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Review

Correlation between the mechanical behavior and the ultrasonic velocity of fiber-reinforced concrete

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HIGHLIGHTS

- Ultrasonic velocity with direct, semi-direct and indirect transmission mode.
- Correlation between consolidation level of UPFRC and ultrasonic velocity.
- Effect of metallic fibers on the ultrasonic pulse velocity.
- Correlation between ultrasonic velocity and mechanical behavior of HPFRC.

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ABSTRACT

Ultrasonic velocity technique is one of the most popular non-destructive techniques used in the assessment of concrete properties. The objectives of this study are (1) to test the use of ultrasonic velocities in the non-destructive evaluation of the curing degree of fiber-reinforced concrete and (2) to find a correlation between the compressive strength, flexural strength, modulus of elasticity, and the ultrasonic velocity. This latter is measured by sensors of 50 mm diameter and 54 kHz frequency, and calculated from the phase slope. The ultrasonic velocity measurements were determined with direct, semi-direct and indirect transmission mode. This methodology is based on European standard EN 12504-4. Samples (prismatic: $10 \times 10 \times 40$ cm and cylindrical: 16×32 cm) are made with different percentages (varying from 0% to 2.5%) of steel fiber.

The results showed that ultrasonic velocity can be very useful to study the homogeneity and the quality of steel fiber-reinforced concrete and it is an effective way for the assessment of the consolidation level during and after the curing period (the measurements are taken at ages of 8 h and from 1 to 28 days).

Contents

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1. Introduction

High performance fiber-reinforced concrete (HPFRC) is a new construction material with superior properties of durability and high strength when compared to ordinary concrete [1]. The composition of HPFRC differs to that of an ordinary concrete; in particular it has a low water/binder ratio, high cement and silica fume content, and high fibers content [1–3]. To determine the mechanical properties, several tests are performed punctually at specific deadlines, as the compressive strength, the flexural strength and the modulus of elasticity. These properties have been the subject of a number of studies [1,4–7]. In addition, Malhotra and Carino [8] presented a comprehensive review of non-destructive methods used on the evaluation of conventional concrete, but there are very few accounts of its application for HPFRC. Among the non-destructive testing that have been used to estimate the quality, to measure the mechanical properties of concrete [9–13] and to survey the internal damage progression [14–17] in cement-based materials, we quote ultrasonic velocity (Fig. 1). The practical issues/limitations associated with using this method is described in detail in literature [8,18,19].

The basic theory of ultrasonic wave propagation in concrete has been described in detail by Jones [20]. It is known that the velocity of waves in concrete is influenced by the same properties that determine its elastic stiffness and mechanical properties [19]. It is primarily dependent on the elastic properties and the density of the concrete [18]. Therefore, if the density and the velocity of the wave propagation are known, then the modulus of elasticity of concrete or of any other medium can be determined. A previous study was made by Washer et al. [21] on the propagation of ultrasonic waves, using the direct transmission in ultra high performance fiber reinforced concrete. The steel fibers utilized by Washer et al. [21] were 0.2 mm in diameter and approximately 12 mm in length. The volume percent of these fibers is approximately 2%. He has determined that the material exhibits isotropic elastic properties within normal operating stress limits. So, it is possible to use this characteristic to estimate the elastic properties of the material. Therefore, this study has been conducted to investigate the suitability and the accuracy of this testing method on fiber-reinforced concrete during the increase of metallic fibers percentage.

Fig. 1. Ultrasonic test equipment.

Table 2
Chemical and physical proprieties of the used materials.

	CEM I	LF	SF	SP
C_3S (%)	67	–	–	–
C_2S (%)	12	–	–	–
C_4AF (%)	9	–	–	–
C_3A (%)	9	–	–	–
SiO_2 (%)	20.5	–	85	–
Fe_2O_3 (%)	2.6	0.04	–	–
Al_2O_3 (%)	5.0	<0.4	–	–
CaO (%)	65.0	–	1.0	–
MgO (%)	1.1	–	–	–
SO_3 (%)	3.6	–	2.0	–
Loss on ignition (%)	1.2	43.10	4.0	–
NaO_2 eq. (%)	0.43	–	1.0	<1.5
cl^-	0.01	–	<0.1	<0.1
Density	3.15	2.70	2.24	1.085
Blaine (cm^2/g)	4750	5550	2200	–
pH	–	–	–	4.5
Dry extract (%)	–	–	–	41

Table 3
Geometrical characteristics of the used fibers.

Fiber	Nature	Length (mm)	Diameter (mm)	Slenderness $\lambda = L/d$	Density kg/m^3	Tensile strength (MPa)
ESF 25	Metallic	25	2.5	10	7.2	1100

Control of hardening phenomena can be used to determine the right moment for formwork removal, or load the structure. Therefore, the knowledge of young concrete is important for both, technical and economical aspects.

The first objective of this study is to identify, depending on time, the effect of metallic fibers, including the percentage, on the ultrasonic pulse velocity using the direct, semi-direct and indirect transmission. The relationship between ultrasonic pulse velocity (V) and compressive strength (S), modulus of elasticity (E), and flexural strength (F) are studied. The second objective is to analyze, for a given time, the evolution of the ultrasonic pulse velocity according to the direct, semi-direct, and indirect transmission modes.

2. Experimental procedure

2.1. Concrete's mixtures

The mix proportion adopted in this study was developed previously at Polytech' Marseille, University of Aix-Marseille [22] and is summarized in Table 1. In the mix, Portland cement (CEM I) with a strength class 52.5 R are used. Two types of supplementary cementitious materials are used: Limestone Filler (LF) and silica fume (SF). The used superplasticizer (SP) is SIKA VISCOCRETE KRONO 20, according to European Standard NF EN 934-2.

Table 1
Mix design of HPC and HPFRC.

		HPC	HPFRC 1	HPFRC 2	HPFRC 3	HPFRC 4	HPFRC 5
Fibers	Percentage (%) (kg/m^3)	0	0.5	1.3	1.5	2	2.5
		–	36	100	108	144	180
SP	%/Binder (B) (kg/m^3)	0.6	0.6	0.6	0.6	0.6	0.6
		8.34	8.34	8.34	8.34	8.34	8.34
CEM I (kg/m^3)		500	500	500	500	500	500
Sand 0/2 (kg/m^3)		730	730	730	725	713	700
Sand 3/6 (kg/m^3)		300	300	300	300	300	300
Gravel 5/10 (kg/m^3)		730	730	730	730	730	730
Silica fume (kg/m^3)		70	70	70	70	70	70
Water (l/m^3)		147.2	147.2	147.2	147.2	147.2	147.2
W/B		0.23	0.23	0.23	0.23	0.23	0.23