

# Experimental and Analytical Studies on the Flexural Behaviour of Hybrid Fiber Reinforced Concrete

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**ABSTRACT:** An experimental investigation was conducted to study the flexural behaviour of hybrid fiber reinforced concrete. The grade of concrete was M25. Hooked end steel fibers and polyester (Recron 3S) fibers were used for the study. The total volume of fibers was fixed as 0.5% of total volume of concrete. Six concrete mixes were selected for preliminary studies. Which include control mix without fibers, steel fiber reinforced concrete (SFRC) with 0.5% steel fibers and four hybrid fiber reinforced (HFRC) concrete of steel and polyester fibers with total volume fraction as 0.5%. From the mechanical properties such as flexure strength, split tensile strength and modulus of elasticity, the optimum HFRC was obtained as HFRC3(0.35% steel + 0.15% polyester). A total of six beam specimens (100x150x750mm) were cast and tested under two point loading. Out of these two were made of NC, two were with 0.5% SFRC and remainder were with optimum HFRC. Modelling of these beams were carried out using ANSYS 16.1 software. Finally the experimental results were compared with the analytical one. The combination of 0.35% steel fibers and 0.15% polyester fibers showed better performance than NC and SFRC. The analytical results were found to be in good agreement with experimental one.

**KEYWORDS:** Steel fibers, Polyester fiber, Hybrid fiber reinforced concrete, Flexural behaviour

## I. INTRODUCTION

Concrete containing hydraulic cement, water, fine and coarse aggregate and discontinuous discrete steel fibers is called Steel Fiber Reinforced Concrete (SFRC). Fibers of various shapes and sizes produced from steel are being used. Steel fibers are the most commonly used fiber in structural and non-structural applications. The behavior of concrete under post cracking can be improved by the incorporation of steel fiber in concrete. Although in the fiber reinforced concrete the ultimate tensile strength do not increase appreciably, but the tensile strain increases at failure points. Compared to plain concrete, steel fiber- reinforced concrete is much tougher and more resistant to impact.[1].

The development of micro cracks leads to the corrosion of reinforcement thereby results in the failure of concrete. The micro cracks are invisible to the naked eye and formed due to the stresses developed during shrinkage and by static and low energy impact loading. By using polyester fiber as a secondary reinforcement material, the micro cracks can be arrested to a great extent. The introduction of polyester fiber in concrete mix substantially reduces the shrinkage stresses of structural members.[2].

Hybrid Fiber Reinforced Concrete (HFRC) is a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. In HFRC, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. The hybrid combination of metallic and non-metallic fibers can offer potential advantages in improving the properties of concrete.[3] The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance.

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## II. RELATED WORK

**Priya and Urmila** (2015) conducted a study on the effect of recron 3s fibers on Ground Granulated Blast Furnace Slag (GGBFS) replaced cement concrete. Their primary objective was to evaluate effective use of pozzalanic materials with fiber to achieve the desire needs for M30 grade concrete. Recron fiber in different percentages i.e. 0, 0.1, 0.2 and 0.3% to the weight of concrete was used. For each fiber concentration GGBFS was varied at 10, 20, 30 and 40% to study the effect of GGBFS replacement. Their major findings include, the replacement of cement by GGBFS decreases the compressive strength. Satisfactory results are obtained with 20% to 30% replacement of GGBFS. Finally they conclude that 0.2% Recron fiber and 20% to 30% GGBS is the optimum combination to achieve the desired need. [4].

**Maniram et al.** (2014) conducted a study on the strength evaluation of steel-nylon hybrid fiber reinforced concrete of M25 grade concrete. The total volume of fiber was taken 0.5 %. Four different mix combinations of steel- nylon 6 fibers were 100-00%, 75-25%, 50-50% and 25-75% selected for the study. They found that for the nylon 6 fibers, adding more fibers into the concrete has a limited improvement on splitting tensile strength and the inclusion of nylon 6 fibers along with steel fibers results in considerable improvement in flexural strength. [5].

**Tamilselvan et al.** (2017) investigated the flexural behavior of hybrid fiber reinforced concrete beam with M30 grade concrete. The steel and Polypropylene (PP) fibers are used in different proportions with 0.5% of volume of concrete. By adding The hybrid fibers various proportions are 33:67, 50:50 and 67:33 for the volume fraction is 0.5% of volume of concrete were used in the concrete mixes. Their major findings include, the compressive strength of hybrid fiber reinforced concrete containing ST0.33PP0.17 is 12-15% higher than the FRC. The final result concluded is that by adding of hybrid fibers increase the mechanical properties of concrete than the fiber concrete. [6]

## III. SCOPE OF THE PRESENT INVESTIGATION

The main objective of this research is to conduct an experimental and analytical (nonlinear FE analysis) investigation on the flexural behaviour of hybrid fibre reinforced concrete to that of normal strength and 0.5% steel fiber reinforced concrete beam specimens. The first stage of the work aimed at fixing the optimum hybrid fiber combination. Then the concrete beam specimens of size 100x150x750mm were cast and tested under two point loading. The results were analysed in terms of load deflection behaviour, first crack and ultimate load, deformation, energy absorption, ductility index, and crack pattern. Modelling of the beams were done using software ANSYS 16.1, Then experimental analysis has been compared with the analytical analysis, which was done using the software ANSYS 16.1.

## IV. EXPERIMENTAL PROGRAMME

The preliminary studies involve the comparative study of effect of steel fibers and hybrid (steel and polyester fibers) on compressive, split tensile, flexural strength and modulus of elasticity of M25 grade concrete at 28 days of curing. Six mixes were selected for preliminary studies. Which include control mix without fibers, steel fiber reinforced concrete (SFRC) with 0.5% steel fibers and four hybrid fiber reinforced (HFRC) concrete of steel and polyester fibers with total volume fraction as 0.5%. Designation of mixes is shown in Table 1. After finalising the optimum Hybrid combination, the flexural behaviour were studied by casting and testing 6 reinforced concrete beams of size 100x150x750 mm. Two numbers of specimens for each mix; Normal concrete, SFRC and HFRC.

Table 1 Mix designation

Sl. No.	Designation	Steel Fiber (%)	Recron3S Fiber (%)
1	NC	0	0
2	SFRC	100	0
3	HFRC 1	90	10
4	HFRC 2	80	20
5	HFRC 3	70	30
6	HFRC 4	60	40

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## A. Material used

Ordinary Portland cement (OPC) conforming to IS: 12269 [7], M sand with a specific gravity of 2.47 conforming to Grading Zone III of IS 383: 1970 (Reaffirmed 2002) [8], and coarse aggregate having a maximum size of 20 mm with a specific gravity of 2.74 were used for the investigation. Hooked End Steel fibres and Recron 3S polyester fibres used for this study are shown in Fig 1(a) and Fig 1(b), and their properties are given in Table 2. In this study as per IS: 9103-1999 [9] Conplast SP430 with specific gravity 1.22 was used as super plasticizer to obtain required workability.



Fig.1 Fibres used, (a) Hooked End Steel fibres (b) Recron 3S polyester fibres

Table 2 Properties of fibers

Property	Polyester fiber	Hooked end steel fibres
Length (mm)	12	30
Equivalent Diameter (mm)	0.036	0.6
Aspect ratio	334	50
Tensile strength (MPa)	400-600	1100

## B. Mix proportions

Mix designs for M25 grade concrete was done as per IS 10262-2009. After five trials final mix proportion was found out. The same mixture proportions were used for all the specimens. The addition of fibres reduced the workability of concrete and the dosages of super plasticizer were adjusted to maintain the workability. The mix proportion details are given in Table 2.

Table 2 Mix proportion

Mix ratio				
Cement	Fine aggregate	Coarse aggregate	w/c ratio	Super plasticizer
383.13 kg/m <sup>3</sup>	736.69 kg/m <sup>3</sup>	1113.34 kg/m <sup>3</sup>	0.45 kg/m <sup>3</sup>	3.83kg/m <sup>3</sup>

## C. Experimental procedure

The mechanical properties obtained from the study were tabulated in Table 3. From the mechanical properties such as split tensile strength, modulus of rupture and modulus of elasticity, it was clear that the optimum hybrid fiber combination is HFR3 with 0.35% steel and 0.15% polyester fibers. Beams of size 100mm x 150mm x 750 mm were cast and tested in flexure under a universal testing machine of capacity 600kN. Three sets of 2 beam specimens were prepared by providing same reinforcement throughout. First set was prepared without using any fiber, second set was prepared with 0.5% steel fiber content and third set will be with optimum hybrid fiber content (0.35% steel +0.15% polyester) which have been selected in the preliminary studies.

All of the beams were designed as singly reinforced under reinforced sections. The beams were reinforced with two numbers of 8mm  $\phi$  bars at bottom and two numbers of 6mm  $\phi$  bars at top as stirrup holders. Stirrups of 6mm  $\phi$  bars were provided at a spacing of 80mm. Fig. 2 shows the prepared specimens and; Fig. 3 shows the test setup. Two dial

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gauges were used to measure the deflections at two loading points i.e., at one-third of effective span. One LVDT was used to measure central deflections.

Table 3 Mechanical properties

Mix designation	Compressive strength (N/mm <sup>2</sup> )	Split tensile strength (N/mm <sup>2</sup> )	Flexural strength (N/mm <sup>2</sup> )	Modulus of elasticity (N/mm <sup>2</sup> )
NC	29.78	2.18	4.64	19249.82
SFRC	33.11	3.44	5.68	24062.28
HFRC1	32.22	3.26	5.88	23779.19
HFRC2	32.11	3.33	6.00	23779.19
HFRC3	32.44	3.55	6.30	24534.09
HFRC4	32.67	3.41	6.04	22646.85



Fig. 2 Prepared specimens



Fig. 3 Test setup

## D. Crack Pattern and Failure

The crack patterns of beams after failure were marked and shown in the Fig 5. It was observed that for NCF1 beam specimen, the first crack developed in the flexural span. As the load increased further along with the additional flexural cracks, diagonal cracks are also developed in the shear span. Further increase of load caused the widening of cracks already formed and beams failed under flexure. In case of steel fiber reinforced specimens (SFRCF) large number of finer cracks were developed the crack propagation rate was found to be less than that of normal concrete specimens. This was due to ability of steel fibers in restricting the propagation of cracks. The width of these cracks was found to be less than that of normal concrete specimens without fibers for the same loading range.



Fig. 5 Crack pattern of specimens

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In HFRCF specimens the crack initiation and propagation was delayed. The cracks were observed to be finer and the number of cracks will be more than that of normal concrete. This was due to the reason that the developments of major cracks are controlled by the synergetic bridging activity of polyester and steel fiber. It was observed that, once the fiber matrix bond breaks, the rate of crack propagation increases till the ultimate load was reached.

## V. EXPERIMENTAL RESULT ANALYSIS

### A. Load-Deflection Graph

Load deflection graph was plotted using LVDT readings placed at mid span and dial gauge readings at L/3 from support of RC beam specimens. Load-mid span deflection curves for normal concrete, mono and hybrid fiber reinforced specimens were shown in Fig. 4. For all the beam specimens the load deflection curve shows linearity up to first crack load. The curves deviate from the linearity on further increment of load. This was due to formation of multiple cracks.

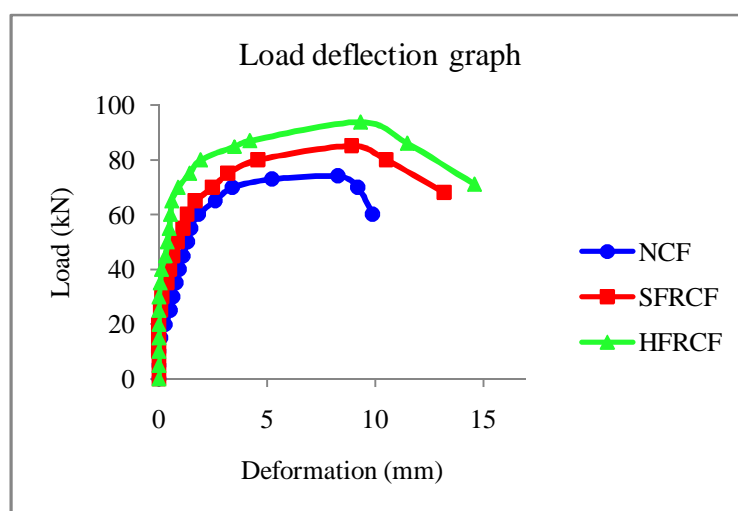


Fig 4. Load –mid span deflection graph

After the formation of first crack the slope of the curves decreases. On increase of load the steel starts yielding and curve become flat till the ultimate load was reached. It was seen that after the yielding occur for HFRCF (Hybrid Fiber Reinforced Concrete Flexural specimen), the specimen continue in the yielding stage for more time compared to SFRCF and NCF specimens. Normal concrete specimens show a sudden drop in load beyond the ultimate load. However both SFRC and HFRC specimens shows more flat portion beyond ultimate load compared to NC specimens. The initial portion of HFRC specimens was little steeper than the SFRC and NC specimens, which means that HFRC was stiffer than the other two. HFRC beams experienced less deformation for the same magnitude of load.

### B. First Crack Load and Ultimate Load

The first crack load was obtained from the load deflection graph. It is that load at which the load deflection curve deviates from the initial straight line. The first crack load and ultimate load obtained for tested specimens are given in the Table 4. The first crack load is found to increase by 31.43 % for SFRCF specimens with 0.5% volume fraction of steel fibers and maximum increase is about 56.86 % for HFRCF specimens with 0.35% steel and 0.15% polyester fibers. This may be due to the ability of polyester fibers in arresting micro cracks which delayed the formation of macro cracks. This may delays the formation of macro cracks. It is evident from the Table 4 that both SFRC and HFRC



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specimen shows significant improvement in ultimate load carrying capacity. The maximum increase of 24.88% was obtained for HFRCF specimens.

Table 4 First Crack Load and Ultimate Load

Beam designation	First crack load in kN	Average first crack load in kN	Percentage increase	Ultimate load in kN	Average Ultimate load in kN	Percentage increase
NCF1	18.1	17.5	-	74.1	73.6	-
NCF2	16.9			73.0		
SFRCF1	22.5	23.0	31.4	85.1	84.3	14.6
SFRCF2	23.5			83.4		
HFRCF1	26.8	27.5	56.9	89.9	91.9	24.9
HFRCF2	28.1			93.8		

## C. Deformation at Ultimate Load and Ultimate Deformation

Table 5 shows the test results of the deformation for all beams. The deformation corresponding to 80% of peak load were termed as ultimate deformation. The mid span deformation at ultimate load and ultimate deformation were tabulated. The average deformation at ultimate load for SFRCF and HFRCF beams were comparable. It is clear from the table that there is significant improvement in the ultimate deformation for all SFRCF and HFRCF beams. This indicates that the material has been changes from brittle to ductile one which in turn delays the collapse of the structure. The ultimate deformation increased up to 51.56% and 36.98% for HFRCF and SFRCF specimen respectively.

Table 5 Deformation at ultimate load and ultimate deformation

Beam	Deformation at ultimate load in mm	Average deformation in mm	Ultimate deformation in mm	Average deformation in mm	% increase
NCF1	8.3	7.9	9.9	9.6	-
NCF2	7.5		9.3		
SFRCF1	8.9	9.1	13.2	13.2	37.0
SFRCF2	9.2		13.1		
HFRCF1	9.3	9.5	14.6	14.6	51.6
HFRCF2	9.7		14.5		

## D. Displacement Ductility Index

Displacement ductility index is the ratio of ultimate deformation to yield deformation. Deformation corresponding to 80% of post peak can use for calculating the displacement ductility index.[10]. So here the deformation corresponding to 80% of post peak had been taken for calculating the ductility index.

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Table 5 Displacement ductility indices

Beam	Average ductility index	% increase
NCF1	6.71	-
NCF2		
SFRCF1	9.93	48.00
SFRCF2		
HFRCF1	12.77	90.30
HFRCF2		

The yield load corresponding to each mix was calculated theoretically by using pure bending theory. Table 6 shows the values of ductility index obtained for all the specimens. The ductility index of SFRCF and HFRCF specimens shows 48% and 90.3% increase than NCF specimens respectively

## E. Energy Absorption Capacity

Energy absorbed by each specimen during the test was calculated by the area under the load deflection curve and the results are given in the Table 7. The energy absorption was calculated as the area under the curve up to the peak load and under the descending portion up to 80 % of the peak load due to the limitation of test setup.. From the test result it was observed that the energy absorption of HFRCF and SFRCF has increased by 44.56% and 75.27% respectively than normal concrete. The energy absorption of HFRC has increased by about 21.25% than that of SFRC.

Table 7 The energy absorption capacity of flexural specimens

Beam	Energy absorption kNmm	Average energy absorption kNmm	Percentage increase
NCF1	670.08	676.79	-
NCF2	683.49		
SFRCF1	980.84	968.69	43.13
SFRCF2	956.55		
HFRCF1	1183.66	1174.45	73.53
HFRCF2	1165.24		

## VI. ANALYTICAL INVESTIGATION

### A. Finite element model

Usually, finite element (FE) analysis is also carried out to counter check the test values. This helps in refining the analytical tools so that, even without experimental proof or check the complex nonlinear behaviour of RC beams can be confidently predicted. ANSYS commercially available Finite Element (FE) software, of version 16.1 was used for the analysis of flexural specimens. The actual behaviour of concrete should be simulated using the chosen element type. For the present type of model Solid 65, Beam 188 and Solid 186 were chosen. Material properties of concrete, reinforcement and fibers are defined and entered as data in the model. For the easy way to model the beam, we use AutoCAD software tool for modelling and then imported to the ANSYS multiphysics.

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## B. Modelling

The material property such as compressive strength, modulus of rupture, Young's Modulus etc. was defined for each mix. The proper meshing, boundary conditions, loading, material definitions were provided for all the models. Finally the solution of the problem according to the problem definitions was obtained. Fig. 6 shows the modelled specimen and the total deformation of NCF specimen is shown Fig. 7.

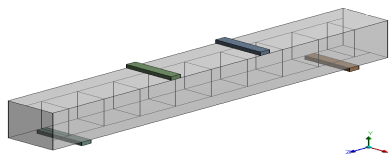


Fig. 6 Modelled specimen

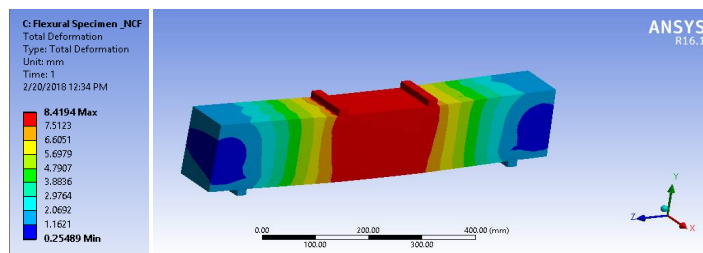


Fig. 7 Total deformation of NCF specimen

## C. Validation of Experimental Results

The validation of the experimental results was worked out in terms of ultimate load carrying capacity and deformation at ultimate load. The experimental and analytical load-deformation curves for HFRCF specimens are shown in Fig. 8. Analytical load deformation curve is just below the experimental one and the ultimate load carrying capacity also less than that of experimental one. Hence we can confidently perform the nonlinear static analysis on FRC beam specimens using this software ANSYS 16.1. The results of validation are shown in Table 8.

Table 8 Ultimate load carrying capacity and deformation at ultimate load of all the beams

Beam	Ultimate Load Carrying Capacity (kN)		Percentage Difference	Deformation At Ultimate Load (mm)		Percentage Difference
	Experimental	Analytical		Experimental	Analytical	
NCF1	73.55	72.891	0.9	7.897	8.4194	6.62
NCF2						
SFRCF1	84.25	81.805	2.9	9.066	9.4887	4.66
SFRCF2						
HFRCF1	92.1	89.768	2.53	9.525	9.7979	2.87
HFRCF2						



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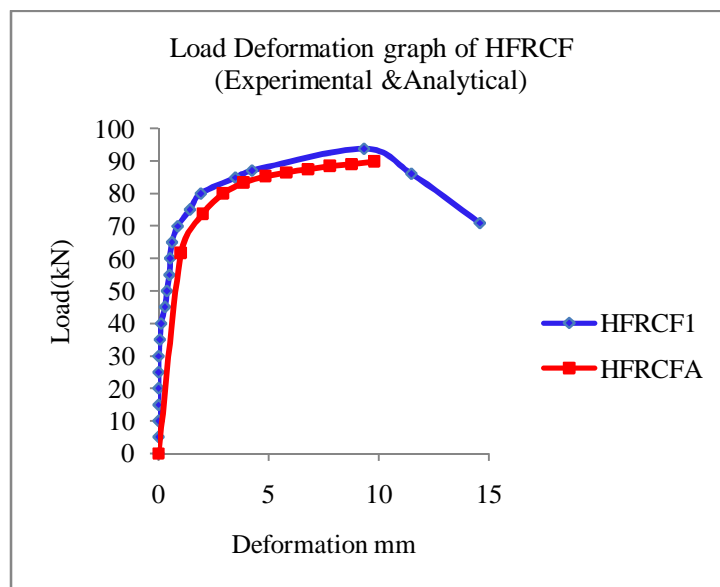


Fig. 8 Comparison of Load Deformation Graph

The results were found to be comparable with respect to the load carrying capacity and deformation. From the table the maximum difference between Experimental and Analytical results was 6.62%, which is less than the acceptable limit of 10%.

## VII. CONCLUSION

Based on the work presented in this study, the following conclusions are drawn:

- (1) All the hardened properties of HFRC shows significant improvement compared to normal concrete.
  - The split tensile strength of HFRC was increased by 63%, and 3.2% over NC, and SFRC respectively.
  - The flexural strength of HFRC was increased by 34.5%, and 9.9% over NC, and SFRC respectively.
  - Modulus of elasticity of HFRC was increased by 27% and 2% over NC and SFRC respectively..
- (2) The optimum percentage of hybrid fiber in concrete was found to be 0.15 % polyester fiber and 0.35% steel fiber by volume fraction
- (3) From the study on flexural behavior of HFRC, SFRC and NC it was observed that, the ultimate load carrying capacity of SFRC and HFRC beam was increased by 24.7% and 33.5% as compared to NC beam specimen .
- (4) The deformation at ultimate load of HFRC and SFRC beam was increased by 43.44% and 35.18% as compared to NC beam specimen .
- (5) The addition of fibers delays the formation of first visible cracks and the first crack load for HFRC was obtained as maximum.
- (6) The number of cracks were increased in SFRC and HFRC compared to NC beams.
- (7) The analytical results were found to be in good agreement with experimental one.
- (8) The HFRCF specimen with 0.35% steel fibers and 0.15% polyester fibers showed better performance than SFRC specimens with 0.5% steel fiber and NCF specimens without fibers.

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