Comprehensive Study on the effect of Discrete Steel Fibre in Short Beams

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Abstract*: Considerable research has been conducted on the shear strength of Fibre Based Concrete, but the debate as to the effect of major variables on the cracking and ultimate shear strength has yet to be unequivocally established. Although in this study the increase in compressive strength of concrete was found marginal through the addition of fibers, yet the increase in Modulus of rupture (Flexural tensile strength) was found to be significantly large (nearly 50% for fiber addition of 1 %). The load-deformation response (stress-strain profile) drawn up for fiber-based concrete, clearly indicate that sufficient amount of ductility in induced in brittle concrete through the addition of fibers rendering the material tough from a seismic point of view. The results of a good number of beam elements which were tested to investigate the influence of steel fibers on the shear and deformation characteristics of Fibre Based Reinforced Beam Elements have been presented. Variables studied include fiber content and tensile reinforcement ratio. It was found that increased cracking and ultimate shear strength and improved ductility largely depends on the volume fraction of fibers. The beam elements with a reinforcement ratio of 1% which failed in shear; exhibited pure moment failure at a fiber content of 1 %. Nonetheless, the Fibre based beams which failed in Flexure and Flexure-Shear mode, did exhibit sufficient ductility. The results were compared with Indian and British Codes and showed good agreement. The results of the Indian Code were found on much conservative side than those of British Code.

Keywords: Fibre based Concrete, Fibre Content, Reinforcement ratio, Shear Strength, Fibre Balling

Notation

A	=	*shear span, mm*
d	=	*effective depth, mm*
vu	=	*ultimate shear strength of FRC, MPa*
Vcr	=	*cracking shear strength*
M	=	*bending moment at the section, N-mm*
V	=	*shear force at the section, N*
Vf	=	*volume fraction of fibers*
ρ	=	*tensile reinforcement ratio*

I. INTRODUCTION

In reinforced concrete beam elements under flexure and shear, a biaxial state of combined tension and compression exists at various points giving rise to principal tensile and compressive stresses [1] [2] [3]. In the event of high shear stress (due to heavy concentrated loads) and relatively low flexural stresses, it is likely that the maximum principal tensile stress is located at the neutral axis level at an inclination of 45 degree to the beam axis, which when exceeds tensile strength of concrete, results in the formation of inclined cracks near the support where shear is maximum and are termed as web shear or diagonal cracks [4] [5]. a beam element B-1(Fig. 1), 400 mm deep, carrying 4-12 mm diameter as tension reinforcement was tested in the laboratory under four-point loading system (shear span = 300 mm). The beam exhibited web shear failure which took place suddenly with a loud sound.

But in beams with a moderate amount of shear reinforcement, shear resistance continues to increase even after inclined cracking, until the shear reinforcement yields in tension [6] [7]. Owing to sufficient yielding of the shear reinforcement, the failure is gradual and ductile in nature. But in the event of high shear reinforcement to resist heavy shear forces (transfer beams), it is likely that prior to yielding of shear reinforcement, the concrete in the compression zone gets crushed resulting in shear compression mode of failure. This is quite undesirable as the failure will occur suddenly without warning.

Thus in both the cases i.e. in beams with and without shear reinforcement, when subjected to heavy shear stresses, the mode of shear failure could be sudden, brittle and treacherous [8] [9] [10]. Thus shear reinforcement alone is not sufficient to avoid such a failure. This should not be permitted at all and hence enforces to look for an alternative treatment rather than providing excessive shear reinforcement alone, in order to avoid such a catastrophic shear failure in the event of heavy shear stresses [11].

There is a little reason to doubt that the random distribution of a small volume percentage, less than 2.5 percent, of high strength ductile fibers in low strength brittle concrete significantly improves many of the mechanical properties of plain and reinforced concrete [12] [13]. The fibers create an effective crack arresting mechanism which improves the pre and post-cracking properties. The fibers add softness to plain concrete and tend the concrete to behave more or less resembling to timber elements. Fig. 3 shows a steel fiber based concrete cylinder (1 % volume fraction, 0.45 mm diameter and 30 mm long crimped fibers), tested for split cylinder strength in a compression testing machine of 200-ton capacity. The compression edges (curved in geometry) instead of crushing directly, were initially compressed into a flat surface as is true in case of timber elements. This shows the flexibility imparted through fibers in concrete. The enhanced mechanical properties of steel fiber based concrete referred to as FBC hereafter; can be used to improve the structural response of beam elements. A very promising application is the use of steel fibers for shear reinforcement and for improving the ductility of concrete. Unlike other fibers, steel fibers impart both strength and ductility to the concrete matrix. Test data have shown that steel fibers by themselves or in combination with conventional shear reinforcement can provide sufficient shear capacity for beams to fail in ductile flexural manner. Batson et el (1972) tested 96

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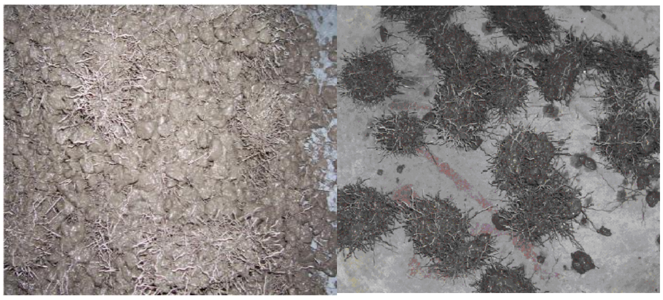
simple span beams 100x150x200 mm with four-point loading system. All beams had conventional flexural steel. Beams tested with an, a/d ratio of 4.8 failed in shear, with and without stirrups, but the addition of a small volume percentage of steel fibers between 0.44 and 0.88 was sufficient to produce moment failures.

Fig. 1: Crack Pattern of laboratory tested Beam element

Fig. 2 Fibre based cylinder after split tension test



(a): Fiber balled concrete (b): Fiber Balls

Fig. 3 Balling of Fibers.

Production Aspects of Fibre Based Concrete

The use of fiber based concrete (FBC) in practical construction industry is gaining faith at a rapid rate, as such the materials and mixtures used in this research have been adopted keeping in consideration the practical field problems encountered in the production of fiber based concrete [14] [15]. The different materials used were thoroughly tested in the laboratory before use and their average characteristics as obtained on relevant testing are enumerated in table1, below

Table 1: Material Properties

S. No.	Particulars	Average value (wherever applicable)	Remarks
Binder (cement) properties			
1	type	OPC 43 grade	Shakti brand
2	Normal consistency	28.0 %	Using Vicat's apparatus
3	Initial setting time	1 hr. & 10 minutes	do
4	Final setting time	4 hr. 15 minutes	do
5	Soundness	1.2 mm	By Le Chatelier apparatus.
6	Fineness/ specific surface	2357 cm^2 / gm	Using Blaine Air Permeability Apparatus.
7	Compressive strength	41.7 N/mm^2	75 mm cube specimens
Water characteristics			
1	type	Portable water	Tap water
2	PH.	8.2	Not to be less than 6
3	Amount of 0.1 normal HCl required to neutralize 200 ml of water using methyl orange as an indicator	0.7 ml	Should not be more than 10 ml
Properties of aggregates			
1	Fineness modulus of fine aggregate	2.26	Confirming to IS grading Zone II
2	Bulking of fine aggregate	32 %	Jar test
3	Moisture Content	3.7 %	Drying Method
4	Max Size of coarse aggregate	12 mm	Crushed stone
Properties of Plasticizer			
1	Type	Normal Range Water Reducing Admixture	Formaldehyde-based compound
Properties of steel fibers			
1	Geometry	Cylindrical shaped, crimped type	

2	Tensile strength	840 MPa	Should not be less than 345 MPa
3	diameter	0.45 mm	
4	length	30 mm	
	Aspect ratio	66.66	

Properties of Reinforcing Bars			
1	Grade	Fe-415 (TMT)	Y-Zag brand
2	Ultimate strength	512 N/mmm2	
3	% elongation	31.30	

A number of trial mixes were prepared and examined to arrive at the selection of appropriate proportions of different ingredients (cement, fine agg., coarse agg, water, and plasticizer) of concrete, fulfilling the desired objectives in terms of strength, cohesiveness/plasticity, and workability. Visual observations and slump tests were conducted to examine the properties of concrete in the green state. The properties of fresh concrete used in the study are shown in the table. 2. The mixture proportion and dosage of plasticizer was adopted after great precession of trail mixes.

Fibers are usually added in small volume fractions ranging from 0.5 to 2 % by volume of total concrete for the reasons of balling at higher percentages, in addition to workability problems being faced while working with fiber-based concrete.

Here different techniques were adopted for the addition of fibers to the concrete matrix so as to avoid balling of fibers in the mix. In the first trial, fibers were added gradually to the dry ingredients in the mixer, it was noticed that under centrifugal force the concentration of fibers increased along the periphery of the mixer as the number of revolutions of the mixer increased, causing separation of fibers from the mixture. With the addition of lubricant (solution of water and plasticizer) the fibers adhered each other and produced balling even at 0.5 % volume fraction.

Table 2: Concrete Mixture Design

Mix.	Cement Kg/m3	Fine agg. Kg/m3	Coarse agg. (12 mm and down) Kg/m3	Plasticizer By wt. Of cement %	w / c ratio	Fiber volume fraction, %	Slump mm
M1	400	720	1320	0.65	0.4	0.0	70
M2	400	720	1320	0.85	0.4	0.5	61
M3	400	720	1320	1.00	0.4	0.75	52
M4	400	720	1320	1.00	0.4	1.0	41

In the second attempt, the fibers were added to the wet mix in the mixer. The fibers have been added manually at a slow rate in isolated form, which took nearly fifteen minutes to mix 0.5 % fiber content in a concrete quantity of 130 Kgs. Though no balling of fibers was observed at 0.5% fiber content but an excess number of revolutions of the mixer produced sufficient heat to increase the rate of evaporation of added water in the mixture, in the prevailing weather conditions, shown in the table. 3 and drastically reduced the slump value of the mix, resulting in the formation of honey-combed end products (Fig. 4). Moreover at a fiber percentage of 0.75 and above the balling of fibers was again noticed.

Table. 3: Weather Report

S.No.	Parameter	Average Value
1	Max. Temp.	$41.7\ 0_C$
2	Min. Temp.	$24.5\ 0_C$
3	Evaporation Rate	5.3 mm
4	Dew point Temp.	$21.8\ 0_C$
5	Relative Humidity	58.3 %

Fig. 4: Honeycombed Product

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Finally, a wet mix was prepared by adding gradually, at the first stage, only two-third of the required amount of the lubricant which was just sufficient to wet the ingredients so as to stick fibers to the matrix referred as zero Slump Mix so that flowing of mix is prevented in order to avoid accumulation or concentration of fibers around the edges while mixing. The mixer was then stopped and operated again and again for each addition of a small quantity of fibers until the whole quantity of fiber has been added. The purpose was to reduce the rate of evaporation as well as to minimize the centrifugal force which causes plucking of fibers from the matrix, what is referred to as separation or segregation. The remaining amount of lubricant was then added and the mixer was given only 5 to 7 revolutions before discharging, otherwise increased revolutions shall again cause separation and hence ball formation at the stage. It was experienced that this process of charging the mixer has certainly avoided the ball formation of fibers in mixes having 1.0 % and above fiber content, besides the significant reduction in the loss of slump. This process of production of fiber concrete was adopted for the whole quantum of work. It should be noted that concrete should be prepared in small quantities at a time, as the production of a large quantity of concrete in one go, again may result in the formation of fiber-balled concrete. Greater concentration should be given to production process, particularly, at high temperature and low relative humidity i.e. in dry-hot weather conditions

II. Test Program

Twelve types of reinforced concrete beam elements with two of each kind were tested to failure to investigate the shear characteristics and ductility of beam elements [16] [17]. The frame property (loading position), Shear span to depth ratio, depth of beam elements, aspect ratio of fibres and mix proportions were maintained constant, while tensile reinforcement ratio and fiber content were changed for each set of specimens in order to evaluate the response of longitudinal steel and fiber fraction on the shear strength and ductility of fiber-based reinforced concrete beam elements.

All test specimens having a length of 1200 mm and cross section of 100 x 150 mm, simply supported over a span of 1000 mm, were tested under four-point loading system over the loading frame of 50-ton capacity, maintaining a/d ratio constant, equal to 2.66. The load was applied at a steady rate through a loading jack of 50-ton capacity and the readings were taken using 20-ton capacity calibrated proving ring mounted in between the top of the specimen and the bottom flange of the top girder of loading frame. A dial gauge with a least count of 0.01 mm was mounted in the bottom at the center of the specimen to take a measure of central deflection of the specimen during testing. The test setup is shown schematically in fig. 5.

A sufficient number of cubes (150 x 150 x 150 mm), cylinders (150 mm dia. and 300 mm long) and prisms (500 x 100 x 100 mm) were also tested to evaluate the properties of hardened concrete. The cubes and cylinders were tested in a 200-ton capacity compression testing machine while the prism elements over 10-ton capacity prism testing machine. The properties (average values) of set concrete so obtained are represented in the table. 4 in the next section. The results shown in the table are the average of 10 specimens of each kind. The casting was performed in different shifts on different days to ensure re-production of concrete. 95.8 % confidence level has been successfully maintained in the test results ensuring reliability in quality control.

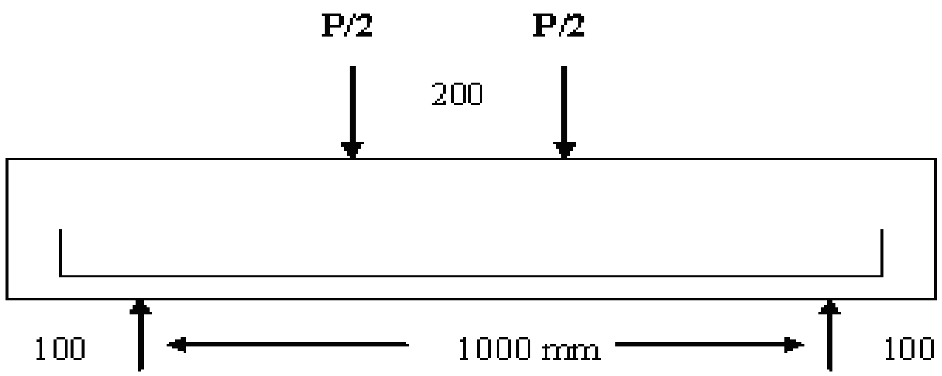

Fig. 5: Testing Setup

III. RESULTS AND DISCUSSIONS

Viewing the table 2, it is found that there is a significant loss in slump and hence workability of fresh concrete as the fiber content in the mix increases and was taken care by increasing the dosage of plasticizer accordingly. The tabular results in table 4 clearly indicate that even though there is just a marginal increase in compressive strength of concrete through the addition of fibers but the increase in flexural tensile strength is very substantial. The increase is as much as 45 % (Fig.6) for the fiber addition of 1.0 %. Conventional concrete having low tensile strength is very prone to cracking under flexural tensile stresses and hence the increase in tensile strength due to the addition of fibers in conventional concrete can be advantageously used in enhancing load carrying capacity of flexural members.

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Table 4: Summary of test results

Specimen No.	Cube Comp Strength (MPa)				Cylinder Comp. Strength(MPa)				Flexural Tensile Strength(MPa)			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
1	44.88	45.77	47.99	52.44	35.79	38.35	40.05	42.61	5.98	6.30	8.38	9.49
2	44.88	45.77	47.99	52.44	36.07	38.06	39.77	42.89	5.94	6.26	7.98	8.97
3	42.66	46.22	46.66	49.77	33.52	38.63	40.34	42.04	5.66	5.98	7.18	8.77
4	42.66	46.22	46.66	49.77	33.52	38.35	39.77	42.04	5.58	5.98	6.78	8.85
5	43.77	43.55	47.55	51.55	34.31	38.63	36.93	40.90	5.18	6.02	7.98	7.94
6	43.99	43.55	47.55	51.55	33.80	38.63	36.93	40.62	5.26	5.98	7.98	7.99
7	39.11*	44.44	46.66	51.55	28.40*	35.79	36.64	39.77	4.38*	6.26	6.78	7.50
8	37.77*	44.44	46.66	51.33	29.54*	36.07	36.93	40.05	3.99*	6.22	7.18	7.38
9	43.99	45.33	46.22	48.88	33.42	36.36	37.50	42.04	5.86	5.98	6.70	8.77
10	43.77	45.33	46.22	48.88	33.42	36.64	38.06	42.04	5.78	6.10	7.18	9.09
Avg. Value	43.82	45.06	47.02	50.82	34.23	37.55	38.29	41.50	5.65	6.10	7.41	8.45

Note: the results marked with * have been discarded for taking average because of inadequate vibration for the specimens during casting due to failure in electricity

Table 5: Summary of Test Results

Beam designation	Percentage longitudinal steel	Fibre volume fraction, V_f %	Con. Comp. Strength f'_c MPa	V_{cr} MPa	V_u MPa	Ultimate deflection mm	Failure mode
B101	1.04	0	34.50	1.18	1.71	2.21	S
B202	2.08	0	34.50	1.42	1.88	2.25	S
B303	3.12	0	34.50	1.66	2.0	2.33	S
B404	4.50	0	34.50	1.71	2.16	2.50	S

B511	1.04	0.5	37.62	1.21	1.76	9.50	F
B612	2.08	0.5	37.62	1.65	2.11	6.33	S
B713	3.12	0.5	37.62	2.00	2.29	6.78	S
B814	4.50	0.5	37.62	2.00	2.40	5.66	S
B921	1.04	1.0	41.30	1.31	1.94	14.9	F
B10,22	2.08	1.0	41.30	1.93	2.28	9.25	F-S
B11,23	3.12	1.0	41.30	2.17	2.57	8.30	F-S
B12,24	4.50	1.0	41.30	2.23	2.57	6.95	S

S = Shear Failure; F = Flexure failure; F-S = Flexure Shear failure

Typical stress-strain behavior in compression of fiber based concrete is shown in Fig. 2. For conventional concrete without fibers, the descending portion of stress-strain curve is sharp and terminates at very low strain value, indicating the brittleness of the material. As the fiber content is increased, a considerable increase in failure strain is noticed. Also, it is found that in the ascending portion of the stress-strain curve, in-elastic behavior is observed for fiber-based concrete, indicating that even after cracking, gain in strength is observed which can be attributed to the resistance shown by fibers to the applied stresses. This is not true in case of conventional concrete, where immediately after cracking the failure takes place. Thus the addition of fibers to conventional concrete all together changes the matrix properties resulting in the enhancement of strength and ductility.

The average values of two identical samples for all the twelve beam types in terms of first diagonal cracking shear strength (vcr) and ultimate shear strength (vu) are reported in table 7. It has been seen that the presence of steel fibers in the concrete greatly affect the observed cracking patterns. Fig. 8 shows the failure pattern of three samples among the twelve sets of tested specimens. All the three samples are identical ($\rho = 1$ %) in all respects except for the addition of fibers. In the specimen B101, which had no steel fibers, flexural cracks first formed within the constant moment zone followed by two shear cracks within the regions of constant shear and the beam failed suddenly along a single shear crack. At a fiber volume of 0.5 % (B611), the failure mode changed from one brittle shear to ductile flexure mode with a large dissipation of energy prior to ultimate collapse as clear from load-deformation response in Fig. 9. With the increase in fiber content to 1.0 % (B921), the failure was again moment failure. Substantially the cracks increased in number and were spaced more closely with a significant deformation prior to collapse and hence increasing further energy absorption capacity. Even in other specimens with fibers which failed in shear or flexure – shear, the mode of failure was gradual enough to dissipate sufficient energy before the collapse.

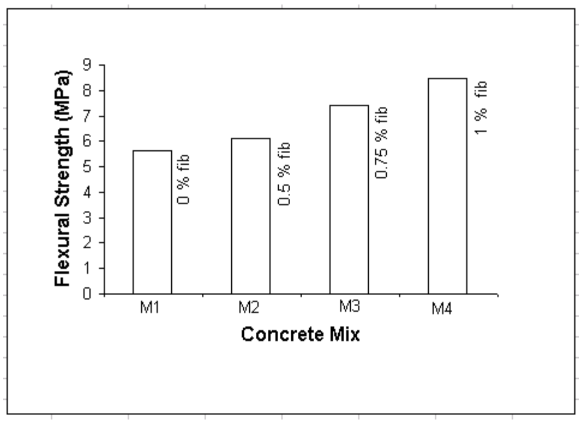

Fig. 6: Flexural Strength verses Fibre Content

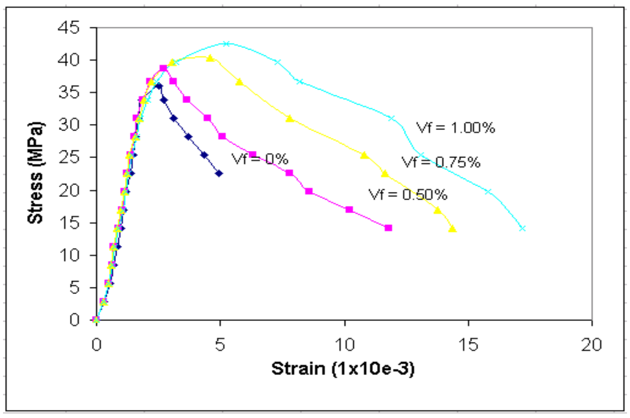

Fig. 7: Typical stress-strain curve in compression of FBC

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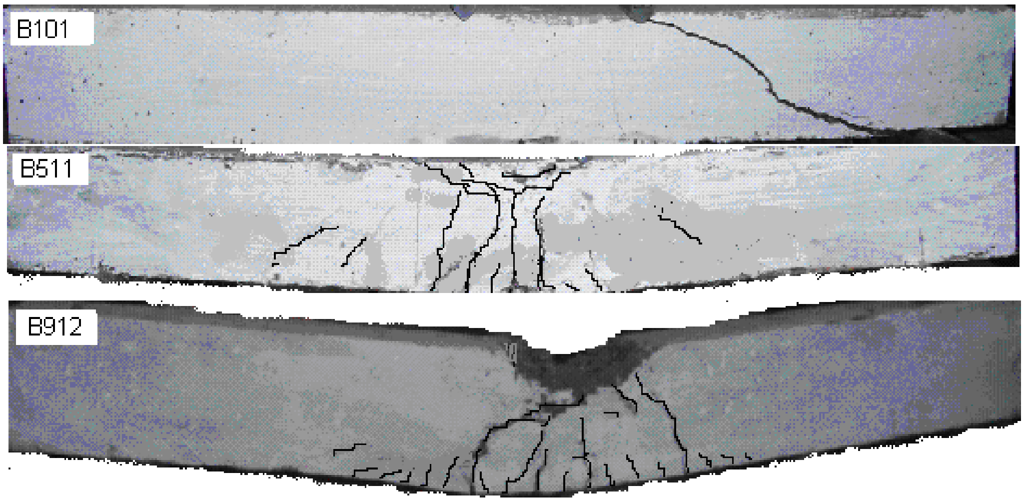

Fig. 8: Typical Crack Patterns (ρ = 1 %)

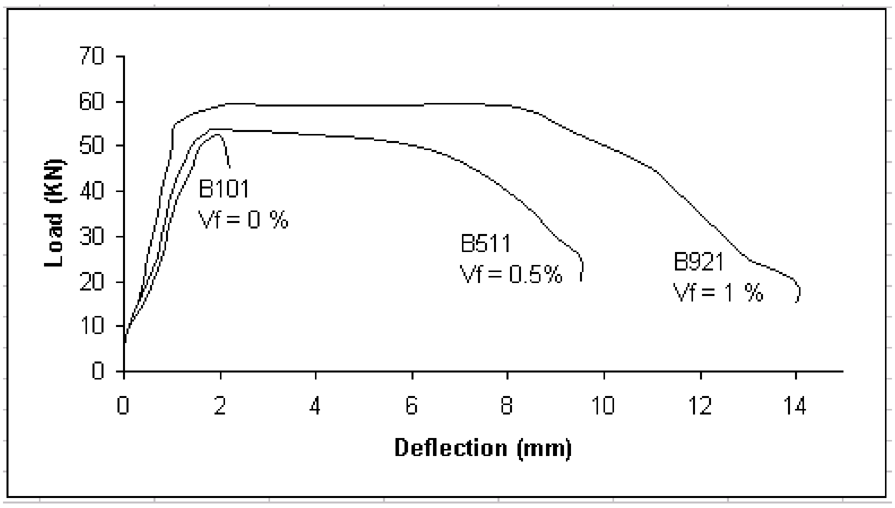

Fig. 9: typical force-Deflection histories

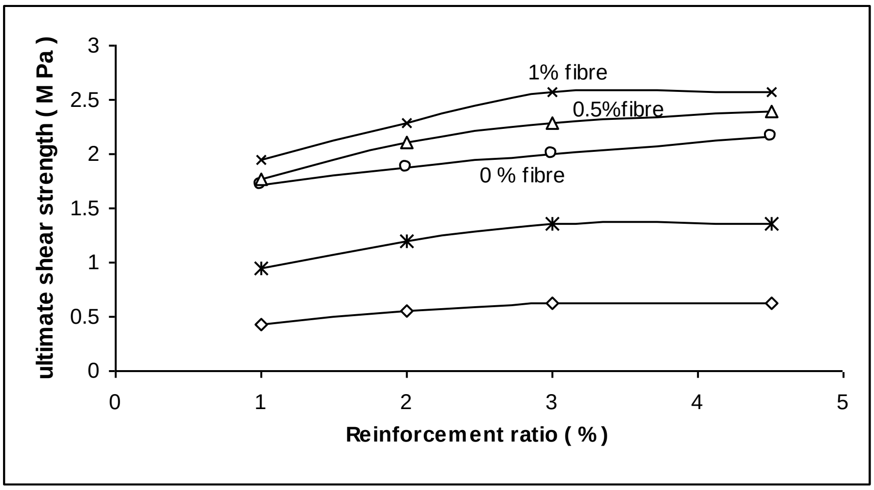

Fig. 10: Ultimate Shear Strength vs Reinforcement Ratio

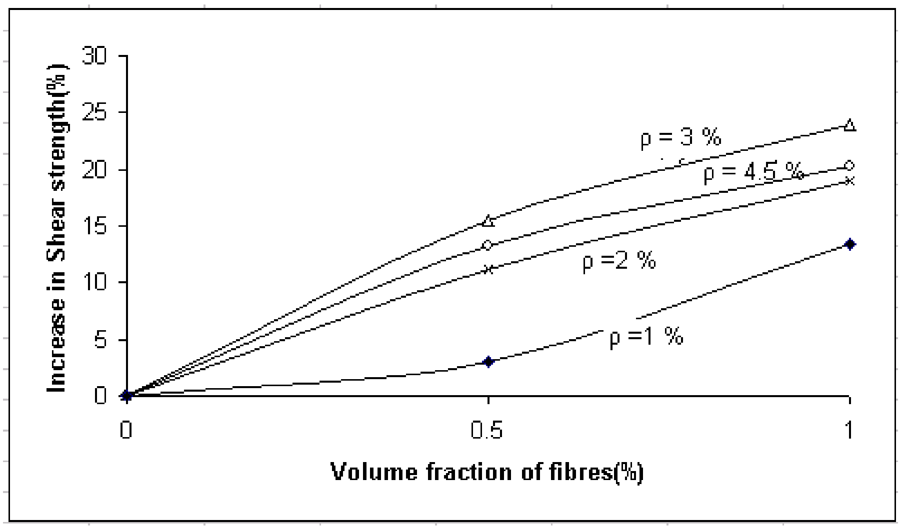

Fig. 11: Influence of fibre volume and Reinforcement Ratio on Shear Strength

In the event of high seismic activity, if the imposed energy due to seismic forces can be intelligently dissipated, the collapse of the structure can be restricted, ensuring life safety. As seen, the addition of fibers produce large number of micro cracks in a structural element before collapse. The energy of dynamic forces can be safely dissipated through chiffing action (friction between cracks) between these cracks and hence can either postpone or totally avoid the collapse of a structure during seismic events. As such the use of fibers in structural elements should be made mandatory in high seismic zones.

The plot (Fig. 10) and tabular results (Table 5) clearly indicate that the average shear stress at first crack and failure consistently increased with the increase in fiber content. The increase in shear strength was as much as 30 % for the fiber addition of 1%, however, the increase was below 15 % in samples which showed moment failure. This can be attributed to the reason that fibers contribute more in shear than in moment carrying capacity, as has been reported by Jindal (1984). Further, it was found that the fibers performed well when the reinforcement ratio (ρ) was less than or equal to 3% (Fig. 11) and at high flexural steel content (ρ = 4.5% here) the growth rate in shear strength development showed a drastically decrease.

It is evident from fig. 11 that the rate of increase of shear strength with the increase in fiber content is significantly large when the reinforcement ratio is on the lower side. The rate of increase is from 3.0 to 13 % when the fiber content is increased from 0.5 to 1.0 % at reinforcement ratio of 1 %, while the increase in shear strength is only from 13 to 19 % for the reinforcement ratio of 4.5 %. This implies that at low reinforcement ratio more fibers can be added to cause an increase in shear strength before saturation stage is reached while as, at lesser fiber content the saturation stage is reached in the case of higher reinforcement ratio. Hence in the defined domain, the optimum value for 1 % fiber content would be tensile reinforcement ratio of less than 3 % for maximum performance in shear.

Finally, the results were compared with codal values [IS-456(2000) and BS-8110(1985)] and are found in good agreement. It was also found that the codal values as per Indian Standard are on much conservative side than British results of beam elements with and without fibers.

IV. CONCLUSION

From the analysis of experimental results, the following conclusions are drawn.

1. The addition of fibers as shear reinforcement, impart ductility and substantially increases the shear strength of beam elements.
2. The addition of fibers in concrete also provide an effective crack arresting mechanism and can serve as an energy dissipation methodology in neutralizing seismic forces during earthquakes.
3. An appropriate selection for the type of fibers plays an important role in the construction process. Very small size of fibers with moderate length, increase the fiber count and lead towards fiber clumping and hence ball formation. The mix should possess good cohesiveness for a better bond between fiber and matrix, resulting in improved post cracking tensile strength of fiber concrete

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Technical Skills
- Seismic Design of Steel Structures
- Instrumentation & Signal Processing in civil engineering
- Geotechnical Aspects of E/Q Engineering
- Educational Technology Development
- Structural modelling software