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Effect of Slag on the Porosity and Microstructure of HPC Reinforced with Hybrid Steel Fiber

Aldjia Boutiba
University of Tizi Ouzou

Rabah Chaid
University of Boumerdes

Laurent Molez
Laboratory of Civil Engineering and Mechanics, INSA Rennes

Abstract: Due to their structural and economic performance, high performance metal fiber concretes are increasingly used in construction, but with the addition of metal fibers, workability decreases as the amount of fibers added increases. In order to improve workability, a larger quantity of fines should be used than for ordinary concrete. The use of granulated slag reduces the amount of clinker needed to make cement. It is considered that granulated slag improves the workability of concrete. According to Manai, this is due to the very low rates of water adsorption by the granulated slag grains at the start of mixing. Also, the addition of granulated slag has a positive effect on the porosity, but also on the microstructure of the hydrates. These two characteristics are factors determining the compressive strength and durability of the cement paste. The aim of this study is to define the effect of blast furnace slag on the porosity and microstructure of high performance fibre-reinforced concrete. The results of SEM and DRX observation of the microstructure of the concrete samples show that the addition of ultra-fine granulated slag resulted in a relative improvement in porosity and microstructure.

Keywords: Characteristics, Fibers, HPC, Slag,

Introduction

The characteristics of the microstructure, that is to say the total porosity and the distribution of the pore sizes, but also the microstructure of the hydrates, are factors determining the compressive strength and the durability of the cement paste (Aïtcin, 2001). The porosity may be connected or occluded, and the pore size distribution may vary widely. These different parameters influence the permeability of concrete.

In recent years, high performance concretes (HPC) have been used extensively worldwide. With HPC, it is possible to build with less formwork, less concrete to place and less reinforcement than with ordinary concrete (Escadeillas,2006), (Ezeldin & Balaguru, 1982). With the increase in compressive strength, the HPC becomes less ductile or more fragile. The latter leads to design and dimensioning problems for certain types of structures. The most evoked track in the literature to overcome this weakness in tensile behavior is the addition of metal fibers to the concrete formulation (Rossi et al., 1987; Swam & Mangat, 1974).

The change in the rheological behaviour of fresh concrete when fibres are added to its matrix is an important factor. For a given matrix (paste and aggregates), workability decreases as the amount of fibre added increases. To improve workability, a larger quantity of fines (sand and cement) should be used than for ordinary concrete

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(Feldman,1983). The presence of fly ash or granulated slag reduces the size of the largest pores. Indeed the Pozzolanic reactions lead to the formation of secondary CSH and reduce porosity, which is good for durability (Mindess, 1984). The presented work is achieved at the laboratory of civil engineering, mechanical engineering (materials) of INSA-Rennes, France. The purpose of our study is to determine the porosity and microstructure of High performance concrete reinforced with a mixture of short fibers and fibers with end hooks, as well as a 15% substitution of cement by blast furnace slag. The dosage in slag optimized in previous studies is 15% (in place of cement). This content induces mechanical strength at 28 days very high (Chaid, 2006).

Materials and Methods

The materials used for making concrete study are:

Portland cement without mineral additives CEM I 52.5 PM ES CP2 of Lafarge France. The chemical and mineralogical composition are shown in Table 1.

Table 1. Chemical and mineralogical composition of cement used

Elements	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	RI	PAF	CaO_L
%	66.60	22.40	2.96	2.33	0.95	0.15	0.10	2.13	0.20	1.59	0.50
Minerals		C_3S		C_2S		C_3A			C_4AF		
%		65.3 %		18.6		4.35			7.14		

A blast furnace slag plant in El-Hajar-Annaba Algeria is an amorphous granular ground to a specific surface area greater than that of cement; whose chemical composition and physical characteristics are reported in Table 2.

Table 2. Chemical composition and physical characteristics of slag

Elements	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	RI	PAF
%	39.77	41.69	7.05	1.41	5.49	0.44	0.10	0.15	0.12	0.11
Physical characteristics		Density			2.99 g/cm^3,					
			Specific surface area		8500 cm^2 / g.					

The aggregates used are silica sand crushed (0/2) and two fractions of silica gravels crushed (2/6) and (6/12). Their physical properties are presented in Table 3.

Table 3. Physical properties of aggregates

Types	Sand	Gravels 2/6,3	Gravels 6 /12
Actual density ρr (Kg/m 3)	2604,00	2620,00	2645,71
Apparent density ρapp (Kg /m 3)	1555,53	1365,63	1338,79

The admixture is a superplasticizer, Sika ViscoCrete TEMPO 9. We used a mixture of short fibers and fibers with end hooks (Dramix RC-80/50BN) shown in Figures 1 and 2. These fibers are added at ratio of 0.35% of volume per cubic meter of concrete. The formulation of the concrete submitted to the tests (studied concrete) is achieved with the method of Dreux-Gorisse while using the software concrete lab free of the LCPC. After convenience tests, the composition of basis kept for these concretes is presented in Table 4.

Figure 1. Short fibres.

Figure 2. Fibres with end hooks.

Table 4. Concrete mixes

Constituents	Quantity (kg/m^3)
Cement	446
Slag	66.9
Gravel 6/12	891.9
Gravel 2/6	85.2
Sand 0/2	738.3
Water	155.6
Admixtures	0.34% of the weight of the cement

The specimens of the studied concretes with slag but without fibers, concrete with slag without fibre and concrete with slag and fibers are placed, after demoulding, in water total immersion at a temperature of 20 °C. The abbreviations used for the different concretes are:
HPC: Control concrete without the slag or fibers,
HPCS: Concrete with the slag but without fibers,
HPCSF: Concrete with the slag and fibers.

Results and Discussion

Characterization of the Fresh Concrete Capillarity, Water Porosity and Density

The results of the cone slumping tests of fresh concrete are summarized in Table 5. The measured slump for the different concretes was between 13 and 14 cm, which corresponds to a plastic vibrated concrete of subsidence class S3, with a good consistency according to the NF-EN 206[9] standard. The addition of fibres resulted in a loss of HPCMF slump when using the same amount of superplasticizer. However, the increase in the quantity of admixture has led to an improvement in the subsidence of this type of concrete.

Table 5. Fresh concrete characteristics

Quantity of superplasticizer	Characteristics	Types of concrete		
		HPC	HPCS	CSF
The same quantity of superplasticizer for the 3 concretes	Abrams cone slumping in (cm)	13	14	10
Increased the quantity of superplasticizer for HPCSF	Abrams cone slumping in (cm)	14	14	13

Capillarity, Water Porosity and Density

For capillarity, water porosity and density tests on high performance concretes made with the same quantity of superplasticizer. The retention periods are 6 and 24 months. After these deadlines the test bodies are dried in an air-conditioned room (50% relative humidity, 20°C).

Porosity Accessible to Water and Density

The porosity accessible to water determines almost all the properties of concrete, and, first of all, its mechanical resistance: when the porosity increases due to the degradation of the concrete, its resistance decreases (Baron, 1992). The average values of the porosities accessible to water and of the densities determined for the concretes studied are represented in figure 03. The porosity of non-fibre-reinforced concrete is lower than that of fibre-reinforced concrete. It is generally accepted that the incorporation of fibers in a HPC leads to a decrease in compactness due to the reduction of rheological properties (Ladaoui, 2010).

The porosity of fibre-reinforced concrete (HPCSF) decreased slightly by 1.36% between 6 months and 2 years, because when the cement hydrates, the hydrates formed block the pores and reduce porosity. Density increases with decreasing water-accessible porosity; this is verified for both types of concrete.

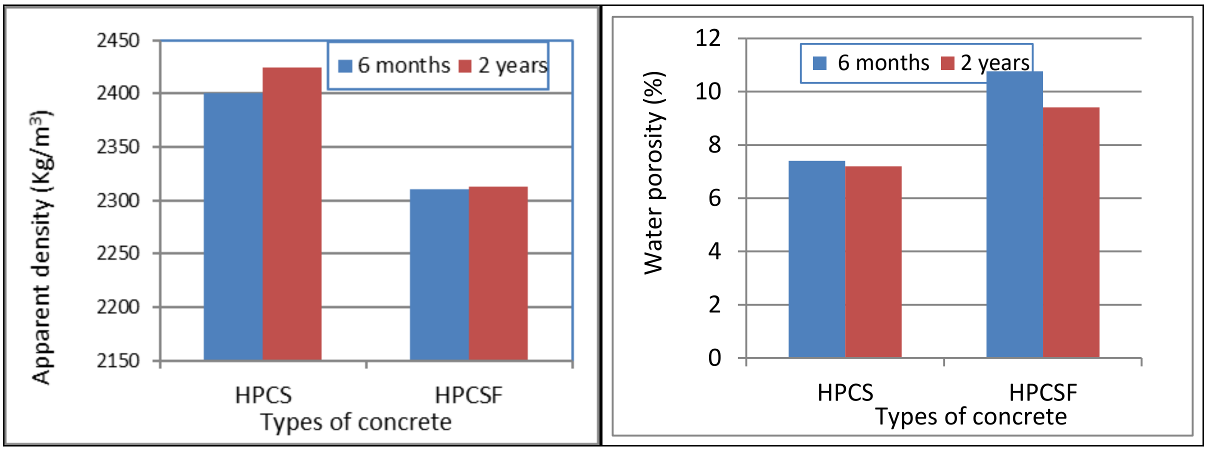

Figure 3. Porosity accessible to water and apparent density variation of the different concretes.

Capillary water absorption

Concrete is indeed a material that has capillary pores whose size varies according to its composition characteristics (W/B ratio, mineral additions, etc.). When a liquid comes into contact with this type of pore, surface tensions cause the liquid to rise inside by capillary action. The test of water absorption by capillarity involves placing the lower surface of the specimen (bottom of the mould) to the contact of water and to follow according to the time, the evolution of the mass. Figure 04 illustrates the evolution of water absorption by capillarity of the survey concretes according to the time.

After 6 and 24 months of storage, the gotten results show that in the first hours of the test (up to 8 hours), the capillary coefficients of absorption of the concretes fibers and non fibers are globally similar. But after 24 hours, the fibre-reinforced concretes show a slightly higher water absorption than the non-fibre-reinforced concretes. The capillary absorption coefficient after 2 years of storage for the two types of concrete is slightly higher, compared to those stored for 6 months.

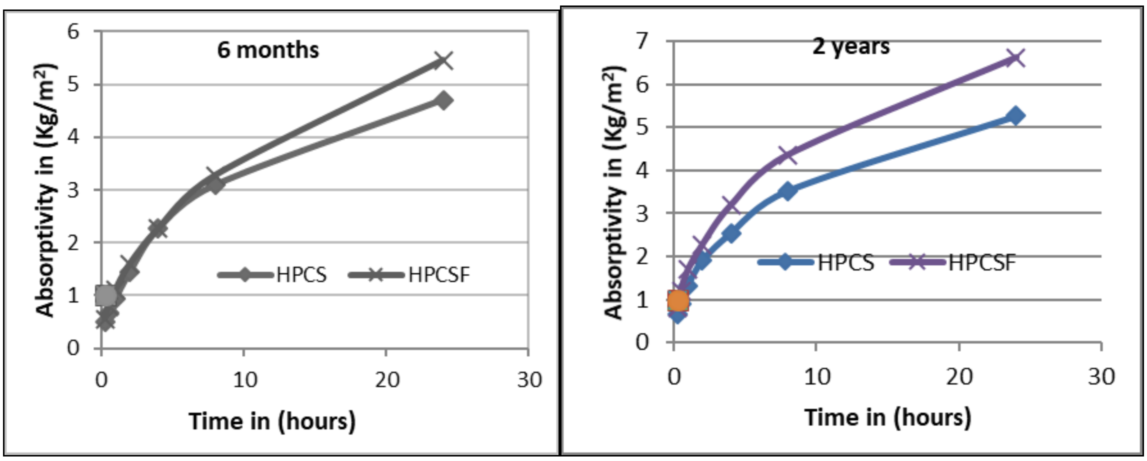

Figure 4. Absorption capillary coefficients of the different concretes,

Microstructure of Specimens Concrete Examined by SEM

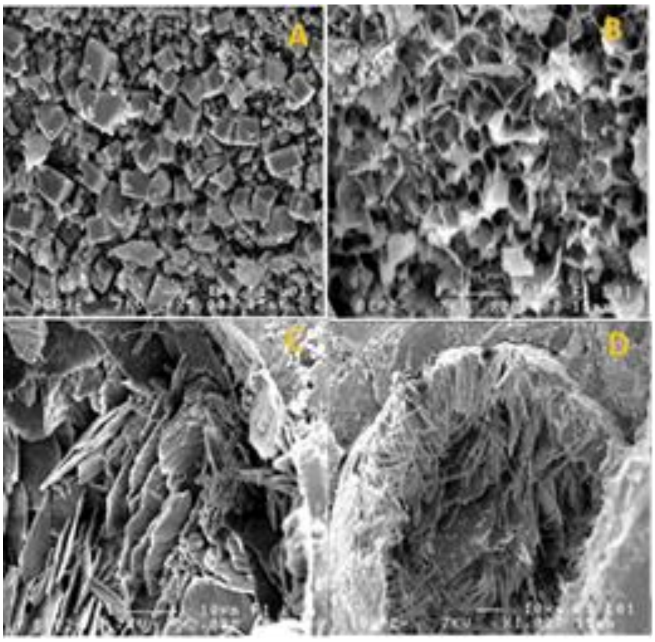

Figure 5. Micrographs of the microstructure of HPC after 6 months of conservation.

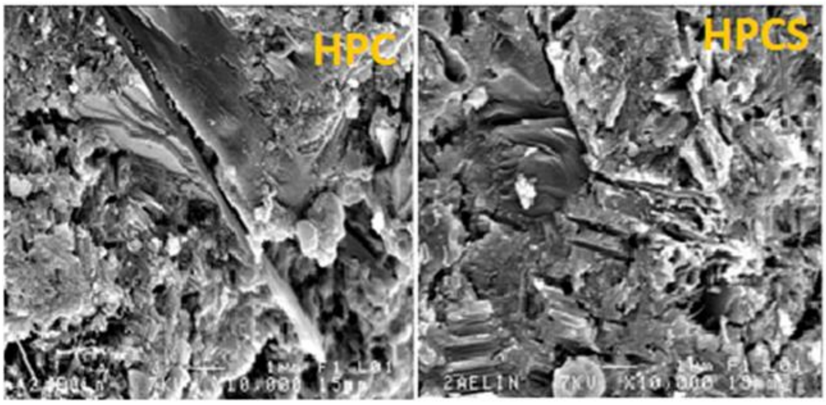

Figure 6. SEM observation of the internal microstructure of HPC and HPCS after 2 years of conservation.

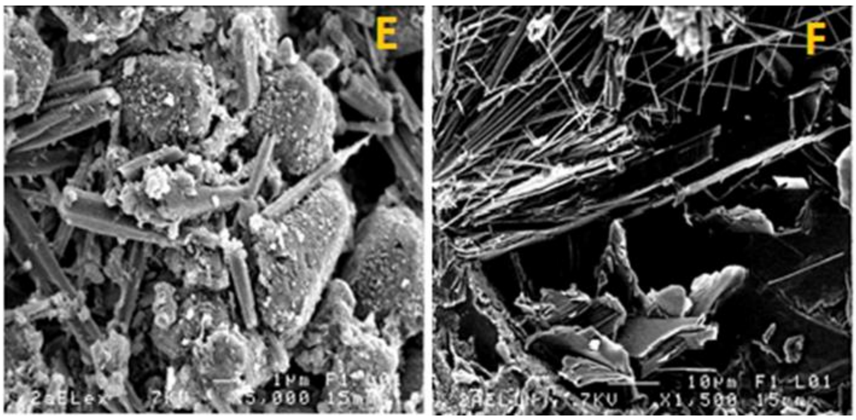

Figure 7. SEM observation of the internal and external microstructure of HPCS after 2 years of conservation.

In order to support the hypotheses formulated regarding the performance of our study concretes, observations with a Scanning Electron Microscope are carried out on HPCS concrete specimens after 6 months of hardening. Figure 5 shows for the external microstructure, the presence of carbonates crystallised in rhomboid (A). For the internal microstructure, we find CSH in sponges (B), ettringite, which crystallised in fine needles and tablets of portlandite (C and D). SEM observations at x10,000 magnification, carried out on samples of HPC and HPCS after two years of hardening figure 6, show a relatively improved microstructure in concrete with added slag (HPCS), with relatively more densified interfaces and rich in CSH, characteristic of HPC with added active cementitious materials. For the external microstructure of the HPCS concrete after two years of hardening (Figure 7), we note the presence of ettringite in short needles (E) of the same type as that formed in healthy HPC [1]. While the internal phases of the concrete present fine needles of ettringite (F), with CSH of high compactness (Figure 6).

Conclusion

The main objectives of our work were, on the one hand, to evaluate the influence of reinforcement by mixed metal fibre and the substitution of 15% of cement by granulated blast furnace slag on the porosity and microstructure of high performance fibre-reinforced concrete. The addition of fibers resulted in a loss of HPCSF subsidence for the same amount of super plasticizer. Nevertheless, the increase in the quantity of admixture has led to an improvement in the workability of this type of concrete. The porosity of fibre-reinforced concrete (HPCSF) decreased slightly by 1.36% between 6 months and 2 years, because when the cement hydrates, the hydrates formed block the pores and reduce porosity.

Density increases with decreasing water-accessible porosity; this is verified for both types of concrete. After 6 and 24 months of storage, the gotten results show that after 24 hours of the test, the fibre-reinforced concretes show a slightly higher water absorption than the non-fibre-reinforced concretes. The micrographs of the cementitious matrix show a relatively improved microstructure in concrete with added slag (HPCS).

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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Author Information

Aldjia Boutiba
Mouloud Mammeri University
Route de Hasnaoua BP 47, Tizi Ouzou, Algeria
Contact e-mail: *boualdjedi@ yahoo.fr*

Rabah Chaid
M'Hamed Bougarra University
Cité Frantz. Fanon, 35000 Boumerdes, Algeria

Laurent Molez
INSA Rennes
20 Av. des Buttes de Coesmes, 35700 Rennes, France

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