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Performance Assessment of Tri-Hybrid Fiber Composites in the Shear Behavior of Concrete Deep Beam

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Abstract

This research examines the improvement of shear strength of reinforced concrete (R.C.) deep beams by using a blending of three different types of fibers: crimped steel fiber, polypropylene fiber, and glass fiber, each offering distinct characteristics. The optimal mix ratios for these fibers in M20 grade concrete are determined to be 1.25% of crimped steel fiber, 0.2% of polypropylene fiber and 0.1% of glass fiber with respect to volumetric proportions of concrete. This specific combination in R.C. deep beam demonstrates that, the shear strength of hybrid fiber reinforced concrete (HFRC) deep beam found to be 42.7%, exceeding that of conventional R.C. deep beam. The addition of these hybrid fibers in the R.C. deep beams promotes environmentally friendly practices by reducing carbon dioxide emissions by approximately 10.92% when compared to standard R.C. deep beams.

Keywords: *Shear Strength, R.C. Deep beam, hybrid fiber, crimped steel fiber, polypropylene fiber, Glass fiber, hybrid fiber reinforced concrete (HFRC).*

Introduction

Reinforced concrete (R.C.) deep beam is constructed with low-strength concrete is damaged to sudden splitting failures in the strut region due to shear–compression stresses. To mitigate this weakness, various strengthening techniques, such as, steel plates, fiber-reinforced polymer sheets, and cementitious composites, have been explored to confine the strut area. Concrete is a brittle material and weak in tension. Traditionally, web reinforcement in the form of vertical stirrups is used in reinforced concrete (R.C.) beams to take care of principal stresses that may cause failure when they are subjected to shear stresses(9). In recent decades, different types of fibers have potential for improving post-cracking behavior of R.C. deep beam and replacing stirrups completely or partially have been studied. Hybrid fibers improved multi-cracking, ductility, and improved the shear capacity significantly (1, 9). The experimental results have shown that steel fibers, improved the shear resistance of the deep beams, decreased the shear crack width, reduced the displacement of the beams, and enhanced the deformation (2). Hybrid fibers increased diagonal cracking load and ultimate shear capacity (3, 4). Hybrid fibers improve diagonal-crack strength and shear capacity; steel fiber aspect ratio most influences cracking; web reinforcement ratio has smaller effect on diagonal cracking of beam. Polypropylene fibers (at certain volume fractions) raises ultimate load over beams without web reinforcement ratio. (5). Also, stiffness, crack resistance, and overall shear strength are improved (4, 6). It has been shown that the use of steel fibers randomly dispersed and oriented in concrete has a significant potential for enhancing mechanical properties of R.C. beams (7). Hybrid (long + short steel) fibers significantly delay diagonal cracking, increase cracking and ultimate loads ,improve ductility and reduce required stirrups; cracking patterns, load–deflection, and strain data are reported (1,10).

In this research experimental investigation is carried out on performance of R.C deep beam using blending of three different fibers viz, crimped steel fiber, glass fiber and polypropylene fiber.

Objectives of the Study

- Examining the ideal ratio of tri-hybrid fibers in a functional M20 concrete blend.
- Experimental studies on the shear performance of HFRC deep beam relative to traditional R.C. deep beam.
- Recognize the decrease in carbon dioxide emissions through the use of tri hybrid fibers in R.C. Deep beam.

Experimental Program

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Materials and Fibers

Concrete mixes were designed for grade M20 using 53-grade OPC cement, crushed sand, and 20 mm metal. The mix ratio (cement: sand: aggregate) was found to be 1 : 2.20 : 3.34 and water to cement ratio was found to be 0.52.The properties of three fibers (crimped steel, polypropylene, glass) used in concrete mix having grade M20 is shown in table1.

Table 1: Fiber properties

Property	**Crimped Steel fiber**	**Polypropylene Fiber**	**Glass Fiber**
Density in kg/m^3	$7850 kg/m^3$	$910 kg/m^3$	$2500 kg/m^3$
Length in mm	50 mm	20 mm	12 mm
Diameter in mm	1 mm	0.048 mm(48μ)	0.014mm (14μ)
Aspect Ratio	50	416.67	857.14
Tensile strength	1000 – 1500 MPa	300 – 700 MPa	2000 – 3500 MPa

Figure 1: Glass Fiber

Figure.2: Crimped Steel Fiber

Figure 3: Polypropylene fiber

Fibers Mix Proportions

All three fibers are mixed in concrete with different proportions such as steel fiber ranging from 0.5% to 1.25 % and glass fiber ranges from 0.1 % to 0.3% and polypropylene fibers ranging from 0.1 % to 0.2% with respect to volumetric proportions of concrete. The concrete mix ID's for varying parentages of steel, glass, and polypropylene fibers are displayed in Table 2, along with the relevant strength metrics, such as the concrete's tensile and compressive strengths, for grade M20.

Table 2:- Different volumetric percentage proportions of fibers w.r.t M20 Concrete Mix.

Mix ID	Crimped Steel Fiber	Glass Fiber	Polypropylene Fiber
A	0.5	0.1	0.1
B	0.5	0.1	0.2
C	0.5	0.2	0.1
D	0.5	0.2	0.2
E	0.75	0.1	0.1
F	0.75	0.1	0.2
G	0.75	0.2	0.1
H	0.75	0.2	0.2
I	1	0.1	0.1
J	1	0.1	0.2
K	1	0.2	0.1
L	1	0.2	0.2
M	1.25	0.1	0.1
N	1.25	0.2	0.1
O	1.25	0.1	0.2
P	1.25	0.2	0.2
Q	1.25	0.3	0.2
Conventional Concrete			

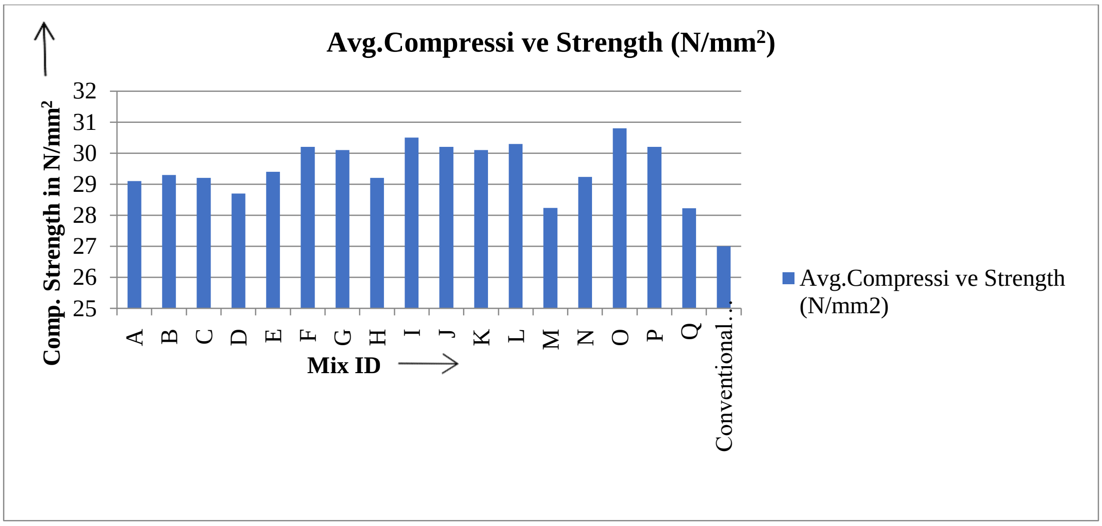

Figure 4: Graph for compressive strength of concrete for different Mix ID.

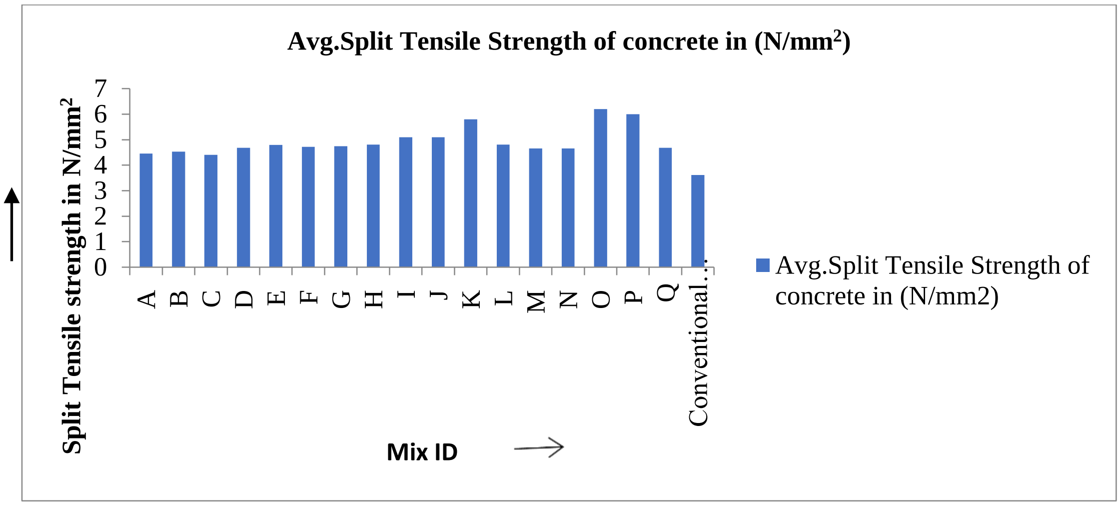

Figure 5: Graph for split strength of concrete for different Mix ID.

It was found that, for mix proportions of 1.25% of crimped steel fiber, 0.2% of polypropylene fiber and 0.1% of glass fibers are found to be optimum mix as compressive strength and split tensile strength is significantly more for this mix.(Refer fig. 4 and fig.5)

R.C Deep beam Details

1. The dimensions of Deep beam are: Length - 0.70 m, depth 0.4 m, and width 0.15m.R.C. Deep is designed using I.S 456-2000 **(**Reaffirmed**:** 2021).

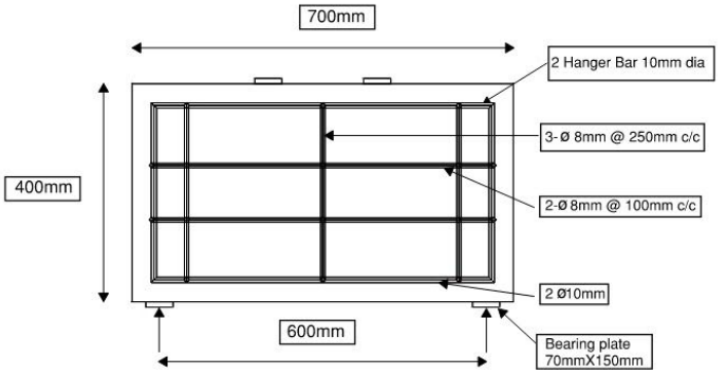

Figure 6: Reinforcement detail of R.C. deep beam

R.C. deep beams are designed for two-point loads of 50 kN each. As seen in Fig. 6, R.C. deep beams with main and side face reinforcement were designed in compliance with I.S. 456-2000. According to several studies adding steel fiber to concrete at a volume of 0.5% to 1.25% can increase its tensile and shear strength (7). Additionally, when combined with steel fiber, glass fiber and polypropylene fiber, can improve concrete's ductility, toughness, and impact strength with low fiber content by volumetric percentage of concrete. In the present study, HFRC deep beams are cast by completely replacing conventional shear reinforcement with optimum fiber combination. (Table 2).

Casting of Deep beam

The steel cage is shown figure 7 and figure 8 for both conventional and HFRC deep beam.

Figure 7: Conventional Steel Cage

Figure 8: Steel Cage without Shear reinforcement

The mix of M20 grade of concrete is designed as per IS 10262:2019. Three beams are casted with conventional steel and mix design of M20 grade concrete and cured for 28 days in curing tank(8). The three beams are casted with optimum mix of 1.25% of crimped steel fiber, 0.2% of polypropylene fiber and 0.1% of glass fibers are added w.r.t volumetric proportions of concrete mix of grade M20. The horizontal steel and vertical steel of R.C. deep beam is replaced with optimum proportion of tri hybrid fiber mix, and cured for 28 days.

Test set up

The arrangement for test set up for both type of beam is made as follows.

End condition is simply supported with centre to centre distance is 0.6 m a shear span to depth ratio is kept as 0.5.

The specimen is tested with arrangement of two point loading and simply supported condition, using a self-restraining loading frame with a capacity of 1000 kN. (Refer fig.9)

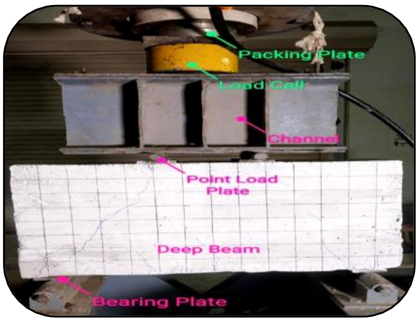

Figure 9: Testing specimen with two point loading

A self-restraining loading frame of 1000 kN capacity was used for testing the beam specimen. The Immetrum Video Gauge Measurement System (VGMS) with 1.0 micron least count measured deflection and strain. M.S. bearing plates (150 mm × 70 mm × 5 mm) were provided at supports and loading points to limit bearing stress. Markings were made on the deep beams for strain, deflection, and crack detection. The load cell was connected to VGMS for synchronized load, strain, and deflection data. Virtual gauges were created in the VGMS interface between selected points on the specimen. A hydraulic jack was operated to apply load gradually to the beam specimens. The loading rate was kept constant as per IS 516 (2021) recommendations. Initial crack load, ultimate load, and corresponding deformations were accurately recorded. Strains, central deflections, and crack pattern were monitored until beam failure.

3.6 Data collection: - The load is applied gradually with interval of 5 kN and reading of central deflection and shear strain is recorded in Video Gauge Immetrum. VGMS provides precise readings of loads, strains, and deflections at various points on a structure. The first crack load was noted as soon as a visible crack appeared on the surface. As the load was increased further, cracks propagated and widened until the beam failed, either in shear, flexure, or a combination of both.

The ultimate load at failure was recorded for each specimen. Crack patterns were marked using a permanent marker, and the failure mode was documented. In R.C. deep beams, cracks begin as vertical flexural cracks near mid-span and evolve into diagonal shear cracks between the load and supports as shown in fig 10 and fig 11.

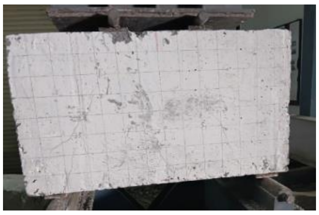

Figure 10: Crack Pattern in HFRC Deep beam

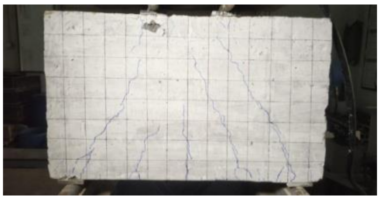

Figure 11: Crack Pattern in R. C. Deep beam

Above crack pattern shows discontinuous crack which is observed in HFRC deep beam while conventional R.C. deep beam shows shear crack from loading point to support end.

Carbon Credit

A carbon credit permits the holder to release a designated quantity of greenhouse gases, typically carbon dioxide (CO_2), into the environment. It signifies the entitlement to release one metric ton of CO_2 or an equivalent quantity of another greenhouse gas(13). Approximately 1.81 kg of CO_2 is released for every 1 kg of newly produced steel.

Typically, the manufacturing of 1 kilogram (kg) of glass fibers can release around 1.7 to 2.5 kilograms of CO_2. The manufacturing of 1 kilogram (kg) of polypropylene fibers can release roughly 1.34 to 3 kilograms of CO_2 (11,12).

Table 3: CO_2 emission for fibers

Material	CO_2 emission per kg	Density (in kg/m^3)
Steel	1.81 kg	7850 kg/m^3
Steel Fiber	1.81 kg	7850 kg/m^3
PP fiber	1.9 kg	910 kg/m^3
Glass Fiber	1.7 kg	2500 kg/m^3

Following table 4 gives the CO_2 emission values for Conventional and HFRC deep beam.

Table 4: CO_2 emission for HFRC deep beam and Conventional deep beam

Sr. No	Type of Deep beam	Steel ReinfoR.C.ement weight in kg	CO_2 Emission from steel and various fibers.
1	HFRC Deep beam (0.7 m x 0.4 m x 0.15 m)=0.042 m^3	Weight of reinfoR.C.ing steel for HFRC deep beam 3.75 kg	Quantity of Steel fiber 1.25% = (0.0125 x 0.042 x 7850) = 4.12 kg , Quantity of polypropylene fiber 0.2% =(0.002 x 0.042 x 910) = 0.076 kg Quantity of glass fiber fiber 0.2% =(0.001 x 0.042 x 2500) =0.105kg
			Consumption of CO_2 = [1.81 x 4.12] +[0.105 x 1.70] + [0.076 x 1.9] + [3.75 x 1.81] = 7.45 + 0.1785 + 0.144 + 6.78 = 14.55 kg CO_2
2	Conventional Beam (0.7 m x 0.4 m x 0.15 m)=0.042 m^3	Steel required = 8.92 kg	Consumption of CO_2 = 8.92 x 1.81 =16.14 kg of Co_2

Results

Table 5: CO_2 emission for R.C. Deep beam and HFRC Deep beam

Grade of Concrete	Co_2 Emission for Deep Beam (0.15 m x 0.4m x 0.7 m)	
	Conventional Deep beam	HFRC Deep beam
M20	16.14 kg of Co_2	14.55 kg of Co_2

Above table shows CO_2 emission in HFRC deep beam is less as compared with conventional R.C. deep beam.

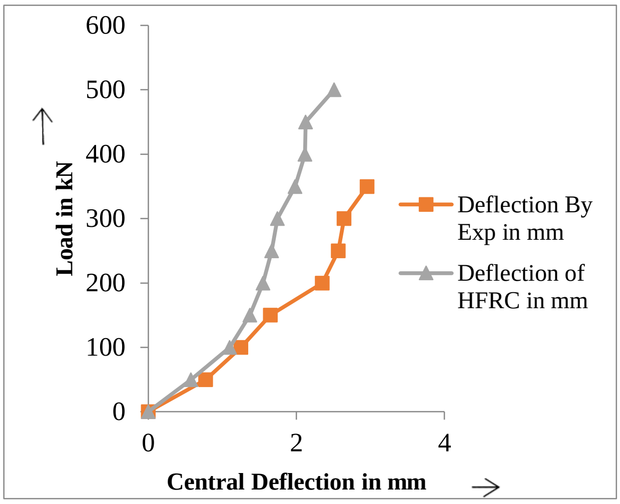

Figure. 12: Graph for Conventional and HFRC Deep beam with load vs deflection

Above fig. 12 shows that ultimate load for HFRC Deep beam is greater than conventional R.C Deep beam.

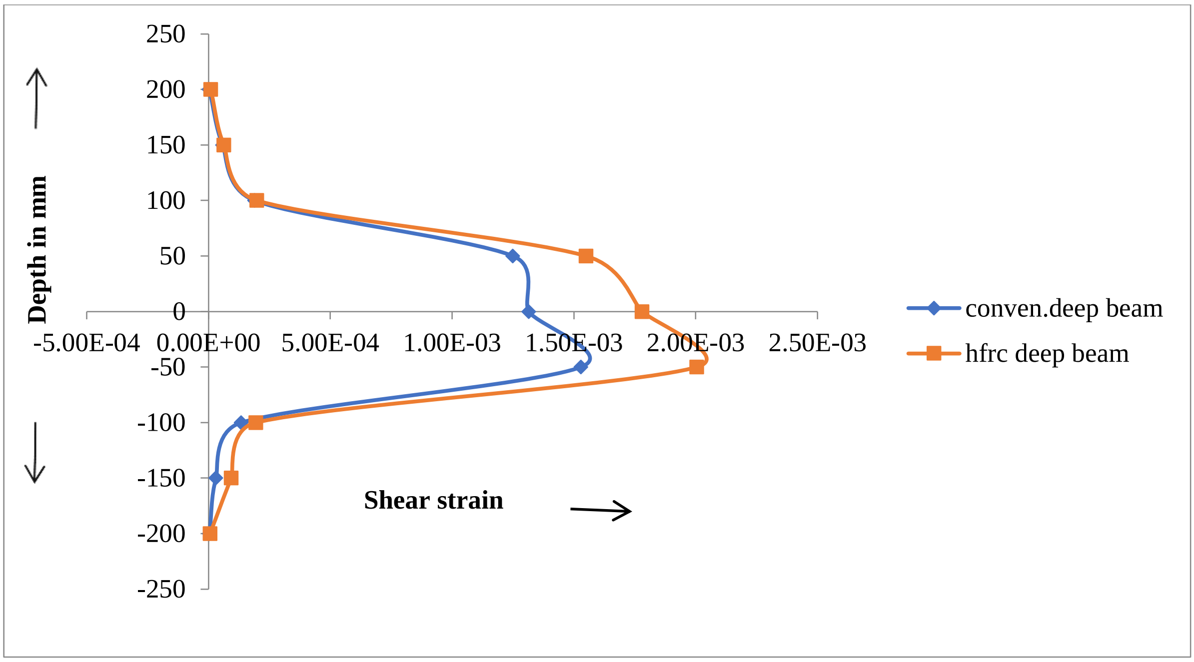

Figure 13: Graph for shear strain of Conventional R.C. Deep beam and HFRC Deep beam for M20 Grade Concrete.

Above fig 13 shows shear strain values of HFRC Deep beam increased measurably and this result in improving shear capacity of HFRC Deep beam tremendously as compared with conventional R.C. deep beam.

Table 6: Shear strength of conventional and HFRC Deep beam (M20)

Type of load	Load Value in kN	Shear Strength in N/mm^2
Design Load	150	1.33
Ultimate Load of Con .Deep beam	350	3.11
Ultimate Load of HFRC Deep beam	500	4.44

Above table 6 shows due to increase in ultimate load of HFRC Deep beam which results increase in shear strength of HFRC Deep beam in comparison with conventional R.C. Deep beam.

Table 7: First crack load and reserve strength of conventional and HFRC Deep beam (M20)

Beam Type	First Crack Load Wc in kN	Ultimate Load Wu in kN	Reserve strength in % (Wu-Wc)/Wc * 100
Conventional	200	350	75%
HFRC	250	500	100%

The reserve strength of an HFRC deep beam is significantly higher than that of a conventional R.C. deep beam, as shown in table 7 above.

Conclusion

The present investigation finds following improvements in behavior of HFRC deep beams in comparison with conventional R.C. deep beams.

- Optimum mix proportion mix for mix ID 'O'in concrete is found to be 1.25% crimped steel fiber, 0.2% polypropylene fiber and 0.1 % glass fiber, as split tensile strength and compressive strength is more for the given mix.
- For design load of 150 kN the corresponding central deflection of HFRC deep beams is observed to be reduced by 10.90% due to improvement in flexural rigidity of HFRC deep beams.
- First crack load of HFRC Deep beam finds improvement of 25% due to improves ductility and strength of HFRC deep beams.
- Ultimate load carrying capacity of HFRC deep beam is increased significantly and hence shear strength of HFRC Deep beams is found to be improved by 42.7%
- Reserve Strength of HFRC Deep beam increased by 25.% due to improved energy absorption in HFRC deep beam.
- By using tri-hybrid fibers in R.C. deep beam 10.92% Co_2 emission can be avoided during manufacturing process by partial replacement of steel instead of using conventional steel in R.C deep beam, thus carbon credit is achieved.

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Author Contribution

Author 1 conducted the experimental and analytical studies and prepared the manuscript. Author 2 supervised the research and reviewed the manuscript.

Ethical Issues

Not applicable. This experiment does not involve any experiments on humans and animals. Hence, ethical approval was not required.

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There are no pertinent financial or non-financial interests that the writers need to disclose.

Conflict of Interest

The authors declare that, they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data and materials availability

Data that support the findings of this study are embedded within the manuscript.

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