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ASSESSMENT OF THE MECHANICAL PROPERTY OF HYBRID FIBRE CONCRETE WITH THE OPTIMAL MIX

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ABSTRACT

When two or more distinct types of fibres are used in conjunction with a combined matrix to produce a composite material known as a hybrid, this type of material can be referred to as a hybrid composite. This hybrid material represents the benefits of each of the individual components used in the fibres. An optimized mix containing hybrid fibres was produced through parametric research on the effects of varying fibre contents on the mechanical properties of the concrete structure, specifically the compressive strength, shear strength, and toughness. The mechanical qualities of the concrete construction were shown to benefit from these modifications. Additionally, it was shown that when utilizing various fibre compositions, the combination of glass and polypropylene fibre produces the best outcomes in terms of compressive strength and toughness. Hybrid fibres were added to the concrete mix at various ratios, but they didn't replace any other ingredients from the M30 mix designs. In this investigation, different amounts of fiber-containing cement (0.5%, 1%, 1.5%, and 2%) were added and tested individually in a compression testing machine with a 2000-ton capacity after 7 and 28 days of curing. The readings were taken to determine the optimal percentage of fibers to add to concrete, aiming to increase the concrete's compressive strength significantly. Additionally, research has been conducted to determine how different types of fibre affect the mechanical properties of concrete structures. It also helps to understand the effect of age on concrete structures. Additional comparisons between various destructive and non-destructive tests have been conducted, and a correlation has been established between the two types of examinations.

***Keywords**: Glass fibre, polypropylene fibre FRPC, hybrid fibres, non-destructive testing, compressive strength, workability of concrete*

INTRODUCTION

It is necessary to evaluate concrete construction after hardening regularly to determine the structure's suitability for its intended use. Such testing should ideally be performed without causing any damage to the concrete. Concrete may be tested using one of two methods, depending on the scenario: non-destructive testing or destructive testing. The term "fibre reinforced concrete" is defined by ACI Committee 544 as referring to a cement-based compound that is blended with aggregate and discontinuous discrete fibres [1],[2]. When polypropylene fibres are added to concrete, the strength of the concrete increases while at the same time the unit weight decreases [3],[4]. Strong concrete must have both high strength and low permeability to be considered good concrete. Polypropylene fibres have a high elasticity modulus, which allows them to increase flexural strength while simultaneously reducing water permeability [5]. Hydrophobic polypropylene fibres resist becoming moistened by cement paste due to their inherent properties. The hydrophobic characteristics of polypropylene have no impact on the amount of water that is required for concrete [6],[7],[8]. There are three distinct varieties of polypropylene fibres: monofilaments, multifilaments, and fibrillated [9],[10]. Monofilaments are the most common variety. The compression strength and splitting tensile strength of polypropylene fibres both have a direct and proportional impact on the volume ratio of the fibres [11],[12].

There are several approaches for testing concrete structures without causing harm and achieving the desired findings. "Penetration method, rebound hammer method, pull out test method, ultrasonic pulse velocity (UPV) method, radioactive methods" are a few of the procedures.

In the test in which concrete is slightly, partially, or fully damaged, the crushing of the specimens is the usual destructive test to assess the strength of concrete. Some of these include corrosion testing, hardness testing, mechanical testing, and aggressive environment testing, as depicted in Figures 1 and 2.

The primary goal of this study is to assess the mechanical and non-destructive performance of hybrid fiber reinforced concrete (HFRC) using ideal fibre proportions. The goal of the study is to determine a quantifiable relationship between results from compressive strength testing and non-destructive testing (NDT) techniques, specifically the rebound hammer and UPV tests. The primary goal of the study is to understand how hybrid fiber insertion affects the surface hardness, internal homogeneity, and compressive strength of concrete. This work aims to develop a trustworthy prediction model for in-situ strength estimation by establishing a regression-based link between NDT and DT outputs, thereby supporting more economical and sustainable structural evaluation procedures.

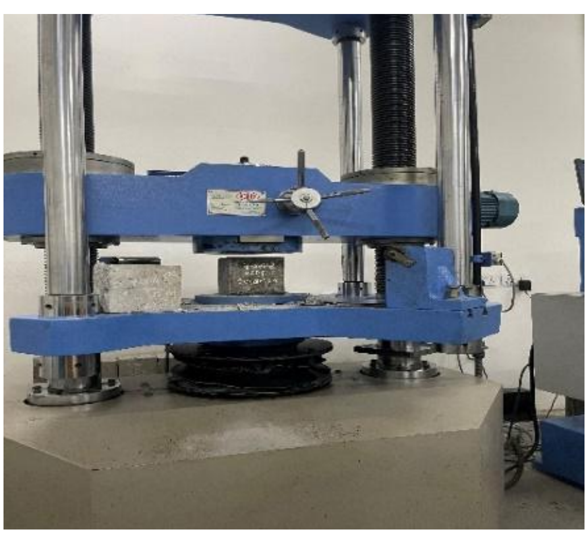


Figure 1 Universal testing machine

Figure 2 Compressive testing machine

EXPERIMENTAL PROCEDURE

To assess the mechanical performance of HFRC with different fiber proportions, the experimental program included both destructive and non-destructive testing techniques. M30-grade concrete specimens were subjected to the Rebound Hammer Test (Figure 3), Ultrasonic Pulse Velocity (UPV) Test (Figure 4), and Compressive Strength Test.

To assess the internal quality and surface hardness of hybrid fibre-reinforced concrete specimens without causing damage, non-destructive testing was conducted. The UPV test and the rebound hammer test were the two NDT techniques used, and they were carried out in accordance with IS: 13311 (Part 1 and Part 2) – 1992.

Each cube specimen's surface was washed and dried before the rebound hammer test. Six readings were taken at various locations, avoiding corners and edges, while the hammer plunger was held perpendicular to the specimen surface. The representative rebound number for that specimen was determined by averaging these measurements. The manufacturer's calibration curve was then used to translate the rebound numbers into equivalent compressive strength values. To ensure

Figure 3 Schmidt rebound hammer test

Figure 4 Pulse velocity test

consistency, all measurements were collected in a vertical downward position using a hammer with an impact energy of 2.207 N·m.

The concrete's interior quality and uniformity were evaluated using the Ultrasonic Pulse Velocity Test. To provide adequate acoustic contact between the transducers and the concrete surface, the cube surfaces were cleaned and covered with coupling gel before testing. A digital UPV device was used to measure the pulse transit time after a pair of transmitting and receiving transducers were positioned on opposing faces of the specimen. Table 1 shows velocity criteria for different concrete gradings.

Table 1 Velocity criteria for different concrete grading

Sr. No.	Pulse Velocity (km/sec)	Grading of Concrete Quality
1.	Above 4.5	★★★★★
2.	3.5 to 4.5	★★★★☆
3.	3.0 to 3.5	★★★☆☆
4.	Below 3.0	★★☆☆☆

To verify the non-destructive test findings and determine the true compressive strength of HFRC, destructive testing was conducted. A compression testing machine (CTM) with a 2000 kN capacity was used for the testing, in accordance with IS: 516 (1959). For all fiber proportions—0%, 0.5%, 1%, 1.5%, and 2%—concrete cube specimens measuring 150 mm by 150 mm by 150 mm were prepared using the same mix design to ensure consistency. To ensure adequate hydration and strength development, the specimens were cured in clean water for 7 and 28 days following casting. To ensure even load distribution, the cube surfaces were dried and positioned in the center of the CTM platen before testing. Until the specimen collapsed, a constant and uniform load was applied at a rate of about 140 kg/cm^2 per minute. The typical compressive strength was determined by averaging three measurements for each mix fraction. To establish a trustworthy link between non-destructive and destructive methods for assessing in-situ concrete strength, the results from destructive testing were compared with those from the Rebound Hammer and Ultrasonic Pulse Velocity tests.

Mix Design Proportions

According to the Indian standard code book, IS 456:2000, various grades of concrete are available; for the current work, see M30 grade mix design, and 24 mm length glass fibres as well as polypropylene fibres were used in a hybrid manner at 0%, 0.5%, 1.0%, 1.5%, and 2% of the cement volume added. Table 2 and Table 3 show the proportions obtained.

RESULTS

The compressive energy and stress-strain behavior of various parameters will be investigated in pilot experiments on M30 grades with and without hybrid fibres, and the control effects will be described.

Table 2 Mix proportion for M30 grade concrete

Cement	11.630 kg/m^3	
Fine Aggregate	15.305 kg/m^3	
Coarse Aggregate - 10 mm	10.860 kg/m^3	
Coarse Aggregate - 20 mm	18.065 kg/m^3	
Water		06.686

Table 3 Mix proportion for M30 grade concrete with the addition of hybrid fibres

Hybrid Fibres (Glass +Polypropylene)	
0.5%	178.969 gm
1.0%	367.939 gm
1.5%	546.908 gm
2.0%	715.878 gm

Slump Test

Slump tests for bare concrete and hybrid concrete were performed to determine the workability of the concrete mix. Table 4 presents the workability of concrete at various percentages of hybrid fibers (glass and polypropylene fibres).

Table 4 Workability of concrete at varying % of hybrid fibres

	% of Hybrid Fibres added	Slump Value
M30 Grade Concrete	0 %	65 mm
M30 Concrete with Hybrid Fibre	0.5%	62.5 mm
	1.0%	40 mm
	1.5%	30 mm
	2.0%	25 mm

Compression Test

The compressive strength of M30 concrete with and without hybrid fibre was measured using a CTM. The compressive strength was obtained in the laboratory after 7 and 28 days of hardening. After 7 and 28 days of curing, the specimen was removed from the curing tank and placed in the CTM to determine the preferred compressive strength of the designed concrete with and without hybrid fibre. The samples were tested using a compression testing machine with a capacity of 2000 KN. From now on, the release of pressure energy at specific percentages of hybrid fibre addition is 0%, 0.5%, 1%, 1.5%, and 2%.

Effect of the Age of Concrete

The compressive strength of the concrete is shown in Figure 6, measured by both destructive testing (the compression test) and non-destructive testing (the rebound hammer test and UPV test) at various ages of the concrete. The resistances acquired through the compression test were found to be greater than those obtained through the rebound hammer test at both the age of 7 days. At 7 days and 28 days, the two approaches produced results that differed by 19% and 22% respectively, when compared to one another in terms of their respective averages. There was even a reversal of the condition by the age of 28 days, the resistances obtained by the compression test were lower than those obtained by the rebound hammer test. This result might be explained by the fact that the concrete has had time to mature. The rebound hammer test is one method that can be utilised in the absence of a core to evaluate the compressive strength of the concrete as well as the homogeneity of the mixture.

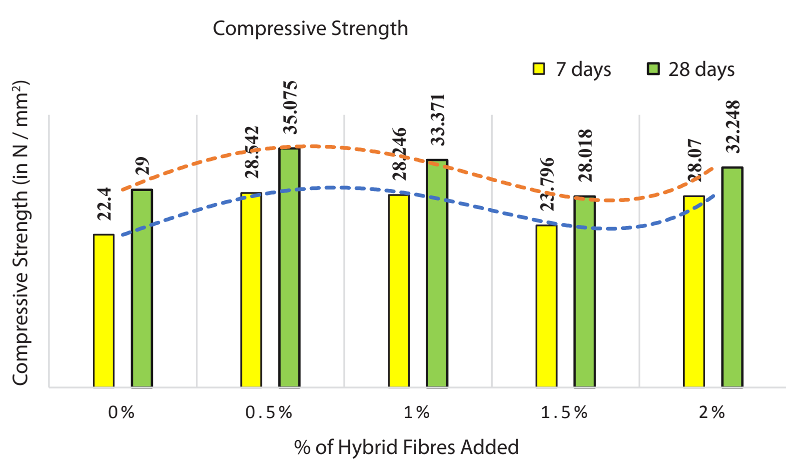
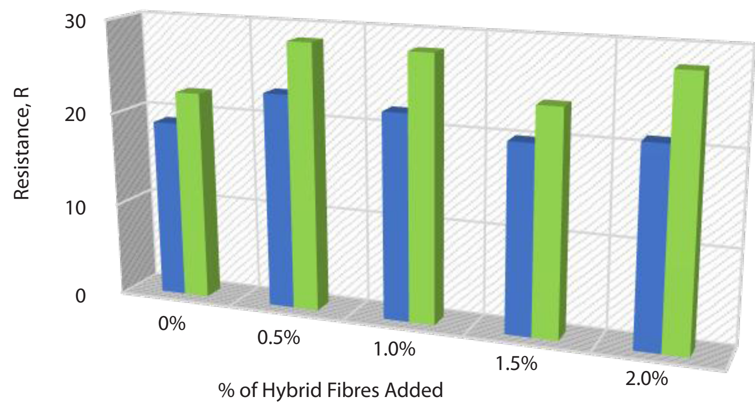
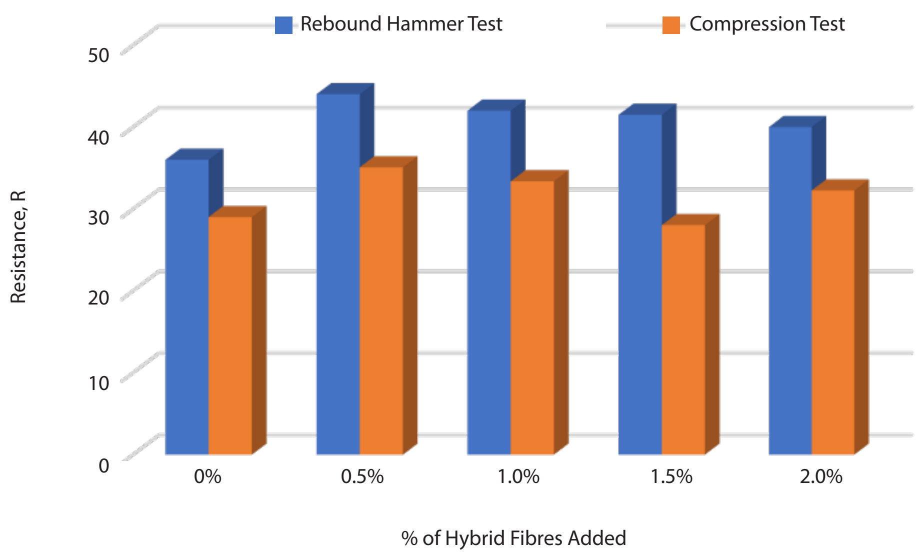


Figure 5 Comparison between compressive strength with different % of fibre



(a) After 7-days of curing



(b) After 28-days of curing

Figure 6 Outcome of destructive and non-destructive tests on the resistance of concrete at diverse ages

Collation Between Compressive Strength And Ultrasonic Pulse Velocity

The quality of the concrete in terms of uniformity, the incidence or absence of internal flaws, cracks, and segregation, etc., which is indicative of the level of workmanship employed, can therefore be evaluated using the guidelines that are given below. This will allow for a more accurate assessment of the quality of the concrete. In order to characterise the quality of concrete used in structures based on the ultrasonic pulse velocity, these guidelines have been developed. Figure 7 depicts the instrumentation that was utilised in the process of measuring the ultrasonic pulse velocity.

The receiving transducer must be able to detect the pulse velocity that is being sent or propagated by the transducer. To guarantee that they maintain an adequate amount of coupling between the concrete and the face of each transducer. In most cases, the components that go into the creation of copulates are things like petroleum jelly, grease, liquid soap, and kaolin glycerol paste.

Validation

The equation 1, derived from the linear regression generated using Minitab software, was preferred to derive the concrete's compressive strength in order to predict it accurately. Henceforth equation 2 finds

Figure 7 Ultrasonic pulse velocity test apparatus

the pulse velocity using an ultrasonic pulse velocity apparatus.

$$f_c = -444.9 + 80.03\, V_p \tag{1}$$

$$V = \frac{L}{T} \tag{2}$$

Where,

f_c = Predictable Compressive strength
V_p = Ultrasonic Pulse Velocity, km/s
L = Path Length, mm
T = Transit Time, µs

Table 5 validates the pulse velocity of M30 grade concrete mix, both without the addition of fibres and with the addition of hybrid fibres (glass + polypropylene), using the UPV apparatus.

Table 5 The pulse velocity of the M30 grade concrete with and without fibres

Hybrid Fibres (in %)	Transit Time, T (in µs)	Path Length, L (in mm)	Pulse Velocity, V k (in km/s)
0	25.00	150	6.00
0.5	24.00	150	6.25
1.0	25.00	150	6.00
1.5	24.78	150	6.05
2.0	24.70	150	6.07

The compressive strength of the material is predicted based on the ultrasonic pulse velocity apparatus using equation 1, and then this predicted compressive strength is compared with the actual compressive strength obtained through destructive testing with the assistance of a compressive testing machine. The results of this comparison are reflected in Table 6.

Table 6 Predicted strength using UPV and actual strength of concrete

Hybrid Fibres (in %)	Pulse Velocity V (in km/s)	fc (MPa)	Fc (MPa)	% Variation
0	6.00	35.55	29.00	0.23
0.5	6.25	55.48	35.08	0.58
1.0	6.00	35.55	33.37	0.07
1.5	6.05	39.09	28.02	0.40
2.0	6.07	40.48	32.25	0.26

The fitted line plot for the linear regression equation obtained to predict the compressive strength of M30 grade concrete is displayed in the graph shown in Figure 8. The fact that 99.8% R-sq(adj) was obtained demonstrates that the good result was achieved.

Analysis of Variance Using MiniTab Software

Source	DF	SS	MS	F	P
Regression	1	272.352	272.352	2165.23	0.000
Error	3	0.377	0.126		
Total	4	272.729			

Discussion and Analysis of Results

The experimental results clearly show that the addition of hybrid fibres has a substantial impact on the mechanical and Non-destructive properties of M30-grade concrete. According to the compressive strength data, the addition of 0.5% hybrid fibre (glass + polypropylene) produced the best compressive strength after 7 and 28 days of curing, indicating optimum fibre distribution and effective stress transfer between the cement matrix and fibres. At increased fibre concentration (1.5%), a minor drop in strength was seen, most likely due to fibre clustering and non-uniform dispersion, which can result in micro-voids and weak zones within the concrete matrix.

The workability findings (slump test) demonstrate a consistent decrease in slump value with increasing fibre content, indicating that adding fibres affects concrete fluidity due to the increased surface area and fibre interlocking effects. This conclusion is consistent with previous studies [39],[40], who also showed a reduction in slump with fibre addition.

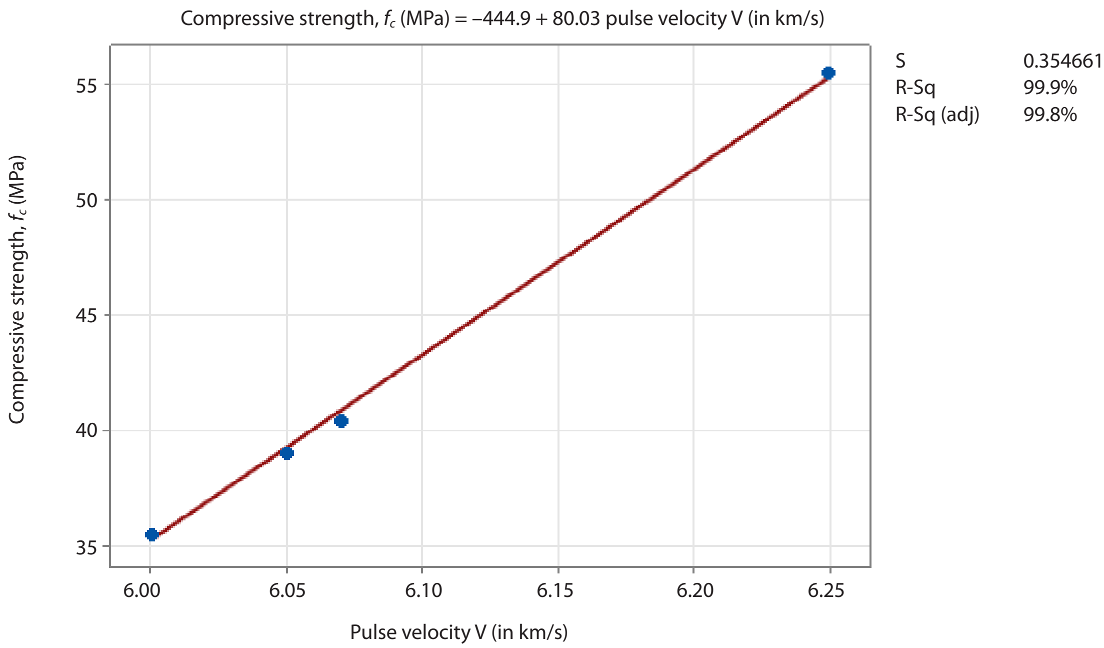


Figure 8 Fitted line plot for predictable compressive strength using UPV technique

The Rebound Hammer and UPV tests showed a high correlation with the compressive strength data acquired during destructive testing. The correlation (R^2 = 0.998) between pulse velocity and compressive strength validates the UPV test as a credible predictor of in-situ concrete strength. The observed rise in UPV measurements with fibre inclusion suggests better internal bonding and less microcracking within the concrete mass. Similar associations between pulse velocity and compressive strength, which supports the results of the current investigation [41],[42].

Overall, the results show that hybrid fibre reinforcement improves surface hardness and structural integrity while retaining acceptable quality, as evidenced by UPV velocities more than 4.5 km/s for all combinations. The experimental results also show that non-destructive procedures, such as UPV and Rebound Hammer testing, can effectively supplement traditional destructive testing, making them ideal for estimating strength in existing buildings.

CONCLUSIONS

To illustrate different methods for calculating compressive strength and modulus of elasticity, structural and non-destructive tests were performed on concrete specimens of varied compositions. The strength findings from destructive and non-destructive procedures were significantly less different after 28 days of cure. When compared to freshly cast samples, the rebound hammer test proved to be more accurate in determining the compressive strength of aged concrete. The 7-day compressive strength for the M30 grade control mix without fibres was 22.4 N/mm^2, while the corresponding values for mixes with 0.5%, 1%, 1.5%, and 2% hybrid fibres (glass + polypropylene) were 28.542, 28.246, 23.796, and 28.07 N/mm^2. These values rose to 29.00, 35.075, 33.371, 28.018, and 32.248 N/mm^2 after 28 days. According to the findings, adding hybrid fibres to concrete increased its compressive strength when compared to plain concrete; the best strength was obtained with a 0.5% fibre addition, while the lowest strength was obtained with a 1.5% fibre addition. After seven days, the compressive strength rose by roughly 27.41%, 26.09%, and 25.31% for fibre contents of 0.5%, 1%, and 2%, respectively, whereas a 6.23% decrease was noted at 1.5%. In a similar vein, after 28 days, the strength increases for 0.5%, 1%, and 2% fibres were 20.95%, 13.10%, and 67.13%, with a minor decline of 3.39% at 1.5%. Hence, 0.5% hybrid fibre content was chosen as the most acceptable proportion for generating maximal compressive strength.

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Declaration of Competing Interest
The authors declare no competing financial interest.

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