Behaviour of Hybrid Fiber Reinforced Concrete Beam Under Shear

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Abstract— An experimental investigation was conducted to study the effect of hybrid fibers on the shear behaviour of 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. The investigation consists of casting and testing of six reinforced beam specimens of size 100x150x750mm. No shear reinforcement was provided in the shear span in order to ensure shear failure. Each specimen was tested under two point loading. Out of six, two were made of NC , two were with 0.5% SFRC and remaining two were with optimum HFRC(0.35% steel+0.15% polyester). Modeling of these beams was carried out using ANSYS 16.1 software. Finally the experimental results were compared with the analytical one. HFRC specimen shows significant improvement (about 58.3%) in the first crack load. The overall performance HFRC specimens (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.

Index Terms—Hybrid fiber reinforced concrete, Polyester fiber, Shear behaviour , Steel fibers

1 Introduction

Concrete is the most widely used man made construction material in the world. Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension. Often steel is used as reinforcement in concrete. New techniques and methods in different aspects have contributed to develop concrete with better performance and properties, and this has kept concrete a competitive material.

The concept of using fibers as reinforcement is not new. Fiber Reinforced Concrete is type of concrete containing fibrous material which increases many of its engineering properties. It contains short discrete fibers that are uniformly distributed and randomly oriented. Commonly used fibers are metallic, synthetic and natural fibers. Moreover, the addition of hybrid fibers makes the concrete more homogeneous and isotropic and therefore it is transformed from brittle to more ductile material [1].

Shear failure of a reinforced concrete beam occurs when the principal tensile stress within the shear span exceeds the tensile strength of concrete and a diagonal crack propagates through the beam web. This failure is usually without any warning due to the brittle nature of plain concrete behaviour in tension. The addition of small discrete steel fibers into the concrete mix helps to improve the post cracking tensile strength of hardened concrete, and hence significantly enhances the shear strength of reinforced concrete (RC) beams[2]. Many reports published over the past 25 years confirm the effectiveness of steel fibers as shear reinforcement. In addition to the improvement in the ductility, fibers are also used to boost the shear capacity of concrete or to replace, in part, the vertical stirrups in RC structural members.

This relieves reinforcement congestion at critical sections such as beam-column joints. Fiber reinforcement may also significantly reduce construction costs and time, especially in an era of high labor costs, since conventional stirrups require relatively high labor input to bend and fix in place.[3].

Only limited information is available regarding the effect of adding more than one kind of fibers on the shear behaviour of concrete. Here an attempt is made to study the shear behaviour of HFRC beams without stirrups under monotonic loading. Steel and polyester (Recron 3S) fibers were used for the study. Modeling of the beams was done using soft ware ANSYS 16.1.then the experimental results were validated. In addition to the above, this investigation also focuses on evaluating the basic mechanical properties of normal concrete without any fibers, mono and hybrid fiber reinforced concrete.

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2 Methodology

1) Collection of literatures in the area of FRC
2) Materials required for the experiments were procured and their properties were found as per IS codes.
3) Mix design of M25 grade concrete was done as per IS 10262-2009.
4) Specimens for determining mechanical properties with control, 0.5% SFRC and hybrid (steel and polyester) fiber reinforced concrete mix were prepared.
5) Split tensile, flexural strength and modulus of elasticity were used for selecting the optimum combination of fibers.
6) Shear behaviour of SFRC and HRFC beams were examined are compared to that of normal RCC beams.

7) Study of the software ANSYS version 16.1
8) Finite element modelling of beams and comparison of experimental results using ANSYS 16.1 soft ware.

3 Experimental Programme

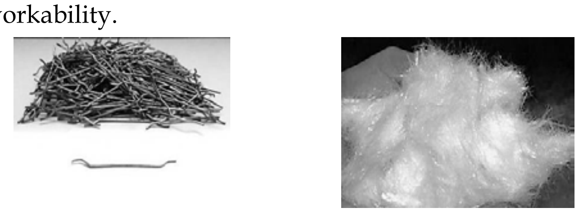
The preliminary studies involve the comparative study of effect of steel fibers and hybrid (steel and polyester fibers) on compressive, split tensile, flexural strength and modulus of elasticity of M25 grade concrete at 28 days of curing. Six mixes were selected for preliminary studies. Which include 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 shear 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 were prepared.

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

3.1 Material Used

Ordinary Portland cement (OPC) conforming to IS 12269:2013 [4], M sand with a specific gravity of 2.47 conforming to Grading Zone II of IS 383: 1970 (reaffirmed 2011) [5], 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 (reaffirmed 2013) [6] Conplast SP430 with specific gravity 1.22 was used as super plasticizer to obtain required workability.



(a) (b)

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

3.2 Mix Proportions

Mix designs for M25 grade concrete was done as per IS 10262:1982 (reaffirmed 2014) [7]. 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 3.

TABLE 3
Mix Proportion

Materials	Quantity (kg/m^3)
Cement	383
Fine aggregate	737
Coarse aggregate	1113
Water	172
Super plasticizer	3.83

3.3 Mechanical Properties

3.3.1 Preparation of specimens

Firstly mixing of dry materials was done in a drum type mixer. Super plasticizer was mixed with water and was then added to the dry materials. The required quantities of steel and polyester fibers were taken according to the volume fraction and these fibers were added during mixing. Workability of fresh concrete was checked using a standard slump cone. The freshly mixed concrete was poured layer by layer, into standard cubes of size 150mm for compressive strength test, 150×300 mm cylinders for splitting tensile test and modulus of elasticity and into 100×100×500mm prisms for finding modulus of rupture. Total number of layers was three. Each layer was compacted by giving 35 strokes per layer with standard tamping bar. The top surface was levelled using a smooth trowel after compaction. For each mix cubes, cylinders and prism were caste. After 24 hours, the specimens were removed from the mould and water cured for 28 days by keeping them in a water tank. After 28 days, specimens were taken out and kept ready for testing.

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3.3.2 Testing of Specimens

The following tests were conducted to determine the mechanical properties of the hardened concrete.

(i) Compressive strength tests as per IS: 516-1959 (reaffirmed 2013) [9]

(ii) Flexural strength tests as per IS: 516-1959 (reaffirmed 2013)

(iii) Split tensile strength tests as per the method suggested in IS:5816- 1999 (reaffirmed 2013) [8] and

(iv) Modulus of elasticity as per IS: 516-1959(reaffirmed 2013)

3.3.3 Test Results of Mechanical Properties

Table 4 shows the various mechanical properties such as cube compressive strength, flexural strength, split tensile strength and modulus of elasticity. It may be noted that addition of fibres in to the concrete enhances all the mechanical properties and the maximum increase flexural strength, splitting tensile strength and modulus of elasticity is about 35%, 63% and 27% respectively for HFRC3 (0.35% steel fibers and 0.15% polyester fiber). The enhancement in strength and flexural properties in HFRC may be due to the ability of polyester fibres in controlling the micro cracks and the steel fibres in bridging the macro cracks. Hence HFRC3 was selected as the optimum hybrid combination for further studies.

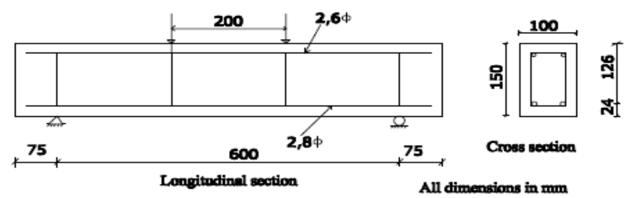
TABLE 4
MECHANICAL PROPERTIES

Mix	f_c (N/mm²)	f_{ct} (N/mm²)	f_{cr} (N/mm²)	E_c (N/mm²)
NC	29.8	2.2	4.6	19249.8
SFRC	33.1	3.4	5.7	24062.3
HFRC1	32.2	3.3	5.9	23779.2
HFRC2	32.1	3.3	6.0	23779.2
HFRC3	32.4	3.6	6.3	24534.1
HFRC4	32.7	3.4	6.0	22646.9

3.4 Shear Behavior

Beams of size 100 x 150 x750 mm were cast and tested in flexure under a universal testing machine of capacity 600kN for monotonic loading. 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 beams were designed as singly reinforced under reinforced sections. The beams were reinforced with two numbers of 8mm ϕ bars at bottom and two numbers of 6mm ϕ bars at top as stirrup holders. No shear reinforcement was provided in order to ensure the shear failure of specimens. Stirrups of 6mm ϕ bars were provided at loading points and supports in order to avoid crushing of concrete at these points. Fig. 2 shows the reinforcement details.



Fig,2 Reinforcement details

The mid span deflection was monitored by a Linear Variable Differential Transducer (LVDT) fixed on the bottom side of the beam with an accuracy of 0.001mm. Two dial gauges were kept on the tension side of the beam to measure the deflections at L/3 distances with a least count of 0.01mm. Deflections were measured for the applied incremental load of 5kN. Loading was continued until the failure of the beams occurs. Formation of cracks, ultimate load and corresponding deflection were recorded. Due to the limitation in the experimental set up post peak response corresponding to 80% of ultimate load were taken. Fig.3 shows the testing of beams under universal testing machine.

Fig.3 Test setup

4 RESULTS AND DISCUSSIONS

4.1 Behaviour of Specimens

During testing of NCS (Normal Concrete Shear) specimen initially cracks are appeared in the flexural span. Increase in load causes the formation of additional flexural cracks and also diagonal shear cracks were developed in the shear span. As the loading continues the cracks widens and almost all of them were traversed up to the top of compression side. Severe shear cracks were observed in NCS specimens without any fibers. One diagonal crack widens at a faster rate and reaches the loading points. The mode of failure as expected was typical shear failure.

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For SFRCS1 specimens also the initial flexural cracks are developed in the mid span. Large numbers of finer cracks were observed as the load increases. The crack propagation rate was found to be less than that of NCS 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.

In HFRCS 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. The formation of diagonal cracks was also delayed and at the ultimate stage of loading one flexural crack propagates to top of the beam and the mode of failure changes from shear to flexure. The load carrying capacity of all FRC beams shows significant improvement with respect to that of normal concrete beams. The values of ultimate load carrying capacity were comparable for SFRCS and HFRCS specimens. Fig.4 shows the crack pattern of all specimens after failure.

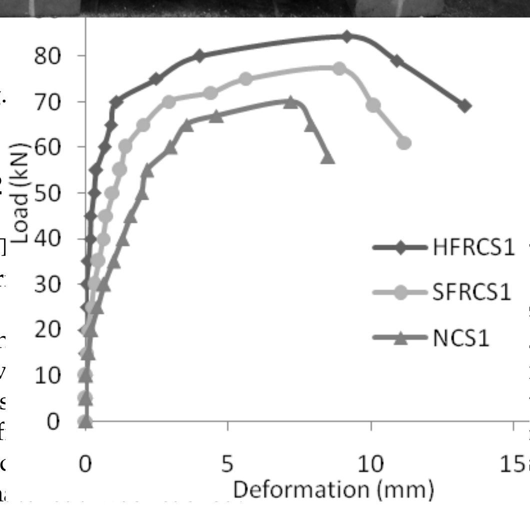

Fig.

4.2

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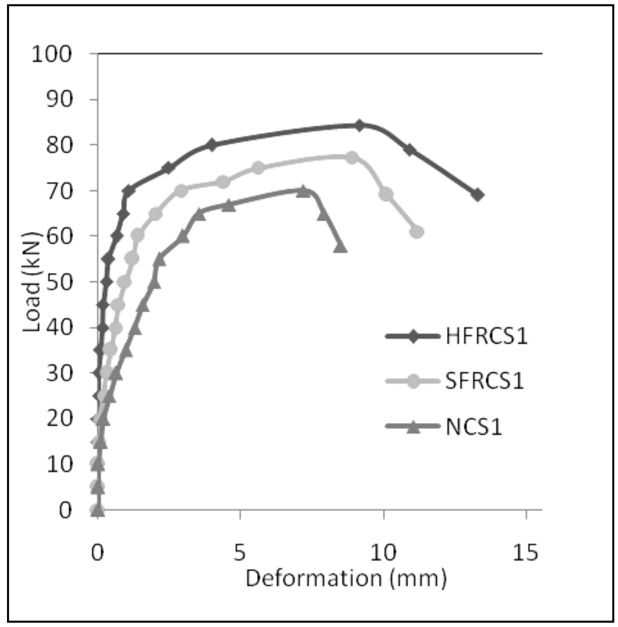

Fig.5 Comparison of Load versus Deflection Curves

The HFRCS specimen has more yielding capacity compared to other specimens. It was seen that the after the yielding occur for HFRCS, the specimen continue in the yielding stage for more time compared to SFRC and NCS 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.

4.3 First Crack 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 average values of first crack load obtained for each mix are given in the Table 5. From the result it was seen that there is significant improvement in first crack load for FRC beams (both SFRC and HFRC).

TABLE 5

FIRST CRACK LOAD

Beam	Average first crack load kN	Percentage increase
NCS	17.5	-
SFRCS	21.9	25.4
HFRCS	27.7	58.3

The first crack load is found to increase by 25.43% for SFRCS specimens with 0.5% volume fraction of steel fibers and maximum increase is about 58.29 % for HFRCS 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. When the micro crack develops in the matrix the polyester fiber will arrest these cracks and prevent it from further propagation. This may delays the formation of macro cracks.

4.4 Ultimate Load Carrying Capacity

The peak point of load deformation curve represents the ultimate load, at which the specimen fails. The average values of test results are shown in Table 6. The average ultimate load for NCS specimens was obtained as 69.6kN. It is evident from the table that both SFRC and HFRC specimen shows significant improvement in ultimate load carrying capacity. The maximum increase of 20.7% was obtained for HFRCS specimens. This may be due to the combined action of polyester and steel fibers in arresting the cracks formed. The polyester fiber delays the formation of macro cracks and after the formation of cracks the steel fibers intercept them and the bridging action of fibers will reduces the widening of cracks. This bridging action demands more energy for their propagation and resulting in increased ultimate load. It may be conclude that hybridization is effective in terms of ultimate load carrying capacity.

TABLE 6
ULTIMATE LOAD CARRYING CAPACITY

Beam	Average ultimate load in kN	Percentage increase
NCS	69.6	-
SFRCS	78.3	12.6
HFRCS	84.0	20.7

4.5 Deformation at Ultimate Load and Ultimate Deformation

Table 7 shows the average of test results of the deformation for all beams.The deformation corresponding to 80% of peak load were termed as ultimate deformation. It is clear from the table that there is significant improvement in the ultimate deformation for all SFRCS and HFRCS 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 24.9% and 41.8% for HFRCS and SFRCS specimen respectively.

TABLE 7
DEFORMATION AT ULTIMATE LOAD AND ULTIMATE DEFORMATION

Beam	Average deformation at ultimate load (mm)	% increase	Average ultimate deformation (mm)	% increase
NCS	7.2	-	9.5	-
SFRCS	8.8	23.0	11.8	24.9
HFRCS	9.1	26.9	13.4	41.8

4.6 Displacement Ductility Index

Displacement ductility index is the ratio of ultimate deformation to yield deformation. Deformation corresponding to 80% of post peak can be use for calculating the displacement ductility index [9]. For all specimens the yield load corresponding to each mix was calculated theoretically by using pure bending theory. The deformation corresponding to yield load was obtained from the load deformation graph for each specimen. Table 8 shows the values of ductility index obtained for all the specimens.

The result shows that the addition of fiber on concrete increased the ductility and the hybrid fiber reinforced concrete is more ductile compared to other beam specimens. The ductility index of SFRCS and HFRCS specimens shows 54.3% and 96.0% increase than NCS specimens respectively. This may be due to the enhancement in yield and ultimate deformation for SRFC and HFRC specimens due to the synergetic bridging activity of polyester and steel fiber.

TABLE 8
DISPLACEMENT DUCTILITY INDEX

Beam	Average Ductility index	% increase
NCS	6.3	-
SFRCS	9.7	54.3
HFRCS	12.4	96.0

4.7 Energy Absorption Capacity

Energy absorbed by each specimen during the test was calculated by the area under the load deflection curve and the average values of the results are given in the Table 9. Due to the limitations in the experimental set up, the load deflection graph could be plotted only up to 80 % of the peak load, in the descending portion of the curve. Thus, 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. From the test result it was observed that the energy absorption of HFRCS and SFRCS has increased by 38.7% and 70.1% respectively than normal concrete. The energy absorption of

HFRC has increased by about 22.6% than that of SFRC.

TABLE 9
ENERGY ABSORPTION CAPACITY

Beam	Energy absorption kNmm	Average energy absorption kNmm	Percentage increase
NCS	567.15	559.20	-
SFRCS	769.99	775.77	38.73
HFRCS	948.62	951.37	70.13

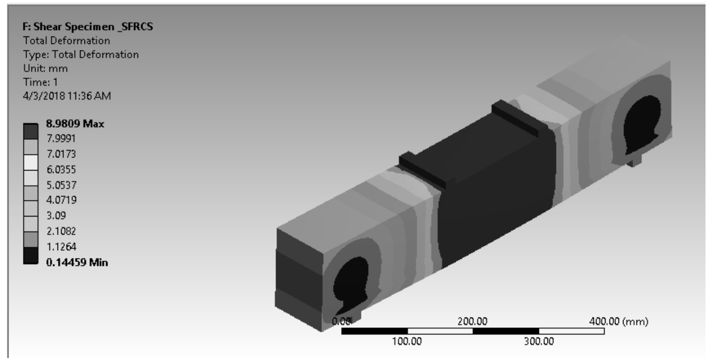

Fig.7 Total deformation of SFRCS specimen

5 ANALYTICAL INVESTIGATION

5.1 Finite Element Model

Usually the finite element analysis (FEA) is also carried out to counter check the experimental results. 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 uses AutoCAD software tool for modelling and then imported to the ANSYS multyphysics.

5.2 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 SFRCS specimen is shown Fig. 7.

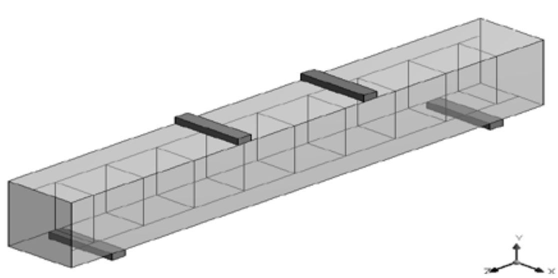

Fig. 6 Modelled specimen

5.3 Comparison 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 HFRCS specimens are shown in Fig.8. The results of validation with respect to ultimate load carrying capacity are shown in Table 10 and that of deformation at ultimate load are shown in Table 11 respectively.

TABLE 10
ULTIMATE LOAD CARRYING CAPACITY

Beam	Ultimate Load Carrying Capacity (kN)		% Difference
	Experimental	Analytical	
NCS	69.55	68.49	1.52
SFRCS	78.30	76.23	2.64
HFRCS	83.95	82.46	1.77

TABLE 11
DEFORMATION AT ULTIMATE LOAD OF ALL THE BEAMS

Beam	Deformation at Ultimate Load (mm)		% Difference
	Experimental	Analytical	
NCS	7.16	7.57	5.78
SFRCS	8.81	8.98	1.99
HFRCS	9.08	9.54	5.05

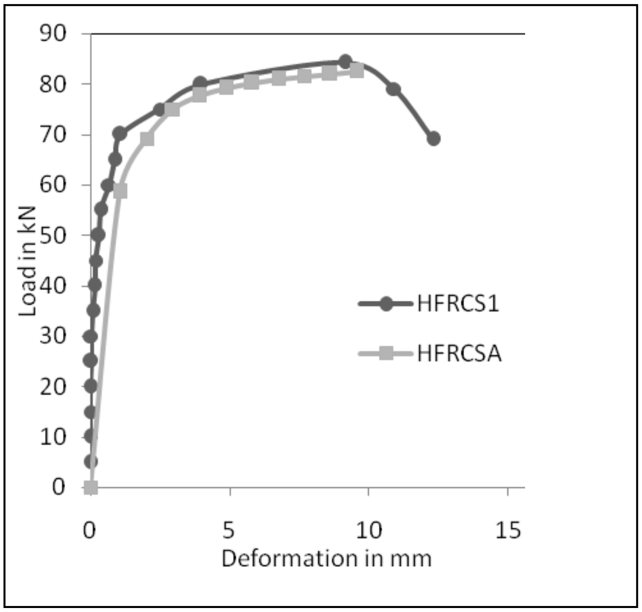

Fig. 8 Comparison of Load Deformation Graph

The analytical and experimental 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 5.78%, which is less than the acceptable limit of 10%. 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.

6 Conclusions

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 shear behaviour of HFRC, SFRC and NC it was observed that, the ultimate load carrying capacity of SFRC and HFRC beam was increased by 12.6% and 20.7% as compared to NC beam specimen .
4) The deformation at ultimate load of HFRC and SFRC beam was increased by 23.0% and 26.9% 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 was increased in SFRC and HFRC compared to NC beams.
7) The mode of failure changes from shear to flexure for HFRC beams.
8) The analytical results were found to be in good agreement with experimental one.
9) The HFRCS specimen with 0.35% steel fibers and 0.15% polyester fibers showed better performance than SFRCS specimens with 0.5% steel fiber and NCS specimens without fibers.

Notations

E_c modulus of elasticity o f concrete
f_c 28 days compressive strength
f_{cr} flexural strength of concrete
f_{ct} split tensile strength of concrete

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