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EXPERIMENTAL INVESTIGATION ON SHEAR STRENGTH OF SFRC BEAMS REINFORCED WITH LONGITUDINAL TENSION STEEL REBARS

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ABSTRACT

In the present work, an attempt is made to investigate shear strength and ductility of fiber reinforced concrete beams by using hooked steel fibers. All the test beam specimens were 100 mm in width, 150 mm in depth and 1200 mm in length and the primary variables of the investigation were percentage of fibers (0.5 to 5 %), percentage longitudinal tension steel (0.8 to 3.22 %) and cube compressive strength of concrete (in the range of 34 to 41 MPa), with a view to cover a wide spectrum of concrete strength in shear. The shear span-to-depth ratio (a / d ratio) was kept constant at 3.20. This has resulted into casting and testing of twenty SFRC beam specimens. All the beam specimens were tested under four-point loading (2-active, 2-passive) test set-up and the failure load, crack pattern and deflections were recorded concisely and precisely. The experimental results clarify the enormous influence of hooked mild steel fibers on shear strength of concrete. At low fiber volume fraction, the influence of fibers is negligible and is significant with the increase in the fiber volume fraction. The concrete beam specimens exhibited substantial increase in their ultimate load as well as in the load at first cracks, enhanced deformation characteristics at all stages of loading up to failure.

In general, the significant improvement in various strengths is observed with the inclusion of steel fibres in the plain concrete. However, maximum gain in strength of concrete is found to depend upon the amount of fibre content.

Keywords: Hooked end steel fibers, Steel Fiber Reinforced Concrete (SFRC) beams, Fibre volume fraction, Cement content, Shear strength, longitudinal tension steel, Failure load and deflection.

1. INTRODUCTION

Concrete is the most widely used construction material all over the world in view of its compressive strength, high mouldabilty, structural stability and economic considerations. Also, it is very strong in compression and very weak in other mechanical properties such as

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tensile strength and shear strength. The direct compression test on concrete is well established and standardized and is found by casting either cubes or cylinder and testing it in direct compression. However, there is no direct way to find out the tensile and/or shear strength concrete. Therefore, attempts have been made to find the indirect split tensile strength of concrete by casting and testing cylinders and prisms [1].

Concrete being a non-homogeneous, heterogeneous material and has non-linearity in its material response [2]. As a result of this, it does not feasible to apply a shearing action (direct shearing force) in a plane, as is customarily done in case of metals. Experiments have to be, therefore, devised to indirectly asses the shear strength of concrete, in one of the popularly adopted devices, a beam of appropriate length subjected to shearing and bending actions under 4-Point Loading System (2- active and 2-passive forces). In the present study, such a device has been adopted to study the performance of concrete under direct shearing action. Once steel bars are introduced, generally along a direction perpendicular to shearing force, these bars start coming into action to resist shearing force. Thus, steel bars become intrinsically linked to resisting shearing force along with the inherent concrete resistance. The shear resistance due to these longitudinal steel bars is commonly referred as dowel effect. However, [2] there are situations where shear has to be transformed across a defined plane of weakness, nearly parallel to the shear force and along which slip could occur. i.e. in case of corbel, precast beam seat and column face plate. Examples are planes of existing or potential cracks, interface between dissimilar materials, interfaces between elements such as webs and flanges, and interface between concrete placed at different times. In such cases, possible failure involves sliding along the plane of weakness rather than diagonal tension. Therefore, it would be appropriate to consider shear resistance developed along such planes in the form of resistance to the tendency to slip. The shear friction i.e. interface shear concept is a method to do this.

However, incorporation of such bars does not increase the inherent tensile strength of concrete. The addition of steel fibers to concrete, increases it’s homogeneous and isotropic characteristics and can improve the tensile and shear response by arresting the micro-cracking mechanism and by limiting crack propagation, thus significantly improving the ductility [3]. Steel Fiber Reinforced Concrete (SFRC) is a composite material, which essentially consists of conventional cement concrete reinforced by randomly distributed steel fibers of finite length and specific geometry. These fibers act as crack arrestors and restrict the development of crack. Thus they transform an inherently brittle material into a strong composite with a superior crack resistance, improved ductility and distinctive post cracking behavior prior to failure. SFRC is superior to conventional concrete because of its capacity to supports substantial load after cracking. One of the disadvantages of cement based matrix is the inherently brittle type of failure under the action of tensile stress system or impact loading. To overcome this situation steel fibre reinforced concrete is used.

Steel fibre reinforced concrete (SFRC) is a composite structural material consisting of concrete and discontinuous discrete steel fibres. The incorporation of steel fibres in concrete converts brittle failure of concrete into ductile one and enhances many properties of concrete such as flexural or tensile strength, ductility, impact resistance, abrasion resistance, fatigue, resistance, toughness of concrete and improve crack control and joint stability and load carrying capacity without widening of cracks. Strength of concrete was on the various types of concrete applications. Basic assumptions in this type of thinking was that all other properties where assumed to be related to the strength [4].

1. Materials and Experimental Methods

1.1 Materials used

The test specimens were Cast using cement; fine aggregate, coarse aggregate, water and supper plasticizer. The materials, in general, confirmed to the specifications laid down in the relevant Indian Standards Codes. For grading of fine and coarse aggregate, sieve analysis was carried out.

Cement: Pozzolona Portland cement (PPC) of 53-grade confirming to IS: 8112:1989 was used throughout the experimental work. All tests were carried out as per IS: 4031-1988. The specific gravity and fineness respectively were 3.14 and 275 m^2/kg.

Coarse Aggregate: Crushed granite metal obtained from a local source was used as coarse aggregate and the maximum size of used was 20 mm along with the 10mm. All tests were carried out as per IS: 2386 (Part-I) -1963

Fine aggregate: Locally available river sand was used as fine aggregate. The specific gravity and fineness modulus respectively were 2.60 and 2.29.

Reinforcing steel: Thermo-mechanically treated (TMT) rebars of diameters 8 mm, 10 mm, 12 mm and 16 mm of F_e 415 grade were used for experimental work.

Super plasticizer: To improve the workability , a super plasticizer was used, The properties are given in Table 1.

Table 1: Properties of Super Plasticizers Used

Sr. No.	Properties	Description
1	Chemical admixture	Choksey SPL 9-M2
2	Color	Brown
3	Setting time	4 - 5 hrs
4	Specific gravity	1.27
5	Chloride content	Nil
6	Air entrainment	Nil
7	Nitrate content	Nil

Fibers: Novocon (Xorex) steel fibres conforming to ASTM A 820 type-I were used for the experimental work. Fibres are high tensile steel cold drawn wire and specially engineered for use in concrete. Fibres are made available from Stewols and Company, Nagpur. Fibers are high tensile steel cold drawn wire and specially engineered for use in concrete. The physical properties of fibers are shown in Table 2.

Table 2: Physical Properties of Steel Fibres

Sr. No.	Property	Values
1.	Diameter	1 mm
2.	Length of fibre	50.8mm
3.	Appearance	Bright in clean wire
4.	Average aspect ratio (l/d)	50
6.	Deformation	Continuously deformed circular segment
7.	Fibre tensile strength	828 MPa
8.	Modulus of elasticity	200 GPa
9.	Specific gravity	7.8

Fibre reinforced concrete can be defined as a composite material consisting of a cement-based matrix containing an ordered or random distribution of fibres. The fibres act as crack arrestors that restrict the growth of flaws in the matrix, controlling them from enlarging under stress into cracks which eventually cause failure. By inhibiting the propagation of cracks originating from internal flaws, considerable improvements in mechanical properties can be obtained and fibres impart to the composite qualities of crack control, toughness, ductility impact resistance.

2.2 Mixture Proportioning

The concrete mixes were designed in accordance with the Indian standard recommended methods of concrete mix design. The proportions of cement, fine aggregate, coarse aggregate is given in the Table 3.

Table 3: Mix proportions

Description	Cement content (kg / m^3)				
	360	**380**	**400**	**420**	**440**
Characteristics cube comp.str. (MPa)	33	35	38	41	43
Mix proportions (C: F.A.:C.A:W/C)	1:1.95:3.96: 0.50	1:1.81:3.67: 0.47	1:1.82:3.31: 0.45	1:1.63:2.93: 0.42	1:1.63:2.93: 0.40
Water (kg/m^3)	180	180	180	180	180
Fibres (% of wt of cement)	0.50	0.5 to 5.0	0.00	0.50	0.50
Plasticizer (% of wt of cement)	0.60	0.75	0.85	1.00	1.15

2.3 Mixing and casting details

2.3.1 Test specimen details

Tests were carried out on twenty rectangular Reinforced Concrete (RC) rectangular beams, simply supported under four-point loading (2-active, 2-passive) test set-up. All the beams had constant span of 1000mm and width of 1 m and depth 150 mm, with 0.1m overhangs on either side of the supports. The spacing between the top two Point-Loads has been kept at 200 mm as shown in Figure 1. Standard cubes (150mm×150mm×150mm), Cylinders (150 mm×300mm) and prisms (100mm×100mm×500mm) were cast with each mix to know the various mechanical properties of concrete. Each of the three series comprised three beams of different hooked steel fiber volume fraction, percentage longitudinal steel and cube compressive strength.

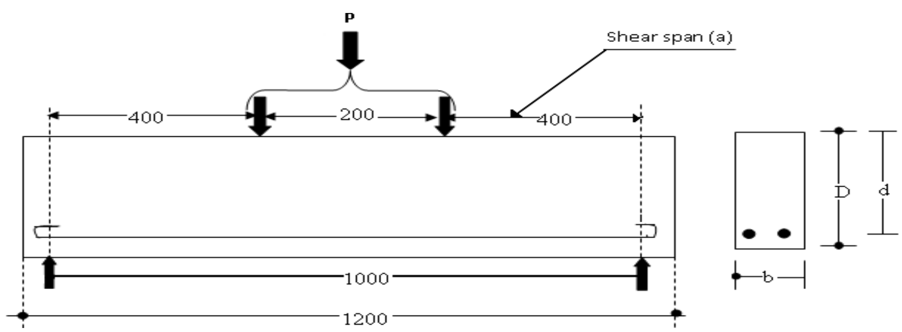


Figure 1. Four point loading test set-up

The Series-I beams were of different hooked steel fiber volume fraction (0.5 to 5%), the Series-II beams were of different percentage longitudinal steel (0.80 to 3.22%) and the Series-III beams were of varying cube compressive strength of concrete (33 to 43 MPa). All the beam specimens were reinforced with main longitudinal steel placed on tension side and without any vertical web reinforcement.

2.4 Testing methodology

After 28-days curing period, the test beam specimens were removed from the curing tank and both sides of the beam were white-washed to aid observations of the crack development during testing. The beams were tested to failure under gradually increasing load in a Universal Testing Machine (UTM). A dial gauge (Least Count = 0.01mm) was fixed at the bottom of beam to measure the mid-span deflection. The cube specimens were tested for compressive strengths, the cylinder specimens for split tensile strength and prism specimens for flexural strength in a compression-testing machine [IS: 516-1975].

3. TEST RESULTS AND DISCUSSIONS

The main objective of this paper was to study the performance of the RC beams in shear experimentally reinforced with longitudinal tension steel only, and reinforced with the steel fibres and to know the relative contributions of the different mechanism through which shear are transmitted between two adjacent planes in a reinforced concrete beam. Thirty six beams were cast and tested for various fibre content (0 to 5), each cement content using the 8, 10, 12, and 16mm TMT rebars and three beams for each rebar. The test set up, loading position, support position can be cleared from Figure 1.

During testing, the load is transferred between the load point and the support point, leads to shear failure, in the form of splitting failure. The tensile stresses in concrete in the direction normal to ultimate crack are much higher than the tensile strength of the concrete, which justifies the formation of the cracks observed in the experiments.

Experimental Results of Series-I Specimens: Effect of Fiber Volume Fraction

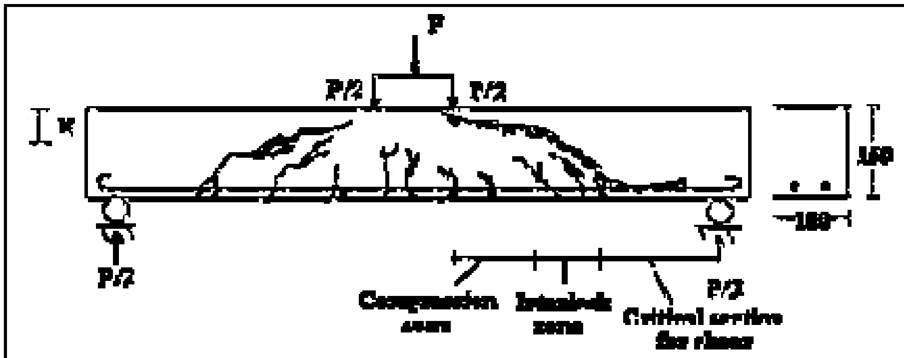
In the Series-I specimens, 3 beams with different fiber volume fraction were carried out. The longitudinal reinforcement ratio ρ was 0.80% and cube compressive strength f_{cu} was 35 MPa. The results of the shear strengths of concrete beams for different fiber volume fraction at 28 days curing age are presented in Table 4 and in Figure 2.

Table 4: Shear Strength of Concrete Beams (Series-I): Effect of Parentage of Fibers

Test beam designation	Fiber (%)	ρ (%)	Stress values in MPa				Shear stress (MPa) τ= V/bd	Deflection (mm)	Mode of failure
			f_{cu}	f'_c	f_t	f_r			
I-1/3.2/0.80 /0.00*	0.00		39.18	11.24	2.06	4.21	1.15	0.90	Shear
I-2//3.2/0.80 /0.50	0.50		41.05	12.43	2.38	4.33	1.22	1.30	Shear
I-2/3.2/0.80 /1.00	1.00		42.52	13.66	2.38	4.47	1.48	1.38	Shear
I-3/3.2/0.80 /1.50	1.50		43.22	14.31	2.42	4.58	1.64	1.40	Shear
I-4/3.2/0.80 /2.00	2.00		44.04	15.03	2.68	4.61	1.69	1.45	Shear
I-5/3.2/0.80 /2.50	2.50	0.8	45.63	16.08	2.82	4.69	1.71	1.55	Shear
I-6/3.2/0.80 /3.00	3.00		46.11	17.37	2.98	4.73	1.72	2.10	Shear
I-7/3.2/0.80 /3.50	3.50		47.15	18.28	3.18	4.80	1.74	2.30	Flexure
I-8/3.2/0.80 /4.00	4.00		48.29	19.37	3.27	4.87	1.77	2.45	Flexure
I-9/3.20.80 /4.50	4.50		49.74	20.45	3.30	4.96	1.82	3.10	Flexure
I-10/3.2/0.80 /5.00	5.00		50.07	21.65	3.98	4.98	1.86	3.40	Flexure

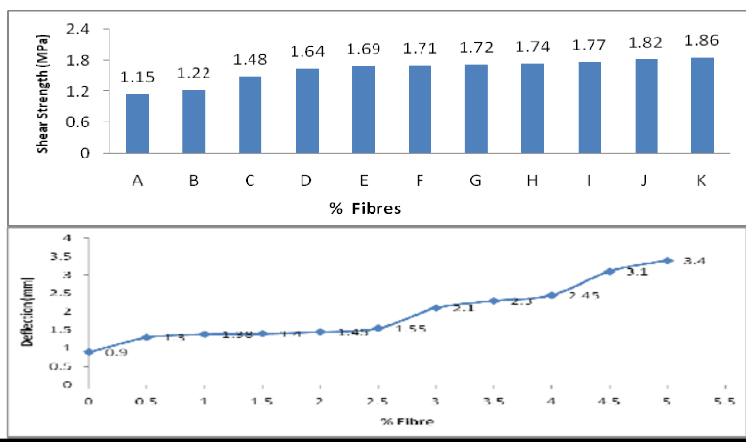
*** Beam notation: Series number is given before hyphen; this is followed by beam no., shear span-to-depth ratio, longitudinal steel (%) and then by percentage of fiber**

Experimental Results of Series-II Specimens: Effect of Longitudinal Steel (%)
In Series-II, the percentage of steel was increased from 0.80 % to 3.22 %. The bar diameter was increased from 8 mm to 16 mm. The percentage fibre was kept constant for each mix that is 0.50 %. The cement content used in series-II was 380 kg/m3, for this cement content the compressive strength was 33 MPa. The results of the shear strengths of concrete beams for different percentage steel at 28 days curing age are presented in Table 5.



Shear Span= 400mm;
Effective Depth=125 mm; a/d ratio=3.2
Steel: 2-8 mm TMT Bars
% Steel= 0.8%
Cement Content=380 kg/m^3

% Fibre
A=0
B=0.5
C=1
D=1.5
E=2
F=2.5
G=3
H=3.5
I=4
J=4.5
K=5



Comments:
1. Shear capacity of the beam increases with the percentage increase in fibre volume fraction.
2. The increment is approximately uniform.
3. For the same cement content with the increase in % fibre from 0.5 % to 5 % the shear shear strength increases up to 18 percent.
4. For the same cement content with the increase in % fibre from 0.5 % to 5 % dowel action capacity increases.
5. The deflection of the beams increases with the increases in % fibres.
6. The reason for this increment in deflection is- As the fibre content increases the concrete becomes more ductile and hence it fails after long deformation.

Figure 2. % Fibres vs shear strength and % fibres vs deflection

Table 5: Shear strength of concrete beams (Series-II): Effect of longitudinal steel (%)

Test beam designation	ρ (%)	Stress values in MPa				Shear stress (MPa) τ= V/bd	Deflection (mm)	Mode of failure
		f_{cu}	f'_c	f_t	f_r			
II-1/3.2/0.80 *	0.80	39.18	11.24	2.06	4.21	0.78	1.68	Shear
II-2//3.2/1.26	1.26	41.05	12.43	2.38	4.33	0.91	2.40	Shear
II-2/3.2/1.81	1.81	42.52	13.66	2.38	4.47	1.26	2.90	Shear
II-3/3.2/3.22	3.22	43.22	14.31	2.42	4.58	1.42	3.20	Shear

***Beam notation: Series number is given before hyphen; this is followed by beam no., shear span-to-depth ratio, longitudinal steel (%)**

Figure 3. Test beam set-up

Figure 4. Failure pattern of beams with different fibre content

Experimental Results of Series-III Specimens: Effect of Cube Compressive Strength of Concrete

In Series-III, all mechanical properties were calculated by increasing the compressive strength. For this the cement content is increased from 360kg/m^3 to 440kg/m^3. The percentage of fibre was kept constant as 0.50% fibre. The percentage steel was also kept constant for each mix that is 0.8%. The results of the shear strength of concrete beams for different compressive strengths at 28 days curing age are presented in Table 6.

Shear Cracks: During testing, the load is transferred between the load point and the support point, leads to shear failure, in the form of splitting failure. The tensile stresses in concrete in the direction normal to ultimate crack are much higher than the tensile strength of the concrete, which justifies the formation of the cracks observed in the experiments.

Table 6: Shear strength of concrete beams (Series-III): Effect of compressive strength of concrete

Test beam designation	ρ (%)	Stress values in MPa				Shear stress (MPa) τ= V/bd	Deflection (mm)	Mode of failure
		f_{cu}	f'_c	f_t	f_r			
III-1/3.2/0.80/33*	0.80	33.15	11.57	2.09	4.07	1.34	3.80	Shear
III-2//3.2/1.26/35		35.24	12.43	2.38	4.21	1.44	2.60	Shear
III-3/3.2/1.81/38		38.71	12.43	2.21	4.34	1.70	2.10	Shear
III-4/3.2/3.22/41		41.56	12.20	2.26	4.53	1.76	1.80	Shear
III-5/3.2/3.22/43		44.15	12.31	2.32	4.69	1.89	1.30	Shear

***Beam notation: Series number is given before hyphen; this is followed by beam no., shear span-to-depth ratio, longitudinal steel (%) and cube compressive strength of concrete**

Modes of Failure: Some beam specimens were failed in shear i.e. a sudden failure without warning and some were failed in flexure. The beam specimens failed in shear makes loud noise at failure with the appearance of single shear crack in the shear span and fine flexural cracks in the middle portion of the beam. The shear crack crosses the compression zone of the beam. Figure 4 shows a typical crack patterns for RC beam specimens of different fibre volume fraction. The type of mode of failure shown in Table 4 and in Figure 4.

Influence of amount of fibre volume fraction

It is observed from the results that as fibre volume fraction increases, the failure pattern changes from shear failure to flexural failure. At the same time the deflection of the beams also increases as percentage fibre increases. The reason for this increment in deflection is- As the fibre content increases the concrete becomes more ductile and hence it fails after long deformation. Also the shear strength increases as fibre volume fraction increases.

Influence of amount of longitudinal tension reinforcement

The longitudinal percent tension steel affects the amount of longitudinal strain and thereby affects crack width, interface shear transfer, dowel action, and thus the shear strength. Thus, for the same magnitude of loading, as the percent longitudinal tension reinforcement decreases, flexural stresses and strains increase. Thus, crack width increases and the shear strength lowers. The influence of longitudinal reinforcement is accounted for in most major codes but in different ways. A significant increase in the shear strength was observed as the percent longitudinal tension steel. The variation of shear strength with the percent longitudinal tension steel is shown in Table 6.

Influence of amount of cube compressive strength

It is proved from the results obtained that the shear strength of the concrete increases with the increase in compressive strength. The failure pattern of all the beams in this series is shear. The deflection of the concrete decreases as cube compressive strength increases. The reason for this decrement in deflection is- As the cement content increases the concrete becomes more brittle and hence it fails earlier by giving small deflection

4. CONCLUSIONS

Gist of this study has been presented in this paper with a view to understand the role of steel fibers, percentage steel and cube compressive strength on shear strength of concrete. Based on the study presented in this paper, the following inferences may be arrived at:

1. The study reveals that by incorporating steel fibers in RC beams is potentially important and practical construction method, as fiber concrete beams exhibit substantial increase in their ultimate load as well as in the load at first cracks, enhanced deformation characteristics at all stages of loading up to failure, as well as improving their shear and spalling resistance.
2. Shear failure has been observed to be sudden with loud noise. The higher the compressive strength, higher level noise is observed at failure. This is a characteristic of brittle failure which must be avoided in all possible situations. The Code, therefore, recommends a maximum value of shear stress to be taken so that violent failure of concrete due to high shear stress can be avoided.
3. The first crack shear strength increases significantly as fibre content increases and the impro vement in ultimate shear strength and the compressive strength of SFRC increases as percent age of fibre increases.
4. The influence of hooked end mild steel fibres on shear strength of concrete beams at lower fibre volume fraction is negligible and is significant with the increase in the fibre volume fraction.
5. The deflection of the beams increases with the increase in percentage fibres and percentage steel. This is primarily because of concrete becomes more ductile and hence it fails after long deformation.
6. The width of cracks is found to be less in SFRC than that in plain cement concrete beam due to addition of fibbers.
7. The failure of concrete is not in true shear but in tensile stresses generated by the shear. This happens because of very low tensile strength of concrete in comparison with its shear and

compressive strength.In general the addition of fibres, mode of failure was changed from brittle to ductile failure when subjected to compression and bending.

8. The contribution to shear strength due to dowel action increases with the increase in tension steel and compressive strength of concrete. Dowel action is increased significantly with the increase in tension steel

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NOTATIONS

Symbol	Name	Unit
SFRC	Steel Fibre Reinforced Concrete	
τ	Shear Strength of concrete beams	MPa
f_{cu}	Cube compressive strength of concrete	MPa
f'_c	Cylinder compressive strength of concrete	MPa
f_r	Flexural strength	MPa
f_t	Split tensile strength of concrete	MPa