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Ultrasonic Pulse Velocity and Rebound Hammer Studies on Concrete with Micro-Reinforcements

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Abstract – This paper presents the results of an experimental study conducted to examine the effect of fibre reinforcement on M60 Grade of concrete using ultrasonic pulse velocity and rebound hammer techniques. In this study a total of 32 cubes of size 150x150x150mm were cast and tested using ultrasonic pulse velocity and rebound hammer. The study parameter was the total fibre volume fraction. Variation of pulse velocity and rebound numbers were studied for fibre contents varying from 0% to 1.5%. The fibres had an aspect ratio of 60. It has been found that the compressive strength of concrete increases by about 15-20% for a fibre content of 1%. The UPV measurement and compressive strength tests were carried out at the concrete age of 7, 14 and 28 days. It has been found that the compressive strength of SFRC increases up to 15.31% when compared with the virgin specimen. This increased strength leads to a more ductile concrete.

Index Terms – Aspect ratio, fibre reinforced concrete, Rebound hammer, steel fibre, ultrasonic pulse velocity, volume fraction.

1. INTRODUCTION

Steel fiber reinforced concrete (SFRC) is a composite material made of hydraulic cements, fine and coarse aggregates, and a dispersion of discontinuous, small steel fibres. It may also contain mineral admixtures and chemical admixtures commonly used with conventional concrete. Addition of fibres significantly improves many of the engineering properties of mortar and concrete making it a ductile material. When concrete cracks, the randomly distributed fibres arrest the micro-cracking mechanism and limit the crack propagation thus improving the strength and ductility. The extent of improvement depends on the type, aspect ratio and volume fraction of fibres as well as the quality of concrete matrix. Some examples of structural and non-structural uses of SFRC are hydraulic structures, airport and highway paving and overlays, industrial floors, refractory concrete, bridges decks, shotcrete linings and coverings, thin shell structures, explosion resistant structures and seismic resistant structures. A number of researchers are evaluating the possibility of enhancing the applicability of micro-reinforcement for structural applications. Strength and ductility are among the important factors to be considered in the design of seismic-resistant reinforced concrete structures. The drawbacks of plain concrete like resistance to cracking and low ductility can be eliminated by inclusion of fibres[1].

The non-destructive testing of concrete has a great technical importance and usefulness. These techniques have grown during recent years especially in the case of condition assessment. The non-destructive measurements have proved to be an effective tool for inspection of concrete quality. Concrete testing in structures is demanding in which the cores cannot be drilled, where the use of less expensive equipment is required [2].

2. ULTRASONIC PULSE VELOCITY METHOD

The principle of the test is that the velocity of sound in a solid material is a function of the square root of the ratio of its modulus of elasticity to its density. This method gives the indication of degree and uniformity in compaction of concrete. Nataraja et.al., studied the quality of SFRC Concrete using ultrasonic pulse velocity. They discussed the UPV test conducted at early age of one day to confirm the quality of concrete. The authors concluded that the pulse velocity increases with increase in volume fraction by about 50m/s to 100m/s compared to unreinforced matrix. Also they concluded that pulse velocity at 7 and 28 days can be easily predicted by knowing the pulse velocity [3]. Ismail Ozgur Yaman et.al., investigated the relationship between velocities of ultrasonic stress waves transmitted along direct and indirect paths. Tests were conducted on plain concrete slabs. They suggested that the indirect UPV is statistically similar to direct UPV measurement on the concrete slab specimens provided that there are uniform properties, including moisture gradient along the surface and along the depth [4].

Lawson et.al., studied the relationship between Ultrasonic Pulse Velocity (UPV) and the compressive strength of concrete with different water cement ratios at different age strengths. They observed that the UPV and the compressive strength of concrete increases with age, but the growth rate varies with mixture proportion. [5].

3. REBOUND HAMMER METHOD

The main principle of this test is that it measures the rebound of an elastic mass when it collides with the concrete surface under the test, this rebound depends on the hardness of concrete and on the energy it absorbs from the collision. The rebound number is an arbitrary measure that means different device might give different rebound numbers in the same test. The rebound number depends on energy stored in the spring and on the size of the mass, consequently each device is combined with a graph containing calibrating curves relating the rebound number with the compressive strength. Schmidt rebound hammer is useful in assessing concrete uniformity. Jen etal investigated the strength of concrete using non destructive test (NDT). They conclude that, the accuracy of calculating concrete strength using surface hardness value was based o input design parameters of materials involved. Also they perform a regression analysis to establish a mathematical formula. Their results indicate that the correlation coefficient may reach 0.9622, indicating that their method has referential value. [6]. Hisham et.al., introduced ultrasonic pulse velocity tester as a tool to monitor basic initial cracking of concrete structures and hence to introduce a threshold limit for possible failure of the structures[7].

Figure 1 (a) UPV Tester

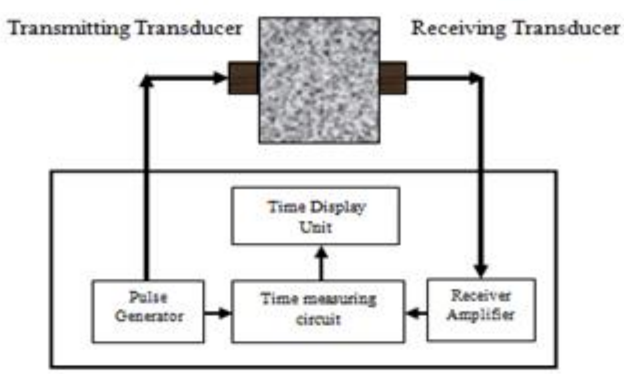

Figure 1 (b) Schematic of UPV Apparatus

Figure 2 (a) Rebound Hammer

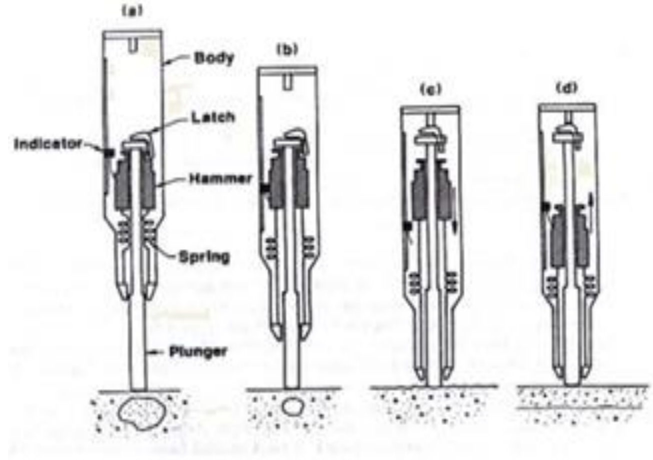

Figure 2 (b) Schematic of the Rebound Hammer

4. EXPERIMENTAL INVESTIGATION

In this experimental investigation, an attempt was made to study the variation in ultrasonic pulse velocity for plain and steel fibre reinforced concrete at different ages. Cement concrete having a compressive strength of 66Mpa was used for casting the specimens. The micro-reinforcements with different volume fractions such as 0.5%, 1% and 1.5% were investigated. A marginal increase in pulse velocity was observed for fibre reinforced concrete at all ages over the plain concrete specimen. Conclusions were drawn based on the observed test results.

Mix Designation	Water Cement Ratio	Fibre Content Kg/m^3	Fibre Length (L) mm	Aspect Ratio l/d	Hyper Plasticizer %
0.5%	0.36	0.132	30	60	0.80
1%	0.36	0.264	30	60	0.80
1.5%	0.36	0.397	30	60	0.80

Table 1 Details of Mixes Considered

5. CASTING AND TESTING

Four 150mm cubes were cast for each parameter to be examined. A total 32 cubes were used in this test. Ingredients were selected and added to the mixer taking all possible precautions to avoid the balling of fibres. Mixes were designed for a high workability of slump value and fibres were added to the mix without any future modifications. All specimens were vibrated using needle vibrator. Rebound number and pulse velocity readings were taken using rebound hammer and ultrasonic concrete tester. The longitudinal pulse velocity results are presented in the Tables 2 to 5. Specimen casting and testing were shown in Figs. 3 to 8.

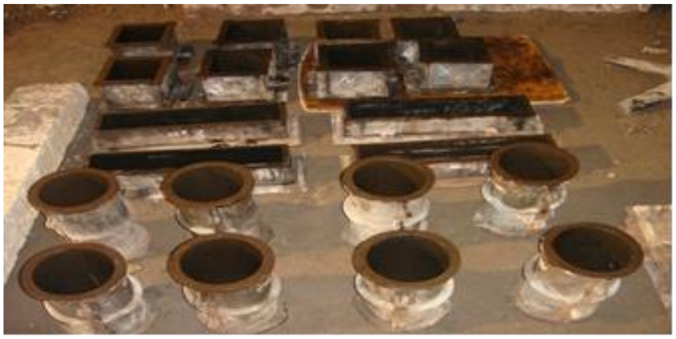

Figure 3 Moulds for Casting

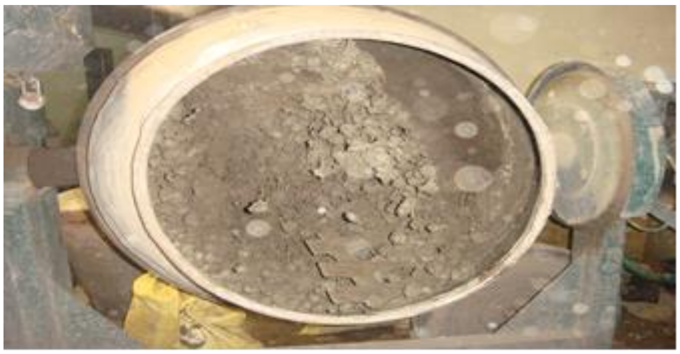

Figure 4 Mixing of SFRC

Figure 5 Placing of Concrete

Figure 6 Cast Specimens

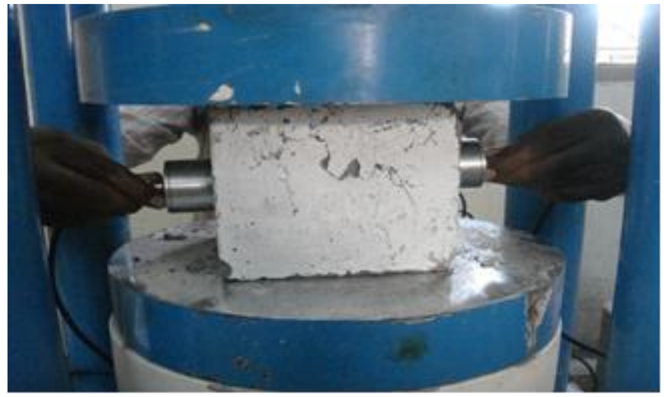

Figure 7 UPV Test

Figure 8 Rebound Hammer Test

Volume Fraction (%)	7-days		14-days		28-days	
	Average Rebound Number	Compressive Strength, MPa	Average Rebound Number	Compressive Strength, MPa	Average Rebound Number	Compressive Strength, MPa
0	36.5	38	42.5	49	49	62.5
0.5	37.5	39	44.5	51	51	65
1	39	40.5	46	54	53	68
1.5	38	39.5	45	52.5	51.5	66

Table 2 Test Results on Rebound Hammer (Aspect ratio=60)

Volume Fraction	Transit Time, u Sec	Length, m	Velocity, m/Sec	Compressive Strength, MPa
0	40.63	0.15	3691	36.51
0.5%	38.41	0.15	3905	37.82

1%	34.75	0.15	4316	42.10
1.5%	35.85	0.15	4184	40.42

Table 3 7-Days Test Results on UPV (Aspect Ratio=60)

Volume Fraction	Transit Time, u Sec	Length, m	Velocity, m/Sec	Compressive Strength, MPa
0	35.84	0.15	4185	51.29
0.5%	34.28	0.15	4375	55.20
1%	30.92	0.15	4851	57.38
1.5%	32.64	0.15	4595	55.64

Table 4 14-Days Test Results on UPV (Aspect Ratio=60)

Volume Fraction	Transit Time, u Sec	Length, m	Velocity, m/Sec	Compressive Strength, MPa
0	29	0.15	5172	59.38
0.5%	28.22	0.15	5315	61.98
1%	25.33	0.15	5921	67.50
1.5%	27.69	0.15	5417	65.25

Table 5 28-Days Test Results on UPV (Aspect Ratio=60)

Note: The above table 4 to 7 results are average values of cubes tested.

6. DISCUSSION OF TEST RESULTS

The compressive strength of different fibre volume fractions corresponding to the different ages obtained from Rebound Hammer and Pulse Velocity test data were shown in Table 2, 3, 4 and 5.

The compressive strength of different fibre volume fraction was higher than conventional concrete for both Rebound Hammer and Pulse Velocity.

The obtained results of rebound hammer inferred that 0.5% variable factor shows an increase in compressive strength which varies from 2.63% to 4.08% with respect to different ages of curing. 1 % variable factor shows an increase in compressive strength which varies from 6.58% to 10.20% with respect to different ages of curing. 1.5 % variable factor shows an increase in compressive strength which varies from 3.95% to 7.14% with respect to different ages of curing.

The obtained results of Pulse Velocity inferred that 0.5% variable factor shows an increase in compressive strength which varies from 3.58% to 7.62 % with respect to different ages of curing. 1 % variable factor shows an increase in compressive strength which varies from 11.87% to 15.31%, with respect to different ages of curing. 1.5 % variable factor shows an increase in compressive strength which varies from 8.42% to 10.70% with respect to different ages of curing.

7. CONCLUSION

From the experimental studies, the compressive strength of concrete with 1% fibre volume fraction attained the maximum values.

The test results clearly indicate that there was a linear variation between Rebound Hammer Number and percentage fibre, pulse velocity and percentage fibre. Thus it can be concluded that the addition steel fibre to concrete increases the compressive strength, Rebound Hammer Number, pulse velocity and the ductility of concrete which in turn improves its durability.

The brittleness of concrete decreased to a considerable extent with the addition of fibres. Even after the repeated successive loading, the specimens did not crumble but still were held by the fibres. It was also observed that failure of the specimens was due to debonding effect rather than yielding of fibres.

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