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PERFORMANCE OF THE SELF-COMPACTING CONCRETE WITH DIFFERENT MINERAL ADMIXTURES.

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ABSTRACT

The building industry is turning increasingly to the use of self-compacting concrete (SCC). It is an innovative concrete that flows under its own self weight to fill the formwork completely and self-compact without any segregation and blocking.

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 economic reasons.

The objective of this study was to evaluate the quality of self-compacting concrete with granulated blast furnace slag (GBFS), limestone powder (LP) and marble powder (MP).

Workability of SCC was determined using slump flow, T_{500} time, L-box, air content, unit weight, sieve stability tests and V-funnel tests. The hardened properties that were determined included compressive and tensile strength determined at 3, 7 and 28 days.

The results indicate that SCC achieves good workability and high long-term strength particularly for the concretes containing GBFS.

Keywords: self-compacting concrete, mineral admixtures, granulated blast furnace slag powder, marble, limestone filler, shrinkage.

INTRODUCTION

The applications of self-compacting concrete (SCC) in actual structures is quite common at present because of its very attractive properties in the fresh state as well as after hardening.

Self-compacting concrete generally have a much higher content of fines fillers. The use of supplementary cementitious materials is well accepted.

At first, the main motivation for using mineral additives was cost reduction. More recently, environmental arguments began to prevail, in particular the need to decrease the overall CO2 production related to the use of cement in concrete (Habert, 2009).

From this viewpoint, a cost effective SCC design can be obtained by incorporating reasonable amounts of pozzolanic or less reactive filler materials. These may include granulated blast furnace slag as pozzolanic material and/or limestone powder, marble powder as filler materials.

It is clear that the concrete containing such by-products or wastes should have equal or slightly lower properties than normal concrete. Therefore, workability and strength characteristics of concrete containing these mineral admixtures as partial replacement of cement should be investigated.

The objective of this study was to evaluate the effectiveness of various mineral admixtures in producing self-compacting concrete. For this purpose, granulated blast furnace slags (GBFS), limestone powder (LP) and marble powder (MP) were used. Workability of SCC was determined using slump flow, T_{500} time, L-box, air content, unit weight, sieve stability tests and V-funnel tests. The hardened properties that were determined included compressive and tensile strength determined at 3, 7 and 28 days.

MATERIALS AND CONCRETE MIXTURES

In production of SCC, Portland Cement CEM II/42.5 with a specific surface area of 3891cm²/g was used in this study. Crushed stone was used as coarse aggregate the size was 3/8 mm and 8/15 mm, a sand 0/3 mm. Besides, three different mineral admixtures were used in the SCC. Granulated blast furnace slags (GBFS), limestone powder (LP) and marble powder (MP). Marble powder was used directly in the SCC without any further processing. The characteristics of cement and mineral admixtures used in this study are given in Table 1.

A superplasticizer high range water reducing admixture (HRWRA) (Conforms with the standard EN 934) was also used. Tap water used was obtained from the laboratory for the production of concrete mixtures.

Table1 the characteristics of cement and mineral admixtures used.

Component (%)	**Cement**	**MP**	**LP**	**GBFS**
SiO_2	27.83	0.15	0.06	38.89
Fe_2O_3	3.12	0.04	0.02	4.09
Al_2O_3	6.21	0.08	0.09	7.07
CaO	57.22	54.86		40.71
MgO	0.94	1.03	0.01	4.56
SO_3	2.02	0.07	0.01	0.04

MIXTURE PROPORTIONS

Three mixtures with mineral admixtures were prepared and examined to quantify the properties of SCC. In the mixtures, cement was replaced with MP, LP, or GBFS at the same content of 20% by mass. After some preliminary investigations, the water– powder mass ratio (w/p) was selected as 0.38 and the total powder content was fixed at 540 kg/m^3. Table 2 presents the composition and labeling of the SCC mixtures.

Table 2 the composition of concrete in 1m^3.

Materials (kg/m3)	**SCC GBFS**	**SCC MP**	**SCC LP**
Cement CPJ 42.5	410	410	410
Sand 0/3	850	850	850
Gravel 3/8	298	298	298
Gravel 8/15	428	428	428
SP	9.26	9.72	9.72
Water	204.5	204.5	204.5
GBFS	130	-	-
MP	-	130	-
LP	-	-	130
W/C	0.50	0.50	0.50

EXPERIMENTAL PROCEDURE

70 mm×70 mm×280 mm prismatic molds were used for the determination of tensile strength, while cylindrical molds 100 mm × 200 mm were used for the determination of compressive strength.

Before casting, slump-flow test, T_{500} test, V-funnel, air content and L-box test were conducted to characterize the workability of the fresh concrete to assess filling and passing abilities according to the European guidelines (EFNARC, 2002).

Specimens (prisms and cylinders) were then cast in steel molds at 20 ± 2°C for 24 h until demolding. Thereafter, the specimens were kept in an ambient atmosphere room (the relative humidity and the temperature were about 50 ± 5% and 23 ± 2°C respectively) and in water until testing (compressive and tensile strength) which is performed at 3, 7, 14 and 28 days. The maximum strength of each specimen was recorded and the average of three samples was considered the compressive strength at the specific day.

The shrinkage specimens of 70x70x280 mm were demoulded after 24 h. The first length measurement was made at 0.5 h after demoulding and the specimens were then left in a room of 23±2°C with a relative humidity of 50 ± 5% and in water. Measurements were carried out every day for a month.

RESULTS AND DISCUSSION

We present the characterization results of mixtures in order to generate a set of information rich enough to be able to link the composition of concretes with their performance. In this study, fresh and hardened properties of SCC were investigated by using waste materials (LP, MP, and GBFS).

WORKABILITY

The ability of SCC for compacting under its own weight is generally the main subject of such studies according to appropriate criteria given by the EFNARC Committee (EFNARC, 2002). In the present study, such properties of SCC produced with LP, MP and GBFS were investigated based on fresh concrete tests, specifically workability tests.

Table 3 the workability test result of SCC mixtures.

	Slump flow (mm)	T_{50} (s)	L-Box	V-Funnel (s)	Air void content (%)	Real density (Kg/m^3)
SCC GBFS	755	4	0.875	16	2.49	2356.85
SCC MP	750	4.32	0.888	20	1.8	2360.28
SCC LP	740	4.52	0.857	16	1.3	2402

The slump-flow values for SCC with LP, MP and GBFS immediately after the mixing process are presented in table 3. Slump flows of 650 mm to 800 mm are typically required for SCC (EFNARC, 2002), and all the mixtures under investigation fall into this category.

As shown in table 3, the mixtures containing MP had a further increase in slump-flow values compared with those containing LP. This might be explained by the increased surface area of the MP particle increasing the water demand (Sahmaran, 2006).

The water content was kept constant for all mixes in this study. So FL needs less water and promotes a wide spread this phenomenon is explained by the surface characteristics of the slag grains that allow better inter granular sliding in the paste (Manai, 1995).

The fine particles fill the voids between the particles of the mortar, thus increasing the compactness of the mixture by enhancing the total arrangement of the particles in the matrix (Yahia, 2005). Therefore the amount of water which occupied the voids is released into the interstitial solution, which results in a better fluidity.

There has been some work on applying marble powder. Thus, Alyamac and his co-workers (Alyamac, 2009) studied the feasibility of using marble powder as filler in self-compacting concrete (SCC). They reported that in general, MP had no effect on the workability of fresh SCC.

Topcu and his co-workers (Topcu, 2009) have investigated fresh and hardened properties of MP additive SCC and the use of MP amount below 200 kg/m3 content is suitable for improving fresh and hardened properties of SCC.

The measured times for reaching 500 mm slump-flow (T_{500}) values are in the range of 2-5 s which means the lower and upper limits of T_{500} time.

The required V-funnel flow times are in good agreement to the values given by European guidelines (EFNARC, 2002). On the other hand, most of the mixtures have good viscosities and segregation resistances by taking part in target range. The GBFS mixture has the lowest viscosities and V-funnel flow times compared to other mixtures.

The L-box ratio characterizes the filling and passing ability of SCC. The blocking ratio (h2/h1) should be between 0.8 and 1.00. All mixtures of SCC are within this target range. According to Table 3 it can be noted that each SCC investigated in the present study has adequate filling capability and passing ability.

The results of air void content and unit weight of SCC with mineral admixtures can be seen in table 3. We note that GBFS provides higher air content with a percentage of 28% compared to MP and 48% compared to limestone filler.

In addition, unit weight is conditioned by the addition type. By using mineral admixtures such as GBFS, LP and MP in SCC, the unit weight can decrease while obtaining improved workability and FC mixture represents a higher density than the others by a percentage of 1.76% compared to SCC FM and 1.91% relative to the mixture SCC FL.

COMPRESSIVE STRENGTH

Fig. 1 presents the compressive strength determined at different ages. The test results showed that the compressive strength for GBFS mixture was higher than the mixtures containing LP and MP and that for all maturities. Indeed, the slag used is reactive but its kinetics is very slow (Behim, 2009). At 7 days, the pozzolanic reactions of GBFS were not sufficient to enhance compressive strength at this early stage and the resistances obtained are lower than those developed by FC and FM mixtures. But, the slower pozzolanic reactions came into play and the GBSF samples had the highest compressive strength results at 28 days. In the case of GBFS, filling of the voids between the larger cement particles, and increasing production of secondary hydrates by pozzolanic reactions with the lime resulting from the primary hydration enhances compressive strength (Sumer, 2011).

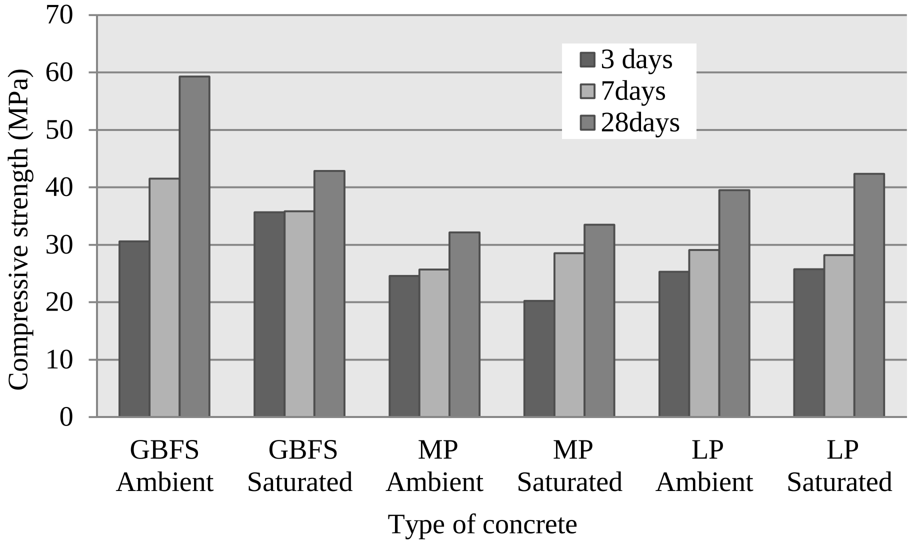

Fig 1: Compressive strength of SCC mixtures at different ages.

The use of fillers in concrete mix generates an acceleration of its mechanical strength at early ages (De Larrard, 1999) (Pera, 1999). The LP and MP act like inert filler reducing the compressive strength of the LP and MP mixtures. But, the SCC LP has shown the best performance both at 7 d and at 28 d compared to the SCC MP.

This is due to the physical nature of better packing, as addition of LP governs the compressive strength due to the denser matrix and the better dispersion of cement grains (Bonavetti, 2003).

Furthermore, The calcareous grains promote formation of heterogeneous nucleation responsible for the early reaction products of CH and CSH, which will accelerate the hydration of cement clinkers (especially C3S) and consequently increase the compressive strength values at early ages (Lawrence, 2005) (Sari, 1999).

Marble powder improve the resistance at early age, the reason is the acceleration of the heat of hydration of the cement (Uysal, 2011). In addition, MP is not pozzolanic, but nor fully inert as it reacts with the alumina phases of the cement. If the cement has a significant amount of tricalcium aluminate (C3A), calcium carboaluminate will be produced from the reaction between calcium carbonate (CaCO3) from the MP and the C3A (Bonavetti, 2001) (Vuk, 2001). This reaction, accelerating the hydration and increasing the compressive strength, increases with the C3A content of the cement and the fineness and specific surface area of the mineral admixture (Uysal, 2011).

It was observed that the resistances of saturated specimens are higher compared to samples stored in ambient atmosphere for MP and LP mixtures but we notice the opposite for GBFS mixture.

The resistances of the samples stored in water are higher than the air for all SCC because the hydration is significantly reduced when the relative humidity inside the capillary pore system is less than 80% (Neville, 2002). To continue the hydration, the relative humidity inside the concrete must be maintained at least 80%. If the relative humidity of the ambient air is less than this value, there will be very little difference between the concrete and the air and it will not necessary to consider active maturation to ensure continued hydration. We know that the hydration of cement can only be developed in the capillaries filled with water that’s why evaporation of capillary water should be avoided.

It is however important to note that the resistances obtained are higher than 30 MPa and up to 60 MPa, which is higher than the resistance obtained at construction sites and this encourage its vulgarization in Algeria.

SPLITTING TENSILE STRENGTH

Tensile strength is one of the most important fundamental properties of concrete. All concrete typically has low tensile strength (-10% of compressive strength) and a low strain capacity (Najim, 2012). However, tensile strength is important in highway design, airfield slabs, and when shear strength and crack resistance are a priority. The addition of LP, MP and GBFS to SCC exacerbates these shortcomings. The tensile strength test results of the GBFS, MP and LP mixtures are represented in fig. 2.

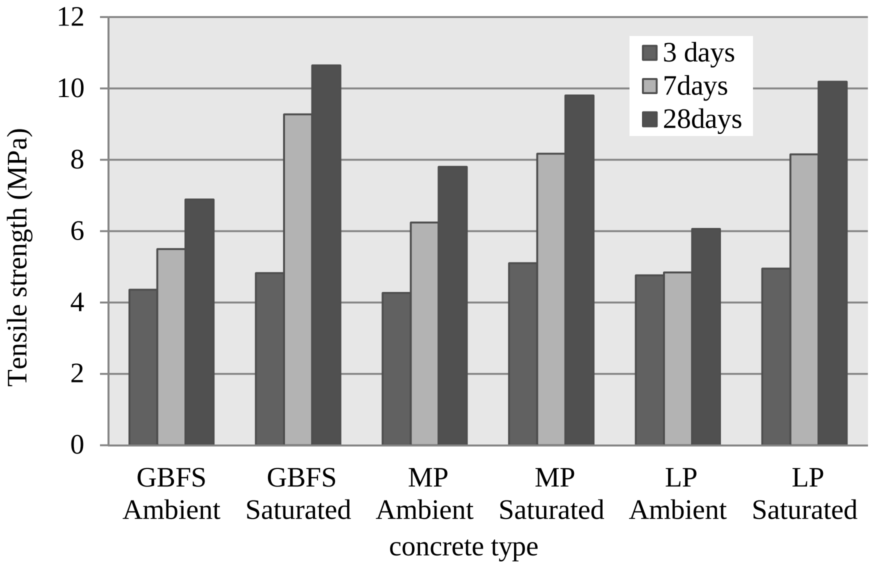

Fig 2: Splitting tensile strength of SCC mixtures at different ages.

The study of conservation mode is still important because of their effect on the strength of concrete. It was found that the tensile strength for SCC immersed in water have better results with a significant difference. This divergence can be observed clearly on LP and GBFS specimens. We also note that the tensile strength is more sensitive to the type of curing compared to compressive strength.

In addition, water loss by autodissication due to the chemical reactions of the hydration of the cement must be replaced by water from the outside. It was concluded that the degree of humidity of conservation of the environment has an important influence on concrete strength (Dreux, 1985).

For samples kept in the water, it can be seen from Fig. 2 that the 28 day splitting tensile strengths of the MP mixtures were slightly lower than that of LP mixture. But the tensile splitting strengths of GBFS were higher than that MP and LP, as was seen for compressive strengths. This may occur because the dense microstructure in SCC mixes leads to increased brittleness and thus decreases the splitting strength. In SCC mixes, high powder contents can increase shrinkage resulting in micro-cracking within the ITZ.

TOTAL SHRINKAGE

Table 4 summarizes the extreme values of measured shrinkage. Each value presented is the average of three measurements. The shrinkage is observed regardless of the nature of the mineral admixture and the curing method.

Table 4 the total shrinkage of SCC specimens.

Notation	**SCC GBFS**		**SCC MP**		**SCC LP**	
Conservation mode	Ambient	Saturated	Ambient	Saturated	Ambient	Saturated
Shrinkage (µm/m)	685,71	562,5	566,07	200.89	523.21	241.07

Following the literature, the shrinkage is the macroscopic response of the material to the capillary depression.

At ambient temperature, there are significant shrinkage deformations which are characterized by the loss of stored water in the capillary pores. The GBFS specimens are slightly more sensitive to shrinkage than MP and LP specimens respectively 686 µm/m, 566 µm/m and 523 µm/m.

The limestone filler can have a positive effect in reducing drying shrinkage of SCC, if it is used with adequate finesse and proportion (Assié, 2004), (Turcry, 2004). As shown in table 6, self-compacting concrete containing limestone filler represents the lowest shrinkage because the limestone filler is the finer among all the mineral admixtures used.

For curing in water, generally the specimens present swelling due to water absorption phenomenon. This information shows that the relative humidity is lower in concrete compered to saturated medium. While in our case there was shrinkage, this shrinkage is related to the concrete autodessiccation (self-drying) during the hydration.

Brue explained this phenomenon as follows: The water present in the microstructure is gradually consumed by the hydration reaction. Due to the very low permeability, the surrounding water cannot fill this consumption immediately. Therefore follows cavitation and balance air/water/solid is set up, leading to capillary pressure in the fluid (negative pressure). As the system has a no macroscopic stress (neglecting the weight) the solid is isotropically compressed to balance the capillary depression (Brue, 09).

This compression at a macroscopic scale is called the autodessiccation shrinkage or self-drying shrinkage, leading to deformations in large part irreversible. Indeed, the gradual resaturation cancels this capillary depression. Despite this, the macroscopic shrinkage remains significant of 200.89µm/m, 241.07µm/m and 562.5µm/m for MP, LP and GBFS specimens respectively. GBFS specimens have the higher shrinkage value and MP specimens have the lowest.

WEIGHT LOSS

Table 5 summarizes the extreme values of measured weight variation of SCC.

Table 5 the weight variation of SCC specimens.

Notation	**SCC GBFS**		**SCC MP**		**SCC LP**	
Conservation mode	Ambient	Saturated	Ambient	Saturated	Ambient	Saturated
Weight loss (%)	-1.761	1.006	-2.371	1.061	-2.511	0.922

For curing in water, we note that the MP samples have a higher swelling than the other two. In parallel GBFS specimens undergo higher water penetration compered to LP specimens who tends to stabilize. Ripening concrete continuously in water, after their implementation, increases in volume and mass. This swelling is caused by the absorption of water by the cement gel. Water molecules act against the forces of cohesion and tend to repel the gel particles, causing subsequently a small expansion (Neville, 2002).

In an ambient medium, the water evaporation of LP specimens is faster than GBFS specimens and with relative similarity to MP samples.

In addition, the weight loss in air is higher than the gain in weight in saturated medium for all cases but the differences between the two variations changes with fines nature. For limestone powder and marble powder the difference is more important than granulated blast furnace slag (GBFS = 2,768 / MP= 3,433 / LP= 3,433) mainly due to their fineness, highlighting the decrease in capillary pores. The capillary pores strongly influence the transfer properties of concrete, especially when they are interconnected. So in conclusion, the finesse is a major factor for this kind of demonstration. In addition, the fines nature seems to have an influence effect (Nepomuceno, 2012).

CONCLUSION

This paper aimed to compare several properties of self-compacting concrete containing different fines. Laboratory tests were performed to determine some fresh and hardened properties of SCC mixtures. As a result of this experimental study, the following conclusions can be drawn:

The use of mineral admixtures improved significantly the workability properties of SCC and all SCC mixtures have remained in target range for each test. All the mixtures had satisfactory self-compacting properties in the fresh state. The use of GBFS, MP and LP had positive effects on the workability. Among the mineral admixtures considered, the best performance has been obtained by GBFS mixture as workability properties.

The use of mineral admixtures in various combinations can provide excellent mechanical properties. The results showed that the highest compressive strength has been obtained by GBFS mixtures. For the two other mineral admixtures, LP specimens give better resistance compared to MP. As pozzolanic materials GBFS increased the late age compressive strengths of SCC mixtures. In addition, filler materials increased the early age compressive strengths of SCC mixtures.

Shrinkage is observed regardless of the mineral admixture nature and the curing methods and the shrinkage of SCC with marble powder is overall the same order of magnitude as that of SCC with limestone filler. At ambient temperature, the GBFS specimens are slightly more sensitive to shrinkage than MP and LP specimens. For curing in water, all SCC exhibit shrinkage instead of swelling, this shrinkage is related to the concrete autodessiccation (self-drying) during the hydration. GBFS specimens have the higher shrinkage value and MP specimens have the lowest.

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