STUDY ON HYBRID FIBRE REINFORCED CONCRETE BEAMS WITH EXTERNAL FRP LAMINATES

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Abstract - *A worldwide use of high strength concrete during the last decade and an expansion in the material technology has made it possible to design concrete having superior mechanical properties and structural behavior. Whilst use of high strength concrete has accelerated, the progress in the development of revised design standards has not progressed at the same rate. Acceleration is due to its enhanced mechanical properties and better structural performance as compared to Normal Strength Concrete. Also High Strength Concrete offers economy and superior performance in terms of strength and long-term behavior.*

The objective of this research work is to evaluate the static response of hybrid fibre reinforced concrete beams with externally bonded GFRP laminates. Two different Glass Fibre Reinforced Polymer (GFRP) types with different thickness in each type were used. The variables considered for the study included type of GFRP laminate and thickness of GFRP laminate. The beams were 150 mm x 250 mm in crosssection and 3000 mm long. The beams were tested in four-point bending over a simple span of 2800 mm. Sufficient data will be obtained on the strength, deformation, fatigue life and failure characteristics of hybrid fibre reinforced concrete beams with GFRP laminates as well as hybrid fibre reinforced concrete beams.

In addition to probing the basic properties of concrete, the present research investigation addresses three major concerns. The first is to explore the possibility of using FRP for improving the performance of hybrid fibre reinforced concrete beams. The second is to examine the enhancement in strength and deformation capacities of hybrid fibre reinforced concrete beams. The third is to evaluate the ductility of hybrid fibre reinforced concrete beams subjected to static loading conditions.

Key Words: hybrid fibre reinforced concrete, static loading conditions, GFRP laminates

1. INTRODUCTION

Need for the study on hybrid fibre reinforced concrete

Fibre reinforced concrete used in practice is mostly with mono fibre system which provides limited enhancement of property. It has been shown recently that by using the concept of hybridization with two different fibres incorporated in a cement concrete, the composite can offer more attractive engineering properties because the presence of one fibre enables more efficient utilization of the potential properties of the other fibres.

Applications of Hybrid Fibre Composites

a) HYFRC composites have high ductility, greater toughness and improved tensile strength and therefore these are very well useful at Beam-Column joints in reinforced concrete structures.

b) Use of high strength concrete with hybrid fibre reinforcement in beam-column joints increases the joint stiffness.

c) HYFRC have greater fracture toughness and therefore they are very much useful in slab-on-grade such as driveways, ware house floors, industrial floors, gauage floors, taxiway on airports and runways subject to heavy traffic and abrasion.

d) Use of High Strength Concrete with micro-reinforcements can be designed to resist structural stress normally found in pre-cast/tilt up applications.

e) Improved shear resistance, impact resistance and energy absorption capacity of HYFRC making them potentially useful in concrete piles, machine foundations earthquake resistant structures, blast resistant structures etc.

2. EXPERIMENTAL PROGRAMME

2.1 PRELIMINARY STUDY

2.1.1 GENERAL

A preliminary study was conducted to identify the optimum fibre volume fraction. For this study, 36 cubes, 36 cylinders and 36 prisms were cast and tested. The variable considered for the study included the hybrid fibre (Steel fibre-80% and Polyolefin fibre20%) volume fraction (0.5%, 1% and 1.5%).

2.1.2 DETAILS OF TEST SPECIMENS

150 x 150 x 150 mm cubes were used for determining the compressive strength of hybrid fibre reinforced concrete. 150

x 300 mm cylinders were used for determining the static modulus of elasticity. 100 x 100 x 500 mm prisms were used to determine the modulus of rupture.

2.1.3 MATERIALS

Ordinary Portland cement 53 Grade was used for all mixes. Fine aggregate used was river sand with a specific gravity of 2.64 and conforming to grading zone II of IS 383-1970 specification. Silica fume with a specific gravity of 2.2 was used as a micro-filler. The coarse aggregate used was crushed granite with a specific gravity of 2.79 and passing through 20mm sieve and retained on 12.5mm. To ensure better workability, a hyper plasticizer (BASF Master Gelinium SKY 8233 Chemicals) was used. Steel fibres having an aspect ratio 80 and polyolefin fibre having an aspect ratio 39.34 were used in the study. Concrete having a compressive strength of 66.1MPa was used. The designed mix proportion was 1:1.73:2.51 with a water-cement ratio of 0.36. For concrete with fibres, hyperplastizer was used in appropriate dosage to maintain a slump of about 100 mm. The mix details are presented in Table 1.

Table -1: Mix details of the fibre

Cement	Silica fume	Fine aggregate	Coarse aggregate	Water
450 kg/m³	25 kg/m³	780 kg/m³	20 mm – 680 kg/m³ 12 mm – 450 kg/m³	160 lit/m³

Steel fibres and non-metallic polyolefin fibres were used in this investigation. The steel fibres were with hooked ends. The Polyolefin fibres were straight. The physical and mechanical properties of both the fibres are presented in Table 2.

Table -2: Physical and Mechanical properties of the fibres

S.No	Fibre properties	Fibre Type	
		Steel	Polyolefin
1	Length	60	54
2	Size/Diameter	0.75 mm dia	1.22x0.732
3	Aspect Ratio	80	39.34
4	Density	7850	920
5	Specific Gravity(GPa)	-	10
6	Young's Modulus(GPa)	210	10
7	Tensile strength(MPa)	1225	640
8	Shape	Hooked at ends	Straight

2.1.4 PREPARATION OF CONTROL SPECIMENS

A tilting type drum mixer was used for mixing fresh concrete. The cement, sand and coarse aggregate were placed inside the drum and then dry mixed. To this dry mixture, 80% of water and 0.80% of hyperplastizer (BASF Master Gelinium SKY 8233 Chemicals) were added slowly and mixed thoroughly. Fibres were then added slowly and evenly along the walls of the drum to avoid formation of fibre balls and clustering. The remaining water and hyperplastizer were added slowly and then mixed thoroughly. The specimens were cast in batches, each batch consisting of three prisms, three cylinders and three cubes. The specimens were cast in steel moulds and vibrated using a vibrating table. All the specimens were de-moulded after 24 hours of casting and then cured for 28-days before being tested.

3. TEST RESULTS AND DISCUSSION

The significant influence of adding fibres in concrete is to delay and control the initiation and propagation of tensile cracking of the composite material. The strengthening mechanism of fibres involves transfer of stress from concrete to the fibre by interfacial shear or by interlocking between the fibre and matrix. The fibre and the matrix share the tensile stress until the matrix cracks and then the stress is transferred to the fibres. This change in the mechanism of failure causes significant improvement in ductility, toughness, impact resistance, shrinkage, fatigue life and durability of composite matrix.

3.1 Effect on Compressive Strength

From the test results, it can be observed that the hybrid fibre (80% steel fibre and 20% Polyolefin fibre) reinforced concrete exhibits an increase in compressive strength with 1% fibre volume fraction. The compressive strength for test specimens with and without fibres is shown in Fig. The increase in compressive strength of hybrid fibre reinforced concrete ranged from 4.77% to 14.11% at volume fractions ranging over 0.5% to 1.5% compared to control concrete at the age of 28 days. From the obtained results, it can be inferred that 1% fibre volume fraction gives optimum results.

Table-3: Compressive strength values for 7, 14and 28days

Specimen Designation	Average Cube Compressive Strength in MPa		
	Age of Curing in Days		
	7-Days	14-Days	28-Days
HF 0%	37.44	48	66.1
HF 0.5%	39.21	50.22	69.25
HF 1%	42.17	53.25	75.43
HF 1.5%	40.30	51.25	71.25

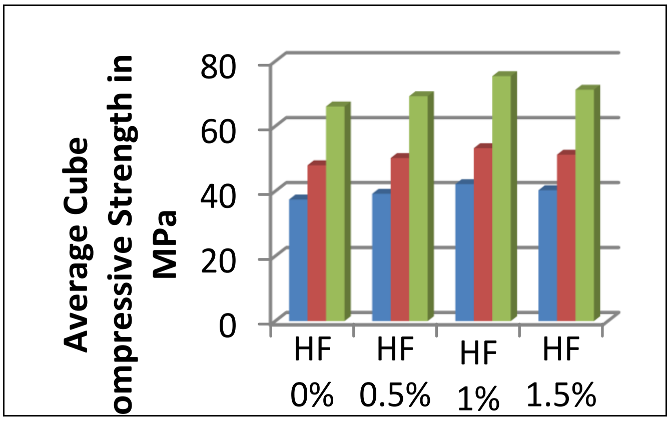

Figure-1: Compressive strength graph

3.2 Effect on Modulus of Elasticity

There was significant improvement in modulus of elasticity of high strength concrete by the incorporation of hybrid fibres (80% of steel fibre and 20% of polyolefin fibre) as shown in Table . The increase in modulus of elasticity of hybrid fibre reinforced concrete ranged from 8.00% to 18.74% at fibre volume fractions ranging over 0.5% to 1.5% compared to control concrete at the age of 28 days. The increase in elasticity modulus slightly increased the flexural rigidity of concrete. The modulus of elasticity of concrete with and without fibres is shown in Fig.2

Table-4: Modulus of Elasticity values for 7, 14 and 28 days

Specimen Designation	Modulus of Elasticity in GPa		
	Age of Curing in Days		
	7-Days	14-Days	28-Days
HF 0%	30.65	35.62	41.25
HF 0.5%	32.45	37.85	44.55
HF 1%	34.68	39.65	48.98
HF 1.5%	33.75	38.78	46.85

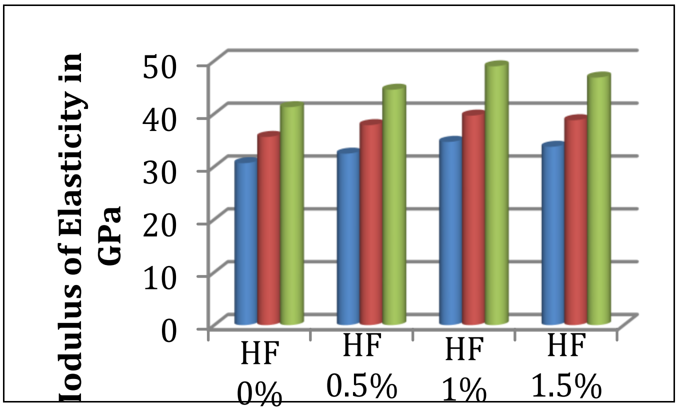

Figure-2: Modulus of Elasticity graph

3.3 Effect on Modulus of Rupture

The results presented in Table indicate that modulus of rupture for fibrous concrete was significantly higher than that of control concrete even at volume fraction as low as 0.5%. The improvement in flexural strength of hybrid fibre reinforced high strength concrete at various fibre volume fractions is shown in Fig. The improvement in flexural strength varied from 41.13 % to 114.18% at fibre volume fractions ranging over 0.5 % to 1.5% compared to control concrete at the age of 28 days. From the obtained results it can be inferred that 1% fibre volume fraction gives optimum result.

Table-5: Modulus of Rigidity

Specimen Designation	Modulus of Rigidity in MPa		
	Age of Curing in Days		
	7-Days	14-Days	28-Days
HF 0%	2.80	4.60	7.05
HF 0.5%	3.90	6.37	9.95
HF 1%	5.10	8.50	15.10
HF 1.5%	4.20	7.05	12.10

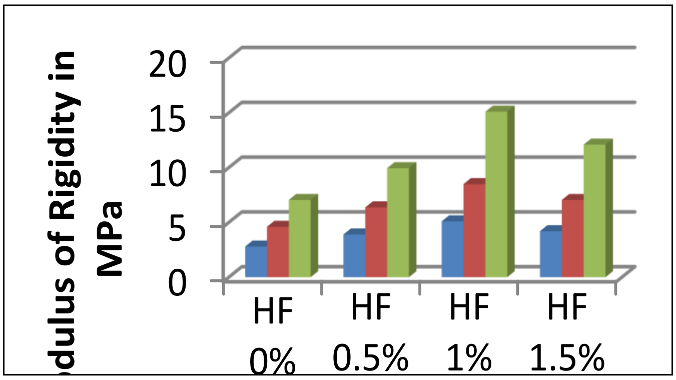

Figure-3: Modulus of Rigidity

From the test results furnished in Tables 4.1 to 4.3, it can be observed that the hybrid fibre (80% of steel fibre and 20% of polyolefin fibre) reinforced high strength concrete exhibits an increase in compressive strength, elasticity modulus and modulus of rupture at different fibre volume fraction. From these results, it can be concluded that the 1% fibre volume fraction gives optimum results.

3.4 Effect of GFRP Plating on Strength

A total of 4 rectangular beams were cast for the present research work. The beams were 150 mm x 250 mm in cross-section and 3000 mm long. The beams were tested in fourpoint bending over a simple span of 2800 mm. Longitudinal steel ratio adopted for the beam specimen was 0.603%. 2 numbers of 12mm diameter bars were used for tension reinforcement and 2 numbers of 10 mm diameter bars were used as hanger bars. 2-legged 8 mm diameter stirrups were provided at 125 mm c/c, in order to avoid any shear failure and ensure flexural action of beams up to failure.

Of the above 4 beams, 1 beam served as baseline specimen, 1 beams were cast with 1% fibre volume fraction, 2 beams were cast with a total fibre volume fraction of 1% and strengthened with GFRP laminate in a virgin condition. The variables considered for the study included type of GFRP laminate and thickness of GFRP laminates.

Figure -4: Placing of Laminate over the Beam Soffit

The static test results of experimental investigation carried out on 4 beams which included the control beam (CB), hybrid fibre (80% of steel fibre and 20% of polyolefin fibre) reinforced concrete beams (HF) and GFRP strengthened hybrid fibre reinforced concrete beams (HFC3-3mm Chopped Strand Mat, HFC5-5mm Chopped Strand Mat, are presented and discussed.

The loads carried by all the test beams at first crack stage, yield stage and ultimate stage were obtained experimentally. The first crack loads were obtained by visual examination. The yield loads were obtained (by inspection) corresponding to the stage of loading beyond which the loaddeflection response was not linear. The ultimate loads were obtained corresponding to the stage of loading beyond which the beam would not sustain additional deformation at the same load intensity.

Table-6: Strength of the beam

Sl.No	Beam Designation	First Crack Load (kN)	Yield Load (kN)	Ultimate Load (kN)
1	CB	50	65	105
2	HF	55	100	160
3	HFC3	60	105	165
4	HFC5	70	110	180

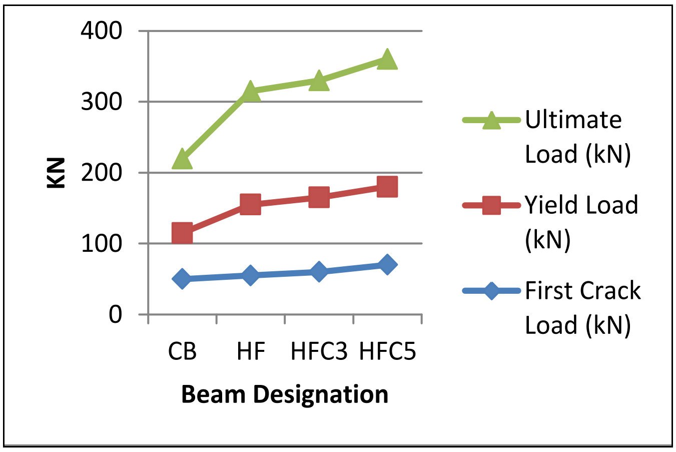

Figure-5

4. CONCLUSIONS

The epoxy bonding of GFRP laminates offers an attractive means of strengthening HFRC beams in flexure. Based on the results obtained from laboratory experiments the following conclusions are drawn.

GFRP lamination has contributed to the increase in the load-carrying capacity at frst crack, yield and ultimate stages of a RC beam than the 'control beam' (that is un-laminated RC beam).

There is a combined effect of lamination and inclusion of hybrid fbres, in contributing to the very high load-carrying capacity and enhanced ductility of laminated HFRC beam, especially, a fibre volume content of 1%,with the ratio of 80:20 (steel: polyolefn). The above unique advantages can be used for structural applications, where, both load carrying capacity and ductility are required.

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