fluxing (Serdar et al., 2009). The use of additives generally results in the improvement of workability and the installation of concrete. These additives increase cohesion and thus lead to a reduction in sweating and segregation of the concrete. This involves a reduction of hydration heat and, consequently, decreases the thermal risk of cracking (Aïtcin, 2001). Also, the mineral additives improve the impermeability and tenacity against chemical attacks (Lapointe, 1997).

Table 1. Physico-chemical properties of cement and fillers

	Cement		Limestone fillers
	Chemical analysis	Fluorescence X (%)	Chemical analysis
SiO_2 (%)	27.97	25.64	5.18
Al_2O_3 (%)	5.43	5.64	-
Fe_2O_3 (%)	3.05	3.06	0.51
CaO (%)	56.37	58.01	33.95
MgO (%)	0.71	0.72	19.32
SO_3 (%)	-	1.73	-
Na_2O (%)	0.30	0.71	-
K_2O (%)	0.43	0.51	-
CaO libre (%)	0.75	-	-
CO_3	-	-	95.30
Insoluble Residues, I.R.	9.11	-	-
Fire loss	3.11	-	42.46
Anhydrite carbonate	-	-	41.93
Blaine specific surface (cm^2/g)	3598		2900
Bulk density (kg/m^3)	0.98	-	41.93
Absolute density (kg/m^3)	3.071		

Table 2. Mineralogical composition of clinker

C_3S	C_2S	C_3A	C_4AF	$C\bar{S}$
59.98	2.15	9.87	9.31	2.94

Several types of additives can be used alone or in combinations in making self-compacting concretes (Felekoglu et al., 2006; Gesoglu et al., 2008). The influence of mineral additives on viscosity depends on proportioning, nature, smoothness, particle shape and granularity (Sahmaran et al., 2006).

The aim of our study is to investigate the influence of limestone fillers on the characteristics of fresh and hardened SCC. These limestone fillers may offer technical and ecological solutions in the estate of construction, while enhancing economic development by the fact that the use of these fine limestones can reduce the high demand on cement, especially since Algeria is experiencing an important development in the construction industry.

The construction companies will be able to benefit from this research to market self-compacting concretes, based on the use of these additives.

Table 3. Quantitative variation of the binder in the composition of BAP (variation by content fillers)

Cement (kg/m^3)	Limestone fillers (kg/m^3)	Filler / Cement
550 (100%)	0 (0%)	0
495 (90%)	55 (10%)	11.11%
440 (80%)	110 (20%)	25.00%
385 (70%)	165 (30%)	42.80%
330 (60%)	220 (40%)	66.66%

Table 4. Formulations of SCC (variation by G/S)

	G/S = 0.8	G/S = 0.9	G/S = 1	G/S = 1.1	G/S = 1.2
Cement (kg/m^3)	440	440	440	440	440
Filler (kg/m^3)	110	110	110	110	110
Sand (kg/m^3)	833.33	789.47	750	714.28	681.81
Gravel 4/8 (kg/m^3)	222.22	236.84	250	261.90	272.72
Gravel 8/16 (kg/m^3)	444.44	473.68	500	523.81	545.45
Water (liter)	275	275	275	275	275
superplasticizer (kg)	6.6	6.6	6.6	6.6	6.6
W/P	0.5	0.5	0.5	0.5	0.5

Materials Used

The mixtures of concrete were prepared with cement from the cement works of Beni-saf (Wilaya of Ain Temouchent), type CPJ CEM II 42.5 (clinker 85%; gypsum 3%; Pozzolan 10%; sandy limestone 2%) with a density of 3.071.

The limestones came from the career of El Malah (Wilaya of Ain Temouchent). The rock is calcareous dolomitic. These limestones have an absolute density of 2.72. Chemical and physical properties of cement and fillers are summarized in Table 1; whereas the mineralogical composition of clinker is given in Table 2.

Calcareous aggregates used in this study (crushed), in particular sand (0/4), came from the career of Ramdani Ocheba (Tlemcen), gravels (4/8) and (8/16) came from the career of Sidi-Abdelli, property of the National Company of Aggregates (ENG). The density of gravels was equal to 2.60; whereas that of sand was 2.77.

We have also used the superplasticizer “TEK superflow 2000R” (marketed by the group of companies HASNAOUI), a high water reducer with retarding effect, especially formulated for the concretes ready to use. At 20°C, it has a density of 1.2 ± 5%.

EXPERIMENTAL PROGRAM

Composition of Mixing

The compositions of concretes in this study were empirically given, starting from tests or former experiments (Taleb et al., 2008; Taleb, 2009). The mixture proportions varied according to experimental feedback.

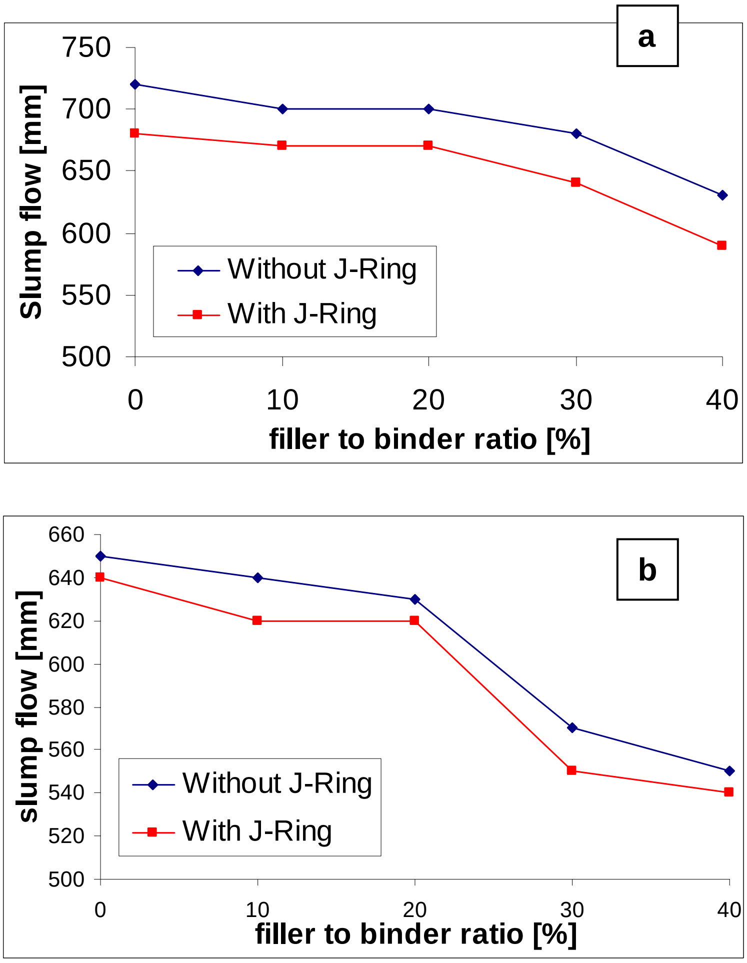

Figure 1: Slump flow of the SCC according to the percentage of fillers ((a): W/P = 0.50, (b): W/P = 0.47))

Of course, some parameters were taken into account. First of all, the composition of the paste was designed according to the requirements for resistance; whereas the volume of the paste was chosen to reach the necessary fluidity and to resist segregation. On the other hand, the aggregates were selected to avoid segregation and blocking. Lastly, the proportioning of superplasticizer saturation has been determined by the cone method of Marsh (EN12715). We have found within the framework of this study that the proportioning of saturation in superplasticizer was 1.5% of the weight of cement. The superplasticizer became useless if we went beyond that proportioning because the cement grains were saturated by the additive.

The superplasticizer was diluted in water before being added to the concrete because that allows a better distribution of the relatively small quantity of additives in the mass of the SCC.

The order of the materials introduced and the time of mixing have great importance. Johansson (1971) found that the time necessary to reach dispersion was related to the diameter of the material considered. This implies that the distribution of the aggregates is reached more quickly than the distribution of sand or of fine particles. As an SCC contains more fine particles than an ordinary concrete, the time of its mixing should be more important.

We have proceeded firstly to dry mixing. During one minute, aggregates were mixed with cement and fillers together, then we added 60% water for a half minute. The remaining 40% water containing the superplasticizer was poured into the mixer which continued to mix for another half minute. The process of mixing continued for 2 additional minutes.

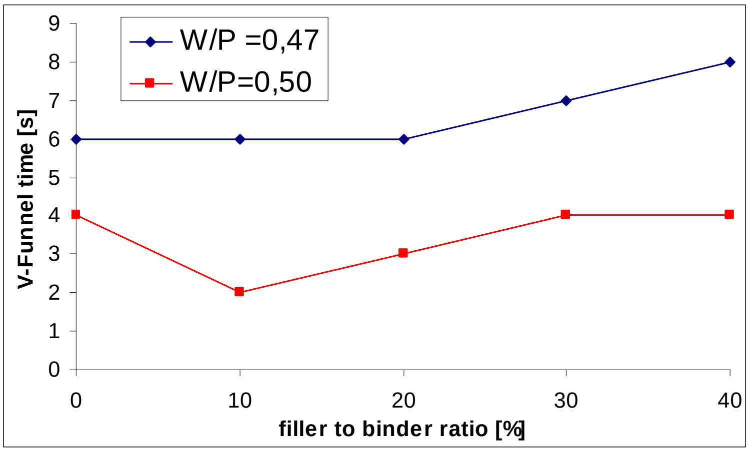

Figure 2: Time of flow in V-funnel according to the percentage of limestone fillers

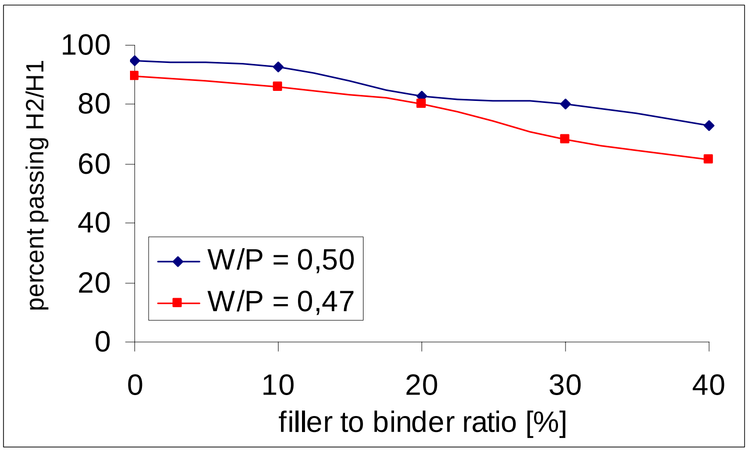

Figure 3: Rate of filling according to the percentage of fillers

Characterization of Concretes

Characterization in the Fresh State

The functional requirements of a fresh SCC are different from those of a vibrated concrete. The properties of SCC can be divided into three measurable criteria by empirical tests: the filling, the resistance to segregation and the capacity to be passed through obstacles (capacity of passage). Each one of these characteristics should be independently evaluated.

(a) The filling or the deformability of the concrete is a criterion which arises directly from its fluidity. Two aspects were highlighted: the capacity and the speed of filling were evaluated with assistance of the test of slump flow (PR NF EN 12350-8) and the test of the V – funnel (PR NF EN 12350-9).

(b) The capacity of passage through obstacles such as narrow sections of the formwork or brought closer bars of reinforcement is mainly affected by the characteristics of the aggregates and the volume of the paste. In our work, this aptitude to cross a reinforced zone was evaluated with the L – Box test (PR NF EN 12350 - 10) and the J - Ring test (PR NF EN 12350-12).

(c) To resist segregation, the SCC should be very fluid and rich in paste. Thus, it is necessary to ensure the stability of fresh materials in order to guarantee the homogeneity of the mechanical characteristics of the final structure. Segregation is known as “dynamic” when it occurs at the time of the installation of the concrete and “static” when it occurs later on following the compression of the components until the catch of materials. The test of stability (GTM) (PR NF EN 12350-11) allowed to check the resistance against segregation for our concretes.

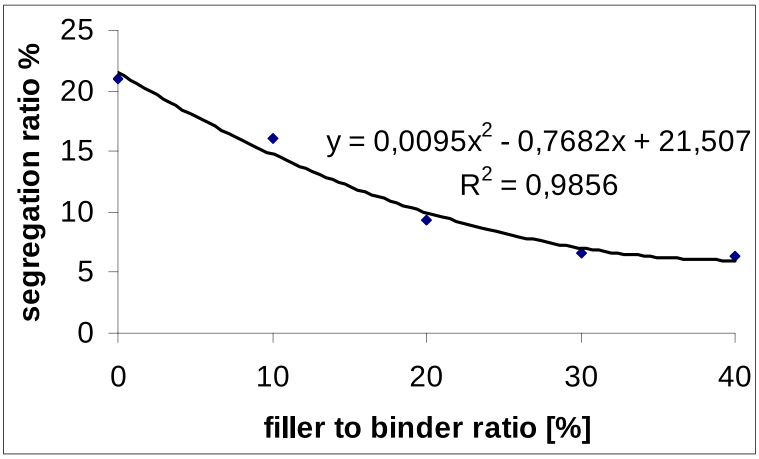

Figure 4: Stability with the sieve according to the percentage of fillers (W/P = 0.50)

Mechanical Properties

Concerning the characteristics of the concrete in the hardened state, the compressive strength was obtained on cylindrical samples (16 × 32 cm) the filling of which was carried out without vibration. After that, the cylindrical samples remained 24 hours in their moulds and were then released from them. Then, they were completely immersed in water at a temperature of 20°C during 28 days of curing.

RESULTS AND DISCUSSION

Influence of Filler on the Characteristics of the SCC

The substitution of a part of the cement by mineral additives, in particular limestone fillers, appears interesting at the economic, ecological and technical levels. In order to study the influence of limestone fillers on the characteristics of self-compacting concrete in the fresh state and on its resistances in the hardened state, several concretes were made while varying the filler proportioning. Filler proportioning was varied in the range from 10% to 40% of the weight of the binder (cement + fillers) by steps of 10% each (see Table 3).

For this reason, two ratios (W/P) were selected for our study : 0.47 and 0.5. We also chose to formulate our concretes with a sand proportioning of 750 kg/m^3, a ratio G/S = 1 and a ratio G (4/8)/G (8/16) = 0.5. During this partial substitution of cement by limestone fillers, we supposed that the powder consumption of the superplasticizer was negligible because the presence of (Al_2O_3) in our fillers was almost zero.

Figure 1 shows that the reduction in spreading out seems to be related to the content of powder. Indeed, this reduction accelerates for a ratio W/L = 0.5 when the powder rate exceeds 30%; while for a ratio W/L = 0.47, this reduction accelerates when the powder rate exceeds 20%.

For an SCC of a 40% content of filler, we have observed a reduction in the diameter of spreading out of 7% compared to that of a 30% content of filler, which presents only a 5.5% reduction compared with an SCC formulated with cement without addition (0% limestone filler). This result does not disturb in the sense that the percentage of additives allowed by European standards must be ≤ 30% of the mass of the binder.

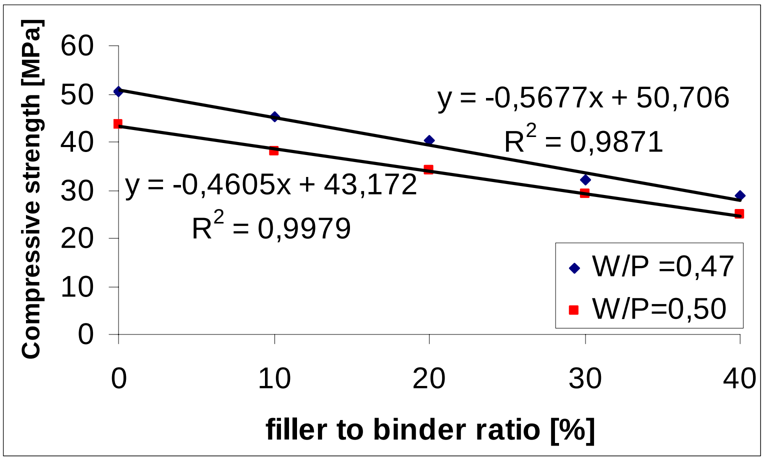

Figure 5: Compressive strength at 28 days according to the percentage of fillers

Concerning the SCC formulated with a ratio W/L = 0.47, the results obtained enable us to advance that it is impossible to obtain a spreading out higher than 600 mm when the content of powder exceeds 20%. For this reason, a reduction of 16.5 liters of water per cubic meter of the concrete can reduce the spreading out from 16% to 10%. So, our results are the same as those of Gallias et al. (2000) showing that the requirement for water is more important when it is a question of using mineral powder in the partial substitution of cement. We can also attribute this reduction in spreading out to the smoothness of the fillers (2900 cm^2/g) used which is lower than that of the cement tested (3598 cm^2/g). Unfortunately, other tests are necessary to confirm this result.

In addition, the difference between the diameters of spreading out obtained with and without the Japanese ring varies between 20 and 40 mm. This difference highlights the loss of filling due to the presence of reinforcements. It remains lower than the threshold recommended by the EFNARC which is 50mm. However, the increase in the water content in the mixture can favour a scrubbing of the paste. Figure 1 shows that the loss of filling to the Japanese ring is definitely higher for a ratio W/C = 0.5.

The results obtained lead us to say that these additives decrease the viscosity of the concrete until a certain rate of substitution. The friction between the particles becomes more important and increases, by consequence, the viscosity of the mixture (Figure 2).

For an SCC with a high content of fillers (40%), increasing the W/P ratio from 0.47 to 0.5 reduced the flow time of the V-funnel to the half.

Due to the presence of a large amount of fines in the mixture, more water is necessary to maintain a good flow. Below a certain threshold of W/P, the friction between the particles can increase, and even double, thus seriously disrupting the flow of concrete.

Mobility in confined surroundings is strongly related to the proportioning of powder limestone. The growth of the content of these additives affects the flow. On the other hand, in an SCC with a ratio W/P = 0.47, the rate of filling was re-examined with L box showing a decrease. We have found for an SCC of a ratio F/(C+F) = 0.30 a reduction in the rate of filling of 16% compared to that of an SCC with W/P = 0.5. This rate is 68% for a ratio W/P = 0.47; whereas it is 81% for a ratio W/P = 0.50 (Figure 3). That is explained by the great influence of limestone fillers of dolomitic nature on the demand on water.

Partial substitution of cement by these additives made it possible to improve the consistency of the paste in such a way that it can maintain the grains of sand and the other aggregates in suspension. For this reason, a mass substitution of 20% of cement by fillers made it possible to improve the stability by 44.5%; whereas a substitution of 40% improved the stability by 70% (Figure 4).

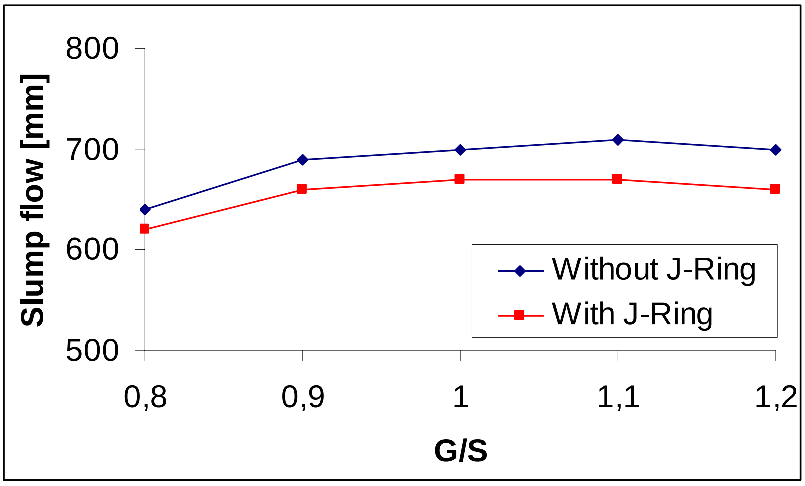

Figure 6: Slump flow of the SCC according to G/S

The need for carrying out a substitution of cement by alternate standard filler components will not be without consequences on the mechanical resistance developed by the concrete.

For a ratio W/L of 0.50, partial substitution of 10%, 20%, 30% and 40% reduced compressive strength at 28 days by 12.5%, 21.5%, 33% and 43%, respectively.

Thus, it is clear that the compressive strength decreases with the rate of substitution of cement by these additives (good correlation R = -0.920, significance =1.21e-006). The mechanical resistance in compression is inversely proportional to the content of fillers as shown in Figure 5. This is mainly explained by the fact that the introduction of a volume of fillers is accompanied by a reduction of the quantity of cement leading to a higher W/C ratio. This modification is due to the reduction in the volume of the formed hydrates resulting in lower resistances. On the other hand, the smoothness of the fillers, which is less important than that of cement, facilitates the reduction in the resistance of concrete.

However, a reduction of W/P ratio from 0.50 to 0.47 for SCC, with a 20% rate of filler, makes it possible to improve the resistance by 18%.

Figure 5 shows that the decrease of resistance according to the fillers is always linear. However, the tangent of the right-hand side has a tendency to increase by reducing the W/P ratio.

The Influence of G/S Ratio on the Characteristics of SCC

The modification of the granular skeleton and thus of the maximum compactness of the mixture directly influences the flow. The optimization of the parameter G/S is essential for self-compacting concrete, which requires a high fluidity and a good capacity of passage.

In order to better understand the influence of this parameter, we have compared SCC different only in their G/S ratios. G/S values recommended for the SCC are between 0.8 and 1.2. This ratio, which is close to 1, makes it possible to improve the workability of concrete by reducing the friction between the coarse aggregates. Aggregate proportioning (G+S) is fixed with a substitution of 20% of the mass of cement by limestone fillers. This rate of substitution is selected in order to not decrease too much the compressive strength at 28 days. The formulations are consigned in Table 4.

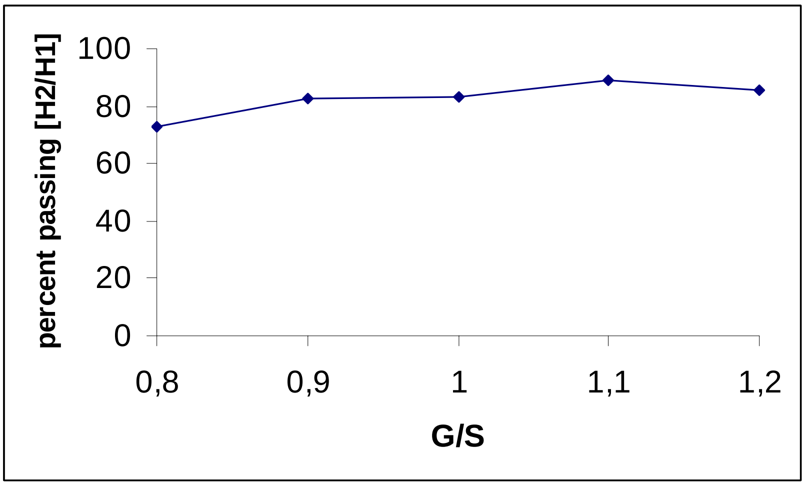

Figure 7: Rate of filling H2/H1 according to G/S ratio

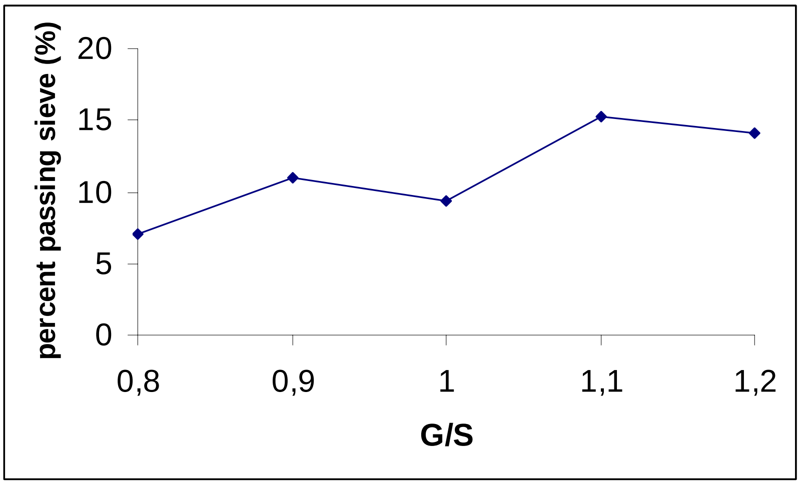

Figure 8: Stability with the sieve according to G/S ratio

Figure 6 shows that the optimum of the G/S ratio appears around 1.1, where we have measured the best spreading out of 710 mm.

For G/S ratios lower than 1.1, spreading out decreases. That occurs because the sand content reduces the quantity of free water which is responsible for the fluidity in the mixture, since the absorption of water by sand is much higher than that of the gravels. This is due to the presence of powder in sand. Deprived of a quantity of free water, the mixture is found less spread.

When G/S ratio is higher than 1.1, the gravel rate becomes approximately higher than that of sand, thus increasing friction in the mixture. This friction will penalize the flow.

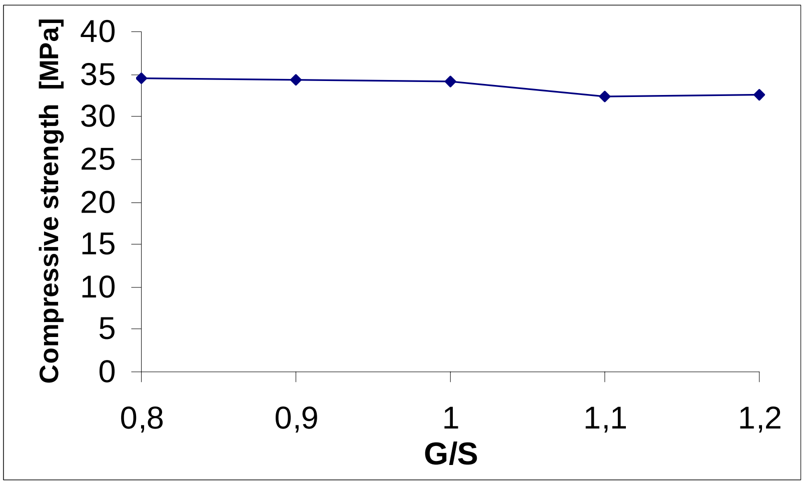

Figure 9: Compressive strength at 28 days according to G/S ratio

Photo 1: Spreading out through the J. ring (G/S = 1.2)

Figure 6 shows clearly that the increase in G/S ratio is marked by a greater loss with the filling when the Japanese ring (J. ring) is used in combination with the Abrams cone. This scenario is allotted to the increase in the coarse aggregates in the mixture (see Photo 1).

The L box results support those obtained previously. SCC with ratios G/S < 1 were penalized by a fluidity reduction that led to weaker filling rates. However (G/S = 1.2) seems to affect the passage of the concrete to the level of the reinforcement bars and to justify the reduction of the filling rate (Figure 7). Figure 8 shows that the increase in the sand content improves the stability of concrete and thus reduces the phenomenon of segregation. The mortar becomes more consistent and maintains the coarse aggregates in suspension. On the other hand, the growth of sand content led to the reduction of free water and coarse aggregates which are generally the segregation origin.

The compression tests performed on the concretes at 28 days made clear as shown in Figure 9 that the reduction in G/S ratio does not influence in a significant way the mechanical resistance of the concrete (variation < 2 MPa). However, it can be noted in our study that the optimization of the skeleton which has the highest strength is with G/S = 0.8. However, this point needs further study and in depth research.

In addition, a variation of the respective proportions of the granular fractions could have only one impact which is a reduction in the mechanical performance, as the proportioning of the paste is important and can play a big role in the level of resistance. This result can also be explained by the fact that the concrete density increases with the ratio S/(S+G), which leads to less cracks in the interface between the paste and the aggregates (gravels). Thus, the compressive strength is controlled by the paste resistance and the interface paste/ aggregates resistance.

CONCLUSIONS

The partial substitution of cement by additives of the type of limestone fillers made it possible to improve the consistency of the paste in such a way that it can maintain the grains of sand and the other aggregates in hanging up. Nevertheless, this substitution will not be without consequences on the developed mechanical resistance. Moreover, the optimal filler proportioning depends on the type of work to realize. Maximum proportioning of 20% filler can be sufficient if the criterion of resistance is imposed. On the other hand, a filler proportioning between 30% and 40% can be tolerated if the prevention of cracks due to withdrawal is the wished criterion.

However, a mixture with a reduced G/S ratio tends to put a great demand on water because of the presence of fines in sand. This factor tends to reduce the spreading out of the concrete. A ratio G/S = 1.1 was identified as being optimal for an SCC containing local materials.

REFERENCES

Aïtcin, P.C. 2001. Bétons haute performance, Editions Eyrolles, France, 683 pages.

Association Française de Génie Civil. 2008. Recommandations pour l'emploi des bétons auto – plaçants, Documents Scientifiques et Techniques, Janvier, 65 pages.

Aydin Serdar, Hilmi Aytac, A. and Ramyar, K. 2009. Effects of fineness of cement on polynaphthalene sulfonate based superplasticizer - cement interaction, *Construction and Building Materials*, 23, June, 2402-2408.

Collection Technique CimBéton, Bétons Autoplaçants. 2003. Monographie d'ouvrages en BAP, Edition Décembre.

Felekoglu, B., Tosun, K., Baradam, B., Altun, A. and Uyulgan, B. 2006. The effect of fly ash and limestone fillers on the viscosity and compressive strength of self-compacting mortars, *Cement and Concrete Research*, 36: 1719-1726.

Gallias, J.L., Kara-Ali, R. and Bigas, J.P. 2000. The effect of fine mineral admixtures on water requirement of cement pastes, *Cement and Concrete Research*, 30: 1543-1549.

Johansson, Arne. 1971. The relationship between mixing time and type of concrete mixer, Swedish Cement and Concrete Research Institute, *Proceedings HANDLINGAR*, Stockholm.

Lapointe, R. 1997. Contribution à l'étude des méthodes d'injections des fissures dans le béton, Mémoire des études graduées, Université McGill, Montréal, Canada.

Mehmet Gesoglu, Erhan Güneyisi, A. and Erdogan Özbay. 2008. Properties of self-compacting concretes made with binary, ternary and quaternary cementitious blends of fly ash, blast furnace slag and silica fume, *Construction and Building Materials*, doi:10.1016/j.conbuildmat.2008.09.015.

Sahmaran, M., Christianto, H.A. and Özgür, Yaman, I. 2006. The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars, *Cement and Concrete Composites*, 28: 432-440.

Taleb, O., Ghomari, F. and Boukli Hacène, M.A. 2008. Amélioration de la qualité du béton fourni par des entreprises locales, *Séminaire National de Génie Civil "SNGC08",* Chlef, 15-16 Décembre 2008 (Algérie).

Taleb, O. 2009. Optimisation de la formulation des bétons auto plaçants à base de matériaux locaux, Mémoire de Magister, Université Abou Bekr Belkaid-Tlemcen, Algeria.