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Experimental Study of Behavior of Fiber Reinforced Concrete Beams

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Abstract: Concrete is currently essentially the most traditionally used construction material. The actual reason of its wide use is because it is easily available, may simply be molded into any appearance, can be inexpensive and possesses a high compressive strength. However it has a little tensile strain capacity which exhibit poor performance in tension and hence it performs in brittle fashion. To overcome these shortcomings, the concrete is reinforced with steel reinforcements. This study has been carried out to generate an experimental data using the mild steel fibers in plain concrete beams and cylinders as well as in conventional reinforced concrete beams.
For the purpose mentioned, a total of twenty cylinders and small beams were prepared. Steel fibers were added in different percentage i.e. 0.1 %, 0.5 % and 1 % along with control samples (0% Fibers) were casted. Concrete mix of 1:1.5:3 was used. The compressive and tensile strength was calculated for all these samples while testing them under the Universal Testing Machine. The results yielded an optimum fiber content of 1% by volume. Similarly, a total of six full scale beams were prepared. These beams were reinforced with conventional reinforcing mild steel bars. Out of these six beams, in four samples the fibers were mixed as secondary reinforcements and in two of fiber reinforced concrete beams silica fume was added as partial replacement of binding materials. The specimens were tested for third point loading, the results were obtained and the final conclusions are drawn.

Keywords: *Steel fibers, Concrete, Beams, Compressive strength, Tensile strength*

1. Introduction:

Concrete is a composite material made of Hydraulic cement, course aggregate, fine aggregate & water. It gains the shape of stone like product due to hydration reaction. The resultant product is very brittle, stronger in compression but weak in tension. For this reason, concrete fractures under very small loads at tension face. Crack development is a result of minimal tensile strength associated with concrete. The technique of providing the fibers in concrete is very effective in boosting the tensile strength of concrete. The fibers capture the crack and prevent their propagation. The fibers are evenly spread and also arbitrarily arranged. This kind of concrete is usually referred as Fiber Reinforced Concrete (FRC).

The orientation and dispersion of fibers plays an important role in transferring the tensile loads across the crack [1]. The deformations on the surface of fibers provide additional mechanical anchorage which is more effective in transferring stress across the cracks [2]. More deformations cause a brittle failure while smooth fibers lead the concrete member in a ductile fashion. [3]

The volume of fibers plays an important role in flexural behavior of concrete beams. A fiber volume from 0.5% up to 2% enhance the post cracking behavior of concrete and control the crack width [4]. The fibers by volume of (1.0 to1.5%) have the ability to improve the flexural strain hardening behavior and can cause multiple minor cracks [5], [6].

Hence this point is important to be noted that there is a fiber saturation point exist above which any addition of fibers in its volume, only marginally improves the behavior of FRC. From past experimental outcomes this limit is around 1.0% [6]. The toughness of plain concrete can also be increased with the higher doses of fibers. The fibers can be used in the range of 0.1% to 3% by volume fraction but above 3% it can leads to low workability [7]. One factor affecting the fiber's performance is length of the fiber L_f. The fibers of shorter length improve the overall response of SFRC [5], [6]. The results of SFRC beams showed that there is a decrease in compressive strength and modulus of Elasticity along with the increase of fiber dosage but there was an increase in tensile strength and toughness.

2. Materials:

In this research, the materials used for preparation of the samples were ordinary Portland cement, sand, crushed stones and mild steel fibers and steel bars.

Fibers:

The mild steel fibers were used. The fibers were prepared from locally available binding wires. The wires were cut in to length of 50mm to 75mm, the diameter is 0.498mm. The aspect ratio ranges from 100 to 150. These binding wires are locally available in the market.

Figure 1 Steel Fibers

Aggregate:
The coarse aggregate were obtained for making the samples from nearby crush machine.

Fine Aggregate:
Locally available sand was used as fine aggregate with the fineness modulus of 2.33.

Cement:
The cement used in the preparation of cylinders, small beams & full scale beams was ordinary Portland cement. The percentage fineness of the cement used is 98.63%.

3. Experimental program:
The experimental program was divided into two stages;
a. Initial testing stage &
b. Final testing stage

Specimen for Initial Testing:
To look for the compressive toughness with the cement 20 cylinders were produced. All of these cylinders were having a height of 300 mm and diameter 150 mm.
Similarly, a total of 20 small beams were prepared following the same procedure as for cylinders to determine the tensile strength of concrete. These beams were of size 150mm×150mm×300mm. The details for these beams is shown in figure 2

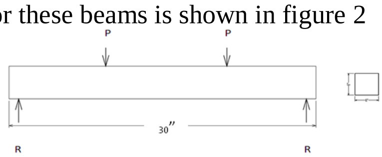

Figure 2 Small beams for modulus of rupture

Specimen for Final Testing:
For studying the behavior of fiber reinforced concrete, six beams are prepared. Out of these six beams two are conventionally reinforced with steel bars, in two the steel fibers with addition to steel bars are added in concrete. In the remaining two beams the same proportions were maintained but in addition to cement silica fume was also added. All these beams were reinforced with 4, #4 bars at the bottom and 2, #4 bars at the top. Also they were reinforced for shear with #3, 2 legged stirrups 15 cm c/c. All the samples are having a cross section of 300 mm×300 mm and a length of 1800 mm. The details of reinforcement and cross section are shown in figure 3

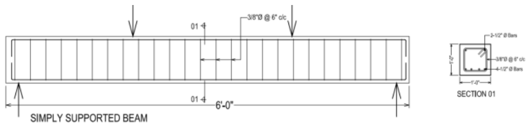

Figure 3 Full-scale beam samples

4. Experimental testing:
a. Initial Testing:
The test setup for initial Testing is shown in figure 4

Figure 4 Assemblage for small beams

To determine the Compressive and Tensile Strength, cylinders and small beams were tested in Universal Testing Machine (UTM). The capacity of UTM is 200 Tons. Four different types of mix were made for cylinders & beams. One named as Control Sample without Steel Fibers and three with different percentage of steel fibers, i.e. 0.1%, 0.5%, 1%. The samples were prepared with mix ratio of 1: 1.5: 3. The samples were casted & demolded after 24 hours. Proper curing procedure was adopted and tested after 28 days for Compressive and tensile strength. The results were obtained and final stage testing specimens were fabricated on basis of the initial testing results.

b. Final Testing:
Out of these six beams, two were reinforced with conventional reinforcing bars; two beams were fabricated with mild steel fibers as secondary reinforcement. The other two beams were fabricated with fibers but in addition to cement 8% of silica fume was added during the mixing operation of concrete. The table shows the composition details of beam specimens.

Table11: Details for compositions of full-scale beams

Specimen label	Reinforcement details	Binding materials
ORCB1	Reinforcing bars	Cement
ORCB2	Reinforcing bars	Cement
FRCB1	Reinforcing bars, Steel fibers	Cement
FRCB2	Reinforcing bars, Steel fibers	Cement
SFRCB1	Reinforcing bars, Steel fibers	Cement, Silica fume
SFRCB1	Reinforcing bars, Steel fibers	Cement, Silica fume

The third point loading test was performed on the beams of 300mm×300mm of cross-section and 1500 mm clear span length to characterize and compare the behavior of all beams in flexure. To distribute the single load from actuator, two steel rods of diameter 38 mm were used as rollers and were placed at one third span length of beam. On these rollers, a rigid steel beam of depth 200 mm was placed to transfer the load to two rollers. The beams were mounted to roller support through chain pulleys of five tons capacity. An actuator of 25 Tons capacity was installed at the mid span of beam. An LVDT was also installed at mid span of the beam to collect mid span deflection values at different loading stages. Before application of load, the LVDT was checked and was initialized to zero. Similarly a data logger was connected to hydraulic actuator and LVDT to record different load values and corresponding deflection values. The load was gradually applied on beam specimens at a rate of 5 T/min.
After appearing of first crack, the application of load rate was reduced to 3 T/min to detect the correct pattern of cracks. After appearing of first crack, the beams were loaded to formation of plastic hinge to compare the highest load carrying capacity of test specimens.

5. Results and discussion:

Initial testing stage:

The Initial Tests were conducted on cylinders & beams. The results obtained after testing are presented as under.

Table 2 Average Compressive Strength

	Percentage of Steel Fibers			
	Control Sample 0%	0.1%	0.5%	1%
Average Compressive Strength	26.78	26.61	26.38	25.68

Table 3 Average Tensile Strength

	Percentage of Steel Fibers			
	Control Sample 0%	0.1%	0.5%	1%
Average Tensile Strength	4.46	4.64	4.90	5.07

It was aimed to inspect the effect of fibers on compressive & flextural strength. There was a gradual decrease in the compressive strength with increase in fiber content. While in case of tensile strength, the Tensile Strength increased with the increase of fiber content. The failure mode of both small plain & fiber reinforced concrete beams are different. At failure load, the plain concrete beams were splitted into two portions while reputre was occurred in fiber reinforced beams. The beams of 1% volume fraction fibers behaved in a best mode. Their failure mode and failure load were quite different from all other beams.

Final Testing Stage:

Six full scale beams are tested in this phase of testing. The specimens were tested for third point loading after 28 days.

a) Ordinary Reinforced Concrete Beams

For comparison purpose, two concrete beams reinforced with ordinary reinforcing bars were prepared. The concrete was in the same proportion as in small beams and cylinders. The load-deflection curve of both beams is presented in figures 5 and 6

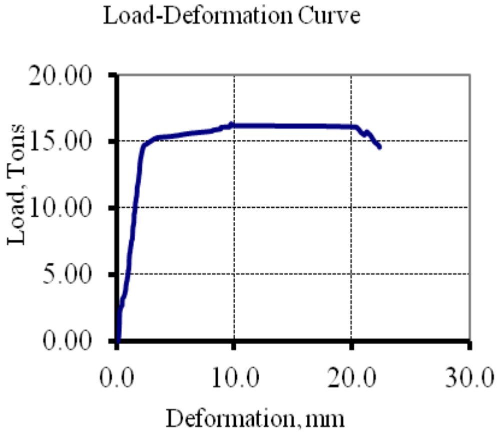

Figure 5 Test results of ORCB1

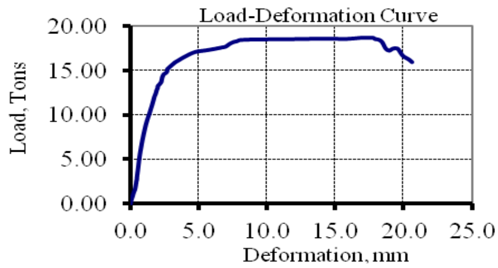

Figure 6 Test results of ORCB2

a) Fiber Reinforced Concrete Beams (FRCBs)

In this phase of testing two full-scale beams were made. These specimens were having same concrete compositions, same dimensions and steel ratio as ORCB$_S$ but these are differentiated only on provision of secondary reinforcements i.e. fibers. The fibers were added 1% by volume fraction. For comparison purpose the testing procedure of these samples was also kept same as that for ORCB$_S$. The load-deflection curves of these two samples are shown in figures 7 and 8

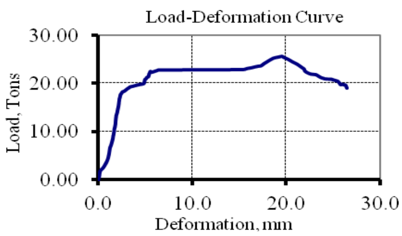

Figure 7 Test result of FRCB1

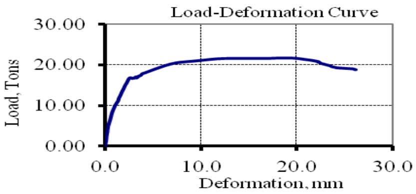

Figure 8 Test result of FRCB2

b. Fiber Reinforced Concrete Beams with Silica Fume (SFRCBs)

This pair of beams is having same dimensions and same proportion as the previously tested samples. To study the effect of silica on behavior of FRC beams, 8% silica was also added to the mix in addition to cement. The test results of these beams are shown in figures 9 and 10

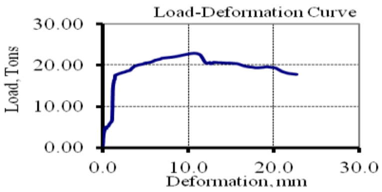

Figure 9 Test results of SFRCB1

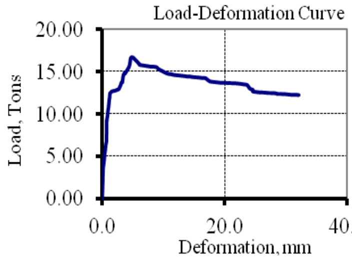

Figure 10: Test results of SFRCB2

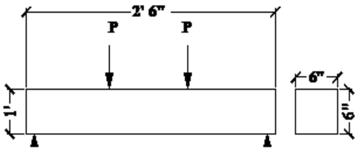

Figure 11: Dimensions of the test specimen

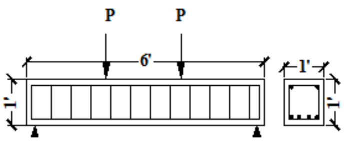

Figure 12: Loading arrangement and reinforcement

6. Analysis of results:

From the load-deflection curve of full-scale beams, it is clear that there is arousing difference in the behavior of ordinary reinforced and fiber reinforced beams. Hence a comparison of strength and percent increase in strength of all the beams is shown in table.

Table 4: Comparison of strength and average strength of all beams

Specimen label	Reinforcement details	Ultimate load (KN)	% increase in strength (Tons)
ORCB1	Reinforcing bars	173.4408	0.000
ORCB2	Reinforcing bars	182.6524	5.311
FRCB1	Reinforcing bars, Steel fibers	252.4309	45.543
FRCB2	Reinforcing bars, Steel fibers	212.3276	22.421
SFRCB1	Reinforcing bars, Steel fibers	226.1499	30.390
SFRCB1	Reinforcing bars, Steel fibers	174.0392	0.345

All the beams behaved different in term of first crack load. The first crack in all beams started at different load. A comparison of first crack load of all samples is made in table.

Table: Comparison of first crack load for different samples

Specimen label	Reinforcement details	First crack load (KN)
ORCB1	Reinforcing bars	144.6975
ORCB2	Reinforcing bars	145.7374
FRCB1	Reinforcing bars, Steel fibers	174.0294
FRCB2	Reinforcing bars, Steel fibers	165.1415
SFRCB1	Reinforcing bars, Steel fibers	172.244
SFRCB1	Reinforcing bars, Steel fibers	122.9193

The toughness values of beams at different values of deflection are

Table 5: Toughness of beams at different maximum deflection values

Specimen label	Toughness (Joules)			
	Max allowable deflection			
	L/480	L/360	L/240	L/180
ORCB1	1506.3	2610.44	5584.87	6886.5
ORCB2	1767.32	2047.92	3032.87	6220.75
FRCB1	2293.16	4903.8	6214.96	7208.705
FRCB2	1857.75	3467.72	6016.73	7088.31
SFRCB1	2639.59	3873.62	5830.931	8204.36
SFRCB1	1173.53	2340.83	3794.44	4197.94

7. Conclusion and recommendations:

From this study the following recommendations and conclusions are drawn:

- With the use of steel fibers an appreciable decrease in slump was observed which confirmed that more internal friction was developed and needed more energy for a given degree of compaction as compared to plain concrete at fixing of some other parameters.
- Unconfined compression test showed that gradual increase in fiber contents caused a reduction in compressive strength, which may be due to either high degree of porosity of concrete or contribution of steel fibers in compression.
- The tensile strength of small concrete beams in modulus of rupture test was observed to increase up to 14.5%.
- An appreciable reduction in displacement is noted at first crack along with increase in load for all of the beams.
- In post cracking zones the crack size of fiber reinforced concrete was small in comparison with ordinary reinforced concrete.
- The toughness of FRC beam samples was found to increase up to 17%.
- The first crack load was found to increase up to 17.7% along with reduction in deflection at mid span of samples.
- The overall performance of fiber reinforced concrete beams was increased up to 17% with an increase in up to 28.3% in cost from which it is clear that it is cost effective in special cases.

Recommendations:

The mild steel fibers can be recommended in the following scenarios:

- Where the environment remains moist for most times of the year.
- Where the sand is contaminated with salts and hazard of Alkali-Silica Reaction is there.
- In hot weather concreting where there is accelerated evaporation and the fresh concrete shrinks extensively.
- Similarly, a list of recommendations is given for future research work
- Further research should be conducted for studying the effect of different sizes of mild steel fibers on slump of concrete mix, compressive strength as well as for tensile strength.
- To study the effect of different sizes of fibers on first crack strength of beams, their toughness and deflection.
- To investigate the possible reduction in beams section with the use of steel fibers without violating the serviceability criteria.
- To develop different guidelines for each size of mild steel fibers for workable concrete, optimum content of each size of fibers for their utility and for compressive strength as well as for tensile strength of concrete.
- To develop empirical formulas which also account for imparting of steel fibers in flexure and shear.
- To study for the possible reduction in reinforcements for flexure and shear in corbels

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Notations and List of Abbreviations:

ASTM: American Society of Testing and Materials
ACI Codes: American Concrete Institute codes
μm: Micrometer
MPa: Mega Pascal
FRC: Fiber Reinforced Concrete
SFRC: Steel Fiber Reinforced Concrete
AR_f: Aspect ratio of Fibers
V_f : volume fraction
f'_c : Crushing strength of concrete
τ_{max}: Maximum shear stress
Δ_{max}: Maximum vertical Deflection
L_f: Length of Fiber
N_f: Number of Fibers
KN: Kilo Newton
UTM: Universal Testing Machine
FM: Fineness Modulus
LVDT: Linear Variable Displacement Transducer
ORCB: Ordinary Reinforced Concrete Beams
FRCB: Fiber Reinforced Concrete Beams
SFRCB: Fiber Reinforced Concrete Beams with Silica fume