Ultrasonic Pulse Velocity of Steel and Synthetic Fiber Reinforced Concretes

Demet Yavuz *, Fuat Korkut and Soner Guler

Abstract**—**The UPV is a widely used non-destructive method for measuring the quality of concrete. In this study, the UPV method is applied to measure the quality of steel and synthetic fiber reinforced concretes at various volumetric ratios.The time required for the ultrasonic wave to travel through the test material and energy attenuation can be obtained by using this method. A total of 15 cubic samples with 150 x 150 x 150 mm dimensions were tested to determine compressive strength and ultrasonic pulse velocity of concrete samples. Four different types of fibers with different aspect ratios are used in this study. The total volume fractions of steel and synthetic fibers are kept 0.25%, 0.5%, and 0.75%. The target compressive strength of plain concrete samples was 35 MPa. The test results clearly show that the UPV is higher for synthetic steel fibers than ones with steel fiber reinforced concrete samples. Furthermore, there is no any linear relationship between fiber volumetric ratio and UPV values.

Keywords**—** Ultrasonic pulse velocity, synthetic fiber, steel fiber, compressive strength.

I. Introduction

USING non-destructive testing methods to determine some properties of concrete is highly popular among the researchers. There are lots of studies in the literature on Ultrasonic pulse velocity (UPV) technique to determine concrete properties [1-10]. The UPV is one of the most promising non-destructive testing methods to determine some characteristics of concretes. The UPV technique is often used to assess compressive strength of concrete and dynamic elastic modulus of concrete. The main advantage non-destructive testing methods for especially existing structures are to avoid concrete damage. The measurement of pulse velocity is affected by number of factors which are:

- Slickness of concrete surface under test: if the surface of concrete is not adequately smooth, it should be ground smooth.
- Moisture condition of concrete: In general, pulse velocity of concrete increases with the increased moisture ratio.
- Influence of path length on pulse velocity: As concrete being a heterogeneous as its innately, it is very important that the path lengths are long enough to cause any errors due to concretes heterogeneity.
- Temperature of concrete: Past studies reported that temperature changes between 5 and 30˚C do not affect UPV results.
- Age of concrete: For a give pulse velocity, the compressive strength is higher for older specimens.

The UPV results can be used:

- To control heterogeneity of concrete
- To designate cracking and voids in concrete
- To control quality of concrete

Plain concrete is a brittle material with low tensile strain and low tensile strength and thereby needs to reinforcing material to be used as a structural member. For over three decades studies were carried out to use fibers as reinforcement. Various types of fibers namely steel, synthetic, glass, carbon were used to improve mechanical properties of concretes. Consequently, fiber reinforced concretes have superior mechanical characteristics compared to plain or conventional concretes.

II. Experimental Study

All the concrete mixes are designed according to Turkish standard TS EN 206–1 (2002) [11]. CEM1 42.5R portland cement, crushed limestone aggregate with maximum size of 19 mm, steel fiber, synthetic fiber, superplasticizer, and entraining air are used in concrete mixes. Specific gravity and specific surface of cement is 3.08 and 3656cm2/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. The absorption capacity of A1, A2, and A3 aggregates were 0.005%, 0.15%, and 0.53%, respectively. Fineness modulus of the mixture is 7.68. Hooked end (HE) steel fibers, polyamide (PA) synthetic fibers are used in all mixes as single form. Tensile strengths of HF and PA fibers are 1100 and 900 MPa, respectively. 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 polyamide (PA) fibers with the length and diameter of PAs are 12 and 0.0075 mm and 54 and 0.55 mm, respectively 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. The concrete mix proportions are given in Table 1.

* The Department of Civil Engineering, University of Yüzüncü Yıl, 65080, Van, Turkey, ddemetyavuz@gmail.com.

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
Entrained air	0.2

The mechanical properties of steel and synthetic fibers are given in Table 2. The compressive strength and ultrasonic pulse velocity was determined on 150 mm cubes samples at 28 days. The UPV tester PULSONIC equipment that consist of the ultrasonic tester 58 E-48, two transducers, one transmitter and one receiver head 54 kHz type, two connecting cables, and two 1.5V alkaline D type batteries are used to measure UPV of cube concrete samples. For each mix, three cube samples are tested and average values of these three samples are used to determine compressive strength and UPV of concretes. Totally, 60 cube samples are cast and tested to determine compressive strength, ultrasonic pulse velocity and dynamic modulus of elasticity of concretes. 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
THE MECHANICAL PROPERTIES OF STEEL AND SYNTHETIC FIBERS

Type of fiber	Length(mm)	Diameter (mm)	Aspect Ratio	Tensile strength (MPa)	Specific gravity (g/cm3)	Elastic module (MPa)	Elongation at failure (%)
HE steel fiber	30	0.75	40	1100	7.86	200000	3.5
	60	0.90	67	1100	7.86	200000	3.5
HE steel fiber							
PA fiber	12	0.0075	12	970	1.14	3500-6800	21
Straight fiber	22	0.40	55	1100	7.86	200000	3.5

Fig. 1: Synthetic and steel fibers

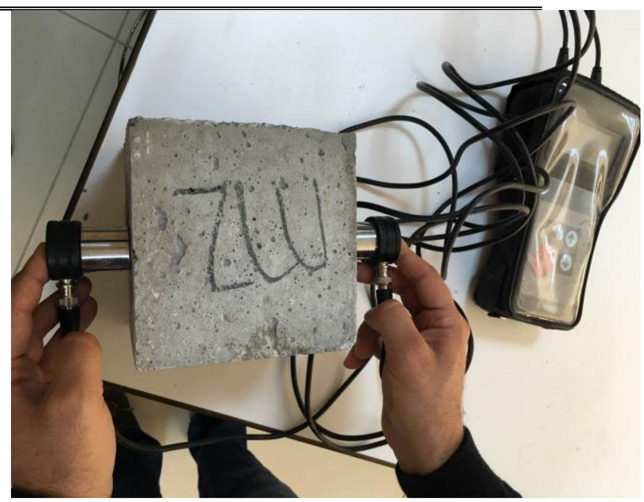

Fig. 2: UPV device

III. TEST RESULTS

The following formula 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 obtained from test results are given in Table 3. The relationship between compressive strength and UPV of steel and synthetic fiber reinforced concrete samples are shown in Fig.3

$$E_d = \left[\frac{(1-\mu)(1-2\mu)}{(1+\mu)}\right](\rho)(Vp^2)$$

V_p = Compression wave velocity
E_d= Dynamic Young's modulus
μ= Poison ratio
ρ= Mass density.

TABLE III
MECHANICAL PROPERTIES OF CONCRETE MIXTURES

Mixture code	Compressive strength of concrete (MPa)	Density (kg/m3)	Ultrasonic pulse velocity (km/sn)	Dynamic Young's modulus(GPa)
Plain	36.22	2313.185	4,26	13.6
S0.25	37.47	2161.778	4.02	14.0
S0.5	38.21	2165.037	4.18	16.7
S0.75	38.36	2252.444	4.39	15.7
HE60_0.25	39.69	2265.185	4.21	16.2
HE60_0.5	40.63	2303.407	4.36	17.5
HE60_0.75	41.67	2245.333	4.23	16.9
HE30_0.25	34.44	2232.593	3.76	15.8
HE30_0.5	35.52	2259.556	4.21	16.2
HE30_0.75	41.35	2086.222	4.32	11.8
PA12_0.25	35.86	2325.926	4.78	20.8
PA12_0.5	45.46	2366.519	4.86	22.3
PA12_0.75	50.85	2184.296	4.73	20.0

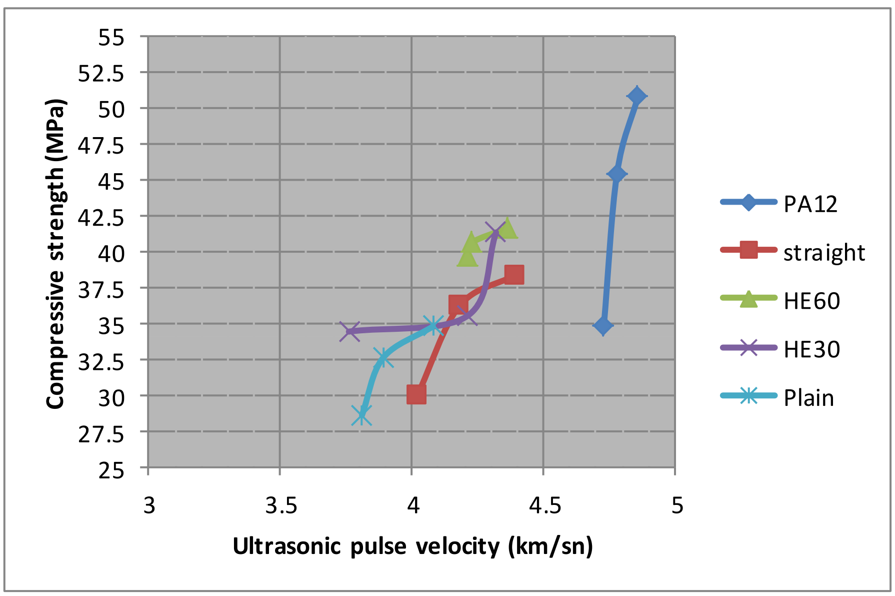

Fig.3: The relationship between compressive strength and UPV values

IV. CONCLUSION

The ultrasonic pulse velocity (UPV) testing method is a highly effective non-destructive testing method to evaluate the quality and uniformity of concrete samples. Results obtainded from labotarutary test results can be summarized as below.

- The UPV values of concrete samples with synthetic fibers are higher than ones with straight and hooked end steel fibers.
- Similarly, dynamic young's modulus of concrete samples with synthetic fibers are higher than ones with straight and hooked end steel fibers.
- There is no any linear relationship between volumetric fiber ratio and UPV of concretes samples. When volumetric ratio of fibers in concrete mix increases, it is not observed that the values of UPV for concretes with steel and syntetich fibers can be enhanced.
- The results show that the incorporation of all type of fibres in concrete improve the compressive strength values moderately except concretes with straight steel fibers.
- Density, curing conditions, and proper vibration of concrete samples are as important as other paramaters such as fiber type and fiber volumetric ratio on UPV and compressive strength of concrete samples.

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