

# Analysis of the influence of metallic fibers in the High Performance Concrete by non-destructive testing

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## ABSTRACT

*High performance Concrete (HPC) reinforced with fibers is now essential in the field of public works. Two characteristics of high performance concrete have limited its use: fragility and low tensile strength. 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 influence of the introduction of metal fibers on the mechanical strength of high performance concrete (HPC) subjected to non-destructive testing. Laboratory experiments with the rebound hammer device and ultrasound were performed on samples of high performance concrete reinforced with fibers. A correlation exists between the percentage of fibers and the evolution of speed sound and also between the percentage of fibers of HPC and the number of the rebound hammer device. The test results show that the main role of steel fibers is to avoid cracking and reduce the openings caused by the ultimate loads. Fibers prevent the spalling of concrete and hinder crack propagation.. The metal fibers control the mechanism of cracking. The introduction of fibers in concrete is a solution that improves ductility and reduces cracking.*

**Keywords:** High performance Concrete (HPC), non-destructive testing, fiber, strength.

## 1. INTRODUCTION

Innovation in construction science through the development of new materials and control their properties. The high performance concrete (HPC) fiber reinforced is one of these materials.

The objective of this study is to see the role of fibers on the strength and hardness of high performance concrete by non-destructive testing.

Or in another way, we want to answer the following questions:

- Adding fiber in the concrete matrix gives it greater resistance to HPC?
- 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 [1-2]. Many researchers believe that the addition of fibers increase slightly the resistance of high performance concretes (HPC) [3-4]. 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.

Non-destructive tests are intended to nondestructively monitor the homogeneity of concrete at the level of a structure. Analysis of the results to determine the quality of materials and seek heterogeneities corresponds to cracks, voids, damaged areas or decompressed, especially after external aggressions such as frost or fire.

In this study, 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.

## 2. 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 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 rebound hammer Test is realized by a device digital

Once the dosage of superplasticizer determined, proceed to the final formulation of concrete. The basic data are: the Cement content 450 kg/m<sup>3</sup>; 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.

**3. RESULTS AND DISCUSSION**

**3.1 Sound propagation speed:**

This test is performed with the ultrasound device (figure 1). This method of measuring the propagation velocity of the ultrasonic pulse is the only that allows performing tests on the resistance of concrete in situ (Rossi, 1994). This method allows to measure the propagation time of a pulse through the concrete. 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.



**Figure 1** The ultrasound device

In general, the resistance increases with the speed of sound. For high resistance, the speed of sound increases practically beyond about 350 bars, because it depends on the compactness of the concrete. The speed of sound is also a function of the nature of the aggregates used. The compressive strength can be deduced from:

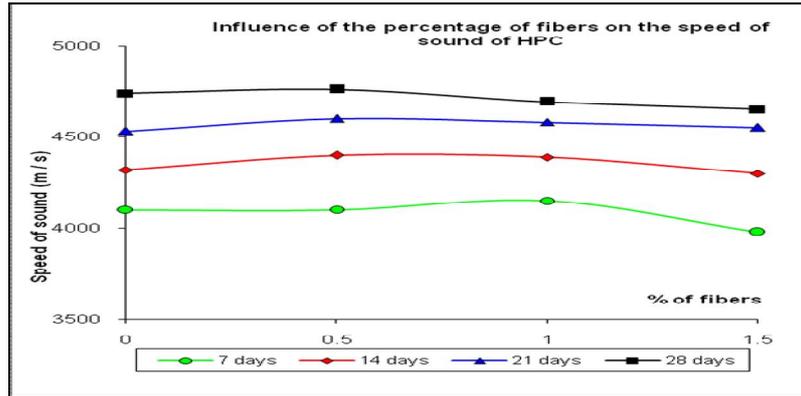
$$f'c = 16,7 \exp^{Ed/122500} \tag{1}$$

Table 1 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 witness concrete, speed of sound is improved in HPC compared to that of witness (ordinary) concrete by 10.81%, at 7days 9.36%, 10.48%, 9.72%, 14, 21, 28 days of age respectively.

**Table 1:** Results of ultrasonic testing of different specimens

Age of concrete	Sound speed (m / s)			
	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

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 2** Effect of % of fibers on the speed of sound

Figure 2 shows 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.

### 3.2 The Rebound hammer Test

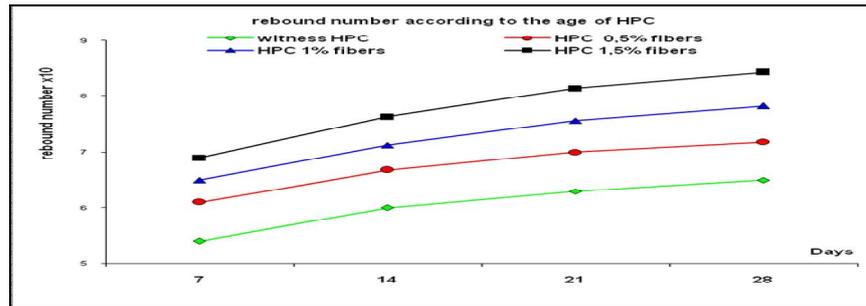
The rebound hammer (figure 3), also known as a Swiss hammer, is a device to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance. Concrete Test Hammers are ideal for fast, inexpensive, nondestructive estimations of in-place concrete strength [5].



**Figure 3** Digital Concrete Test Hammer

A mass controlled by a spring on a plunger moves in a protection tube. The mass is thrown against the concrete surface by the spring, and the rebound hammer number is measured on a scale. The surface on which the test is performed can be horizontal, vertical or at any angle, but the correlation should take into account the inclination of the device relative to the surface. The results are influenced by factors such as the smoothness of the surface, the size and shape of the test, the moisture content of the concrete, type of cement and aggregate. The rebound hammer is applied to one side of the part of the element to auscultate by hand pressure and allows a small mobile mass bounce to determine the surface hardness of the concrete. A fairly clear relationship exists between the surface hardness and strength of the concrete [5]. This Relationship between compressive strength and rebound number

$$f_c = I^2 / 3 - 2I \quad (2) \quad \text{with: } f_c \text{ crashworthiness and } I: \text{ rebound number}$$



**Figure 4** Rebound number x10 according to the age of HPC

Figure 4 shows the evolution of the rebound number depending on the age of the concrete. An increase of rebound number in the HPC compared to witness concrete, the increasing percentage was 68.63%, 80%, 67.85%, 63.33% at 7, 14, 21, 28 days, respectively. This increase rebound number is assigned by the good compactness of HPC, which is provided by the combined use of silica fume and superplasticizer [6]. The introduction of metal fibers in HPC shows a correlation between the percentage of fiber and strength concrete. Indeed, an increase in strength was observed depending on the amount of fibers introduced in HPC. The majority of researchers say the fibers slightly improve the compressive strength [7]. While other researchers have found that fiber decreases the compressive strength slightly. In the High Performance Concrete matrix, the fibers may have two effects:

- the metal fibers have an effect sewing cracks;
- fibers prevent damage to the structure and, therefore, limit the maximum load.

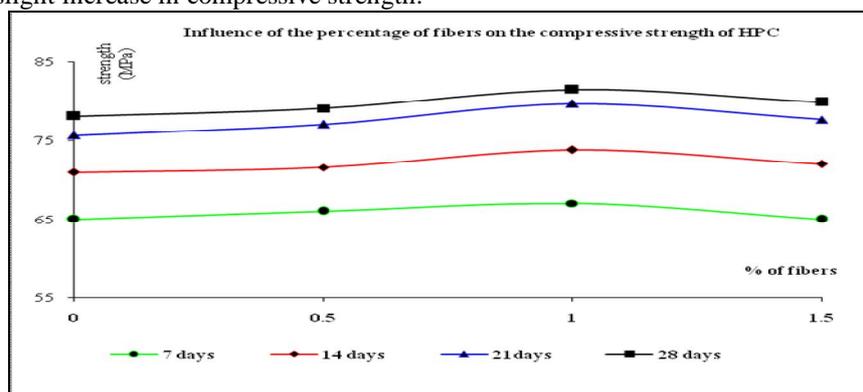
In this study, the introduction of metal fibers in the HPC show very little influence on the compressive strength of concrete.

**3.3 Comparison of nondestructive results with the results of the compressive strength testing**

Tests measuring compressive strength are performed on of cubic dimensions samples of (10 × 10 × 10) cm

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.



**Figure 5** Influence of the percentage of fibers on the compressive strength of HPC

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 [3]. The increase in compressive strength can be attributed also to the use of a 450 kg / m<sup>3</sup> cement content, to the reduction of the W / L ratio and to the use of high water-reducing superplasticizer.

**4. CONCLUSION**

The study of high-performance concrete through non-destructive testing showed that the fibers improve the behavior of the concrete matrix. 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 fibers content plays an important role; increasing the percentage of fibers in concrete with fibers increases their effectiveness vis-à-vis the compressive strength. The fibers can play the role of sewing on microcracks developing at the early stages of loading. 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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