Shear Performance of R.C. Deep Beam Using Hybrid Fiber as Reinforcement

Pradugn Varhade[1], S.B. Javheri[2], S.K. Kulkarni[3]

Abstract

Researcher have established that the use of fibre reinforced concrete for casting of R.C. deep beams can prevent early cracking, improve the shear strength of deep beam and increase strain carrying capacity of concrete. Furthermore, it is found that using Hybrid fibre reinforced concrete (HFRC), reinforced with two or more different types of fibres, can produce superior results. The use of combination of small, discrete, randomly oriented fibres improves the strength and resistance against deformation of concrete members. The present study focuses on inclusion of hooked end steel fibre (SF), fibrillated polypropylene fibres (PP) and alkali resistance glass (GF) fibres in predefined proportion in the concrete mix to cast HFRC deep beams and study the effect on strength of deep beams. It is observed that HFRC deep beams, cast with a workable mix with a maximum fibre content of 1% steel + 0.3% PP + 0.16% glass fibre by volume of concrete, exhibit improvements of 49.67% in first crack load and 88.13% in load at failure when compared to conventional deep beams with a shear span to depth ratio of 0.5.

KeyWords: Deep beam, HFRC, two point load, shear strength, ultimate load capacity

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1. Introduction

In structural applications like pile tops, foundation wall, corbels, transfer girders and tall buildings, reinforced concrete deep beams are useful. The slender beam theory based on Navier's hypothesis is not relevant to deep beam. The behavior of deep beam is significantly different because of their large depth in relation to span. Generally deep beam are heavily loaded structural members and strength of deep beam it's usually controlled by shear. The diagonal compression and tension in a perpendicular direction results from the shear action in the beam web.

Throughout their lifespan, conventional R.C. deep beam structures experience severe deterioration. Conventional shear reinforcement cannot provide efficient resistance to cracks formation and unable to provide isotropic elastic properties to concrete [1]. This results in low shear strength, low reserve strength, low first crack load and sudden failure.

The incorporation of fibres significantly improves the mechanical performance, including the tensile strength, fracture toughness, and fatigue resistance of the reinforced concrete. The fibres serve as not only the crack control reinforcement, but also the vehicle to allow for significant internal plastic stress redistribution to increase the strength of the specimens after the first crack forms[2,3]. HFRC is a type of reinforced concrete with two or more different kinds of fibres. It is recognized that HFRC can help produce better results [4].

S.K. Madan , G. Rajesh Kumar and S.P. Singh[5] found that shear strength increases with increasing fibre volume and decreasing shear span to-effective depth ratio.AvinashGornaleet al.[6] recorded good amount of increase in compressive strength, flexural strength and split tensile strength due to addition of glass fibres in concrete mix. Dr. Srinivas Rao et al.[7] examined durability of glass fibrereinforced concrete and found that durability of concrete was increased by addition of alkali resistant glass fibres. They also found that addition of glass fibres reduces segregation/bleedingand improves acid resistance of concrete. Suhail Shaikh et.al. [8]

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experimentally found that steel fibres are instrumental in enhancement of first crack load, load at permissible deflection and shear strength of concrete deep beams. S.K. Kulkarni et.al. [9] performed experimental study on Hybrid fibre Reinforced Concrete Deep Beams and reported that the strength acquired due to inclusion of steel + glass fibre is higher by 13% than same amount of steel & PP fibre. S.K. Kulkarni, Dr.S.A.Halkude [10] carried out experimental study on hybrid fibre reinforced concrete deep beam and found that using steel and PP fibre, increases reserve strength and lowers reinforcement congestion.

Hooked end steel fibres, as result of better bond with matrix, improve ductility, tensile strength shear strength and control the crack width in concrete [4]. Fibrillated polypropylene fibres improve resistance to plastic shrinkage during curing and to explosive spalling [10]. Concrete's durability, lack of segregation, workability, and acid resistance are all improved by alkali-resistant glass fibres [7,9]. In the present work, a combination of hooked end steel fibre (SF), Fibrillated polypropylene fibres (PP) and Alkali resitant glass fibres (GF) are used in predefined proportion in concrete to cast the deep beams.

2. Objectives

The objectives of the current investigation are:
To arrive at workable mix with maximum fibre content for high shear strength HFRC deep beams.
Experimental evaluation of shear strength of conventional R.C. and HFRC deep beams and there comparative study.

3. Experimental Work

A. Materials And Mix Proportion

Concrete mix M 25 were designed using 53 grades Ordinary Portland cement, artificial crushed sand and 20 mm aggregates [12]. Concrete mix proportion obtained was 1:1.96:2.97 with a water-cement ratio of 0.485. Fe 500 steel bars were used as flexural reinforcement in both conventional & HFRC deep beam and as shear reinforcement in conventional deep beam. HFRC deep beam were cast by replacing conventional shear reinforcement with hooked end steel fibre, fibrillated polypropylene fibres and alkali resistance glass fibres in predefined proportions [2].

Table 1: Properties of fibres used

Properties	Hooked end steel fibre	Fibrillated Polypropylene fibre	Alkali resistant glass fibre
Length	60 mm	20 mm	12 mm
Diameter	0.75 mm	48 micron	14 micron
Aspect ratio	80	416	857
Density	7850 kg/m3	910 kg/m3	2700 kg/m3
Tensile strength	1100 (MPa)	453 (MPa)	1300 (MPa)

B. Study of proportions of concrete

According to the specifications of the concrete mix design, the concrete was precisely cast. By adding the fibres to the mix in little amounts at a time, the balling-up of the fibres was avoided during mixing. For evaluating the quality of the concrete, specimens were cast using standard cube moulds measuring 150 x 150 x 150 mm [14] and standard cylindrical moulds measuring 150 mm in diameter and 300 mm in length [15] from each mix.

C. Workability

Due to the stiffness rendered by the metallic fibres, slump test does not produce reliable results for HFRC. Hence, the compaction factor (CF) test is recommended, and workability was measured in terms of the compaction factor [13]. The minimum compaction factor recommended by I.S. 456-2000 for concrete with medium workability is 0.85 [11]. The properties of concrete, including workability, compressive strength, and split tensile strength, are shown in Table 2 obtained for varying fibre inclusion proportions.

With increased fibre content, it is found that concrete loses workability. The medium workability limit (C.F>0.85) is satisfied by mixtures including up to 1% steel fibre, 0.3% PP fibre, and 0.16 % glass fibre (1% SF + 0.3% PP + 0.16%GF). For higher percentages of fibers, for sufficient workability, use of super plasticizer becomes necessary.

Table 2: Variation in Workability of concrete withfibre inclusion

Mix Designation	% offibres			Compaction Factor (CF)	% drop of CF	Compressive Strength (MPa)	% increase in compressive Strength as compared to conventional concrete	Split Tensile Strength (MPa)	% increase in Split tensile Strength as compared to conventional concrete
	SF	PP	GF						
Conv.	-	-	-	0.930	-	31.787	--	3.635	--
H-1	0.35	0.15	0.08	0.901	3.11	31.987	0.623	4.410	21.320
H-2		0.30	0.16	0.886	4.73	32.052	0.834	4.530	24.622
H-3		0.45	0.24	0.879	5.48	32.712	2.909	4.924	35.461
H-4	0.7	0.15	0.08	0.868	6.67	33.125	4.209	5.683	56.341
H-5		0.30	0.16	0.862	7.31	33.240	4.537	5.720	57.359
H-6		0.45	0.24	0.859	7.63	33.627	5.788	5.791	59.312
H-7	1	0.15	0.08	0.857	7.84	34.724	9.239	5.986	64.676
H-8		0.30	0.16	0.853	8.27	35.494	11.662	6.2	72.902

D. Compressive Strength of concrete

Table 2 shows that the compressive strength of the M 25 HFRC slightly rises as the proportion of fibre content increases. At a combination of 1% SF + 0.3% PP + 0.16 GF fibre content without super plasticizers, the largest improvement in compressive strength recorded in comparison to conventional concrete is 11.662%. As conventional concrete is strong in compression, improvement in it is marginal and it is due to density increase of concrete.

E. Split tensile strength of concrete

As a result of the addition of hybrid fibres, the split tensile strength of concrete has significantly increased (Table 2). For M 25 concrete, the split tensile strength of HFRC has increased by 72.902% in comparison with conventional concrete. The variations in split tensile strength of concrete for different mix designations are shown in Fig. 1.

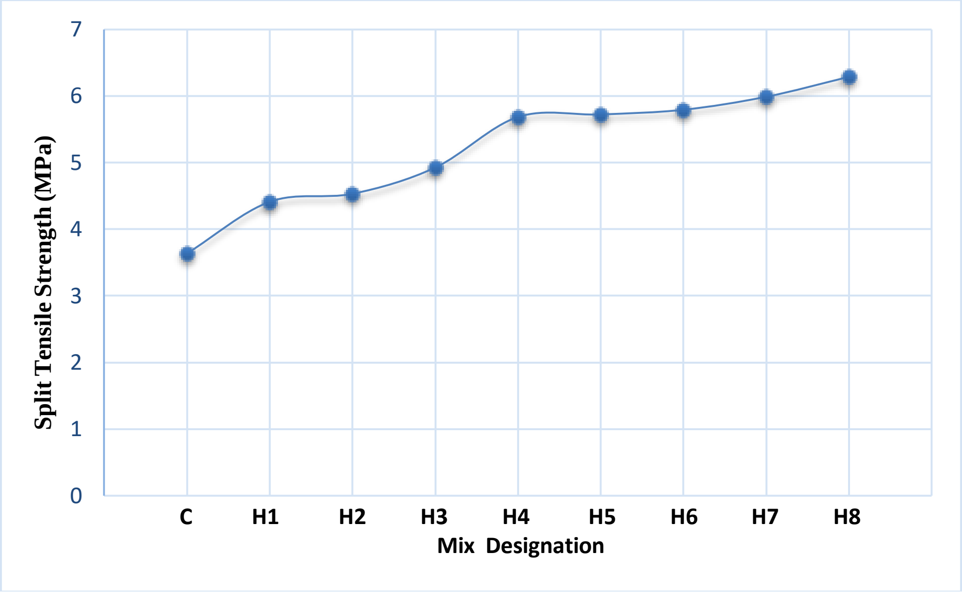
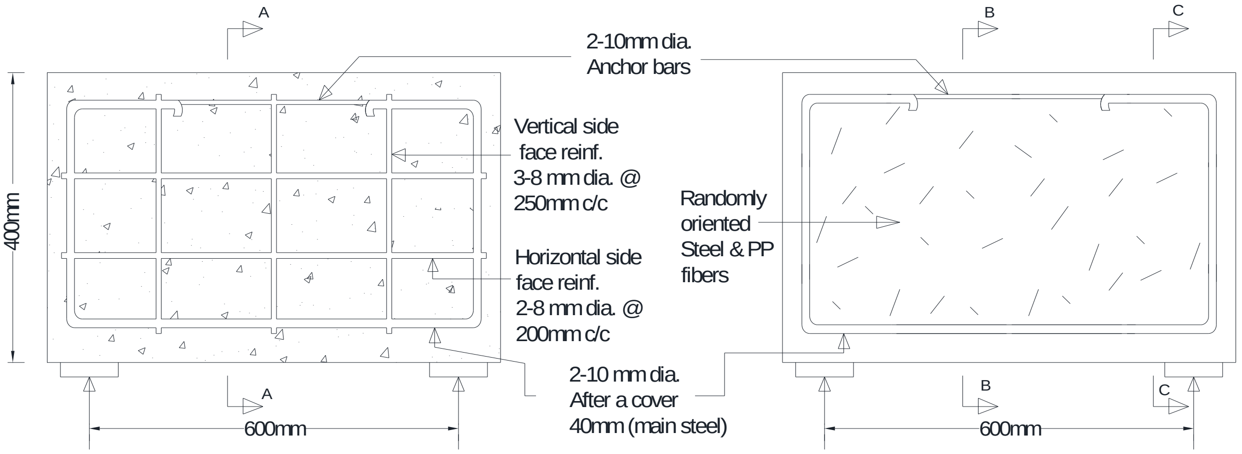


Figure 1: Variation in Split Tensile strength

F. Design of deep beam

Deep beams were designed for two-point loads of 50 kN each. The design stress was calculated to be 1.38 MPa by using partial factor of safety of 1.5. According to I.S. 456-2000 [11], conventional R.C. deep beams with main and side face reinforcement were cast (Fig. 2 a). Past studies have shown that adding steel fibres to concrete in amounts ranging from 0.5 to 2 % by volume can increase the concrete's tensile and shear strength. Additionally, polypropylene and glass fibres, when combined with steel fibre, can improve the ductility, toughness, and impact strength of concrete with fibre contents as low as 0.3% and 0.16%, respectively, by volume of concrete. As a results, in the current investigation, HFRC deep beams are cast using (1% steel + 0.3% PP + 0.16% GF) fibre content by volume of concrete in place of conventional shear reinforcement. Three deep beam specimens are cast for these mixtures.



a) Conventional Deep Beam b) HFRC Deep Beam

Figure 2: Details of Deep Beam

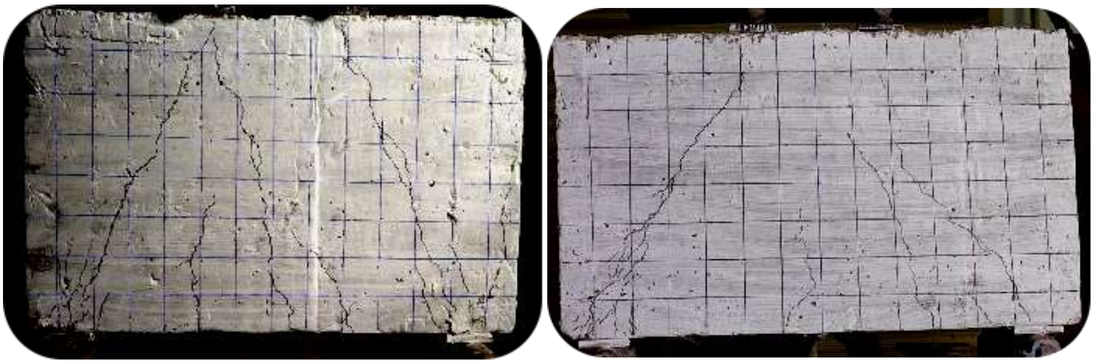
G. Test Specimen, Casting and Curing Procedures

Three conventional and three HFRC specimens for the M 25 concrete grades were cast. The parameters for the study included span to depth ratios, concrete grade, and fibre percentages. Each deep beam measures 700 mm in length, 400 mm in depth, and 150 mm in width. After casting, specimens were held at 90% humidity for 24 hours. Specimens were then water cured for 28 days.

H. Test Procedures

According to I.S.516-1959 the flexural test on deep beams was performed. The beams were tested under two-point loading for shear span to depth (a/d) ratios of 0.50 after 28 days of curing. The ratio of effective span to total depth was kept constant at 1.5.

The deep beams were tested using a loading frame with a 1000 kN capacity. The central deflections of the beams and shear strains at different points on beam specimens were both measured using the Imetrum Video Gauge measurement system (VGMS), which has a minimum count of 1.0 micron. M.S. bearing plates with dimensions of 150 mm long, 70 mm wide, and 5 mm thick were used at loading points and at the supports to keep the bearing stress within allowable limits. In accordance with I.S. 516-1959 recommendations, the rate of loading was kept constant at 4 kN/minute. At applied load, the ensuing deformations, initial crack load, and the maximum load for each specimen were all noted.



a) Continuous & more cracks in conventional beam **b) Discontinuous & less cracks in HFRC beam**

Figure 3: Cracks in deep beam less than two point loading

I. Cracking pattern

In the case of a conventional R.C. deep beam, cracks start close to the support of the beam's bottom and move diagonally upward with increasing load toward the loading point and the centre of the shear span (Fig. 4 a). A further rise in loading causes 2-3 cracks to combine, and at the moment of maximum loading, these cracks become continuous and deepen even further. It was seen that the failure was brittle failure.

The first hair fracture that developed in the case of HFRC deep beams was inclined and located close to the midpoint of the shear span along the diagonal joining loading point to support. As the stress increased, the second fracture began in the nearby area as the first crack, but after small interval from the previous crack. The addition of fibres has another benefit, as evidenced by the slow crack propagation rate. Numerous minor discontinuous cracks were seen at intermediate gaps along the diagonal at higher load (Fig.4 b). Due to the addition of fibres to the concrete, the crack width is controlled. Additionally, no concrete spalling was noted, as PP fibres play a key role in preventing spalling. All of the specimens were shear-failed. As a result of improved post-cracking behavior, concrete's greater ductility was also noted.

4. Shear Strength Of Deep Beam

A. First Cracks Stress And Ultimate Stress

For a M 25 conventional concrete deep beam, the initial crack stress was 2.49 MPa, and the shear failure occurred at a stress of 4.16 MPa. For M 25 HFRC deep beams with 1% SF + 0.3% PP + 0.16 GF fibre, the first fracture stress was 3.82 MPa, and the failure occurred in shear at a stress of 7.80 MPa. This shows an average increase of 53.41% in first crack stress and 87.50% in ultimate stress of HFRC deep beams when compared to conventional deep beams.

Table 3: Shear strength of M 25 deep beam, conventional and HFRC with workable fibre mix

Types of beam	Sample No	fibre Percentage			First Crack Stress (MPa) (a)	Ultimate Strength (MPa) (b)	Reserve Strength [(b - a)100]/ a	Avg. Reserve strength	% increase in Reserve strength w.r.t. Standard Deep beams
		SF	PP	GF					
Conventional	S-1	0	0	0	2.71	4.20	54.982	67.08	--
	S-2				2.33	4.15	78.112		
	S-3				2.45	4.12	68.163		
HFRC	H-1	1	0.3	0.16	3.75	7.71	105.60	104.46	55.75
	H-2				3.83	7.83	104.43		
	H-3				3.87	7.87	103.36		

B. Reserve Strength

The reserve strength of deep beams, which measures the post-cracking behavior of deep beams, is the percentage increase in shear stress from the initial crack to the ultimate stress level[10]. Early microcracks and later macrocracks have been successfully bridged by hybrid fibre reinforced concrete [9].

At their highest workable fibre concentration, M 25 HFRC deep beams have a reserve strength gain of 55.75% (Table 3) over conventional M 25 deep beams. Hence, the reserve strength of deep beams has considerably improved when steel, PP, and GF are used in combination with concrete.

By preventing crack propagation and regulating fracture width, PP fibres help steel fibres in enhancing concrete's post-cracking behavior [10]. This is because of their high percent elongation and energy absorption capability. The analysis of the HFRC deep beams' crack pattern reveals that concrete fibres act as crack arrestors by providing pinching strains at the crack tips, delaying the onset of cracks and establishing a state of sluggish crack propagation. The rate of propagation is regulated by PP fibres. Steel fibres with hooked ends increase flexural stiffness, increasing reserve strength.

C. Load Vs Deflection

Figure 4 shows central deflection of deep beam for M25 grade concrete for conventional & HFRC beam for varying load.

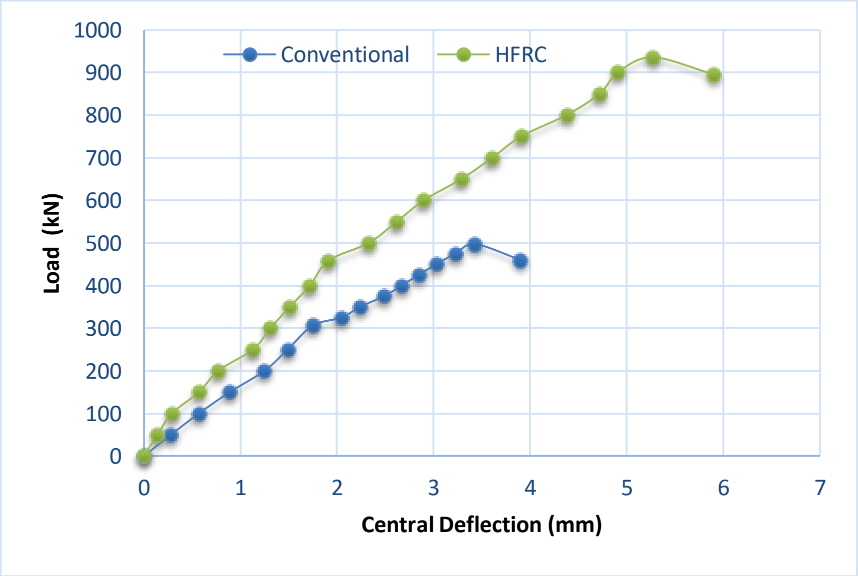


Figure 4: Load vs Central deflection of Conventional and HFRC deep beam

With maximum workable fibre content, the central deflections of M 25 conventional and HFRC deep beams were 0.89 mm and 0.57 mm, respectively, at a design stress of 1.38 MPa, indicating a reduction in central deflection of 34.95%. This is clear from the fact that fibre inclusion increases the stiffness of beams and decreases deflection at the same load level. It is observed that (Fig. 3) area covered by load deflection curve of HFRC deep beam is larger than that of conventional deep beam. This shows that energy absorption is high in HFRC deep beam.

5. Conclusion

Based on study the following conclusions are drawn. The workable mix with maximum fiber content is 1% hooked end steel fibre + 0.3% of polypropylene fibre + 0.16% of glass fibre by volume of concrete. Percentage improvement in different parameters, mentioned below is in comparison with conventional concrete or conventional deep beams.

The inclusion of fibre reinforcement improves the shear strength of HFRC deep beams substantially. For M 25 HFRC, an average improvement of 53.41 % in first crack stress and 87.50 % in ultimate shear stress is observed at workable mix with maximum fiber content when compared with M 25 conventional R.C. deep beams.

Improvement in reserve strength of M25 HFRC deep beams for the workable mix with maximum fiber content is 55.75 % in comparison with M25 conventional deep beams.

Comparing HFRC deep beam with conventional deep beam, there is a 35.95% decrease in centre deflection for the workable mix with maximum fiber content.

It is possible to completely replace conventional shear reinforcement in R.C. deep beams by the addition of 1 % hooked end steel fibres + 0.3% fibrillated polypropylene fibres + 0.16% glass fibres by volume of concrete. It results in an improvement in first crack load, ultimate shear strength, ductility, reserve strength and energy absorb of deep beams while reducing reinforcement congestion.

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