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Full Length Research Paper

Strength improvement of a High Performance Fiber Reinforced Concrete (HPFRC) containing local raw materials

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Improvement of mechanical strength of a High Performance Fiber Reinforced Concrete (HPFRC) containing local raw materials at a cheap rate was investigated in this present work. An experimental study was conducted on different concretes based on dune sand and reinforced by metallic fibers. The concretes studied are formulated based on a Portland Cement (PC), Dune Sand (DS), Dust of Electro-filter (DE), Metallic Fibers (MF) and Superplasticizer (SP). The obtained results show that it is possible to manufacture concrete based local raw materials (inexpensive) giving compressive strength of about 105 MPa, with an improvement in ductility resulting from a tensile strength up to 20 MPa. Also, this strength improvement of the studied concrete is ensured by a simple heat treatment at a temperature of 90°C for 48 h after 28 days of curing.

Key words: Sand of dunes, dust of electro-filter, high performance fibers concrete (HPFC) thermal treatment, mechanical properties.

INTRODUCTION

Progress in the manufacture field of cement, of additive and the incorporation of other components (fibers and fines) in the concrete compositions with the reduction of Dmax of aggregates to ensure the maximum material compactness gave rise to a new generation of the concretes (UHPFC, ultra high performance fiber concrete) (Rougeau and Borys, 2004; Rossi et al., 1996; Maeder et al., 2004). These concretes are more resistant and compact and confer best durability compared to other concrete types (Long et al., 2002).

Generally, an additive fines used in the HPFC composition are the crushed siliceous sand and the silica fume; the scarcity of the latter and their unavailability in all the areas in Algeria leads to a more expensive material. So it is necessary to look for other types of mineral addition or to recycle the by-product as dust of electro-filter recovered during the clinker manufacture (AFPC-AFREM, 1997; Saidi et al., 2010) and dune sand finely crushed (Tafraoui, 2009; De Larrard, 1989). The choice of these matters was carried out according to two criteria:

i) The valorization of the waste which has a negative influence on the environment.
ii) The availability of the dunes sand in the southern area of Algeria.

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Table 1. Characteristics of cementitious materials.

Components (%)	Cement (C)	Dust of Electro-filter (DE)	Silica Sand (SS)	Fine Sand (FS)
SiO_2	19.31	17.02	92.03	79.07
Al_2O_3	04.91	04.14	02.77	08.06
Fe_2O_3	03.20	02.70	00.45	03.45
CaO	61.77	62.01	01.04	02.22
MgO	02.02	02.28	00.10	00.67
SO_3	02.12	01.82	00.51	00.01
$K_2O + Na_2O$	00.78	00.70	01.74	02.90
C_3S	63.08	-	-	-
C_2S	12.75	-	-	-
C_3A	05.74	-	-	-
C_4AF	01.64	-	-	-
Specific gravity (g/cm^3)	3.10	2.83	2.62	2.91
Specific surface (cm^2/g)	3900	8180	4000	-
Compressive strength (MPa)				
2 days	21.50	-	-	-
28 days	49.00	-	-	-

The addition of metal fibers ensures the ductile behavior of the HPC, in this study; the metal fibers of the cut out cables of breakdown service (pieces of diameter 0.537 mm and length 14 mm) are used (Swamy and Mangat, 1974). The essential characteristics of this type of cable are its tensile strength (Rossi, 1998).

The heat treatment is a significant factor to improve the HPFC characteristics, thus determination of the best method of treatment in water or the saturated air, the good temperature and best time belong to this study (Yazici, 2007; Sharon and Ling, 2006).

The final context of this study is to determine the effect of electro-filter dust of clinker, fibers and the heat treatment on the UHPFC characteristics. In order to improve the mechanical properties of the concretes, this work focused on the UHPFC development, to use the local raw materials and at a cheap rate (Ordinary Portland cement, natural sand, siliceous sand, cable of breakdown service vehicles and a superplasticizer).

MATERIALS AND EXPERIMENTAL PROGRAM

Cement (PC): The cement used is CEMII 42.5 type; it comes from the Algerian cement (east of Algiers). Physical, chemical, and mineralogical characteristics are given in Table 1, and are according standard norm NF EN 197-1 (AFNOR, NF IN 197-1, 2001; AFNOR, NF IN 934-2/A2, 2006).

Dust of electro-filter (DE): This dust is recovered by the electro-filter of the cement factory. It has a smoothness of 8180 cm^2 /g and contains 62% of CaO.

Dune sand (DS): In this work dune sand is used as fine sand and was sieved on a sieve 2 mm diameter, then washed on a sieve of 0.063 mm µm.

Silica sand (SS): This sand is ground and also characterized by a high percentage of silica> 90% and SSB = 4000 cm^2/g.

Fibers (MF): Metallic fibers are used as reinforcement for concrete (Table 2). These fibers are breakdown cables of service vehicles. The characterization was effected at the laboratory of the research unit (UR-MPE). For the preparation of fibers, we used the cable derange manually cut out using a grip with lengths of 14 Misters (Figure 1).

Superplasticizer (SP): A high reducing water is used as a superplasticizer of type Tempo 12 manufactured by SIKA.

Mixtures of concretes

All concrete mixtures were established using the BOUNEAU method used for HPF concrete and the AFGC recommendations (Bonneau, 1997; Bache, 1981; AFGC, 2002). Three concrete compositions in this work were chosen which are given in Table 3 and high performance concrete HPC in 1 m^3 is given in Table 4.

Experimental program

In order to improve the mechanical properties of the concretes, the local raw materials used in this work are the Portland Cement (PC), the Dust Electro-filter (DE), the Dune Sand (DS), Silica Sand (SS) and the Metallic Fibers (cable of breakdown service vehicles). To carry out this work after having made the characterization of the various components, the work methodology followed:

i) Optimization of the high performance concretes (HPC) with optimal dust electro-filter level by measuring the mechanical strength at 3 and 7 days;
ii) Application of heat treatment for curing (the test-tubes by immersion in water) of High Performance Fiber-reinforced Concrete (HPFC) at temperature 30, 60 and 90°C, during 4 and 24 h;
iii) Thereafter, the processing time and optimum temperature have been determined for the HPFC with better mechanical properties.

Table 2. Characteristics of metallic fibers used.

Properties	Metallic fiber
Length [mm]	14
Diameter [mm]	0.54
Bulk density [g/cm^3]	7.80
Young modulus [GPa]	-
Tensile strength [MPa]	1678
Form	Corrugated

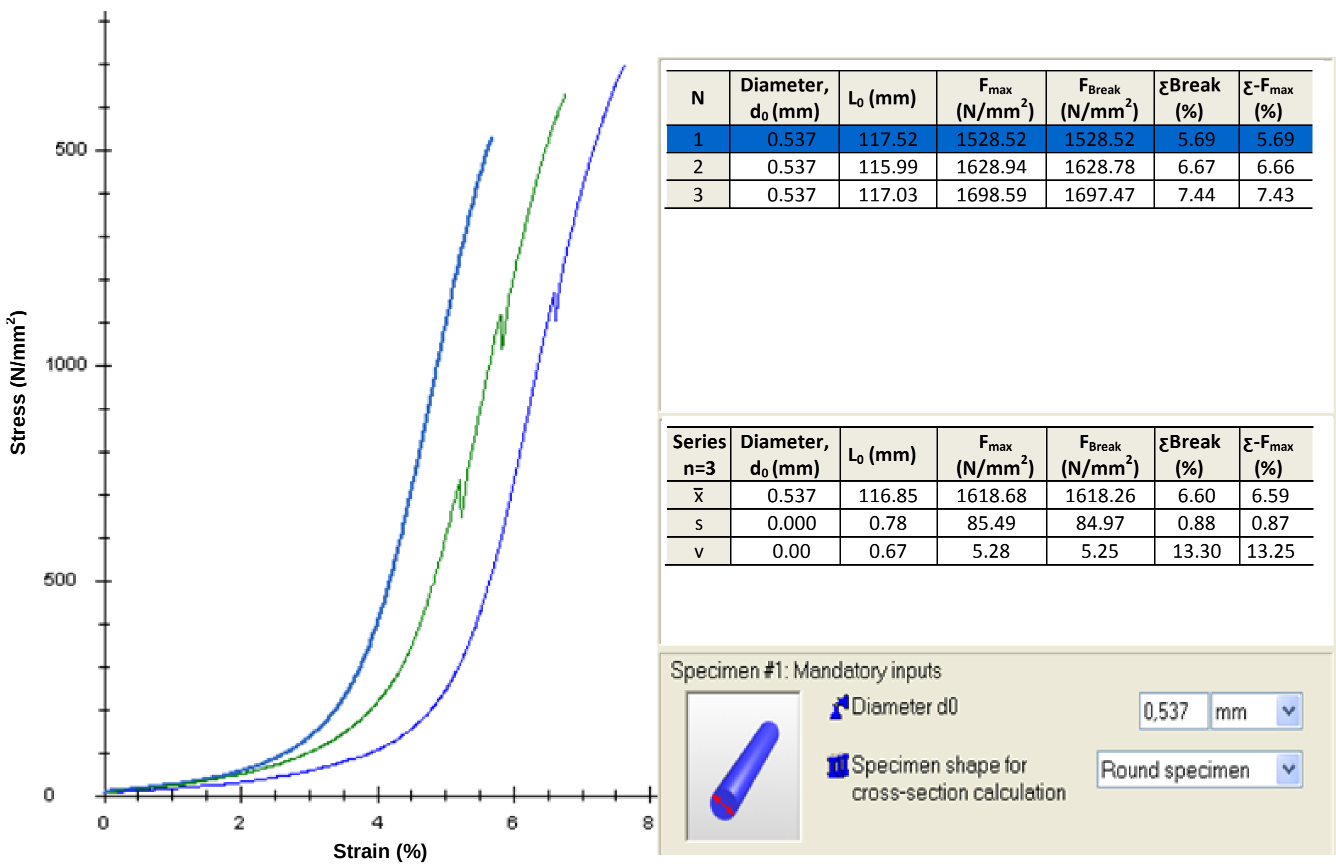

Figure 1. Mechanical behavior of fibers used (tensile test).

Casting and curing of concrete specimens

All the mixtures were mixed and prepared using a mortar mixer. Before casting, slump-flow test is attempted as workability tests on fresh concrete. Thereafter, a total of three (3) specimens were cast in prismatic molds of (40×40×160 mm^3), for each concrete mixture. One day after casting, specimens' samples were stored in water under 21±1°C.

Test methods

Rheological tests: All rheological tests were carried using a viscosimeter VT550 type with coaxial cylinder geometry (Figure 2). Rheological measurements were conducted according to following protocol (in first step: a pre-shear and a ramping of the shear rate at 350 s^{-1} during 60 s. Second step: maintaining a constant shear rate at 350 s^{-1} for 300 s). It was noted that this protocol can be used for the cementitious pastes (Safi et al., 2011; Struble and Sun, 1995; Ferraris, 1999). All cementitious pastes tested, were prepared with fixed dosage of superplasticizer and a ratio W/C = 0.29 which, was kept constant.

Tests on fresh concrete: The flow test was carried out on the studied concretes, by the Abrams cone used for HPFRC. The flow test procedure was according to specification and guidelines for self compacting concrete (EFNARC, 2002).

Tests on hardened concrete: Both the compressive and flexural strength of concrete were determined. A compressive test machine

Table 3. Concrete compositions.

Components	HPC(1)	HPC(2)	HPC(3)
PC [Kg/ m^3]	710	710	710
DS [Kg/m^3]	1020	1020	1020
SS [Kg/m^3]	220	330	110
DE [Kg/m^3]	220	110	330
SP [Kg/m^3]	15	15	15
W/C	0.29	0.29	0.29

Table 4. Formulation of high performance fiber concrete HPFC in 1 m^3.

Components	HPFC
Cement PC [Kg]	710
Sand fine DS [Kg]	1020
Sand Crushed SS [Kg]	110
Dust of electrostatic DE [Kg]	330
Superplasticizer SP [Kg]	15
Metallic fibers MF [Kg]	125
W/C	0.29

Figure 2. Equipment used for rheological tests.

was used to test concrete samples, which have been cured in saturated water at 22±1°C for 3, 7 and 28 days according to ASTM C348 and C349 (ASTM C348 – 08, 2008; ASTM C349 – 08, 2008). The bulk density is also measured for all studied concretes, according the ASTM test C642 (ASTM C642, 1993).

RESULTS AND DISCUSSION

Rheological study of cementitious pastes

The saturation point is the dosage beyond which the superplasticizer has no effect on the rheological properties of the cementitious pastes or concretes. In this work, it is determined using the viscometer VT500. The saturation point of superplasticizer with a ratio W/C = 0.29, was first determined for the cement paste of studied concretes. The results are shown in the rheograms as follows in Figures 3 and 4. Based on the viscometer records, all the shear stress curves (Figure 3) were modelled to the Herschel-Bulkley Equation (1):

$$\tau = \tau_0 + K.\dot{\gamma}^n \qquad (1)$$

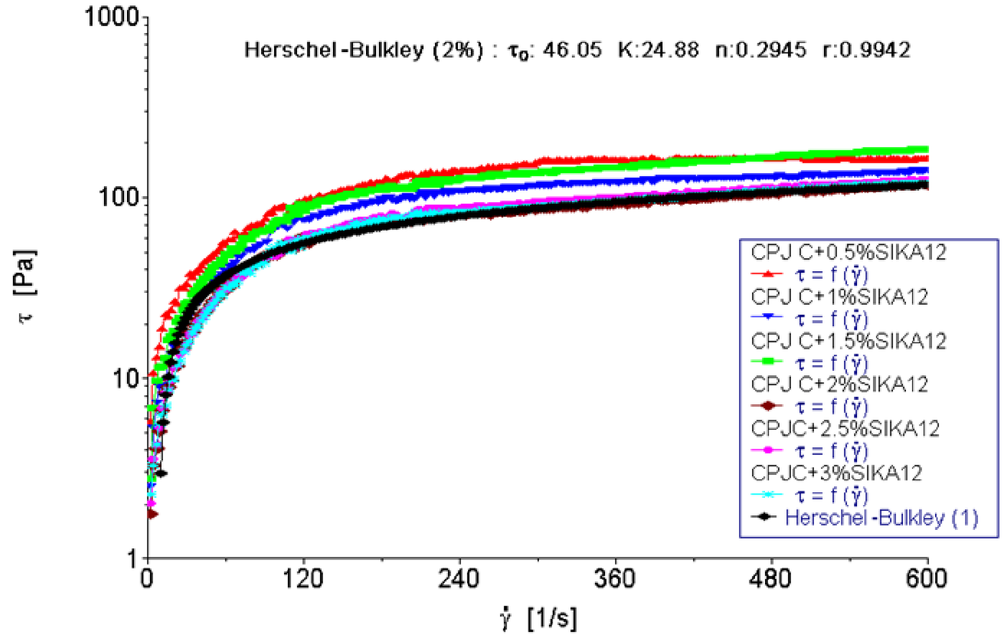

Figure 3. Variation of the shear stress as a function of shear rate.

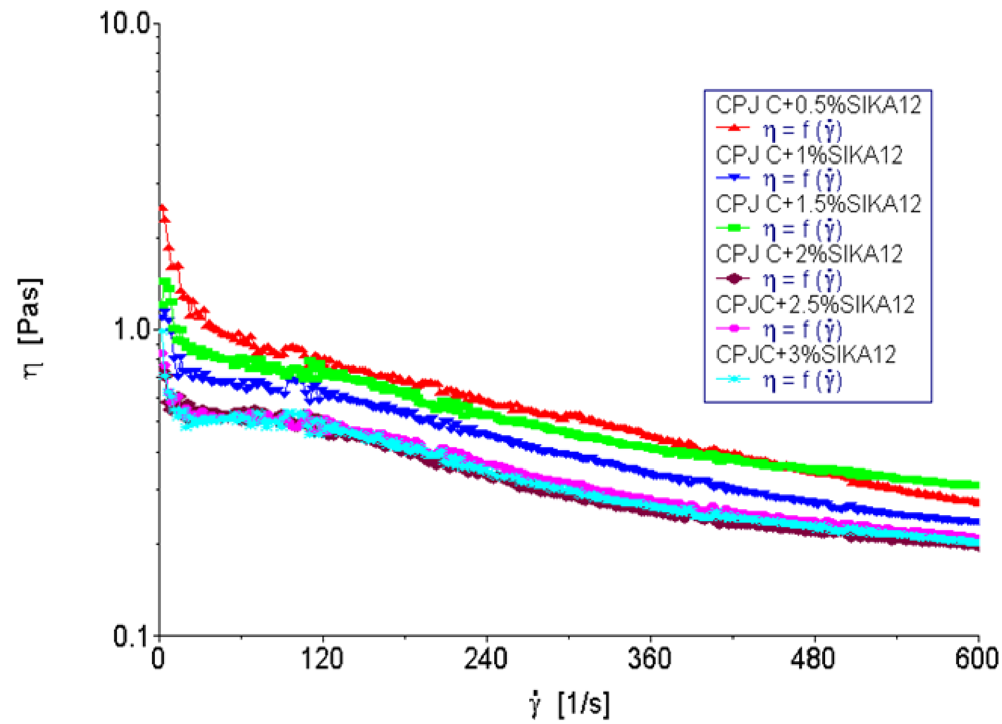

Figure 4. Variation of the plastic viscosity as a function of shear rate.

Where: τ is shear stress; τ_0 is yield stress; *K*: is consistency and γ^* is shear rate. Exponent n characterises paste behaviour: n<1 denotes shear thinning and n>1 shear thickening. Further to that rule, all the cement pastes studied exhibited shear thinning behaviour, which is in conformity to the one found in the literature (Struble and Sun, 1995; Ferraris, 1999).

After having tested cement with various proportions of

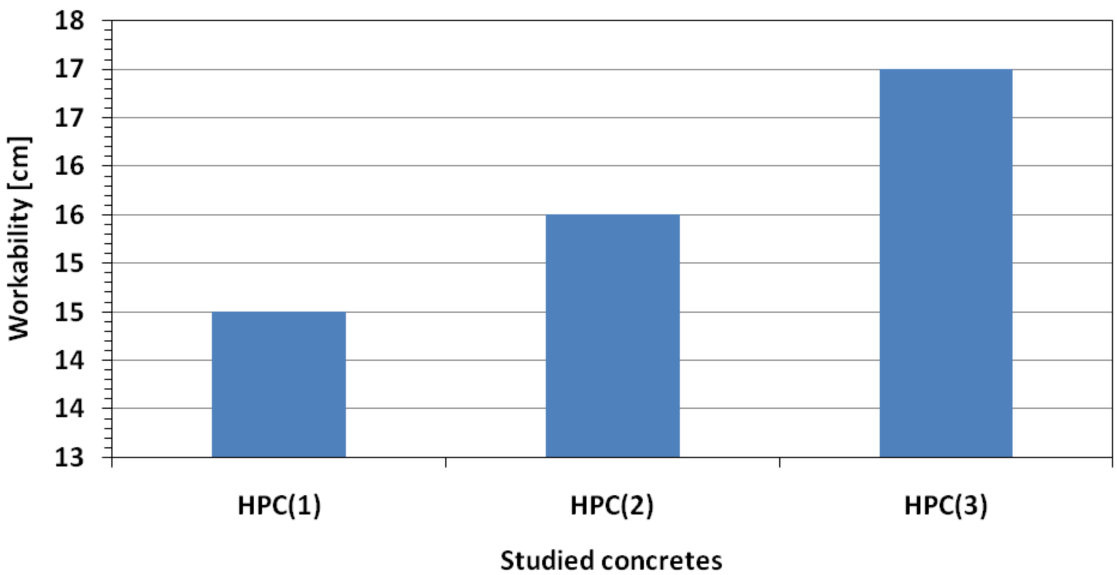

Figure 5. Slump of studied concretes.

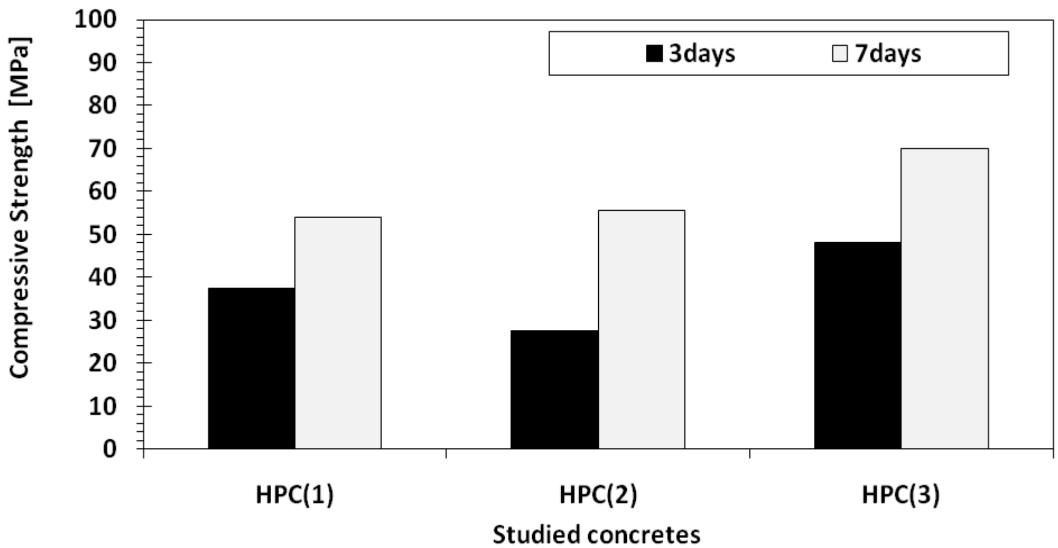

Figure 6. Compressive strength of studied concretes.

superplastifiant, it was noted that SP effect is appreciably on the main rheological parameters (plastic viscosity and shear stress) of cement pastes. Indeed, increase in the percentage of superplastifiant resulted in decrease in the viscosity and shear stress (Figure 4). That can be explained by the dispersing effect of SP which causes a steric repulsion between the cement particles, reducing their agglomeration thanks to the principal length of the superplasticizer chains as well as the grafting of the unadsorbed side chains. In addition, the more SP percentage increases, the more the flow of the cementitious pastes approaches the Newtonian flow, up to the saturation point. Besides, superplasticizer does not influence on the cement pastes flow.

Optimization of the high performance concrete

The first step will be to optimize composition of the concretes by measuring the fluidity and mechanical strength. Also, these concretes were subjected to heat treatment for different temperature chosen. The obtained results are presented in Figures 5 and 6.

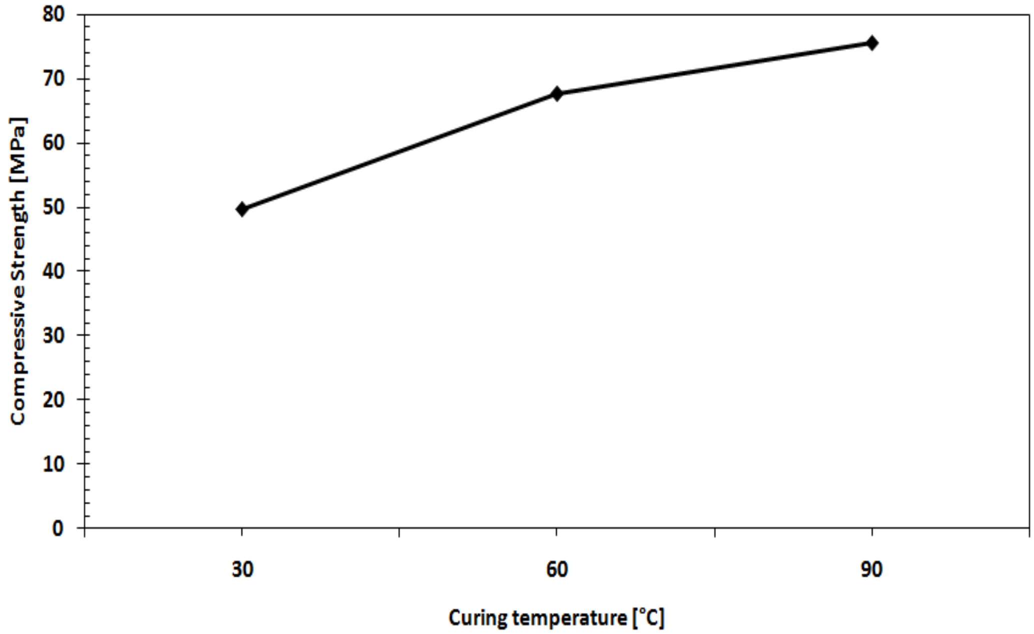

Figure 7. Compressive strength evolution as function the heat treatment.

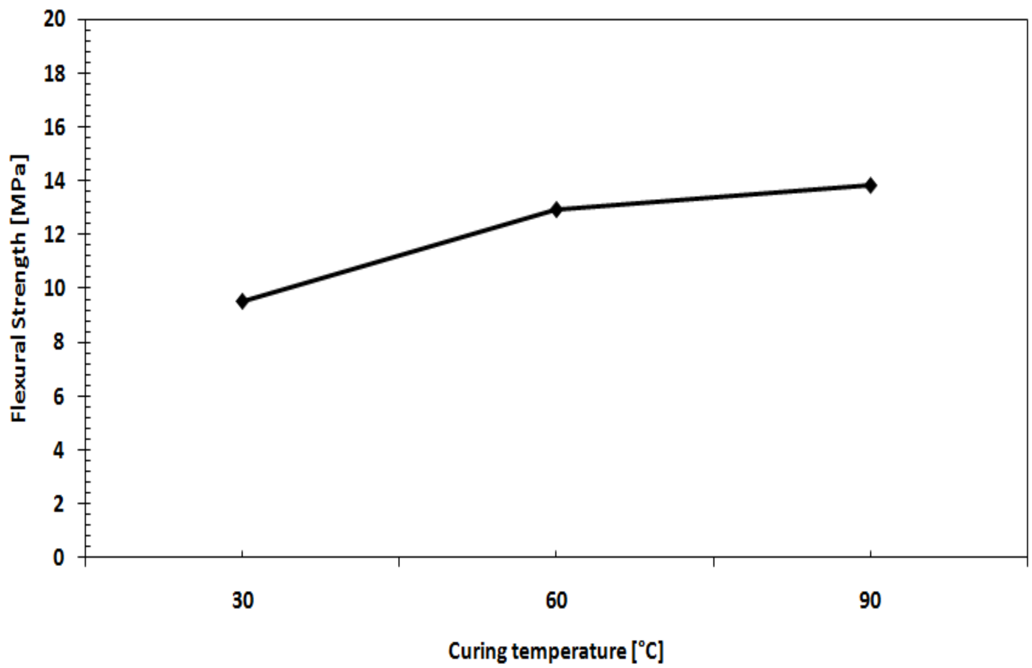

Figure 8. Flexural strength evolution as function the heat treatment.

Heat treatment by immersion of the test-tubes in water

Mechanical strength with heat treatment

The heat treatment was done by immersion of the test-tubes in a vat filled with water inside the drying oven. Figures 7 and 8 show showed the compressive and flexural strength evolution as function of the heat treatment of studied concrete. According to this result, it is clear that for strength improvement, the best suitable heat treatment is at 90°C during 24 h. Indeed, the figures

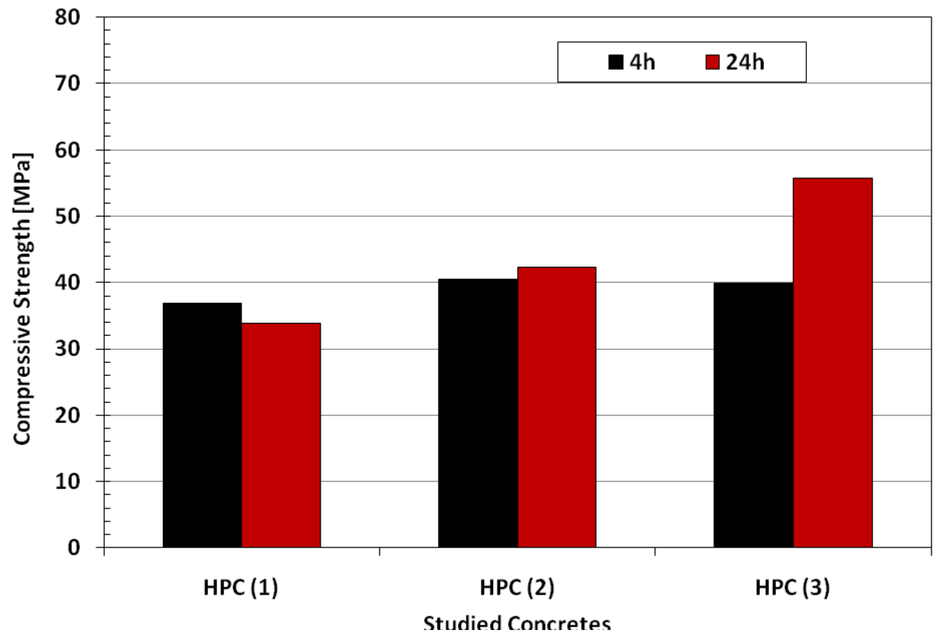

Figure 9. Compressive strength evolution as function the processing time of heat treatment.

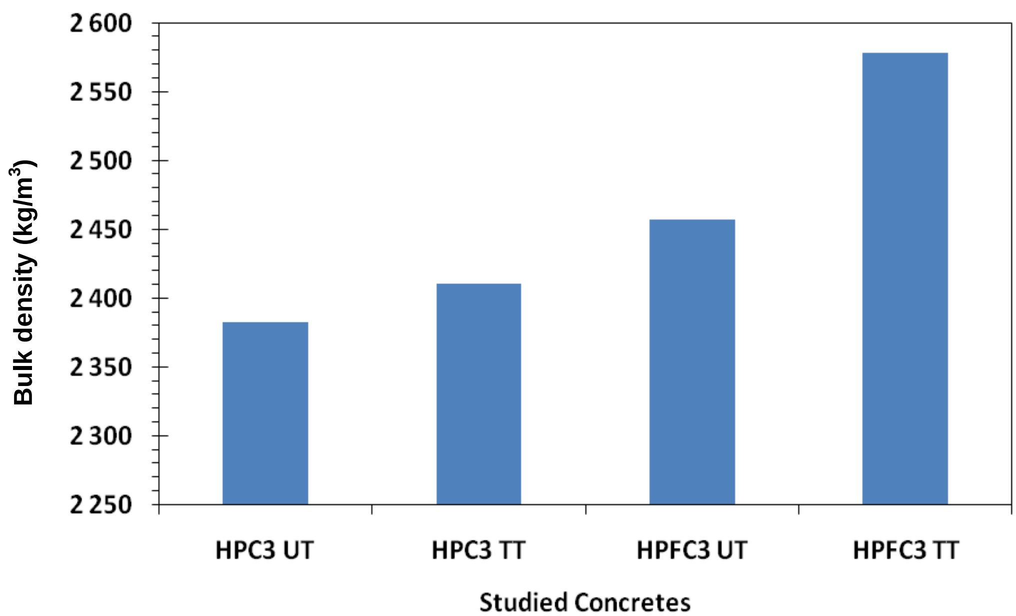

Figure 10. Bulk density of studied concretes.

show a significant increase of the compressive strength of concrete samples. Indeed, the figures show a significant increase in the compressive strength of concrete samples. This increase is about 60% for compressive strength and about 40% for flexural strength.

Figures 9 show the compressive strength evolution as a function of the processing time and of heat treatment evolution as a function of the heat treatment of studied concrete at 7 days of curing age. The obtained result show that, during 24 h of heat treatment the strength of concretes can be improved and also when compared with 4 h of treatment, the increase in strength is about 38%. The increase in strength accompanying increase in the bulk density of studied concrete can be explained by the densification of the cementitious matrix (Figure 10).

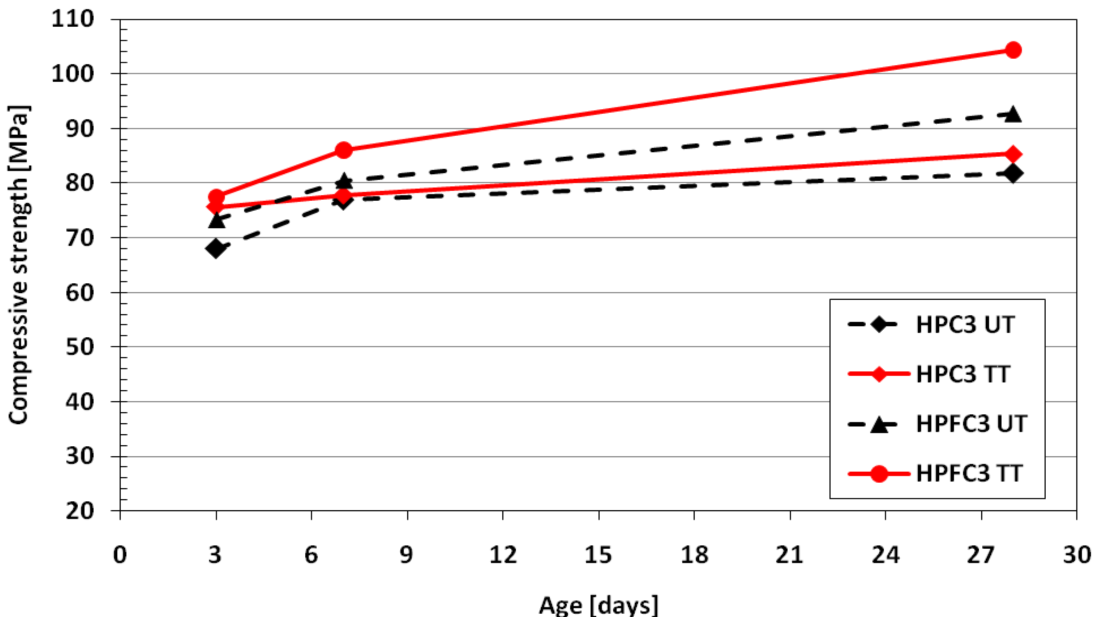

Figure 11. Compressive strength development of the studied concretes (treated and untreated) as function curing age.

According to the results obtained, it can be noted that the mechanical resistances to compression are high for the 3rd composition. Also for depression with the slump test, the HPC3 PC3 give good fluidity compared to the others. These results force to us to choose the 3rd composition and to proceed with treatment by immersion. The temperature of cure has a major role on the development of the mechanical properties of the concrete. At the youth level, all seems to show that it is simply the increase in the degree of reaction which is responsible for higher resistances at high temperature.

A rise in temperature during the first stages of hydration results in a faster hydration. According to Kjellsen et al. (1990), the influence of temperature results in a kinetic effect of the increase in temperature. This results in an acceleration from the process of hydration and the evolution of resistances, whereas reduction in the temperature slows down the process of hydration; the density and size of the crowns of inner H-S-C are increased, the portlandite crystallizes in the form of fine hexagonal plates and the sulphate rates measured in the H-S-C are more significant, and an increased polymerization of the silicate chains which is densifient and rigidifies the H-S-C, therefore obtaining a very compact structure (Kjellsen et al., 1990, 1991). Our result is similar and in agreement with works of Mouret et al. (1999).

The preceding results confirm that there is improvement in the performances of concrete samples. The next step will be preparation of high performances fiber-reinforced concrete (HPFC), with the HPC3 composition and a thermal 90°C treatment during 48 h.

Mechanical strength development of HPFC

Figures 11 and 12, given compressive and flexural strength development of the studied concretes (treated and untreated) as function curing age (3, 7 and 28 days). A significant improvement in mechanical strength (compressive and flexural) of concretes was noted and clearly observed in these figures. This improvement in strength is probably due to heat treatment suitable for concretes which have made increase of about 25% for the fiber reinforced concrete and 10% for concrete without fiber. However, heat treatment effect is more significant of the flexural strength of fiber reinforced concretes, while the improvement of strength flexural is about 37%.

Conclusion

According to experimental results, released remarks can be quoted below:

i) An increase in the compressive and flexural strength of the concretes thermally treated compared with untreated (with or without fibers). Increase in the compressive and flexural strength of the concretes thermally treated compared with untreated (fibers or not fibers).
ii) The heat treatment and fibers presence, have improved the mechanical performances of UPFC by improving the microstructure of the cementitious matrix.
iii) The purpose of the fiber addition is to improve ductility while acting on the cracking on two scales: On the scale

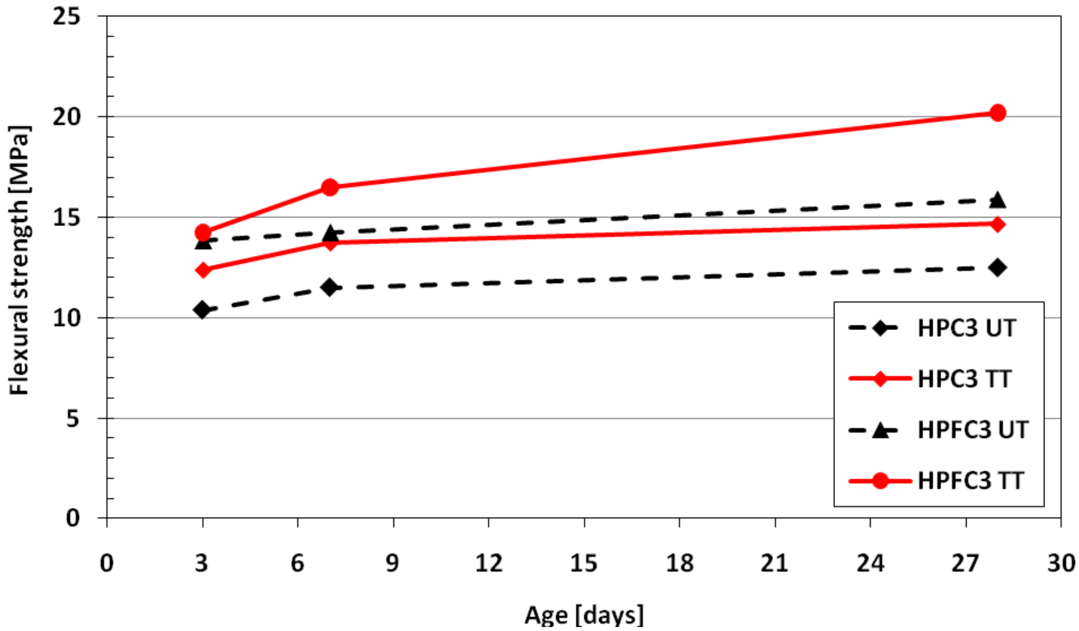

Figure 12. Flexural strength development of the studied concretes (treated and untreated) as function curing age.

of the material (increase in the tensile strength) and on the scale of the structure.

iv) The results of this work show that it is possible to make a concrete with mechanical performances acceptable, using local materials (inexpensive) such as the dust electro-filter, the dune sand and the metallic fibers of breakdown cable of service vehicles.

v) Comparatively to concretes based silica fume, concretes studied in this study may be acceptable from the viewpoint of cost price of the concrete material. Because the dust is an element which has a mineralogical and chemical composition close to that cement, therefore it can be used in substitution of silica fume.

As known, the UPFC are concretes which have a good ductility by introducing the fibers. Indeed these fibers can make obstacle the formation and propagation of the cracks which cause the damage of the structure. The fibers used in this work, have significantly improved the flexural strength reaching 15.90 MPa.

During a high thermal temperature treatment, the HPFC containing a certain percentage of fibers reach maximum compressive stresses because the fibers act on the microfissuring induced by the high thermal gradients and the mineralogical changes (104.34 MPa for compression and 20.22 MPa for the inflection).

Conflict of Interest

The authors have not declared any conflict of interest.

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