

Experimental and Analytical Studies on Steel and Basalt Fiber Reinforced Concrete beams

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ABSTRACT: The objective of this paper is to investigate and compare the flexural properties of steel and basalt fiber reinforced concrete beams with plain M30 grade concrete beams. Experimental and analytical studies are conducted on steel and basalt fiber reinforced concrete beams reinforced with optimum fiber content, which was obtained by varying the fiber dosages from 0%, 0.25%, 0.50%, 0.75%, 1.0% of total volume of concrete. The plain concrete normally contains numerous micro and macro cracks and it will begin to propagate in the matrix when load is applied. The addition of randomly spaced, discontinuous fibres helps in arresting the propagation of cracks and it cannot be achieved by continuous reinforcement. Thus fibers will help to improve the tensile and flexural strength of concrete. This study includes two phases, first phase is the comparative study about the shear and flexural behaviour of beams reinforced with optimum fiber content and second phase is the analytical study of these beams using ANSYS 16.1 software. The optimum fiber content for BFRC is 0.75% and for SFRC is 0.5% of total volume of concrete. For shear and flexural behaviour of beams, total twelve beams were prepared and tested over an effective span of 700 mm under two-point loading. The beams were designed as balanced-section. The values obtained from experimental and analytical studies were comparable for all the beams. Hence the analytical studies were extended for the full scaled beam elements.

KEYWORDS: Basalt fiber, steel fiber, BFRC, SFRC, Flexural strength, tensile strength, FRC-Fiber reinforced concrete, ANSYS 16.1

I. INTRODUCTION.

Plain concrete is very weak in taking tension because it contains numerous micro-cracks. When an externally applied load will act on the matrix, the micro cracks begin to propagate. As a result, plain concrete members cannot withstand tensile stresses developed due to the applied forces without the addition of re-bars in the tensile zone. Thus a rapid propagation of micro-cracks and macro-cracks will occur and it cannot be arrested or slowed by the use of continuous reinforcement [7]. So a number of studies are concentrated over this area to modify the properties of concrete. Most of the studies found that by the addition of fibers, cracking was controlled and the mechanical properties of plain concrete such as durability and serviceability of the structure were improved. The uniformly distributed and randomly oriented fiber will also improve fracture resistance and resistance to impact and dynamic loads. The unique feature of fiber reinforced concrete is that, it gives a warning before it fails or it possesses a post-cracking ductility. The research over the years on fibers has shown that fiber reinforcement has actually sufficient strength and ductility to be used as a complete replacement to conventional reinforcement in some types of concrete structures, such as foundations, walls and slabs on grades. In beams and suspended slabs, fibers are used in combination with conventional reinforcement which improves both the load bearing capacity and the stiffness of the structure.

Basalt fibre is produced from a volcanic rock called Basalt and it is an inorganic material. The basalt fibres are environmentally safe and it is non-toxic in use. Basalt fibers are stable in all aggressive environments and possess high tensile strength and good thermal endurance [6]. Steel fiber reinforced concrete (SRFC) is the commonly-used fiber concrete, originally used as a combination with conventional reinforcement for crack control in flat slabs, pavements

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and tunnel linings. The excellent properties such as high modulus of elasticity, high strength, high ductility and a very good durability made steel fiber more popular. Steel fibers greatly increase the properties of concrete such as toughness and resistance to repeatedly applied loads.

II. RELATED WORK.

Padmarajaiah and AnanthRamaswamy [1] conducted a study on flexural strength of steel fibre reinforced high strength concrete in fully and partially prestressed beam specimens. The important conclusion of this study is that the toughness and ductility of prestressed high strength concrete beams have increased with the increase in fibre content. The maximum increase in ductility was about 18%, 45% and 68% and percentage increase in energy absorption was 25%, 78% and 88% for fully prestressed beams with full depth of steel fibre content of 0.5%, 1.0% and 1.5% volume fractions. Joshi A. A et al [2] studied about the use of basalt fibers to improve the flexural strength of concrete beam. They chose different samples of M30 grade of concrete with water cement ratio as 0.5, to show the effect of basalt fibers additions as 0%, 0.5% 1.5% and 2% of binder replacement. Results in flexural test showed that as the basalt percentage increases up to 0.07% flexural strength of beams goes on increasing and after that from 0.07% again it goes on decreasing. The optimum fiber content is 2% of total volume of concrete.

HayderQaisMajeed [3] presented a nonlinear finite element modelling and analysis of steel fiber reinforced concrete (SFRC) deep beams with and without openings in web subjected to two- point loading. In this study, the beams were modeled using ANSYS nonlinear finite element software. The percentage of steel fiber added was varied from 0 to 1.0%. The results obtained demonstrated that web openings may be provided in the compression zone of the beams and fiber content of 0.75% by volume may be added to improve the strength of the structure. The openings in the tension zone weaken the beam. A fiber content of 0.75% by volume of the beam improves the ultimate load. Also the results of the experimental and analytical studies were comparable.

Finite element analysis of high strength concrete beams in shear - without web reinforcement and with fiber in shear predominant regions was done by Sudheer Reddy .L et al [4] . They study about the improvement of shear strength of high strength concrete beams (65 MPa) with different shear span to depth ratios ($a/d = 1, 2, 3, \text{ and } 4$) and various dosages of fibers (0.4%, 0.8%, and 1.2% by volume of concrete) only in shear predominant regions, without shear reinforcement. The experimental studies were validated analytically by modeling the beams in ANSYS. The important conclusion is that, an increase in shear capacity with addition of fiber at different shear span to depth ratios (a/d) ratios. Further the test results of the beams with fiber only in critical regions indicated almost the shear capacity similar to that of the beams reinforced with fiber throughout, thus usage of fiber in shear critical regions shall be more cost effective.

Mohamed A. A. El-Shaer[5] investigated about the structural analysis of concrete beams reinforced with basalt FRP bars. A non-linear finite element analysis (FEA) has been done to analyze the flexural analysis of reinforced simple concrete beam strengthened with (BFRP) bars under short-term static vertical loads. Finite Element software ANSYS 12.0 has been used to analyze the three-dimensional model. The reliability of the model was demonstrated by comparison with experimental results of concrete beam strengthened with BFRP bars carried out by another author, and the theoretical prediction agrees well with the test results. While replacing the traditional steel bars with BFRP bars has remarkably increased the ultimate load and ductility of the concrete beams by about 34% to 53%, decreased the maximum deflection by about 30%, increased the ultimate tensile force in bars by about 82% to 104% and increases the ultimate concrete stress by about 220% to 268%.

III. OBJECTIVES AND METHODOLOGY.

1. Objectives: -The primary objective of this investigation is to compare the shear and flexural behaviour of RCC beams reinforced with optimum fiber contents of basalt and steel fibers. The optimum fiber dosage for basalt is 0.75%

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and steel fiber is 0.5% of total volume of concrete, which was obtained by comparing the compressive and split tensile values. Then experimental analysis has been compared with the analytical analysis, which was done using the software ANSYS 16.1. Full scaled beams are analysed in ANSYS 16.1 to simulate the practical situations.

2. Methodology: - Materials required for the experiments were procured and their properties were found. Mix design of M30 grade concrete was done as per IS 10262-2009. Flexural and shear behaviour of fiber reinforced beams are compared to that of normal reinforced beams. Modelling of the beams in ANSYS 16.1 and meshing the model. All the mechanical properties are then applying to the model by inputting the values of density, Poisson's ratio, Modulus of elasticity, ultimate uniaxial strength, grade of concrete and steel, tensile strength of steel etc. Apply two-point loading as done in the experimental analysis. Compare the results obtained with those from experimental works. Full scaled beam elements are analysed by varying span, cross-sections and support conditions.

IV. EXPERIMENTAL INVESTIGATION.

1. Materials Used

Cement used was Portland Pozzolanacement (PPC) of "ACC" brand of super grade. The various properties of cement were found to confirm as per Indian Standard. The coarse aggregate of maximum nominal size 20 mm was used for preparing the mixes. The properties of coarse aggregate which confirms to IS 383:1970 (Part III) specifications. The fine aggregate used confirms to Zone III grading curve of IS 383:1970 (Part III). The specific gravity of fine aggregate is 2.5 and void ratio is 0.50. Conplast SP430 with specific gravity 1.22 was used as super plasticizer. Chopped basalt fibers of length 12mm were used. The hooked end steel fibers of 30mm length and aspect ratio of 50 were used. Figure 1 shows chopped basalt fibers and hooked end steel fibers.



Figure 1: (a) Chopped basalt fibers and (b) Typical Hooked End Steel fibres

2. Experimental procedure

The optimum fiber content obtained from the study was tabulated in Table 1. It was clear that the optimum fiber content for basalt fiber is 0.75% and for steel fiber is 0.5% of total volume of concrete. Thus, total 12 beam specimens are prepared and tested for the same. Three sets of 4 beam specimens were prepared by providing same reinforcement throughout. First set is prepared without the use of any fiber, second set is prepared with optimum steel fiber content and third set with optimum basalt fiber content. In each sets of 4 beams, 2 beams reinforced for shear and 2 beams for flexural study.

The target mean strength M30 grade concrete was 38.5MPa for the control mixture, the total cement content was 380 kg/m³, fine aggregate 665kg/m³ and coarse aggregate 1350 kg/m³, the water to cement ratio was kept as 0.45 for all mixtures. All the beam specimens were of dimension 100mmx100mmx750mm with an effective span of 700mm. All the beams were designed as singly reinforced beam with 2 numbers of 8mm diameter bars at tension and compression with stirrups of diameter 6mm. The specimens were tested using two-point loading in a 600kN capacity UTM. Figure 2 shows different stages of concreting; Figure 3 shows the test setup. Two dial gauges were used to measure the deflections at two loading points that is at one-third of effective span. One LVDT was used to measure central deflections.

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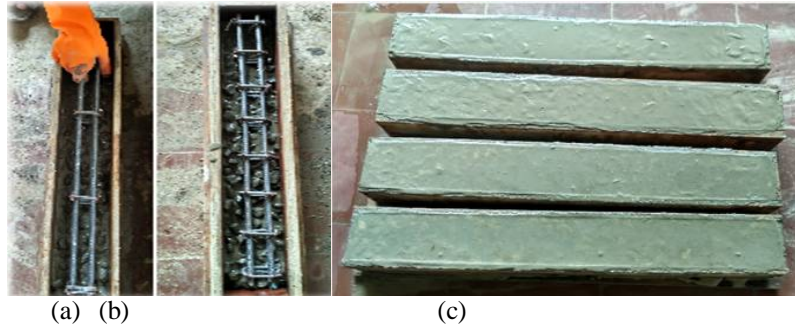


Figure 2: Different stages of concreting- (a) shear specimen (b) flexural specimen and (c) prepared beams.

Table 1: Compressive and split tensile strength of FRC specimens.

% of fiber content in the matrix	Compressive strength (N/mm ²)	Split tensile strength (N/mm ²)
Zero % fiber content	37.4	2.46
0.25% basalt fiber	38.5	2.69
0.5% basalt fiber	39.8	3.35
0.75% basalt fiber	40.8	3.52
1.0% basalt fiber	36.9	2.90
0.25% steel fiber	40.61	3.129
0.5% steel fiber	41.81	3.64
0.75% steel fiber	38.79	3.09
1.0% steel fiber	38	2.99

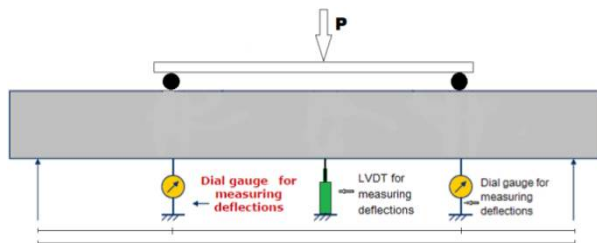


Figure 3: (a) Schematic Diagram of Test Setup and (b) Test setup

V. ANALYTICAL INVESTIGATION.

1. The Finite Element Model

ANSYS 16.1 software tool is used for modelling and transferring material properties of the specimen. We use one of the most accurate finite element software for analysing. 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.

2. Procedure for Analysis

Analytical investigation is performed in two phases. First phase is the validation of experimental results with analytical results. For that, beam elements are modeled and all the parameters of test setup as in the experiment are assigned to the models. Second phase is the software analysis of full scaled beam elements in ANSYS 16.1 to investigate the practical situations.

Linear static analysis was performed for all the specimens. The beams are modeled in AutoCAD and then imported to the ANSYS Multiphysics. The material property such as Young's Modulus was defined for static analysis. 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. Figure 4 shows the actual geometry of beam model and total deformation of SFRC-F1 beam.

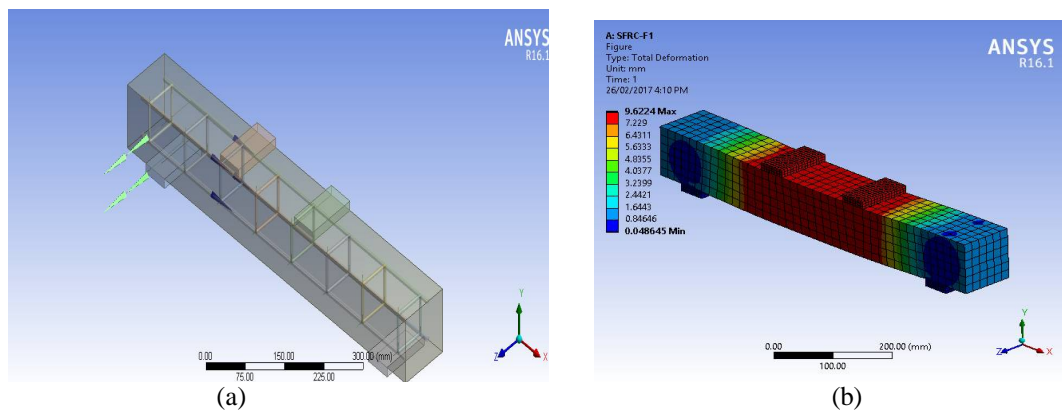


Figure 4: (a) The actual geometry of beam model (b) Total deformation of SFRC-F1 beam

3. Analysis of full scale beam elements.

Full scaled beam elements are considered to study the practical situations. For that we consider full scaled beam elements (NSRC, BFRC and SFRC) with different lengths, cross sections and different support conditions. The two support conditions used are fixed and simply supported. Total 18 beams were analyzed by varying above mentioned parameters. Each beam is designed on the basis of IS 456 and SP16 provisions. All the beams are analyzed by an externally applied UDL calculated as the sum of its dead load and live load of 9.8kN/m. Thus for all the beams total deformations are obtained. Table 2 shows the specimen details full scale beams.

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Table 2: Specimen details of full scaled beams.

specimens	Size		
	Length (mm)	Breadth (mm)	Depth (mm)
B ₆	6000	250	450
B _{4.5}	4500	250	300
B _{3.5}	3500	220	300

VI. RESULTS AND DISCUSSION

1. Ultimate load carrying capacity, first crack load and ultimate deformation

All the beams are tested under two-point loading test in UTM. Ultimate load carrying capacity and first crack load are noted and it is listed in Table 3. The ultimate load carrying capacity and first crack load are lesser for normal strength reinforced concrete beams than that of fiber reinforced concrete beams. SFRC and BFRC beams have 11.3 % and 9.2 % greater ultimate load carrying capacity than NSRC beams. The analytical studies showed comparable results with that of experimental studies as shown in Table 4. Ultimate deformation obtained from experimental and analytical results were comparable. The maximum percentage difference obtained was 8.9%.

Table 3: Ultimate load carrying capacity and first crack load.

	First crack load in kN				Ultimate load in kN			
	Shear behaviour of beams		Flexural behaviour of beams		Shear behaviour of beams		Flexural behaviour of beams	
	S-1	S-2	F-1	F-2	S-1	S-2	F-1	F-2
NSRC beams	16	14.2	19.6	18	33	32	38	36
BFRC beams	17.3	16.4	22	20.8	36	34.6	41.6	39.2
SFRC beams	18.9	17.5	23.4	21.5	38	37.4	42	40

Table 4: Ultimate load carrying capacity and deformation of all the beams

Specification	Ultimate load carrying capacity(kN)		Percentage difference	Ultimate deformation (mm)		Percentage difference
	Experimental results	Analytical results		Experimental results	Analytical results	
NSRC-F1	38	40.8	7.4	6.38	6.71	5.1
NSRC-F2	36	37.9	8.1	6.07	6.37	5
NSRC-S1	33	35.9	8.6	5.06	5.24	3.6
NSRC-S2	32	34.9	8.8	4.03	4.2	3.9
BFRC-F1	41.6	43.8	5.2	8.47	8.83	3.9
BFRC-F2	39.2	40.7	4	7.98	8.83	8.9
BFRC-S1	36	38.8	7.7	5.98	6.2	3.5
BFRC-S2	34.5	35.4	3.1	5.13	5.32	3.5
SFRC-F1	42	45	7.2	9.25	9.62	4
SFRC-F2	40	41.7	4.4	8.89	9.25	4.1
SFRC-S1	38	40	5.2	6.21	6.43	3.47
SFRC-S2	37.4	39.3	5	5.91	6.13	3.5

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2. Load-deflection behaviour

The central deflections and L/3 deflections of all the beams are noted with respect to 5kN loading intervals. The maximum deflections are obtained at the centre for all the beams. Thus load versus deflection curves are plotted for mid-span deflection. Figure 5 shows load versus deflection curve for NSRC, BFRC&SFRC beams showing flexural and shear behaviour respectively. Initially the graph is linear, then after the first crack the graph become nonlinear. From the load deflection graph, the energy absorption capacity was obtained. From the graphs it's clear that the type of failure is tension failure for all the beams. There is no crushing of concrete before the steel yields. From the graph it's clear that the failure of control specimen occurs earlier than that of basalt and steel fiber reinforced concrete. Flexural and shear behaviour of BFRC and SFRC specimens are better than that of the control specimens.

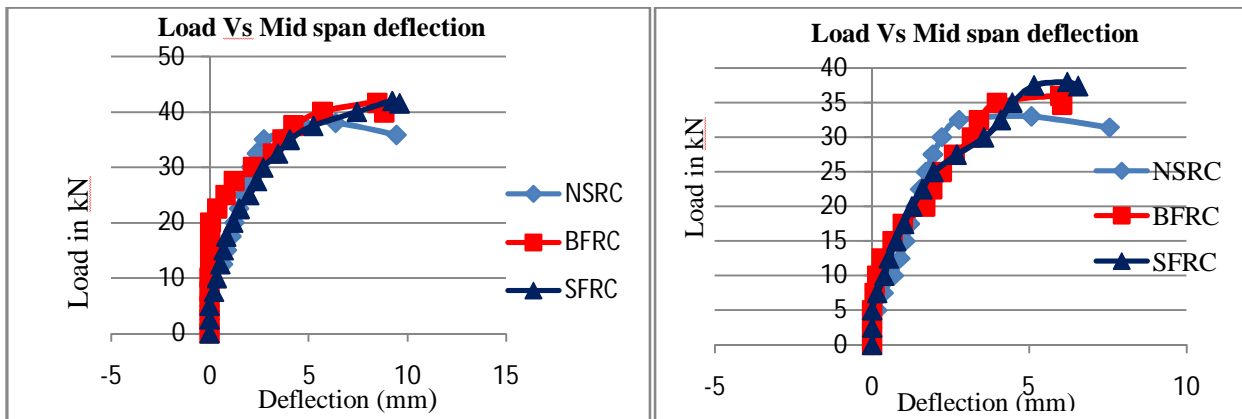


Figure 5: Load versus deflection curve for NSRC, BFRC&SFRC beams showing (a) flexural behaviour (b) shear behaviour.

3. Energy absorption capacity

Present seismic design philosophy relies on energy absorption and dissipation by post elastic deformation for survival in major earth quakes. The energy absorption of the beams was obtained from the load deflection graph. The area under the load deflection graph up to the peak load is taken as the energy absorbed by the beams. Table 5 shows energy absorption capacity of all the beams obtained from experimental and analytical results. SFRC and BFRC beams have 72.5% and 47% greater energy absorption capacity than that of NSRC beams.

Table 5: The energy absorption capacity of all the beams obtained from experimental and analytical results.

Beam specimen	Energy Absorption Capacity (kN-mm)		Percentage difference
	Experimental	Analytical	
NSRC-F1	206	224	8
BFRC-F1	304	324	6.2
SFRC-F1	336	363	7.6
NSRC-S1	143	154	7.5
BFRC-S1	180	197	8.7
SFRC-S1	200	211	4.92

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4. Failure Pattern of Beams

Failure pattern of beams are shown in figure 6. Vertical flexural cracks are formed in the constant-moment region and final failure occurred due to crushing of the compression concrete with certain amount of ultimate deflection. When the maximum load was reached, the concrete cover on the compression zone started to fall for the beams with and without fibers. Crack formations were marked on the beam at every load interval of 5kN at the tension steel level. It was noticed that the first crack always appears close to the mid span of the beam. Out of twelve specimens, six shows shear behaviour and remaining shows flexural behaviour. More cracks were formed for fiber reinforced specimens. The failure modes obtained from experimental and analytical results are almost comparable.

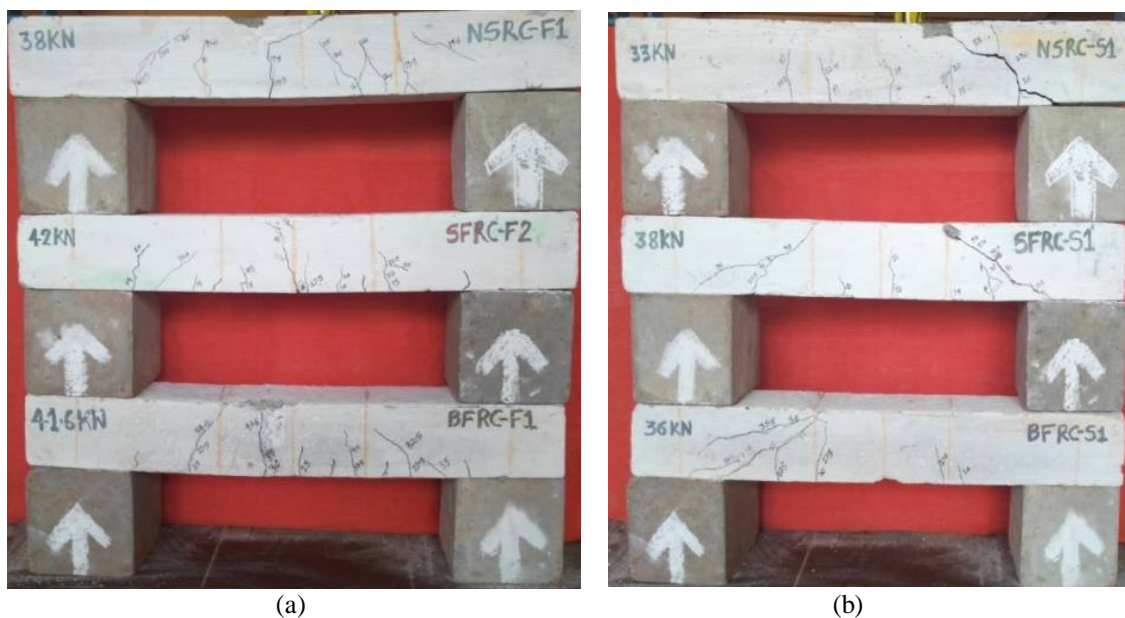


Figure 6: (a) Flexural behaviour of beams and (b) Shear behaviour of beams

5. Full scaled beam elements.

Table 6 shows the ultimate deformation of full scaled beam elements. From the analytical results, the ultimate deformation is very less in SFRC beams which than in BFRF beams and NSRC beams. Hence we can conclude that while adding fibers to the concrete, cracks are arrested and the beam gives warning before it fails. Figure 7 shows ultimate deformation of BFRF and SFRC beams with fixed supports.

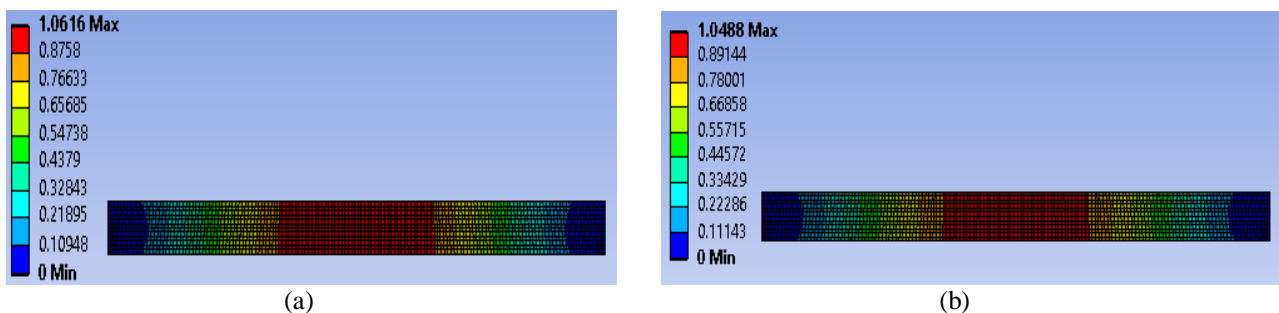


Figure 7: Ultimate deformation of (a) BFRF beam with fixed support and (b) SFRC beam with fixed support

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Table 6: Ultimate deformation of full scaled beam elements

specimens	Beam- B ₆				Beam- B _{4,5}				Beam- B _{3,5}			
	Fixed support		Simply supported		Fixed support		Simply supported		Fixed support		Simply supported	
	Deformation (mm)	% difference	Deformation (mm)	% difference	Deformation (mm)	% difference	Deformation (mm)	% difference	Deformation (mm)	% difference	Deformation (mm)	% difference
NSRC	1.12	-	10.91	-	1.04	-	2.45	-	0.46	-	2.66	-
BFRC	1.06	5.5	9.52	9.8	0.96	7.52	2.28	7.43	0.44	5.42	2.28	14.8
SFRC	1.05	6.9	9.21	9.9	0.94	8.86	2.26	7.76	0.43	7.57	2.21	16.9

VII. CONCLUSIONS

Based on the work presented in this study, the conclusions can be summarized as follows:

1. SFRC and BFRC beams have 11.3 % and 9.2 % greater ultimate load carrying capacity than NSRC beams
2. SFRC and BFRC beams have 4% and 5.6% greater ultimate .deformation than NSRC beams in experimental analysis.
3. The energy absorption capacity of SFRC and BFRC beams are 72.5% and 47% greater than that of NSRC beams in experimental investigation.
4. Also it was found from the failure pattern of the specimens, that the formation minor cracks is more in the case fiber reinforced concrete than concrete without fibers.
5. It shows that the presence of fibers in the concrete acts as the crack arrestors.
6. The ductility characteristics have improved with the addition of fibers. The failure of fiber concrete is gradual as compared to that of brittle failure of plain concrete.
7. The values of ultimate load, total deformation, energy absorption, load-deflection behaviour from experimental studies where comparable for all the beams.
8. Thus, steel fiber reinforced concrete is better in overall comparing with basalt fiber reinforced concrete.

VIII. ACKNOWLEDGEMENT

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