RESEARCH ARTICLE

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Ultrasonic Pulse Velocity Test on Hybrid Fiber Reinforced Concrete

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Abstract

Concrete is a material of high importance in infrastructure and development projects. Concrete is characterized as a brittle material. In order to minimise the brittle failure, it is beneficial to add the fibers to the concrete mix without compromising the quality of concrete. The length of polypropylene fibers (PPF) and steel fiber (SF) used in concrete mixtures are 50 mm and 35 mm respectively. The aim of this paper is to learn the quality of concrete and dynamic modulus of elasticity by using Ultrasonic Pulse Velocity (UPV). The percentages of polypropylene fiber are 0%, 0.3%, 0.6%, 0.7%, 1% and steel fiber are 0%, 0.1%, 0.4%, 0.7%, 1%. Comparison of conventional and Hybrid fiber-reinforced concrete (HFRC) is studied further. Experimental investigation is carried out on 18 cubes of M40 grade concrete of size 150X150X150 mm for Ultrasonic Pulse Velocity (UPV) and compression test. The results show that conventional as well as fiber-reinforced concrete are of excellent and of good quality with 28-day strength of 60.74 MPa. Conventional concrete has the highest pulse velocity and dynamic modulus of elasticity of 5.1903 5Øß5Ø'Ü and 62.43 GPa. Next to it C-3-5 has a pulse velocity of 4.886 5Øß5Ø'Ü, dynamic modulus of elasticity as 48.61 GPa and compressive strength of 61.77 MPa. Among FRCs Polypropylene fiber-reinforced concrete with 1% fiber volume fraction showed appreciable value of pulse velocity and elastic modulus. In hybrid fiber-reinforced concrete C-3-3 with 0.7% SF and 0.3% PPF has proven to have better quality as compared with other HFRCs.

Keywords- Hybrid fiber-reinforced concrete, Dynamic modulus of elasticity, Quality of concrete, UPV

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Introduction

According to the necessity of the construction industry, it has become the trend of development in nearer future to implement the cheap price and performance of fiber-reinforced concrete. The fibers are divided into organic, organic, metal, synthetic, natural etc. the improvement of use of fibers in concrete is shown in aspects mentioned below, first is organic synthetic fiber with less strength can productively reduce the crack's forming initially while the curing of concrete. Secondly fibers with high strength constructively disperse the loads to improve the strength of FRC. HFRC is said to be a composite material, consisting of two or more types of fibers which are added simultaneously. The performance of FRC is enhanced by using different characteristics of fibers.

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Non-destructive testing (NDT) is a valuable tool for determining concrete qualities (mechanical or physical). In the case of structural optimization and productivity of budget, is a technique for determining the strength under compression and other parameters of concrete matrix of existing architecture. Among the few characteristics of concrete compressive strength is one of the dominant features. An investigation from this perspective can provide an overview of a building's structural integrity. This type of analysis assists civil engineers in optimising the structural intervention process by deepening their understanding of how the structure works structurally while also taking into account the concrete mix design and its associated physical, mechanical, and durability properties. As a result, interventions can be focused at elements with poor behaviour, which can have detrimental consequences for the system. Traditionally, the most dependable way of determining concrete compressive strength has been destructive testing (DT), which has been referred to as the reference method. This test delivers fast findings as well as the concrete structure's actual strength and characteristics.

Although there is no direct measurement of structural concrete strength qualities due to the fact that the determination of strength requires force that damages the specimen, therefore many NDT have been established. These are based such that some physical qualities are linked to strength and are evaluated by using NDT. Hardness, bullet penetration resistance, capacity of rebound, and potential to transmit the ultrasonic pulses. Penetration, pull-out, radioactive, dynamic, rebound all these tests are some examples of non-destructive techniques.

Bogdan Bolborea et al.[1] have predicted the compressive strength by means of UPV for the non-destructive determination of static and dynamic modulus of elasticity. Mahdi Nematzadeh et al.[2] learned about the mechanical properties of steel fiber-reinforced concrete with recycled nylon granule and naturally available zeolite exposed to temperatures around 20^{0}C, 300^{0}C and 600^{0}C. Addition of nylon granules adversely affected the mechanical properties but adding steel fiber and zeolite equalise the reduction of strength as well as improves the properties in comparison with conventional concrete. Saman Hedjazi and Daniel Castillo[3] experimentally investigated relations between compressive strength in addition of UPV of fiber reinforced concrete for example steel, nylon and glass. Further Julion Carrillo et al.[4] also proposed an empirical formula for dynamic modulus of elasticity and poisons ratio for steel fiber-reinforced concrete, synthetic FRC and Hybrid fiber reinforced concrete. Q. Z. Khan et al.[5] studied two diverse kinds of fibers i.e., steel and polypropylene and effect of both the fibers together. Concrete cylinders were casted and tested for properties like compressive and tensile behaviour of concrete and to predict the elastic modulus of Hybrid fiber reinforced concrete. Ahemad S D AL-Ridha et al.[6] attempted to study the UPV test on Self compacting light weight concrete with and without the use of steel fiber. With increase in the volume fraction of steel in fiber reinforced concrete compression strength increase considerably, a good amount of enhancement can be observed in spilt tensile strength and bulk density increases slightly. Nakin Suksawang et al.[7], evaluated elastic modulus for types of fibers incorporated in concrete such as steel, polypropylene, macro-polyolefin, polyvinyl alcohol (PVA) and basalt fiber. Dongquing He et al.[8], carried out experiments to find the mechanical properties of HFRC consisting of steel-polypropylene fibers and results are excellent such as Hybrid fiber-reinforced concrete are better compared to singly doped basalt or polyvinyl alcohol fiber reinforced concrete.

The modulus of elasticity is an important property used in designing, analysing and studying fiber reinforced concrete structural component. There is the need to study the effect of use of distinct fibers together on quality, dynamic modulus and mechanical properties. Hence in this study the effect of use of two discrete fibers on quality, dynamic modulus of elasticity and strength is studied.

Ultrasonic Pulse Velocity (UPV) Test

At present the UPV method is that which it shows the potential (ability) for testing concrete strength on-site. This test measures the time of travel of ultrasonic pulse travelling into the concrete. The setup of UPV is shown in Figure 2.2 (c).

The setup of UPV available commercially consists of generator and a pulse receiver. Pulses are generated and the time taken is measured by electronic circuits. The tests are often administrated on ready construction and even on small sized specimens.

The surface for contact must be smooth, and gel like substance is compulsory as a coupling medium. It is also recommended that the path length shall be at least 30cm, for the purpose to avoid errors caused by heterogeneity.

The use of reinforcement in concrete has a significant effect on velocity of pulse. Therefore, it is advisable and sometimes necessary to settle the pulse paths which avoid the influence of steel or to rectify if reinforcement is within path of pulse.

MATERIALS AND METHODS

Materials used are Cement, GGBS, Fine aggregates, Coarse aggregates, Polypropylene fibers, Steel fibers, Water and Admixture. OPC 53 grade cement conforming to IS 269:2015 is used, maximum size of aggregates used is 20mm. Chemical admixture used is Auramix 300 is a high-performance retarding superplasticiser. Water used is fresh water. Type of aggregate are crushed angular aggregate, Source from Lonikand. Specific gravity of the coarse aggregate 20mm is 2.9, specific gravity of the coarse aggregate 12.5mm is 2.89 and the specific gravity of the fine crushed sand is 2.86. Mix Design of grade M40 is calculated as per IS: 10262:2019. Mix proportions for M40 grade of concrete is tabulated in Table-1, and nomenclature and description are given in Table-2.

Table-1: Mix Design

Material Name	Cement	GGBS	Water	Manufactured sand	12.5mm	20mm	Chemical admixture	Water-cement ratio
Quantity in kg/m^3	215	215	150	832	464	699	5.16	0.350

Table-2: Nomenclature

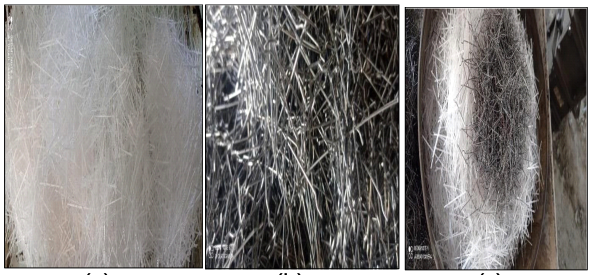
Sr. No.	Description	Cube Specification
1	No fibers	C-0
2	0.9%PP+0.1%SF	C-3-1
3	0.6%PP+0.4%SF	C-3-2
4	0.3%PP+0.7%SF	C-3-3
5	1%SF	C-3-4
6	1%PP	C-3-5

Properties of polypropylene and steel fiber used in the experimental investigation are tabulated in Table-3 below and are shown in Figure 1 (a), Figure 1 (b) and Figure 1 (c).

Table-3: Properties of Polypropylene and Steel Fiber

Sr. No.	Type	Length	Aspect ratio	Modulus of Elasticity
1	Polypropylene fiber	45mm - 55mm	64 or greater	5 GPa
2	Steel fiber- hooked end	30/35 mm	47	200 GPa

The fibers used in this study are macro synthetic fibers (polypropylene fibers) and steel fibers because this improves the mechanical properties such as compressive strength, split tensile, flexure and fracture properties of concrete on adding it in certain volume fractions. The total volume fractions considered in this study are 1% and less because exceeding the percentage of fibers results in improper mixing, not so smooth finish and bleeding of concrete while mixing and placing.



(a) (b) (c)

Figure 1 (a): Polypropylene Fiber; (b) Steel fiber; (c) Polypropylene and steel fiber added together

Experimental program: The ingredients utilised in preparing Fiber reinforced concrete was mixed in standard mixer first in dry state and then water was added. 150x150x150 mm cubes were prepared and cured for 28 days, and tested for UPV according to IS 13311 (Part 1): 1992 and compression test as per IS 516 (1959).

The steps followed in ultrasonic pulse velocity are as follows:

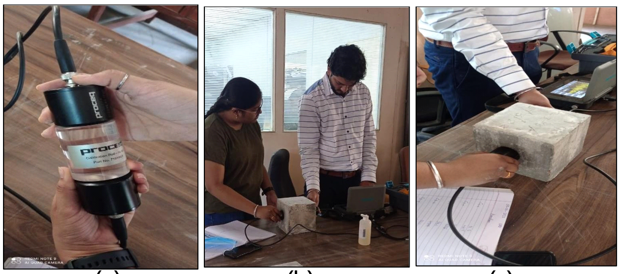
Preparation of apparatus: There are two transducers which are connected to sockets before switching the V-meter on.

Setting of reference: for the instrument to be zero i.e., Zeroing as shown in Figure 2(a), a reference bar is provided and before placing it on opposite sides of the specimen apply a small amount of get to face of transducer.

Selection of range: The range suggested is 0.1 μs for path length of about 400 mm for better reliability.

Arrangement: Carefully place the transducers on opposite faces (direct transmission) and press it hard. At the time of taking readings the transducers shall not be moved to avoid any errors in measurement as shown in Figure 2 (b) and Figure (c) Readings of time of pulse travelling up to 'L' distance in microsecond appears on the instrument.

Compressive strength test is a destructive test for finding out compressive strength of concrete cube or cylinder specimen. This test is carried out by placing concrete cube in the Compression testing machine (CTM) and applying gradually increasing load unit the specimen fails. The maximum load at which the cube fails is recorded, and dividing the load by the cross-section area gives the compressive strength of HFRC.



(a) (b) (c)

Figure 2: (a) Zeroing; (b) UPV test performance; (c)Setup of UPV

Dynamic Modulus of Elasticity: The value found by the actual loading on concrete is known as static modulus of elasticity. This method comes under destructive method as the specimens are loaded till its failure occurs. This elastic modulus does not truly show the elastic behaviour of concrete because of phenomena known as creep. For greater amount of stresses modulus of elasticity is seriously affected. Therefore, non-destructive testing method defined as dynamic method is approved for finding the modulus of elasticity. In this case no load has been applied on the specimen.

The dynamic Modulus of Elasticity is calculated by performing UPV test. The formula by which dynamic modulus of elasticity is calculated is given by [10][12].

$$E = \frac{\rho v^2 (1+u)}{[1-u][1-2u]} \tag{1}$$

Where, ρ=density in kg/m^3

u=dynamic Poisson ratio (0.24)

v=pulse velocity in m/s

Results and Discussion

Referring to Table-2 "Velocity Criterion for Concrete Quality Grading" of IS 13311 (Part 1) 1992 the quality of concrete is defined based on velocity of ultrasonic pulse.

The results of Ultrasonic Pulse Velocity are in terms of time with microsecond (μs) as unit. Quality of concrete is given in Table-4

Density of HFRC is calculated based on weight and volume of cube, hence are tabulated in Table-5 with dynamic modulus of elasticity found by equation (1) mentioned above.

Table-4: Quality of Concrete

Sr. No.	Cube specification	Distance (mm)	Time (μs)	Velocity (km/s)	Quality of concrete
1	C-0	150	28.9	5.1903	Excellent
2	C-3-1	150	30.7	4.399	Good
3	C-3-2	150	34.1	4.532	Excellent
4	C-3-3	150	33.1	4.732	Excellent
5	C-3-4	150	31.7	4.615	Excellent
6	C-3-5	150	32.5	4.886	Excellent

Table-5: Density and Dynamic modulus of elasticity of HFRCs

Sr. No.	Cube Specification	Weight (kg)	Volume of Cube (m^3)	Density (kg/ m^3)	Dynamic Modulus of Elasticity (GPa)	Average Compressive strength (MPa)
1	C-0	9.219	3.375×10^{-3}	2731.55	62.43	60.74
2	C-3-1	9.040	3.375×10^{-3}	2678.51	43.97	55.89
3	C-3-2	9.020	3.375×10^{-3}	2672.59	51.09	60.75
4	C-3-3	9.175	3.375×10^{-3}	2718.51	53.31	65.13
5	C-3-4	9.180	3.375×10^{-3}	2720.00	50.39	70.40
6	C-3-5	9.210	3.375×10^{-3}	2730.00	55.29	61.77

The UPV of concrete is generally related to its density and modulus of elasticity. This also depends upon the materials used and mix design prepared for making concrete as well as the placing method adopted, compaction and curing of concrete specimens. If the concrete is not compacted properly and as thoroughly as possible, or if segregation occurs during the placing of concrete or the formation of internal cracks, the velocity of pulse will be lower, even if the same mix and materials are used.

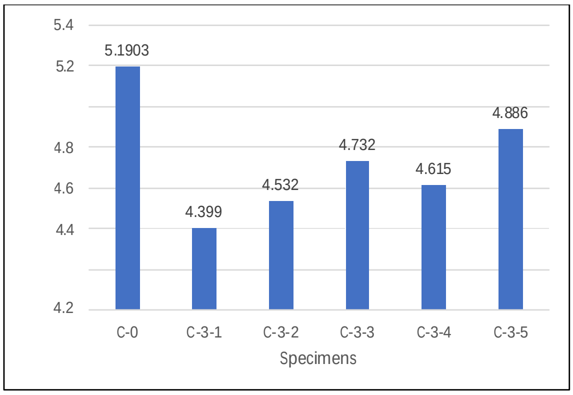


Figure 3: Variation of Pulse velocity for different fiber volume fraction

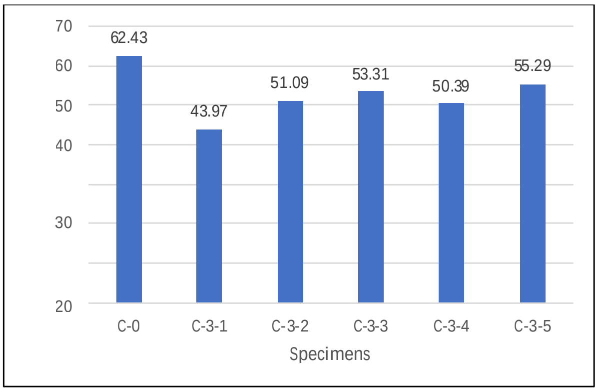


Figure 4: Variation of Dynamic Modulus of elasticity for different fiber volume fraction

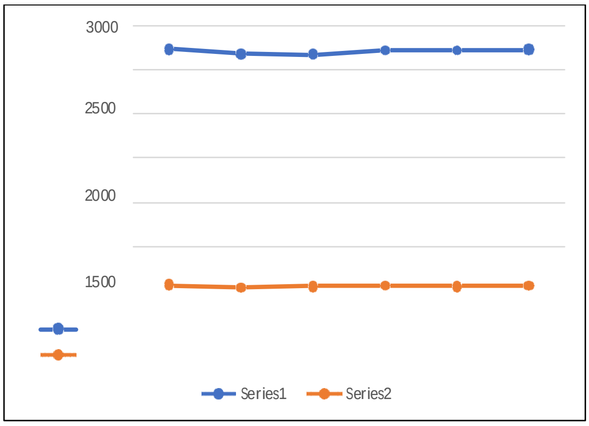


Figure 5: Variation of Dynamic Modulus of elasticity and density of HFRC for different fiber volume fraction

From Figure 3 and Figure 4 it can be observed that hybrid fiber-reinforced concrete and control specimen all have good and excellent concrete quality and dynamic modulus of elasticity. Addition of fibers have reduced the pulse velocity and dynamic elastic modulus by some amount.

From Figure 5 as the density of concrete is increasing the dynamic modulus of elasticity is also increased. More the density means lesser the voids and thus improved pulse velocity, which leads to better quality.

The quality of FRC is defined in terms of uniformity, less internal flaws, cracking and segregation etc., can be known by Table 2 of IS 13311-1: 1992, which is developed for identifying the quality of concrete by using the ultrasonic pulse velocity.

Therefore, the actual values of the velocity of pulse measured depends on various parameters, criterion for determining the quality of concrete on the basis of pulse velocity is given in Table 2 of IS 13311-1:1992. It can be satisfactory only to some extent. Although, when the comparison is done between different parts of structure, which had been built at the same time with believably similar materials, methods of construction and supervision, the quality assessment becomes more relevant and reliable.

Conclusions

1. From the experimental study performed it is concluded that the use of fibers had significant effect on quality of concrete, dynamic modulus of elasticity without compromising compressive strength and quality. The optimumpercentage of fiber is 1% PP has better performance with respect to fiber reinforced concrete.
2. From the above graph it can be concluded that after control specimen, mix C-3-5 has the highest pulse velocityi.e., 4.886 km/s, dynamic modulus of elasticity as 55.29 GPa and 61.77 MPa of compressive strength, because of use of polypropylene fiber and better mixing and compaction of concrete.
3. Among the hybrid fiber-reinforced concrete C-3-3 with 0.3 % PPF and 0.7 % SF had excellent quality of concrete with a pulse velocity of 4.732 km/s and dynamic modulus of 53.31 GPa with 7.22 % increase in compressivestrength. Due to use of two fibers, there is no much compromise in the quality of concrete based on UPV test.
4. The quality of all fiber reinforced concrete is good and excellent and can be further used in applications.

Acknowledgement

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