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Flexural Strength of High Strength Steel Fiber-Reinforced Concrete Beams with Stirrups

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ABSTRACT
Twenty five tests were conducted on high strength fiber reinforced concrete beams with three steel fiber-volume fractions (0.5 to 4%), three shear span-depth ratios (2, 3, and 4) The flexural strength test had been conducted as pe IS 516. The results demonstrated that flexural strength increased with increasing fiber volume. As the fiber content increased, the failure mode changed from shear to flexure.
The results of 139 tests of high strength fiber-reinforced concrete beams with stirrups were used to measured flexural strength.

Keywords: beam; cracking; Flexural strength.

I. INTRODUCTION

The addition of high strength steel fibers to a reinforced concrete beam is known to increase its shear strength and, if sufficient fibers are added. The increased flexural strength and ductility of fiber-reinforced beams stems from the post-cracking tensile strength of high strength fiber-reinforced concrete. This residual strength also tends to reduce crack sizes and spacing's. The use of steel fibers is particularly attractive for high-strength concrete, which can be relatively brittle without fibers, or if conventional stirrups can be eliminated, which reduces reinforcement congestion.

The literature describes numerous studies of rectangular, high strength fiber-reinforced beams with stirrups,[2-21] of which 16[3-18] were reviewed by Adebar et al[2]. %atson, Jenkins, and Spat-ney performed the first large experimental study of such beams[4], which included 42 tests of high strength fiber-reinforced beams with stirrups that failed in shear. Subsequent investigations of normal-strength concrete6[7,9,17] (primarily in the 1980s) and high-strength concrete[3,5,19,21] (primarily in the 1990s) confirmed the effectiveness of adding steel fibers and identified key parameters that affect shear strength. The increase in shear strength can vary drastically depending on the beam geometry and material properties. For example, in tests reported by Narayanan and Darwish,[13] the increase in shear strength attributable to steel fibers varied from 13 to 170%.

As with conventional reinforced concrete beams,[22-24] the ultimate shear strength decreases with increasing shear span-depth ratio a/d;[3,4,5,9-13,21] increases with increasing flexural reinforcement ratio ρ;[3,5,13] and increases with increasing concrete compressive strength f_c'.[13,21] These effects are attributable to

the development of arch and dowel action in beams with low values of a/d, and to the diagonal-tension failure mode (beam action) in beams with higher values of a/d. Li, Ward, and Hamza[9] also report that, as has been observed in conventional beams, the average shear stress at failure decreases with increasing beam depth.

The increase in shear strength attributable to the fibers depends not only on the amount of fibers, usually expressed as the fiber volume fraction V_f, but also on the aspect ratio[6,7,9,12,13] and anchorage conditions for the steel fibers.[9,13,21] For example, from the point of view of workability, it may be convenient to use stocky and smooth fibers, but after the concrete cracks, such fibers will resist tension less well than elongated fibers with end deformations (hooked or crimped).

Investigators have also developed empirical expressions for calculating shear strength. For example, Sharma;[16] Narayanan and Darwish;[13] Ashour, Hasanain, and Wafa;[3] and Imam et al.[25] have proposed equations for predicting the ultimate average shear stress V_u. Although the onset of shear cracking is difficult to establish reliably, Narayanan and Darwish[13] also proposed a procedure for estimating the average shear stress at the onset of shear cracking V_{cr}.

Despite this research activity, the existing design expressions have not been evaluated with a large amount of test results and, in some cases, the data used to calibrate models of shear strength included tests of beams that failed in flexure rather than in shear. Proposed and existing design procedures for estimating shear strength need to be evaluated using a large collection of test results for beams that failed in shear.

II. RESEARCH SIGNIFICANCE

Previous studies have documented many tests of high strength fiber-reinforced concrete beams with stirrups that failed in shear. The results of new tests, combined with the results of previous tests, provide the opportunity to evaluate the accuracy of existing and proposed design procedures. Such an evaluation is needed before building codes[22] will recognize the contribution of steel fibers to the shear strength of reinforced concrete beams.

III. TEST PROGRAM

Twenty five reinforced concrete beams were tested to failure to evaluate the influence of fiber-volume fraction ald and concrete flexural strength. The total fiber-reinforced, higher-strength concrete beams were constructed with concrete having a compressive strength near 70 MPa. These higher-strength beams included all combinations of three steel-fiber volume fractions 05%.

Figure 1 shows the details of the test beams. All of the beams had nominally identical cross-sectional dimensions (100x100 mm), effective depths (100 mm), and flexural reinforcement (two D8 bars). These dimensions correspond to a flexural reinforcement ratio of 1.5%. The longitudinal bars were hooked upwards behind the supports and enclosed by three D8 stirrups at each end. This detail precluded the possibility of anchorage failure, which can be important in practice. No stirrups were included within the shear span.

To prevent the beam from developing significant axial forces, which could create artificial strut action, the beams were supported by a roller on one end and a hinge at the other as shown in Fig. 1. At both of these locations, the contact area between the concrete and the supports measured 125 mm (the width of the beam) x 100 mm. Two equal loads were applied to the beam using a steel spreader beam and 80 mm-wide x 40 mm-thick loading plates. At the beginning of each test, deflections were imposed by increasing the load in small increments but, as the beam approached its capacity, the test was controlled by gradually increasing the beam deflection. The applied load and the beam deflection at midspan were recorded continuously until failure.

IV. Material properties

Table 2 provides the mixture designs and slumps for the four mixtures. The water-cement ratio (w/c) was 0.28 for the High Strength concrte.

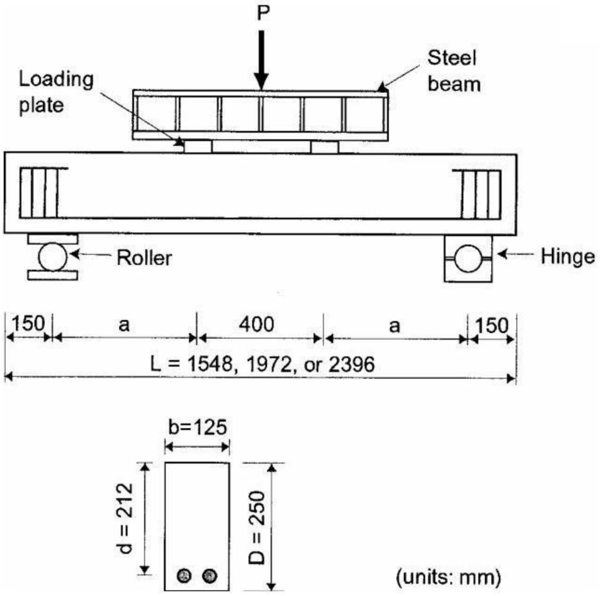


Fig. 1—Details of test beams.

Table 1—Concrete mixture designs

Material	Proportion by weight	Weight in Kg/m^3
Cementatious Material	1	556
Fine Aggregate	1.26	701
Course Aggregate (12.5 mm)	1.87	1040
Water	0.27	150

higher-strength beams (FHB1, FHB2, and FHB3) and 0.62 for the normal-strength beams (FNB2). The concrete was made with Ordinary portland cement. The coarse aggregates were crushed gravel with a maximum size of 12.5 mm, and the fine aggregates were Godavari river sand from Paithan with a fineness modulus of 2.65. A high-range water-reducing admixture was used to improve the workability of the higher-strength concrete.

The steel fibers were used are hooked end steel fibres, flat steel fibres and waving steel fibres. Length of fibres are 60 mm, 40mm and 30mm respectively. The diameter of fibres are 1mm, 2mm and 0.45mm. Which corresponds to different aspect ratio. The nominal yield strength of the steel fibers was 1079 MPa. The flexural steel had a yield stress of 442 MPa and an ultimate strength of 63 8 MPa.

The flexural strength was evaluated for 100 x 100 x 500 mm concrete beams. As shown in Table 3, the addition of fibers increased flexural strength.

Table 2

FSF READINGS OF BEAM										
0.5%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	1.5	2	3	4	4		
1.0%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	1	2	3	4	5		
1.5%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	1	2	3	4	5	6	
2.0%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	0	1	1	4	4	5	6	
2.5%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	2	2	3	4	5	6	
3%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	2	3	4	5	6	7	7.5
3.5%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	2	3	4	5	6	6	
4%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	2	3	4	5	6		

Table 3

HSF READINGS OF BEAM										
0.5%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	1	2	3	3	4		
1.0%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	2	3	4	4	4		
1.5%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	2	2	3	4	5	5	
2.0%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	2	3	4	5	5	6	
2.5%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	2	3	3	4	5	5	
3%	Load	0	300	400	500	600	700	750	775	800
	Deflection	0	1	1	2	3	4	5	6	7
3.5%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	2	2	3	4	5	6	
4%	Load	0	300	400	500	600	700	750	775	
	Deflection	0	1	1	2	3	4	5		

Table 4

WSF BEAM READINGS									
0.5%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	1	2	3	4	5	
1.0%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	1	2	3	4	5	
1.5%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	2	3	4	4	5	6
2.0%	Load	0	300	400	500	600	700	750	775
	Deflection	0	0	1	2	3	4	5	6
2.5%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	1	2	3	3	4	5
3%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	2	3	3	4	5	6
3.5%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	2	3	4	5	6	7
4%	Load	0	300	400	500	600	700	750	775
	Deflection	0	1	2	3	3	4	5	

Fig. 3 - Typical crack patterns (a/d = 2).

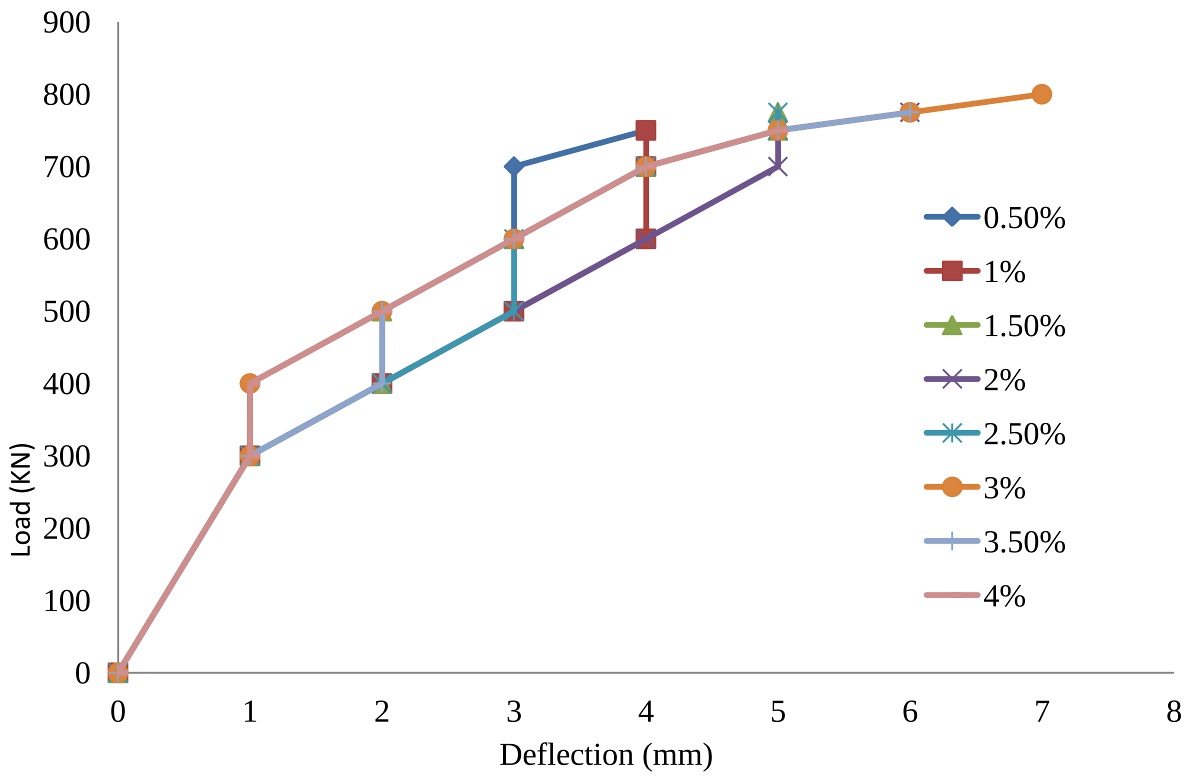


Figure 4.3 Variation of load with respect to Central Deflection for HSF

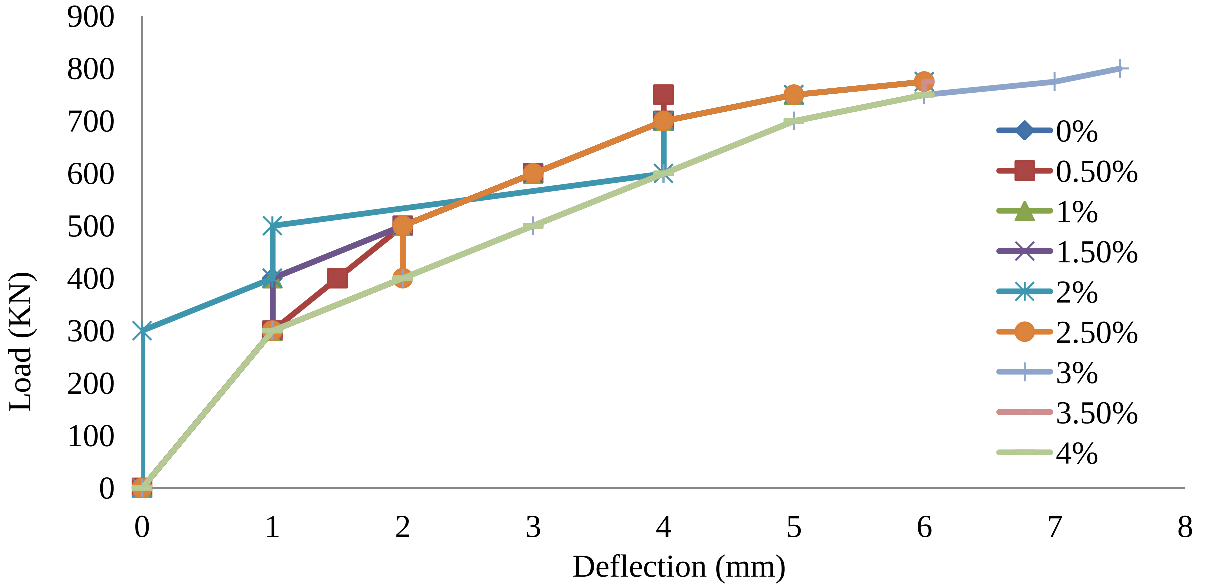
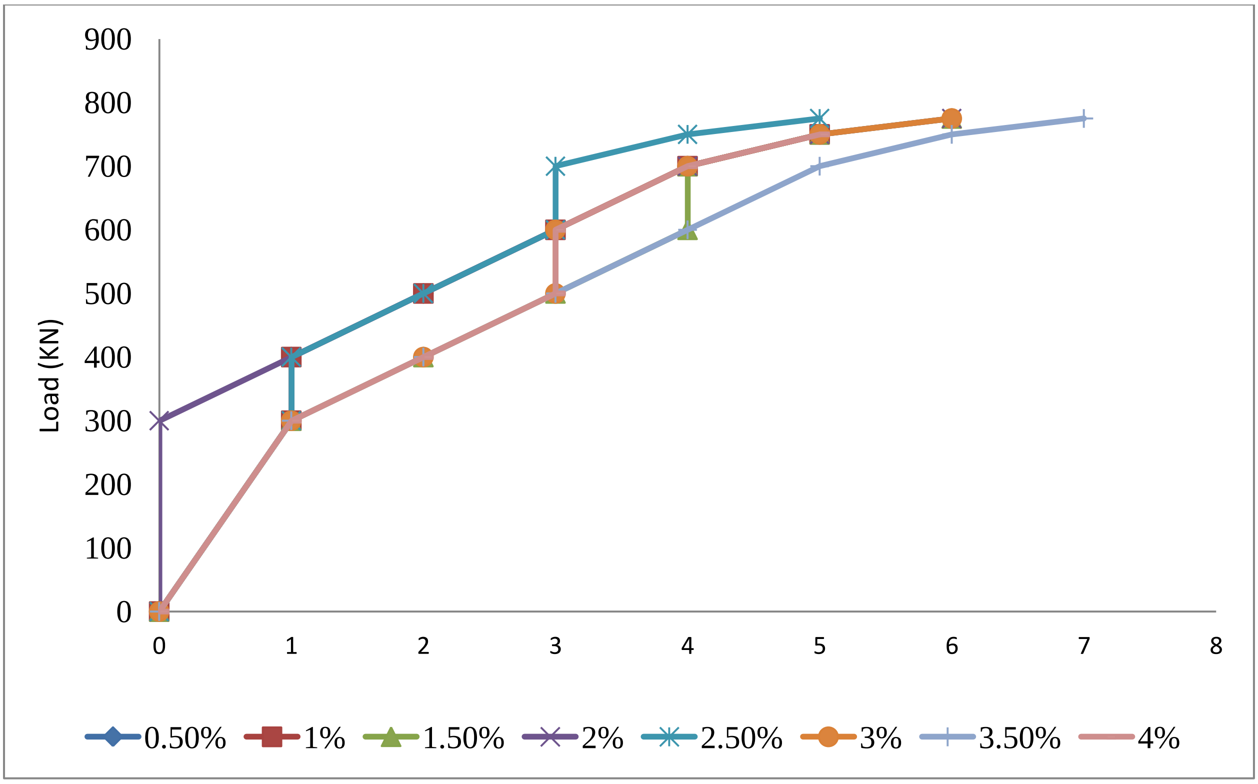


Figure 4.3 Variation of load with respect to Central Deflection for FSF



Deflection (mm)

Figure 4.3 Variation of load with respect to Central Deflection for WSF

SF

V. TEST RESULTS

Typical force-deflection relationships are shown in above fig. for the three types of higher-strength concrete beams. As the fiber content increased, both the maximum applied load and ultimate deflection increased also. This behavior was typical of the other beams.

Flexural strength

The flexural strengths of the 25 beams are reported in above Table 1, 2 and3 in terms of the maximum flexural strength.

VI. SUMMARY AND CONCLUSIONS

The experimental results from 25 fiber-reinforced concrete beams demonstrate the influence of steel-fiber volume fraction, flexural strength and failure mode. The increase in flexural strength was particularly large for beams with the smallest *a/ds* (*a/d* = 2), which failed in a combination of shear and flexure. The addition of steel fibers consistently decreased crack spacings and sizes, increased deformation decreased crack spacings and size, increased deformation capacity, and changed a brittle mode to a ductile one.

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