Experimental Study on Hybrid Fiber Reinforced Concrete Deep Beams

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Abstract

Improving and/or altering the characteristics of concrete have been focus of study by many researchers over past few decades. Combination of two or more types of fibers for getting high quality hybrid fiber reinforced concrete (HFRC) is a topic of interest amongst researchers. Use of small, discrete, randomly oriented steel fibers improves the strength and resistance against deformation characteristics of concrete members. Glass fibers improve shear strength, tensile strength, crack resistance, and energy absorption of concrete. This paper presents data obtained from experiments carried by using combination of these two fibers in predefined proportions in the concrete and its effect on strength characteristics of HFRC deep beams. The deep beams cast & cured were tested using 1000 kN capacity loading frame. The two-point loading is applied. During experiment, first crack load, deflection at first crack load and load at permissible deflection of deep beams are recorded. It is observed that, in comparison with conventional deep beams with shear span to depth ratio 0.5, there is improvement of 14% in first crack load and 11% in load at permissible deflection of HFRC deep beams cast with optimum mix containing 0.7% steel fiber and 0.3% glass fiber by volume of concrete. However workability of concrete with steel & glass fiber is observed to be lower than concrete with steel & Polypropylene fiber, whereas the strength acquired is higher by 13% in comparison with steel & PP fiber.

Keywords: *Deep Beam, Steel fiber, Glass fiber, Hybrid fiber reinforced concrete, two points loading.*

I. INTRODUCTION

The behavior of deep beams is significantly different from that of conventional beams, therefore requires special consideration in analysis, design, and detailing of reinforcement. Because of their small span to depth ratio (less than 2), they are likely to have their strength controlled by shear rather than flexure. Conventional shear reinforcement is unable to provide efficient resistance to crack formation under the effect of external loading. This results in low first crack load, low shear strength and brittle failure in deep beams. Many researchers have carried out experiments in past with addition of small, discrete, randomly oriented fibers in concrete to improve strength and post cracking ductility of concrete. Some of the studies reported are as follows.

T.M. Robert et al.[1] experimentally studied shear strength of steel fiber reinforced concrete deep beams and reported that fibers improve shear strength considerably and also failure of deep beams was observed to be ductile in nature. Avinash Gornale et al.[2] carried out experiments on glass fiber reinforced concrete, recorded good amount of increase in compressive strength, flexural strength and split tensile strength due to addition of glass fibers in concrete mix. Dr. Srinivas Rao et al.[3] examined durability of glass fiber reinforced concrete and found that durability of concrete was increased by addition of alkali resistant glass fibers. They also found that addition of glass fibers reduces segregation/bleeding and improves acid resistance of concrete. Kavita Kene et al [4] mentioned that addition of glass fiber along with steel fibers improves compressive and tensile strength of concrete. Suhail Shaikh et.al[5] experimentally found that steel fibers are instrumental in enhancement of first crack load, load at permissible deflection and shear strength of concrete deep beams.

II. OBJECTIVES

The objective of the current research is to find effective alternative to conventional shear reinforcement in deep beams in the form of combined hybrid fiber reinforcement consisting of steel and glass fibers that can improve first crack load and shear strength of deep beams.

Study of literature reveals that generally steel fiber content in the range of 0.5% to 1% by volume of concrete improves strength and deformation characteristics of concrete with insignificant effect on workability. Glass fiber up to 0.3% is efficient in minimization of cracks in concrete. Therefore to study the effect of combination of both fibers in concrete, the steel fiber content considered is 0.5, 0.7, 0.9, 1.1 and 1.3% and for each percentage of steel fiber the glass fiber content taken is 0.1, 0.2 and 0.3% by volume of concrete.

III. EXPERIMENTAL PROGRAM

A. Materials Used for Casting of Deep Beams:

1) Casting of Conventional Deep Beams:

The materials used for concrete are 43 grade ordinary Portland cement conforming to I.S:269:2015, natural sand conforming to zone II of IS: 383:1997, and coarse aggregate of maximum size 20 mm. Fe 500 steel is used as tensile reinforcement as well as shear reinforcement.

2) Casting of HFRC Deep Beams:

For casting of HFRC deep beams, all the materials used are same as in case of conventional deep beams except shear reinforcement, which is replaced completely by hooked end steel fibers and glass fibers. Steel fibers used are of aspect ratio 80 with diameter 0.75 mm and length 60 mm as shown in Image 1 (a). The modulus of elasticity of steel fiber is 200 GPa and tensile strength is 1100 MPa. Alkali resistant glass fiber with modulus of elasticity 72 GPa and average tensile strength of 1700 MPa is used. Glass fibers used are as shown in Image 1 (b).

a) Hooked end steel fibers

b) Glass fibers

Image1: Fibers used

B. Mix proportions:

1) For Conventional Deep Beams:

Design mix of M20 grade concrete is carried out in accordance with IS: 10262:2009. Mix proportion obtained is 1:1.98:3.09 (by weight) with water cement ratio of 0.55.

2) For HFRC deep beams:

Same concrete mix, as mentioned above is used for HFRC deep beams, only change being addition of fibers in HFRC mix.

C. Mixing of Conventional Concrete and HFRC, their Workability and Compressive Strength:

Dry mixing of ingredients for conventional concrete was done. Wet mixing was carried out by adding exact amount of water and uniform mix was obtained. For HFRC uniform addition of fibers was done to avoid balling effect. Slump of each mix was measured using slump cone apparatus. Standard cubes of size 150 x 150 x 150 mm were cast from each mix. After casting the specimens were kept under 90% humidity for 24 hours, then moulds were removed and specimens were immersed under water in a curing basin. After 28 days of curing, cubes were tested in Compression testing machine. The various proportions of fibers taken, their workability and compressive strength of cubes are as shown in Table No.1 below.

Table 1: Variation in Slump and Compressive Strength of Concrete with Addition of Fibers:

Type of Concrete	Steel fiber %	Glass fiber %	Slump (mm)	Percentage drop in slump compared to conventional concrete (%)	Permissible slump as per IS:456 (2000) for medium workability (mm)	Compressive strength of cubes (MPa)	% increase in compressive strength in comparison with conventional concrete.
Conventional concrete	--	--	98	--	75-100	26.91	--
Hybrid Fibre Reinforced concrete	0.5	0.1	93	5.10		27.55	2.32
		0.2	92	6.12		28.10	4.32
		0.3	88	10.2		28.22	4.75
	0.7	0.1	83	15.3		28.11	4.36
		0.2	81	17.3		28.27	4.94
		0.3	79	19.4		29.05	7.77
	0.9	0.1	74	24.5		28.34	5.19
		0.2	73	25.5		29.15	8.13
		0.3	72	28.6		30.10	11.6
	1.1	0.1	72	29.6		29.45	9.22
		0.2	70	26.5		29.85	10.7
		0.3	69	28.6		30.11	11.6
	1.3	0.1	69	27.6		29.44	9.18
		0.2	68	29.6		29.85	10.7
		0.3	68	30.6		30.86	14.3

***Workability**:* In comparison with conventional concrete, there is a drop in slump of 5.1% for minimum fiber content i.e. combined 0.5% steel and 0.1% glass fiber content. For the same steel fiber content, when glass fiber content was increased to 0.2 % & 0.3 %, slump drop was observed to the extent of 6.12 % & 10.2% respectively in comparison with conventional concrete. This indicates that workability of concrete decreases with increase in glass fiber content .When steel fiber content is 0.7% along with glass fiber content 0.1%, the slump drop observed is @ 15.3% in comparison with conventional concrete. This shows that the increase in steel fiber also causes decrease in workability of concrete. Same trend is observed in case of 0.9, 1.1 & 1.3 % steel fiber content combined with 0.1, 0.2 & 0.3% glass fiber content as presented in Table 1 & Fig.1.

It can be observed from Table no. 1 that the mix with 0.7% steel and 0.3% glass is having the slump of 79 mm (>75 mm) within permissible limit, as per I.S. 456-2000. With further increase in steel and glass fiber content, the slump of mix drops beyond permissible limit. Therefore the mix with 0.7% steel and 0.3% glass fiber can be termed as optimum mix. All mixes with percentage of steel fiber higher than 0.7 for any percentage of glass fiber are non workable mix.

Fig.1 shows variation in slump of M 20 mix with variation in percentage of fibers. Clearly it can be observed that increase in steel as well as glass fiber content leads to reduction in workability of mix. Steel and glass fibers, both are metallic fibers having higher modulus of elasticity than matrix. This leads to reduction of slump value.

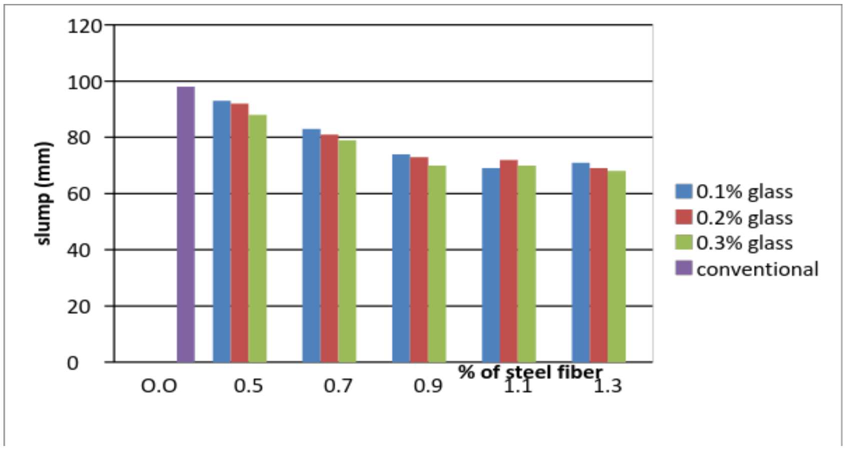

Fig.1.Variation in Slump Value Of M20 Concrete Mix with Different Fiber Percentages.

D. Compressive strength of concrete cubes:

The compressive strength of HFRC is observed to increase by 2.32 % with addition of minimum fiber content i.e. combined 0.5% steel and 0.1% glass fiber as compared to conventional concrete. For the same steel fiber content, when glass fiber content was increased to 0.2% & 0.3%, the increase in compressive strength observed was by 4.32% and 4.75% respectively. This indicates that the compressive strength of concrete increases only marginally with increase in glass fiber content. When steel fiber content is 0.7% and glass fiber content 0.3%, compressive strength of concrete is observed to be 7.77% more than conventional concrete. Further it is observed that there is increase in compressive strength of concrete with 0.9%, 1.1% and 1.3% steel fiber content along with glass fiber content from 0.1% to 0.3%, however they are not acceptable on the basis of workability requirement criterion.

E. Design of Deep Beams:

Deep beams are designed as per IS 456:2000. The loading considered for design is two point loads of 75 kN each. Shear spans to depth ratio considered is 0.50. Reinforcement used for conventional and HFRC deep beam is as shown in Figure 2 (a) and (b) respectively. Conventional shear reinforcement is completely eliminated (Figure 2 b) for HFRC deep beams, and is replaced by combination of steel fibers (0.5% to 1.3% by volume of concrete) and glass fibers (0.1% to 0.3% by volume of concrete) as presented in Table No.1.

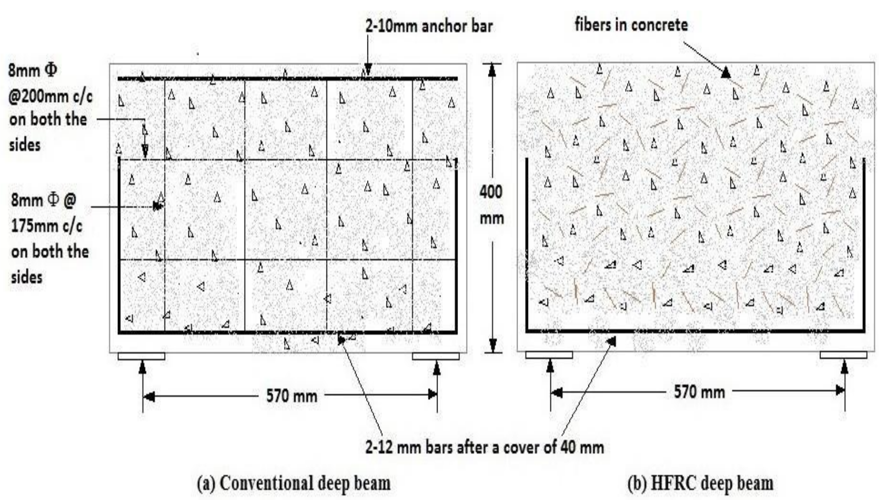

Figure 2: Reinforcement Details of Deep Beam.

F. Test Specimen, Casting and Curing Procedures:

A total of forty eight HFRC deep beams having length 700 mm, height 400 mm and thickness 150 mm were cast. For comparison purpose, 03 nos. of conventional deep beams of same dimensions were also cast. After casting, all the specimens were kept under 90% humidity for 24 hours, then formwork was removed and specimens were cured in a curing basin for 28 days.

G. Flexural Testing of beams:

The experimental setup is shown in Image 2. Beams were tested using loading frame of capacity 1000 kN. Initial arrangements of supports and loading points were checked to confirm design requirements. Bearing plates were placed on roller supports over which the beam is positioned. Initiation was made by checking dial gauge reading. In order to avoid failure at supports and loading points the bearing plates were provided to transfer the point load into pressure on specimen. For a given thickness, the area of bearing plate required is determined by considering the permissible bearing stress in concrete. The rate of loading was 400kg/min as per IS 516:1959. Deflection of beam was observed using dial gauge for each load interval of 50 kN. The first-crack load and ultimate load were observed as presented in Table 2.

Image 2: Experimental Set Up

IV. TEST RESULTS

Shear strength and behavior of deep beams:

The observations of first crack load, ultimate crack load and deflection are recorded as shown in Table 2 below. It can be observed that there is consistent increase in first crack load with increase in percentages of fibers.

Table 2. Details Of Reinforcement Type, Fiber Percentage, First Crack Load, Ultimate Load, and Deflections for Deep Beams With Shear Span to Depth Ratio 0.50

Type of shear reinforcement in beams	% of fiber by volume of concrete		First crack load (kN)	Deflection at first crack load (mm)	Permissible deflection as per IS 456 (mm)	Load at permissible deflection (kN)
	Steel	Glass				
Conventional	--	--	340	1.80	2.28	380
Hybrid fiber reinforced	0.5	0.1	350	1.62		400
		0.2	365	1.67		410
		0.3	370	1.75		415
	0.7	0.1	380	1.72		420
		0.2	385	1.76		423
		0.3	390	1.79		425
	0.9	0.1	385	1.84		435
		0.2	395	1.88		440
		0.3	400	1.90		465
	1.1	0.1	405	1.86		480
		0.2	410	1.93		490
		0.3	420	1.96		505
	1.3	0.1	425	2.01		510
		0.2	430	2.07		515
		0.3	450	2.11		520

V. DISCUSSION ON TEST RESULTS:

A. Conventional deep beams:

i) First crack initiated at a load, which was 89 % of load at permissible deflection (as shown in Table No. 2). It originated in shear zone near the support and with further increase in load the crack propagated towards the loading point. The failure of beams observed was in shear mode.

B. Hybrid Fiber reinforced deep beams:

Effect of fiber inclusion: The load at first crack of beams is observed to increase with increase in percentage of fibers. First crack initiated at a load, which is 85% of load at permissible deflection for HFRC beams (as presented in Table No. 2). Crack originated in shear zone near support and with further increase of load, new cracks developed and propagated in the direction towards the loading point. Majority of the beams failed in shear mode. Consistent improvement in first crack load and ultimate load was observed with increase in percentage of fibers. For lower fiber content of 0.5% steel and 0.1% glass fiber, the improvement in initial crack load and load at permissible deflection for HFRC beams in comparison with conventional beams was observed to be 3% and 5 % respectively. Whereas for steel fiber content of 0.7% steel and 0.3% glass fiber, improvement was found to be 14% and 11% respectively.

At permissible deflection (as per I.S. 456 for conventional beams), HFRC beams showed 11% more shear strength than conventional deep beams for combined 0.7% steel and 0.3 % glass fiber. This shows improved ductility and post cracking behavior of beams due to inclusion of fibers.

It shows consistent improvement in load carrying capacity of beams with increase in fiber content. Even though for steel fiber contents of 0.9%, 1.1% & 1.3%, improvement in load carrying capacity are observed, but still they are not workable concrete mixes, therefore cannot be practiced.

C. Comparison between workability of mix & strength of deep beams with steel + PP fibers and Steel + Glass fibers:

Previous research has shown that combination steel fibers and polypropylene (PP) fibers can replace conventional shear reinforcement in deep beams. In case of concrete mix with steel and Polypropylene (PP) fibers, it was observed that PP fiber helps in improvement of slump value[5]. PP fiber being a non metallic fiber, having very less modulus of elasticity than matrix and least density in all synthetic fibers, helps in improvement of slump of concrete, due to good cohesion &mix ability of PP fiber with concrete, whereas adhesiveness of glass fibers with concrete, adversely affects the workability of concrete. Steel and glass fibers both are having higher modulus of elasticity than matrix; hence, workability gets reduced even at lower percentage of fibers.

Table 3 shows, comparison between results with Steel fiber + Glass fiber and Steel fiber +PP fiber in R.C. Deep beams. When Optimum mixes are compared, first crack load of Steel and Glass (0.7%steel + 0.3% Glass) fiber concrete is more than Steel and PP (0.9% Steel + 0.3% PP) fiber by 13%. In addition, it is observed that load at permissible deflection of optimum mix of steel + Glass fiber concrete is more by 4% than that of Steel + PP fiber mix.

Table 3: Comparison Between Results with Steel Fiber + Glass Fiber and Steel Fiber +PP Fiber in R.C. Deep Beams.

Type of shear reinforcement in beams	% of fiber by volume of concrete		Slump (mm)	Slump (mm)	First crack load (kN)	First crack load (kN)	Deflection at first crack load (mm)	Deflection at first crack load (mm)	Permissible deflection as per IS 456 (mm)	Load at permissible deflection (kN)	Load at permissible Deflection (kN)
	Steel	Glass/PP	Steel+ Glass	Steel+ PP	Steel+ Glass	Steel+ PP	Steel+ Glass	Steel+ PP		Steel+ Glass	Steel+ PP
Conventional	--	--	98	96	340	310	2.27	2.27	2.28	380	340
Hybrid fiber reinforce	0.5	0.1	93	93	350	300	2.14	2.14		380	340
		0.2	92	94	365	310	2.15	2.15		410	345
		0.3	88	94	370	320	2.15	2.15		415	355
	0.7	0.1	83	80	380	320	2.16	2.16		420	355
		0.2	81	81	385	325	2.09	2.09		425	370
		0.3	79	83	390	330	2.11	2.11		425	375
		0.1	74	74	385	330	2.06	2.06		435	380

	0.9	0.2	73	76	395	340	2.07	2.07		440	385
		0.3	72	77	400	345	2.08	2.08		465	405

VI. CONCLUSIONS

The conclusions have been arrived at based on the general observations, experimental results, analytical results and comparison of results of analytical with experimental. The conclusions based on workability, strength, deflection and failure mode are as follows:

- The optimum mix for HFRC deep beams, based on workability, compressive strength of mix and shear strength of deep beams, is a mix with 0.7 % steel and 0.3% glass fibre content.
- There is reduction in workability of concrete mix with increase in percentage of steel fiber and glass fibers. In comparison with concrete for conventional deep beams, there is reduction in workability by 5 % in beams with lower fiber content (i.e.0.5 % steel and 0.1% glass) and by 19.4% in beams with optimum mix.
- Compressive strength of HFRC cubes increases with increase in fibre content. In comparison with conventional concrete, the improvement in compressive strength of HFRC mix was 2.32% at lower fiber content, whereas this increment was 7.77% for optimum mix.
- First crack load and load at permissible deflection of HFRC deep beams increases with increase in fibre content. In comparison with conventional deep beams, increment of 14% in first crack load and 11 % in load at permissible deflection is observed for beams with optimum mix.
- Polypropylene (PP) fiber helps in improvement of workability of concrete due to its good mix ability property. Whereas Steel and Glass fiber reduces workability of concrete. On the other hand, strength of HFRC deep beams with optimum mix using steel and glass fibers is 4% more than that with beams using steel and PP fibers.

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