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Original Research Paper

Impact of the addition of metal fibers on the strength of high performance concrete (HPC)

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Abstract 27 January 2013

High performance concrete reinforced with metal fibers is increasingly used in practice, particularly in the implementation of roads, airfields, towers and constructions. High performance concrete reinforced with fibers is now essential in the field of public works. Metal strands embedded in the concrete mass are commonly known as composite metal fibers. Their use has been necessary to reduce some defects in the concrete materials. The objective of this study is to see the contribution of the introduction of fibers in the concrete matrix with regard to resistance and ductility. Experiments of compression and bending using ultrasonic testing on samples of fiber concrete were conducted. From the study, it appears that the main role of steel fibers is the reduction of cracking and the security improvement of ultimate loads states of high performance concrete. The metal fibers control the mechanism of cracking. Tensile failure of concrete with steel fibers becomes ductile rather than brittle. The introduction of fibers in concrete is a solution that improves ductility and reduces cracking.

Keywords: Concrete, fiber, strength, ductility

INTRODUCTION

The high performance concrete reinforced with steel fibers is the subject of numerous studies. Indeed, these concretes reach very high compressive strengths, but the behavior of high performance concrete at failure is very fragile. Furthermore, the tensile strength remains very low. The objective of this study is to see the behavior of high performance concrete fibers subjected to compressive forces. These solicitations appear in all cases of loading and during earthquakes. They can reach large amplitudes, resulting in the ruin of the structure. The addition of fibers within the concrete matrix gives the concrete higher ductility after the cracking? How much fibers should be added to the concrete matrix to improve the resistance of these concretes? The HPC are studied in many research programs and has displayed different results (Benamara et al., 2010) (Jacobs, 2007). The work is to achieve several specimens of HPC with different percentage of metallic fibers. The specimens are concocted out of Constructions Materials Laboratory, Department of Civil Engineering at the University of Chlef. The manufacturing is carried out in a tempered pug mill of 100 liters capacity. The procedure is:
- Stirring the mixture dry sand + gravel + cement + silica fume for 1 minute;
- Adding water + 1/3 of the plasticizer and mixing for 2 min and Adding 2/3 of plasticizer (mixing for 2 min)
- Putting fibers in the concrete for 15 seconds and

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stirring for 1 minute. The metal fibers are dispersed by hand ensuring a good distribution in the concrete mass. We optimize the composition obtained by using an experimental method based on the method of "Baron-Lesage" (NF P 18-407), and then determining the mass of fibers to be incorporated into the concrete for fiber percentages of 0.5, 1 and 1.5% by volume for the formulation of high performance concrete reinforced with metal fibers. For the workability of concrete, we use the Abrams cone. Destructive testing of compression, tensile bending, tensile splitting and nondestructive testing such as ultrasonic tests are performed on specimens at the age of 7, 14, 21 and 28 days of age. The results are recorded and interpreted for each test.

MATERIALS AND METHODS

The crushed aggregates are irregular in shape and come from the career of the Algerian company of aggregates (ALGRAN), located in Oued Fodda (Chlef). Their dimensions are in millimeters 3/8, 8/14.
- Sand rolled river Oued Chlef size 0/4 (mm)
- Composed CPJ Portland cement CEM II / A 42.5, produced by Oued Sly cement firm (Chlef)
- A silica fume produced by the Canadian company SKW and marketed by the company "Sika"
- An adjuvant superplasticizer "SIKA VISCOCRETE TEMPO 12" marketed by the company "Sika"
- The metal fibers marketed by the company under the name of Sika Dramix (METAL FIBERS VISCOCHAPE).

The tests for the compressive strength measurements, cubic specimens of (10 × 10 × 10) cm are used. The press has a capacity of 2000 KN. The tensile test was performed on cylindrical specimens of (16 ×32) cm using the same compression press. The tensile test is performed by bending prismatic samples of (7x7x28) cm. The ultrasonic testing (NF P 18-418) is a nondestructive test that is done by measuring the speed of sound which is even higher than the concrete is denser, therefore, more resistant. It consists of putting the two probes (transmitter and receiver) of the ultrasound at the two ends of the specimen (10 × 10 × 10) cm between two determined points of the concrete. The final results represented in Figure 1 show the determination of saturation and the flow time of torque binder (cement + 3% silica fume) / superplasticizer.

Figure 1shows the pair bonding (CPJ42.5 3% FS) - Sika Viscocrete tompo 12. Once the dosage of superplasticizer determined, proceed to the final formulation of concrete.

The basic data are: the Cement content 450 kg/m3; the determination of silica fume to 3% by weight of cement; the dosage of superplasticizer to 1.6% by weight of cement, to better optimize the composition of metal fiber concretes, using an experimental method of Baron-Lesage, already used for standard concrete. The Baron-Lesage method is based on the following assumptions:

The dosage of water and cement is initially set (E / C is fixed). The optimal mix of aggregates is determined and The addition of steel fibers does not modify the first two hypotheses.

In practice, we proceed in three steps to form high-performance concrete fiber. At the beginning, the W / C and the percentage of fibers to be incorporated are fixed. Next, we vary the ratio S / G (Sand / Aggregate) and finally, we determined for each ratio the workability of fibers.

RESULTS AND DISCUSSION

Resistance to compression

Tests measuring compressive strength are performed on of cubic dimensions samples of (10 × 10 × 10) cm. The press has a capacity of 2000 KN. Table 1 shows the evolution of compressive strength of tested concrete. There is a considerable improvement in the compression strength of HPC compared to ordinary concrete reference. The compressive strength of high performance concrete (HPC) has improved by 91.17%, 81.12%, 71.81% and 69.56% at 7, 14, 21 and 28 days of age respectively on ordinary concrete (Table 1).

Table 1 shows the results of compression tests of different specimens. This improvement in compressive strength is attributed at one side to the good quality local materials used, since even for ordinary concrete, the compressive strength is satisfactory, and on the other hand, the introduction of the silica fume has led to a significant growth in the resistance in the concrete matrix. Silica fume densify cement paste with its ultrafine particles which filled the pores created during cement hydration (Malier, 1992). The increase in compressive strength can be attributed also to the use of a 450 kg / m3 cement content, to the reduction of the W / L ratio and to the use of high water-reducing superplasticizer.

Figure 2 shows the influence of the percentage of fibers on the compressive strength of high performance concrete (HPC). It is found that at 7 days of age, the percentage of fibers has little influence on the compressive strength and the addition of 1.5% metal fibers causes no increase in resistance. This is attributed to the increase of voids because of the large volume of metal fibers. At 14, 21 and 28 days of age there was a slight increase in the compressive strength of high performance concrete fibers of 1% and 1.5% compared to HPC without metallic fibers.

Note that the addition of steel fibers in small percentage in high-performance concrete HPC (up to 1% volume fraction), brings a slight increase in compressive strength.

Tensile strength and flexural splitting

Flexural tensile tests are performed according to standard NF P 18-407 on prismatic samples of

Table 1. Results of compression tests of different specimens

	Compressive strength (MPa)			
Age of concrete	7 days	14days	21days	28 days
ordinary concrete	34	39,2	44	46
HPC witness	65	71	75,6	78
HPC (with 0,5% of fibers)	66	71,6	77	79
HPC (with 1% of fibers)	67	73,8	79,6	81,5
HPC (with 1,5% of fibers)	65	72	77,6	79,8

Table 2: Results of ultrasonic testing of different specimens

	Sound speed (m / s)			
Age of concrete	7 days	14days	21days	28 days
ordinary concrete	3700	3950	4100	4320
HPC witness	4100	4320	4530	4740
HPC (with 0,5% of fibers)	4100	4400	4600	4762
HPC (with 1% of fibers)	4150	4390	4580	4693
HPC (with 1,5% of fibers)	3976	4300	4550	4650

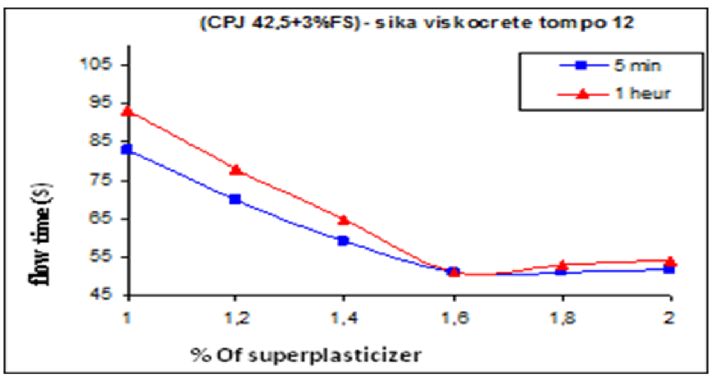

Figure 1. pair bonding (CPJ42.5 3% FS) - Sika Viscocrete tompo 12

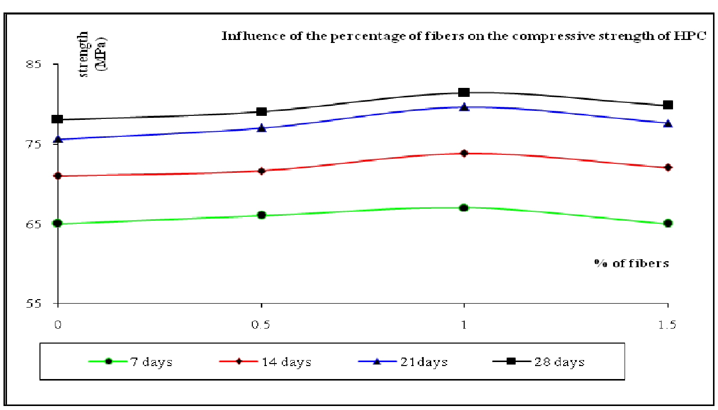

Figure 2: Effect of metal fibers % on the compressive strength of high-performance concrete

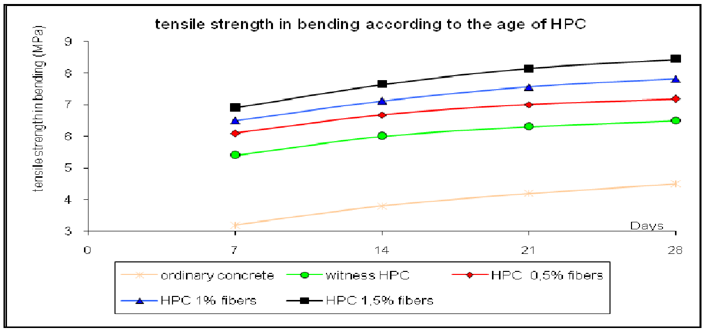

Figure 3. Results of the evolution of the tensile strength by bending of HPC versus time (days)

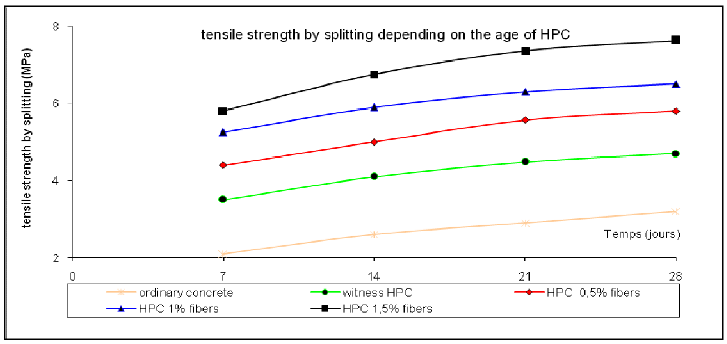

Figure 4. Results of the evolution of the tensile strength by splitting of HPC versus time (days)

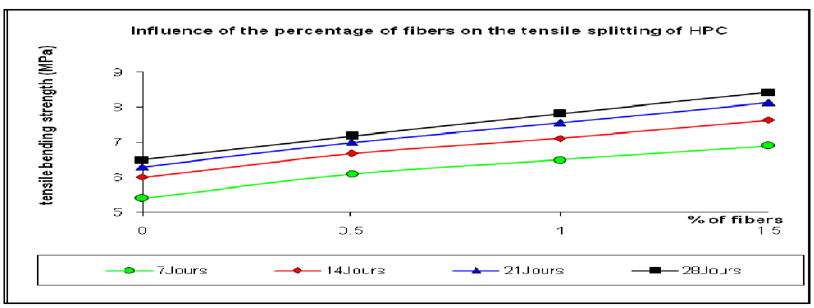

Figure 5: Effect of metal fibers % on the flexural tensile strength at different ages of HPC

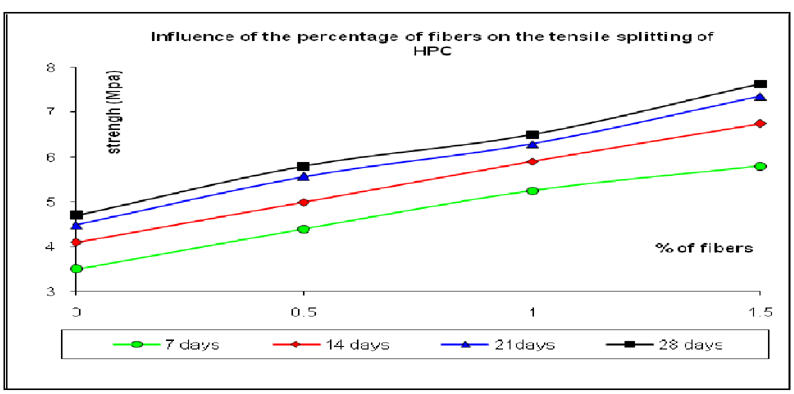

Figure 6: Effect of metal fibers on the splitting tensile strength at different ages of HPC

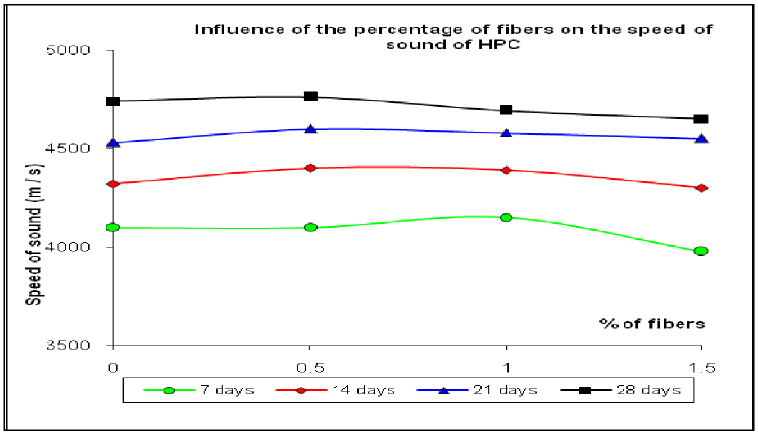

Figure 7. Effect of% of fibers on the speed of sound

(7x7x28cm) from each batch of concrete. The splitting tensile tests are performed according to standard NF P 18-408 on cylindrical specimens of (16x32cm) from each batch of concrete.

Figure 3 shows the evolution of the tensile strength by bending of high-performance concrete (HPC) with different percentages of steel fibers. We notice an increase in tensile strength by bending of high strength concrete compared with ordinary concrete. The percentage of the increase in tensile strength by bending of high-performance concrete compared with ordinary concrete is 68.75% at 7 days, 57.9% at 14 days, 50% at 21 days and 44.44% at 28 days.

Figure 3 shows the results of the evolution of the tensile strength by bending of HPC versus time (days)

Figure 4 shows the evolution of the tensile strength by splitting of high-performance concrete with different % of fibers at all ages compared with ordinary concrete. There is an increase of tensile strength of high-performance concrete by reference to ordinary concrete.

Figure 4 shows the results of the evolution of the tensile strength by splitting of HPC versus time

This increase can be attributed to the role of metal fibers and a significant reduction of the porosity of the cement matrix and the good dispersion of cement particles throughout the mixture (Nevile, 2000). The improvement of tensile strength by bending and splitting is also due to the introduction of silica fume, which lead to a significant growth of the resistance and densify cement paste due to its small ultrafine particles, which filled the pores created during the hydration of the cement (Wu et al, 2000).

Figure 5 shows the effect of metal fibers % on the flexural tensile strength at different ages of HPC

Figure 5 shows the influence of the percentage of metal fibers on the tensile strength by bending of high-performance concrete. At the age of 7 days, the percentage of the increase in tensile strength by bending of high-performance concrete is 12.69% with 0.5%, 20.37% with 1% and 27, 77% with 1.5% of metal fibers compared with ordinary concrete. At 28 days the percentage of the increase in tensile strength by bending of high-performance concrete is 0.46% for 0.5%, 20.30% for 1% and 29.69% for 1.5% metal fibers compared with ordinary concrete. The tensile resistance increases with the percentage of fibers (Rossi, 1994).

Figure 6 shows the percentage of steel fibers significantly affects the splitting tensile strength of high-performance concrete (Figure 6). The rate of the resistance increase in high-performance concrete with fibers compared with high performance concrete without fibers is:

-25.71% for 0.50% of fibers, 65.71% for 1% and 1.5% fibers at 7 days.

-23.40% for 0.5% of fibers, 38.3% for 1% of fibers and 62.34% for 1.5% fibers at 28 days.

The addition of steel fibers volume fraction up to 1.5% in high-performance concrete has caused a significant increase in tensile strength by bending and splitting compared with high-performance concrete without steel fibers at all ages of testing. This increase is attributed to metal fibers mechanism (Rossi et al, 1989). The shape of the fibers plays an important role in braking the cracks. Fibers with hooks are those with the most benefits because of their good mechanical grip. The anchor hook develops gradually and then dissipates energy by plasticization thereof and by friction at the interface with the matrix. The fibers content also plays an important role in increasing the tensile strength by bending and splitting. The short fibers more numerous can be active by playing the role of sewing the microcracks that develop in early stages of loading. Thus, the tensile strength can be found increased. Gradually, as the load increases, the cracks grow and cause tearing of short fibers. Therefore, the use of short fibers aims to improve the tensile strength.

Sound propagation speed

This is a simple method and relatively less expensive to determine the homogeneity of concrete. It can be used not only as a production monitoring but control over work as well. High speed propagation usually indicates a good quality concrete.

Table 2 shows the change in sound velocity as a function of concrete age. There is an increase of the speed of sound propagation in the HPC compared to that of ordinary concrete (BO), speed of sound is improved in HPC compared to that of ordinary concrete by 10.81%, 9.36%, 10.48%, 9.72% at 7, 14, 21, 28 days of age respectively.

This increase in speed of sound is assigned to, on one hand, to the presence of good aggregates and on the other hand, to the composition of coarse aggregates and cement in both cases. This slight increase can be interpreted by the good compactness of HPC, provided mainly by the strong reduction in the amount of mixing water and the combined use of silica fume and superplasticizer, which ensure a good homogeneity and densification of the concrete matrix.

Figure 7shows the influence of fibers % on the speed of sound. It is found that at seven days of age the sound propagation speed presents no increase for 0.5% fibers content. It has a slight increase of 1.21% for 1% fibers content. On the contrary, the addition of 1.5% of steel fibers causes a slight decrease in sound propagation speed; the percentage was 3.11% at 7 days. This is attributed to the increase of voids because of the large volume of steel fibers. At the age of 14, there is a slight increase in the speed of sound of 1.85% and 1.62% for HPC of 0.5% and 1% metallic fibers. Again, the addition of 1.5% steel fibers causes a slight decrease in the velocity; the percentage was 0.46% at 14 days compared with HPC without steel fibers. At the age of 21 days there is a slight increase in the speed of sound and the increasing percentage was 1.54%, 1.1% and 1% for HPC of 0.5%, 1% and 1, 5% metallic fibers content compared with HPC without steel fibers. At 28 days of age, there is a slight increase in the speed of sound and the increasing percentage was 0.46% for HPC of 0.5% metal fibers. Again, the addition of 1% and 1.5% of metallic fibers causes a slight decrease in the speed of sound; the increasing percentage was 1% and 1.93% for HPC of 1% and 1.5% steel fibers at 28 days of age compared with HPC without steel fibers. The addition of steel fibers in the HPC at low percentage (up to 1% volume fraction), provides a slight increase in the speed of sound, but, by increasing the volume of fibers (volume fraction of 1.5%), it tends to decrease the speed of sound and this is probably due to the creation of some porosity within the material.

CONCLUSION

The study of high-performance concrete through compression tests showed that the fibers improve the behavior of the concrete matrix. The strength and ductility increase due to the action of sewing fibers that delay the onset of cracks and their propagation. This study also allows us to draw some important conclusions:

- The fibers prevent the spalling of concrete and slow crack propagation. The practical interest is to maintain the works damaged during an earthquake in place and prevent more damage.
- The introduction of fibers increases the bearing capacity of beams.
- The fibers delay the onset of the first cracks through its work sewing cracks.
- The addition of fibers, at low percentage, brings a slight increase in compressive strength, but by increasing the volume of fibers, it tends to decrease. It is probably due to the creation of some porosity within the material which tends to weaken it.
- The addition of metal fibers up to volume fraction of 1.5% in high performance concrete causes a significant increase in tensile strength by bending and by splitting compared with high-performance concrete without metal fibers at all ages of testing. This increase is attributed to the mechanism of metal fibers. The shape of the fibers plays a very important role, the hooked fibers are those with the most benefits because of their good mechanical grip hook gradually developing an anchor, then dissipates energy by laminating it and friction at the interface with the matrix. The fibers content also plays an important role; increasing the percentage of fibers in concrete with fibers increases their effectiveness vis-à-vis the tensile strength (flexural, splitting). The short fibers which, in the same dosage, outnumber can be active by playing the role of sewing on microcracks developing at the early stages of loading. The tensile strength can be found increased. Gradually, as the load increases the crack opening increases. This causes tearing in short fibers. Then the fibers during their use are intended to improve the tensile strength. The addition of a fraction up to 1% of metal fibers improves the speed of sound propagation. By adding 1.5% of the fibers in high-performance concrete, the speed of sound decreases. This is probably due to the creation of porosity within the material.

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