A Study on Shear and Flexure Behavior of Fiber Reinforced Concrete T-Beams

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Abstract— The failure of reinforced concrete structural member which are not reinforced in the web is sudden and catastrophic. Shear reinforcement ensures reasonable ductility and possible suppression of shear failure. Shear reinforcement is provided in the form of stirrups, bent up bars, or by fixing steel plates in the shear zone. Studies in last few decades indicated that the use of steel fibers as shear reinforcement in reinforced concrete beams appears attractive due to the enhancement of first crack tensile strength and ultimate tensile strength, resulting in increase in shear strength and possible prevention of shear failure.

Key words: Steel Fiber, SFRC Beams, Ductility

I. Introduction

A structural member may, in general, be subjected to , shear, axial thrust or tension, and torsion, or a combination of these forces. Shear effects are generally combined with flexural effects.

The failure of reinforced concrete structural member which are not reinforced in the web is sudden and catastrophic. Hence, it is desirable to have a beam develop its design flexural resistance before premature failure occurs in shear. For this purpose shear reinforcement is very essential. Shear reinforcement ensures reasonable ductility and possible suppression of shear failure. Shear reinforcement is provided in the form of stirrups, bent up bars, or by fixing steel plates in the shear zone. The presence of stirrups improves the shear resistance in several ways. First, the stirrups themselves contribute to the resistance; secondly, they help in preventing the widening of the diagonal cracks thus ensuring better aggregates inter lock. They also improve the dowel action by supporting the tension reinforcement at intermediate points.

This investigation was designed to provide a comprehensive experimental and analytical evaluation of steel fibers as shear reinforcement.

A total of eight beams of identical nominal dimensions bf = 250, b_w = 100, Df = 50mms were casted and tested with two concentrated loads placed in shear span of the beams. Under flexural load up to complete collapse the steel fiber reinforced concrete (SFRC) beams consists of 2-8mm 0 steel bars in tension zone. In this investigation span/depth ratio, aspect ratio of fibers (80) and volume percentage variation from 0.5% to 1.25% are made.

II. Objective of Study

To study the structural behavior of fibrous and non-fibrous beams. The characteristics, like cracking load, ultimate load/ load deflection, behavior shear and strains on concrete surface and cracking patterns were studied rigorously. Economics of fibrous concrete was also studied.

III. Analysis for Shear

A. *Pre Cracking Shear Resistance of RC Beam*

f = MY/I and v = VAY/Ib

Principle Tension

$$f_1 = 0.5\left(f + \sqrt{f^2 + 4v^2}\right)$$

Principle Compression

$$f_2 = 0.5\left(f - \sqrt{f^2 + 4v^2}\right)$$

The inclination "0" of the principle tensile stress with respect to the bending axis is given by: Tan 2θ = 2v/f

B. *Post Cracking Shear Resistance of RC Beam*

(Classical Approach):

Shear stress is calculated using the formula.

v = V/bd.

C. *Post Cracking Shear Resistance of RC Beam (Mechanical Approach)*

$$V = V_C + V_d + V_a + V_S$$

V_d and V_a can be neglected.

The design formula adopted in IS 456 – 1978, for estimating the permissible shear strength of concrete is; V_C =

$$0.85\ \sqrt{0.8 f_{ck}}\ \left(\sqrt{1+5\beta}-1\right)/6\beta$$

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and for vertical stirrups

$$V_S = 0.87\ f_y\ A_V/Sb$$

D. *Post Cracking Shear Resistance of SFRC Beam (Mechanism Approach)*

The shearing force V may be equated to:

$$V = V_a + V_C + V_d + V_f$$

IV. Analysis for ultimate shear strength

SHARMA in (1996) assumes that the ultimate shear stress is the sum of the contribution to shear by the stirrups (V_S) and fiber (V_{cf}).

$$V_u = V_{cf} + V_S$$

$$V_{cf} = Kf'_t\,(d/a)^{0.25}$$

$$V_S = A_S f_y d/s$$

In which (d/a) is the effective depth to shear span ratio f'_t is the tensile strength of concrete obtained from the results of indirect tension test on 150 x 300mm cylinder and K is a constant equal to 2/3. SHARMA also suggests that the tensile splitting strength f^l_t can be obtained from compressive strength by: $f^l_t = 9.5\,(f^l_c)^{0.5}$ Where both f^l_t and F^l_c are in P_{Si}.

A. Shear Capacity of Fiber Content & Plasticity Theorem

The lower and upper bound limit state solutions for simply-supported beams with vertical or inclined stirrups subjected to symmetrical concentrated loads or single concentrated load are given by NELSON (1984) and CHEU (1982) as under:

$$C / f^{1}_{c} = \sqrt{\phi(1-\phi)} \qquad \text{for } \phi \leq 0.5$$

$$= 0.5 \qquad \text{for } \phi \leq 0.5$$

Where $\phi = r_f f_y / f^{1}_{c}$ and is called the degree of shear reinforcement.

To compare the test data with the lower bound theorem requires the introduction of an effective strength factor □ (0 < □ < 1.0). The lower bound theorem in terms of the effective shear strength is :

$$C / f\,l\,c = \sqrt{\phi(\mu-\phi)} \qquad \text{for } \phi \leq 0.5$$

$$= 0.5 \qquad \text{for } \phi > 0.5$$

Where $\mu = 0.8 - (f^{1}_{c} / 200)$

The extent the value of is affected by fibers is slight because the fibers do not increase the compressive strength very much. Research needs to be done on determining the appropriate value of for fiber concrete.

V. RESULTS

A. Test Results of Material

Sl. No.	*Test*	*Results*
1.	*Cement*	*7.2% retained on 90u*
i)	*Fineness*	*IS Sieve*
ii)	*Consistency*	*29.5% Mass of Cement*
iii)	*Initial Setting Time*	*67 Minutes*
iv)	*Specific Gravity*	*3.15*
2.	*Coarse Aggregate*	
i)	*Shape Test*	
a)	*Flakiness Index*	*26.77%*
b)	*Elongation Index*	*89.55%*
c)	*Angularity Index*	*6.168%*
ii)	*Bulk Density*	*1.695 Kg/Lit.*
iii)	*Voids*	*39.18%*
iv)	*Max. Nominal Size*	*10mm*
v)	*Impact Value*	*5.952%*
vi)	*Specific Gravity*	*2.65*
3.	*Fine Aggregate*	
i)	*Fineness Modulus*	*2.65*
ii)	*Specific Gravity*	*2.7*

Table 1: Properties of cement

(Source: Indian rayon & industries limited, gulbarga – Karnataka, India)

Sl. No.	Test	Results
1.	Specific Gravity	3.15
2.	Normal Consistency	29%
3.	Soundness(LeChatelier)	1.00mm
4.	Setting Time in Minutes	
	a) Initial	125
	b) Final	215
5.	Compressive Strength	
	a) 3 Days	39.5 N/mm^2
	b) 7 Days	52.5 N/mm^2
	c) 28 Days	71.0 N/mm^2
6.	Fineness (Specific Surface)	3050 cm/gm

Table 2: Results

B. Concrete Mix Design

The mix proportion adopted for the test beams is

Cement	**Sand**	**Coarse Aggregate**	**Water Cement Ratio**	**Aspect Ratio**
1	1.55	2.54	0.5	80

Table 3(a): Fine Aggregate Grading

IS Sieve Designaton	**Grading Zone I**	**Grading Zone II**	**Grading Zone III**	**Grading Zone IV**
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600 Micron	15-34	35-59	60-79	80-100
300 Micron	5-20	8-30	12-40	15-50
150 Micron	0-10	0-10	0-10	0-15

Table 3(b): Target Design Strength of Concrete

Grade of Concrete	Assumed Standard Deviation for a 'Good' Degree of the Control MPa	Target Design Strength MPa
M 15	3.5	21
M 20	4.6	28
M 25	5.3	34
M 30	6.0	40
M 35	6.3	46
M 40	6.6	51
M 50	7.4	62
M 60	7.8	73

Table 3(c): Approximate Entrapped Air Content

Nominal Maximum Size of Aggregate mm	Entrapped Air, as Percent of Volume of Concrete
10	3.0
20	2.0
40	1.0

Table 3(d): Approximate sand and water contens per cubic metre of concrete W/C = 0.60, workability = 0.80 CI. (Applicable for concrete up to Grade M 35)

Maximum Size of Aggregate (mm)	Water Content Per Cum. of Concrete (Kg.)	Sand as % of Total Aggregate by abs.
10	200	40
20	186	35
40	165	30

Table 3(e): Approximate sand and water contens per cubic metre of concrete W/C = 0.35, workability = 0.80 cf. (Applicable for concrete up to Grade M 35)

Maximum Size of Aggregate (mm)	Water Content Per Cum. of Concrete (Kg.)	Sand as % of Total Aggregate by abs.
10	200	28
20	190	25

Table 3(f): Test Results

VI. CALCULATION OF MATERIALS

A. Steel

Sl. No	Particulars	No. of Beams	No. of Rods Per Beam	Length of Rod Per Beam	Unit Wt. Kg/m	Qty/Kgs	Rate/Kgs	Amount
1.	Tension Steel	8	2	2	0.88	29	20	580
2.	Comp. Steel	8	2	2	0.39	13	20	260
3.	Stirrups @ 150mm C/C	8	13	0.55	0.22	12	20	260
4.	Binding Wire	8	-	-	-	5	26	130

Table 4: Calculation of Steel

B. *Fiber*

Sl. No	Particulars	No. of Beams	Volume of one Beam	% of Fiber	Unit Wt. Fiber/m^3	Qty/ Kg	Rate/ Kg	Amount
1.	B_1 (0.5% by Vol) of Concrete	2	0.065	0.5	7860	5.1	36	184
2.	B_2 (1% by Vol) of Concrete	2	0.065	1	7860	10.2	36	367
3.	B_3 (1.25% by Vol) of Concrete	2	0.065	1.25	7860	12.8	38	460

Table 5: Calculation of Fiber

C. *Cement*

Sl. No	Particulars	No. of Beams	Volume of one Beam	% of Fiber	Unit Wt. Fiber/m^3	Qty/Kg	Rate/Kg	Amount
	CEMENT	8	0.065 x 0.2986	-	1440	2245 Bag	145	725

Table 6: Calculation of Cement

D. *Sand*

Sl. No	Particulars	No. of Beams	Volume of one Beam	% of Fiber	Unit Wt. Fiber/m^3	Qty/Kg	Rate/Kg	Amount
	CEMENT	8	0.065 x 0.4628	-	-	0.24m^3	188/m^3	45

Table 7: Calculation of Sand

E. *Coarse Aggregate*

Sl. No	Particulars	No. of Beams	Volume of one Beam	% of Fiber	Unit Wt. Fiber/m^3	Qty/Kg	Rate/Kg	Amount
1	(Ballast Stone Hard)	8	0.065 x 0.7586	-	-	0.70m^3	290/m^3	116
								3127-00
2	Form Work	-	-	-	-	-	L.S.	2000-00
3	Labor for Lifting of beams on loading frame	(8x80)					L.S.	640-00
4	Labor for curing etc.						L.S.	300-00
						TOTAL		**6066-00**

Table 8: Calculation of Coarse Aggregate

Designation of Beams	% of Vol. of Fiber	Av. Crushing Load	Av. Compressive Strength	Grade of Concrete
B_0	0%	49.66 N	22 N/mm^2	M20
B_1	0.5%	56 N	24.8 N/mm^2	M20
B_2	1%	57.66 N	25.6 N/mm^2	M20
B_3	1.25%	65.33 N	29.0 N/mm^2	M20

Table 9: Increase in compressive strength with the increase in fiber percent

It shows that there is increase in compressive strength with the increase in fiber percent.

Designation of Beam	% of Fiber	Grade of Concrete	Av. Crushing Load N	Av. Camp. Strength (Actual)	Expected Comp. Strength Designed	Spacing 6mm of Stirrups	ri = $\frac{f_y A_{sv}}{b.SV}$
B_0	0%	M20	49.66 x 10^4N	22 N/mm^2	20 N/mm^2	150mm C/c	0.9423
B_1	0.5%	M20	56 x 10^4N	24.8 N/mm^2	20 N/mm^2	150mm C/c	0.9423
B_2	1%	M20	57.66 x 10^4N	25.6 N/mm^2	20 N/mm^2	150mm C/c	0.9423
B_3	1.25%	M20	65.33 x 10^4N	29.0 N/mm^2	20 N/mm^2	150mm C/c	0.9423

Table 10: Details of Specimen Beams

Beam No.	Cra ck No.	Width	Distance from Centre	Heig ht from	Remaks

				Bot	
Beam1 0%	1	10mm	550mm to R	186	Shear

	2	3mm	205mm to L	182	Shear
	3	2.5mm	452mm to R	152	Shear
	4	2.5mm	262mm to R	156	Shear
	5	2.6mm	457mm to L	86	Shear
	6	2.1mm	255mm to L	180	Flexure
Beam2 0%	1	18mm	502mm to R	184	Shear
	2	12mm	457mm to R	86	Shear
	3	3mm	357mm to R	92	Shear
	4	2.5mm	554mm to L	182	Shear
	5	2mm	567mm to L	172	Shear
	6	2mm	672mm to R	181	Shear
	7	2.1mm	236mm to L	66	Flexure
Beam1 0.5 %	1	12mm	562mm to R	189	Shear
	2	2mm	584mm to R	66	Shear
	3	2mm	288mm to L	181	
	4	1.6mm	189mm to L	92	Flexure
	5	1.72mm	583mm to R	52	Shear
Beam2 0.5 %	1	12.5mm	84mm to C	184	Flexure
	2	13mm	87mm to C	67	Flexure
	3	2.2mm	510mm to L	98	Shear
	4	2mm	515mm to R	102	Shear

Table 11: Propagation of Cracks, their Width and Distance from Centre

Beam No.	Crack No.	Width	Distance from Centre	Height from Bot	Remarks
Beam2 0.5 %	1	13.5mm	32mm to C	192	Flexure
	2	13mm	38mm to C	180	Flexure
	3	5mm	28mm to C	171	Flexure
	4	1.75mm	555mm toR	187	Shear
	5	2.5mm	558mm toL	191	Shear
	6	2mm	551mm toL	162	Shear
Beam2 1 %	1	13mm	42mm to C	168	Flexure
	2	2.5mm	48mm to C	172	Flexure
	3	2.6mm	238 mm to L	161	Flexure
	4	2mm	45mm to C	178	Flexure
	5	1.56mm	555mm to R	102	Shear
	6	1.82mm	38mm to C	66	Flexure
	7	1.2mm	602mm to L	52	Shear
Beam1 1.25%	1	10mm	172mm to R	58	Flexure
	2	8mm	186mm to R	52	Flexure
	3	5mm	165mm to L	167	Flexure
	4	3mm	192mm to L	152	Flexure
	5	2mm	66mm to R	560	Shear
	6	2mm	66mm to L	869	Shear
Beam2 1.25%	1	8mm	182mm to L	152	Flexure
	2	6mm	192mm to L	147	Flexure
	3	5mm	202mm to L	132	Flexure
	4	3mm	89mm to R	142	Flexure
	5	2mm	101mm to C	22	Flexure
	6	1.86mm	66mm to R	562	Shear

Table 12: Propagation of Cracks, their Width and Distance from Centre

Sl. No.	**Design of Beam**	**Fiber Volume**	**Observed Load at First Crack**	**Observed Load at Failure**	**Shear at Ultimate**	
					Test	**Theory**
1.	B_0	0%	50 KN	70 KN	35 KN	32.6 KN
2.	B_0	0%	55 KN	75 KN	37.5 KN	32.6 KN
3.	B_1	0.5%	85 KN	106 KN	53 KN	37.4 KN
4.	B_1	0.5%	86 KN	107 KN	53.5 KN	37.4 KN
5.	B_2	1%	90 KN	98 KN	49 KN	37.5 KN
6.	B_2	1%	89 KN	112 KN	56.0 KN	37.5 KN
7.	B_3	1.25%	95 KN	115 KN	57.5 KN	38.0 KN
8.	B_3	1.25%	97 KN	124 KN	61 KN	38.0 KN

Table 13: Beam Test Results

Load	**B_0 0%**		**B_1 0.5%**		**B_2 1%**		**B_3 1.25%**	
	S^*_C	**S^*_L**	**S_C**	**S_L**	**S_C**	**S_L**	**S_C**	**S_L**
0.2	0.45	0.4	0	0	0	0	0	0
0.4	0.55	0.6	0.30	0.25	0	0	0	0
0.6	0.68	0.75	0.32	0.3	0.2	0.2	0	0
0.8	0.87	0.90	0.38	0.32	0.3	0.25	0.2	0.25
1.0	1.05	1.5	0.55	0.45	0.35	0.35	0.4	0.3
1.2	1.25	1.55	0.75	0.65	0.45	0.50	0.6	0.35
1.4	1.40	1.60	1.20	0.85	0.65	0.55	0.85	0.42
1.6	1.60	1.65	1.27	1.25	0.85	0.85	1.25	0.55
1.8	1.75	1.70	1.65	1.45	1.30	0.90	1.30	0.62
2.0	2.00	1.80	1.7	1.6	1.5	1.4	1.4	0.75
2.2	2.18	2.0	1.78	1.70	1.60	1.25	1.55	0.8
2.4	2.35	2.10	1.85	1.85	1.65	1.42	1.60	1.0
2.6	2.45	2.4	2.0	1.40	1.72	1.65	1.75	1.1
2.2	2.6	2.7	2.15	2.4	1.85	1.70	1.80	1.25
3.0	2.8	2.8	2.35	2.80	2.2	1.85	1.90	1.35
3.2	3.4	3.25	2.47	2.70	2.45	2.0	2.20	1.4
3.4	3.64	3.40	2.82	2.95	2.60	2.25	2.4	1.54
3.6	3.80	3.65	3.40	3.0	2.81	2.50	2.65	1.65
3.8	3.92	3.7	3.42	3.1	2.9	2.65		1.7
4.0	4.0	3.8	3.5	3.2	3.0	2.8	2.8	1.6

Table 14: Load and Defection

First Crack Load = 55KN
First Crack Load = 85KN
First Crack Load = 90KN
First Crack Load = 95KN
Ultimate Load = 75KN
Ultimate Load = 107 KN
Ultimate Load = 112 KN
Ultimate Load = 124 KN
S_C = Deflection at Centre
S_L = Deflection at Load Point

Depth of Beam (mm)	B_0		B_1		B_2		B_3	
	Load	Centre	Load	Centre	Load	Centre	Load	Centre
12.5	+ 1.86	+ 1.89	+ 1.83	+ 1.84	+ 1.61	+ 1.76	+ 1.58	+ 1.63
0.0	+ 0.76	+ 0.83	- 0.72	+ 0.81	- 0.63	- 0.71	- 0.63	- 0.69
12.5	- 2.07	- 2.11	- 2.01	- 1.98	- 1.92	- 1.82	- 1.67	- 1.74

Table 15: Strain reading (S (10^{-4}) at load 60 KN Compression (+Ve) Tensile (-Ve)

VII. Conclusion

1) The test results have indicated that with an optimum percentage of fiber 1.25% by volume of concrete has shown increase in the shear carrying capacity of the flanged (T-Section) as 60 to 70% as compared with conventional RC Beam.
2) Flexural failure has been observed in the beam B2 (1%) and B3 (1.25%). This shows that with the addition of fiver the shear strength of the beams has increased.
3) Another advantage of addition of fiber is the shear reinforcement provided as vertical stirrups with a minimum spacing of 150mm C/C as per code provision also can be increased from 150mm to 250mm C/C.
4) For 1% of steel fibers by volume of concrete, result have shown good workable concrete in comparison to 1.25% by volume of concrete.
5) The ultimate load increases with the increase of volume of fibers restricted to 2% steel fibers by volume of concrete, as the uniform stresses are developed due to addition of fibers.
6) It is economical since it has the above properties by which we can reduce the concrete section and the stirrups also.

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