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An Investigation on Ultrasonic Pulse Velocity of Hybrid Fiber Reinforced Concretes

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Abstract**—**Because of the easy applying and not costing too much, ultrasonic pulse velocity (UPV) is one of the most used non-destructive techniques to determine concrete characteristics along with impact-echo, Schmidt rebound hammer (SRH) and pulse-echo. This article investigates the relationship between UPV and compressive strength of hybrid fiber reinforced concretes. Water/cement ratio (w/c) was kept at 0.4 for all concrete mixes. Compressive strength of concrete was targeted at 35 MPa. UPV testing and compressive strength tests were carried out at the curing age of 28 days. The UPV of concrete containing steel fibers has been found to be higher than plain concrete for all the testing groups. It is decided that there is not a certain relationship between fiber addition and strength.

Keywords**—**Ultrasonic pulse velocity, hybrid fiber, compressive strength, fiber.

I. Introduction

CONCRETE has been widely used in most civil engineering practices and its popularity is even increasing. Using concrete in construction has its advantages such as low cost, easy applying etc. Because of these facts concrete has been used so many different applications such as bridges, dams, roads and buildings. As known, concrete is a brittle material which would fail under compressive load without any warning signal. For that reason, to improve the strain capacity and ductility of concrete is very important for reinforced concrete buildings. One of the ways to do that is adding fibers to the concrete mix. Because of the reasons mentioned above, researches have been adding different fibers to the concrete mix [2]-[4]. Different fibers have different effects on concretes' mechanical and physical properties. For instance, adding carbon fibers strengthens concretes impact resistance, steel fibers have effect on concretes' tensile and flexural behavior, polypropylene fibers have no use on improving compressive strength of concrete in fact in some studies it is shown that they reduce compressive strength around 1% [25]. Polypropylene fibers prevent micro cracks [26]. And it is reported from researchers that with adding fibers there has been significant improvement with concretes tensile and flexure strength [27]. One of the ways, to determine concretes properties is non-destructive testing methods. Nowadays, non-destructive testing methods in construction industry are mainly used to check the quality of concrete. While they do not provide the certain results for concretes mechanical properties such as compressive strength they have many advantages draw attention to them. One of the main advantages of these methods is that they do not harm specimens during testing. Same specimens used for these methods can be also used for other testing methods.

UPV can be described as a measurement of sound through a material. Besides, it will mostly verbalize with unit second for meter [22]-[24]. UPV devices have a transmitter and a receiver which provides waves that goes through concrete specimen. This testing methods is not just for designating concretes mechanical properties. UPV can also be used for determinations of cementitious materials at early age. Even though the application of UPV for characterization started decades ago, its behaviors through hybrid reinforced concrete have not been identified clearly [5]-[10].

The main purpose of this study is to investigate the behavior of UPV through hybrid fiber reinforced concrete with different volume fractions of steel fibers and synthetic fibers at the curing age of 28 days. With this aim steel and synthetic fibers were added to the concrete mix by the volume of 0.25%, 0.50% and 0.75%. Panzera et al. [11] reported an equation to determine dynamic Young's modules (E) by using UPV.

$$E_d = [(1-\mu)\,(1-2\mu)/(1+\mu)]\,(\rho)\,(V_p^2) \qquad (1)$$

where V_v = Wave velocity; E= Dynamic Young's module; γ= Poison ratio; ρ= Mass density.

As it can be seen from (1) [1], velocity is independent of the shape of material and depends only on elastic properties of the apparatus through which it passes. Also, ultrasonic pulse speed can be affected with unit weight of concrete, homogeneity and uniformity. Technical errors can also affect the test results such as inappropriate use of transducers. These types of errors can be prevented by following instructions.

II. Experimental Study

All the concrete mixes are designed according to Turkish standard TS EN 206–1 (2002) [11]-[15]. CEM1 42.5R Portland cement, crushed limestone aggregate with maximum size of 19 mm, steel fiber, synthetic fiber, superplasticizer are used in concrete mixes. Specific gravity and specific surface of cement is 3.08 and 3656 cm^2/g, respectively. The aggregates were separated into three different size fractions as 0-5 mm (A1), 5-12 mm (A2), and 12-19 mm (A3). Specific gravity of A1, A2, and A3 aggregates were 2.59, 2.69, 2.62, respectively. Fineness modulus of the mixture is 7.68. Tensile strengths of HF and PA fibers are 1100 and 900 MPa, respectively. Steel fibers with hooked ends and polyamide (PA) synthetic fibers are used in all concrete mixes as hybrid

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form. The lengths of HE fibers are selected as 30 and 60 mm, respectively. The aspect ratios (length/diameter) of HE are selected as 40 and 67 in this study. For synthetic fibers, two types of PA fibers with different aspect ratios and an elongation rate between 15 and 25% are used in this study. Three different fiber volumes were added to mixes at 0.25%, 0.5%, and 0.75% by volume of concrete. In addition, polycarboxylate based superplasticizer is added concrete mixes at 0.5% by weight of cement [16]-[18]. The concrete mix proportions are given in Table I.

TABLE I
M35 CONCRETE MIX PROPORTIONS

Component	Quantity, kg/m3
Cement (C)	400
Water (W)	160
Coarse aggregate (5-12 mm)	350
Coarse aggregate (12-20 mm)	900
Fine aggregate (0-5 mm)	700
Superplasticizer	2
W/C	0.4

The mechanical properties of steel and synthetic fibers are given in Table II. The UPV was determined on 150 mm cubes samples at 28 days. The UPV tester PULSONIC equipment is used to measure the pulse velocity of concrete samples. It consists of the ultrasonic tester, two transducers, one transmitter, one receiver head 54 kHz type, two connecting cables, and two 1.5 V alkaline D type batteries. For every mix, three cube samples are tested and average rates of these three samples are used to detect compressive strength and UPV of concretes. Totally, 60 cube samples are cast and tested to determine compressive strength, UPV and dynamic modulus of elasticity of concretes [18]-[21]. The setup for measuring UPV of concrete is shown in Fig. 1. The synthetic and steel fibers with different aspect ratios are shown in Fig. 2. The setup for measuring UPV of concrete is shown in Fig. 1. The synthetic and steel fibers with different aspect ratios are shown in Fig. 2.

TABLE II
PROPERTIES OF CONCRETE MIXTURES

Mixture code	Steel fibers (l=30 mm) %	Steel fibers (l=60 mm) %	Synthetic fibers (l=12 mm) %	Synthetic fibers (l=54 mm) %	Density (kg/m^3)	UPV (km/sn)	Dynamic Young's modulus (GPa)
Plain	-	-	-	-	2313.185	4.26	13.6
H60_0.15—H30_0.1	0.1	0.15	-	-	2478.452	4.72	22.1
H60_0.1—H30_0.15	0.15	0.1	-	-	2412.065.	4.78	22.0
H60_0.1—H30_0.1—PA12_0.05	0.1	0.1	0.05	-	2342.785	4.31	17.4
H60_0.35—H30_0.15	0.15	0.35	-	-	2375.125	4.76	21.5
H60_0.15—H30_0.35	0.35	0.15	-	-	2349.196	4.66	20.4
H60_0.2—H30_0.2—PA12_0.1	0.2	0.2	0.1	-	2379.542	4.76	21.6
H60_0.5—H30_0.25	0.25	0.5	-	-	2396.183	4.53	19.7
H60_0.25—H30_0.5	0.5	0.25	-	-	2395.746	4.63	20.5
H60_0.3—H30_0.3—PA12_0.15	0.3	0.3	0.15	-	2459.781	4.70	21.7
PA54_0.15—PA12_0.1	-	-	0.1	0.15	2278.498	3.83	13.4
PA54_0.4—PA12_0.1	-	-	0.1	0.4	2201.357	3.79	12.6
PA54_0.6—PA12_0.15	-	-	0.15	0.6	2207.341	3.82	12.9

III. TEST RESULTS

The formula mentioned above is used to calculate the dynamic modulus of elasticity of concrete samples. Poisson ratio of concrete was taken as 0.2 for all concrete samples for this study. Mechanical properties of concrete mixtures acquired from test results are given in Table III.

Fig. 1 Synthetic and steel fibers

Fig. 2 UPV Testing System

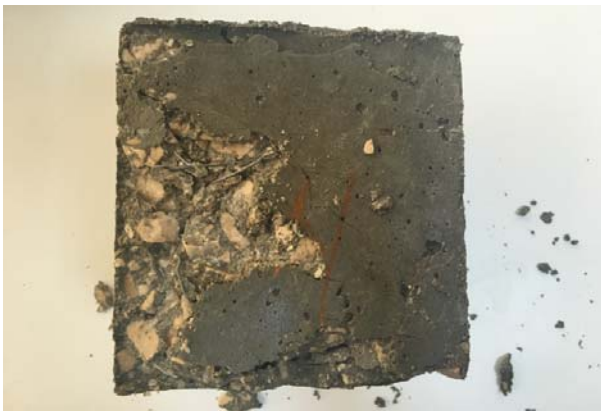

Fig. 3 Cube specimen after compressive strength test

Fig. 4 Mixing process

TABLE III
THE MECHANICAL PROPERTIES OF STEEL AND SYNTHETIC FIBERS

Type of fiber	Length (mm)	Diameter (mm)	Aspect Ratio	Tensile strength (MPa)	Specific gravity (g/cm^3)	Elastic module (MPa)	Elongation at failure (%)
HE steel fiber	30	0.75	40	1100	7.86	200000	3.5
HE steel fiber	60	0.90	67	1100	7.86	200000	3.5
PA fiber	12	0.0075	12	970	1.14	3500-6800	21
Straight fiber	22	0.40	55	1100	7.86	200000	3.5

IV. CONCLUSIONS

Based on the objective of this study, investigating of UPV for hybrid fiber reinforced concretes, various results are obtained as a result of this study. The UPV testing may not be regarded as a challenging test method compared to other conventional destructive test methods. The main reason of this that to check the quality of concrete depend on several factors such as fiber volume, fiber orientation, slenderness ratio of fibers, etc. Therefore, this study shows that there is no obvious trend between the UPV values and density. Similarly, when fiber volume is increased for hybrid fiber concrete mixtures, it is not seen to be a clear decrease the UPV values of hybrid fiber reinforced concrete mixtures. However, it can be said that the UPV values are higher for smaller fiber volume fractions than larger ones.

Fig. 5 Cube specimens before compressive strength test

Fig. 6 Preparations of molds before installation

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