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Experimental Study on Hybrid Fiber Reinforced Concrete Deep Beams under Shear

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Abstract

The main objective of this paper is to study the effect of addition of hybrid (Crimped steel-Polypropylene) fibers on shear strength of reinforced concrete deep beams without shear reinforcement. The effect of hybrid fibers on shear strength of reinforced concrete deep beams with different steel fiber volume fractions (0 %, 1.0 % and 2.0 %), and shear span-to-depth (a/d) ratios 0.60 and 0.66 by keeping tensile reinforcement constant is studied. All the beam specimens are tested under four-point bending test set-up up to failure, and failure load, first crack load, and central deflection are recorded precisely. The tests results are compared with the equations proposed by different codes and authors available in the literature. The test results indicate that the hybrid (Crimped steel-Polypropylene) fiber have significant influence on the shear strength of longitudinally reinforced concrete deep beams. Shear strength increases with increase in fiber volume fraction and decrease ina/dratio.

Keywords: *Shear strength, deep beam, concrete, a/d ratio, hybrid (Crimped steel-Polypropylene) fiber*

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1.0 INTRODUCTION

Many a structural elements like walls of bunkers, load-bearing walls in buildings, plate element in folded plates and pile caps behave as deep beams [1]. A beam is considered deep, according to the Indian Standard Code IS: 456-2000, when the ratio of effective span to overall depth (L/D) is less than 2.0 for simply supported members and 2.5 for continuous members [2].

Deep beams transfer heavy gravity loads predominantly through shearing action by forming a diagonal crack. The conventional plane section remaining plane approach is not applicable to analyses of deep beams [3]. Besides, for beams without web reinforcement, it has been shown that shear strength decreases as member size increases. This is associated with a phenomenon called size effect [4].

Concrete being a non-homogeneous, heterogeneous material and has non-linearity in its material response [5]. As a result of this, it does not feasible to apply a shearing action (direct shearing force) in a plane. Thus, Shear strength in reinforced concrete beams has been the subject of many controversies and debates since the beginning of 20th century. Transversely loaded reinforced concrete beams may fail in shear before attaining their full flexural strengths if they are not adequately designed for shear. Unlike flexural failures, shear failures are very sudden and unexpected, and sometimes violent and catastrophic. A thorough knowledge of the different modes of shear failures and the mechanisms involved is necessary to prevent them [6].

To reduce the brittleness and increase the resistance to cracking, reinforcement with short randomly distributed fibers has been successfully used and the resulting composite is known as fiber reinforced concrete (FRC). The performance of FRC depends on many factors such as fiber material properties, fiber geometry, fiber volume content, matrix properties and interface properties. Most types of FRC used in practice contain only one type of fiber.

However, it is known that failure in concrete is a gradual, multi-scale process. The pre-existing cracks in concrete are of the order of microns. Under an applied load, these cracks grow and eventually join together to form macro-cracks. A macro-crack propagates at a stable rate until it attains

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conditions of unstable propagation and a rapid fracture is precipitated.

For optimal result therefore different types of fibers may be combined and the resulting composite is known as hybrid-fiber-reinforced concrete (HFRC). Steel fibers can be used either to boost the shear capacity or to replace the web reinforcement in conventional RCC deep beams. Synthetic fibers can be used to control the micro-crack. Thus, it transforms an inherently brittle material into a strong composite with a superior crack resistance and improved ductility.

2.0 EXPERIMENTAL PROGRAM

A. Material Properties

The test specimens were cast using cement, fine aggregate, coarse aggregate, water, admixture and crimped steel fibers. The materials, in general, confirmed to the specifications laid down in the relevant Indian Standard codes. For grading of fine and coarse aggregate, sieve analysis was carried out.Ordinary portland cement of 53-grade confirming to IS 12269:1987 was used throughout the experimental work. The maximum size of coarse aggregate used was 20 mm along with 12.5 mm of same parent rock in 60-40 % fraction. Locally available Krishna river sand was used as fine aggregate. The specific gravity of sand was 2.85 and fineness modulus was 2.7. Crimped steel fibers of length 50 mm and diameter 1.0 mm were used throughout the experimental work. Polypropylene fibers of cut length 12mm were used. Reinforcing steel of grade Fe 500 was used as tensile reinforcement.

B. Concrete Mix Design

The concrete mixes were designed in accordance with the D.O.E method of concrete mix design. The concrete mix was prepared for M-50 grade of concrete. The water-cement ratio is kept at 0.32. Super Plasticizers (3.5 ml/Kg of cement) was used to enhance the workability of mix throughout experimental work. The mix proportion is given in Table I.

C. Test Specimens

Total 18 deep beams were casted. The span of the deep beam has been kept constant at 600 mm with 50 mm overhangs on either side of the supports. The shear span (a) has been kept at 200 mm. The depths of beam selected were 360 mm and 330 mm to achieve desirea/d ratio. Beam specimens were divided into two groups, namely, series-I and series-II. All the beams of

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series-I were reinforced with Ast =829.38 mm2. All the beams of series-II were reinforced Ast = 603.19 mm2. All beams were rectangular in cross section with 90 mm width. Standard cubes of size 150 mm x 150 mm x 150 mm were cast with each mix to know the compressive strength of concrete. The details of test beams are given in Table II.

Table I Mix Proportion

Material	*Cement*	*Sand*	*Aggregate*	*Water*
Quantity (Kg/m^3)	*500*	*792*	*1140*	*160*

Table II Test Beam Details

Beam Designation	**Beam Size LxD(mm)**	**Fiber Content (%), V_f**		***a/d* ratio**	**Effective Depth *d* (mm)**
		Steel (Crimped) Fibers	**Polypropylene Fibers**		
I-0%	700x360	0	0	0.60	330
I-1%	700x360	0.5	0.5	0.60	330
I-2%	700x360	1	1	0.60	330
II-0%	700x330	0	0	0.66	300
II-1%	700x330	0.5	0.5	0.66	300
II-2%	700x330	1	1	0.66	300

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D. Test Procedure

After 28-days curing period, the beam specimens were removed from the curing tank and both sides of the beams were white-washed to aid observations of the crack development during testing. All the beams were tested to failure under two-point loading test set-up as shown in Fig 1. The cube specimens were tested for compressive strength.

E. Shear Design Models

Various shear strength models have been used to verify the strength of FRC deep beams in the present investigations.

I. ACI 318-05 Design Model [7]

The shear strength of beam without stirrups can be computed as follows,

In S.I. system (N, mm system)

$$V_c = \left(3.5 - 2.5\frac{M_u}{V_u}\right)\left(0.16\sqrt{f'_c} + 17\rho\frac{V_u d}{M_u}\right)bd$$

where, M_u and V_u are the ultimate moment and shear at the section under consideration. f'_c is the concrete compressive strength in MPa, ρ is the longitudinal reinforcement ratio (A_s/bd) and A_s is the area of longitudinal reinforcement.

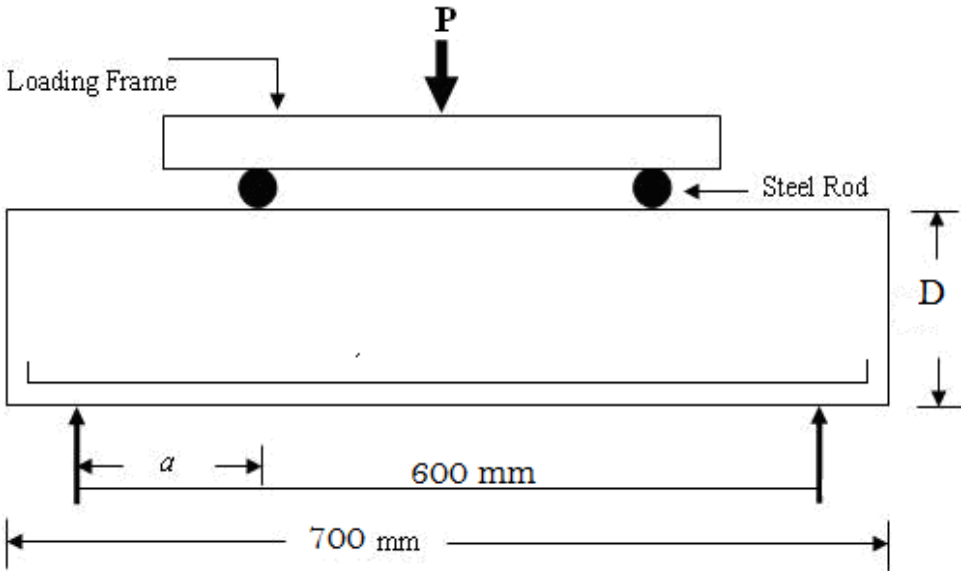


Figure 1 Two point bending test set-up

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II. CIRIA Guide-2 Design Model [8]

CIRIA Guide-2 applies to simply supported beams of span-to-depth ratio (L/D) less than 2 and to continuous beams of span-to-depth ratio (L/D) less than 2.5.

The shear strength of beam without shear reinforcement is given as follows.

$$V_c = \lambda\left[\left(1-0.30\frac{a}{d}\right)\sqrt{f'_c}bd\right].$$

where,b is the width, d is the effective depth of beam, $f'_c$is the characteristic compressive strength of concrete and λ(=0.44) is empirical coefficient for normal weight concrete.

III. Khuntia's Proposed Equation[9]

The shear strength of FRC beams is governed by the concrete contribution in the shear without stirrups and contribution of fibers. The shear strength FRC beam is given as follows,

$$V_{frc} = (0.167\alpha_1 + 0.25F)\sqrt{f'_c}bd$$

where, V_{frc}= Shear strength of FRC, α_1= 2.5(d/a), and

$F = V_f \frac{l_f}{d_f}$ = fiber factor.

in which

V_f = fiber volume fraction, l_f=length of fiber and d_f=diameter of fiber.

IV. Mansur's Proposed Equation [10]

The equation proposed by Mansur *et* al[10] for shear strength of FRC is follows

$$V_{frc} = (0.16\sqrt{f'_c} + 17.2\rho\frac{d}{a} + 0.41\tau F)bd$$

where, f'_c =Characteristic compressive strength of concrete, ρ = Longitudinal reinforcement ratio, b and d = width and effective depth of beam, a = shear span, and

$F = V_f \frac{l_f}{d_f}$ = fiber factor

in which

V_f = fiber volume fraction, l_f=length of fiber and d_f=diameter of fiber.

Using equation (I) through (IV) shear strength are computed and compared with those of present investigation.

3.0 RESULTS AND DISCUSSION

The results obtained from experimental investigation are tabulated in Table III.

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From the results obtained, the effect of various parameters on shear strength of concrete deep beam are analyzed and discussed below.

A. Effect of Depth of Beam in Terms of Shear Span-to-Depth Ratio and Fiber Volume Fraction:

The compressive strength, ultimate and cracking shear stress of concrete for different fiber volume fractions and shear span-to-depth ratios at 28 days of curing age are given in Table III. The variation of ultimate shear strength of deep beam with respect to fiber volume fraction for beam series I and II are given Table III. It is evident that the ultimate shear strength of deep beam increases with increase in fiber content.

Fig 2 shows the effect of a/d ratio on ultimate shear strength of concrete. It is evident from the figure that the higher shear strength is developed at lower value of shear span-to-depth ratio.

Ultimate shear stress at diagonal cracking, which is obtained by dividing measured failure load to the nominal cross sectional area (b x d). In deep beams, the significant portion of the shear is transmitted directly to the support by inclined strut. This mechanism is frequently referred to as arch action and the magnitude of the direst load transfer increases with decreasing a/d ratio.

B. Influence on Cracking Shear Stress:

Results of cracking shear stress are presented in Table III. It is concluded from Table III that cracking shear strength of deep beam increases with increase in fiber content and decreases with increase in a/d ratio.

C. Central Deflection of Deep Beam:

Typical load-deflection relationships for beam series I and II are shown in Fig 3and Fig 4. From the graph it is evident that the central deflection of beam increases with increase in fiber content. Due addition of fibers, beam carries considerable load even after first cracking.

D. Influence on Cube Compressive Strength:

Cube compressive strength of concrete for different fiber content is given in Table III. Cube compressive strength of concrete increases with increase in fiber content.

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Table III Details of Test Results

Test Beam Design a-tion	Effecti ve Depth (d) mm	*a/d* rati o	Longitudin al Steel (A_{st}) mm^2	Compressi ve Strength (MPa)	Cracki ng Shear Stress (MPa)	Ultima te Shear Stress (MPa)	% increas e in Cracki ng Shear Stress	% increas e in Ultima te Shear Stress
I-0%	330	0.60	829.38	55.47	2.72	4.71	0.00	0.00
I-1%	330	0.60	829.38	58.77	3.43	5.52	26.10	17.19
I-2%	330	0.60	829.38	61.79	3.90	5.75	52.71	22.08
II-0%	300	0.66	603.19	55.47	2.70	4.51	0.00	0.00
II-1%	300	0.66	603.19	58.77	3.25	5.07	20.37	12.41
II-2%	300	0.66	603.19	61.79	3.85	5.48	42.59	21.50

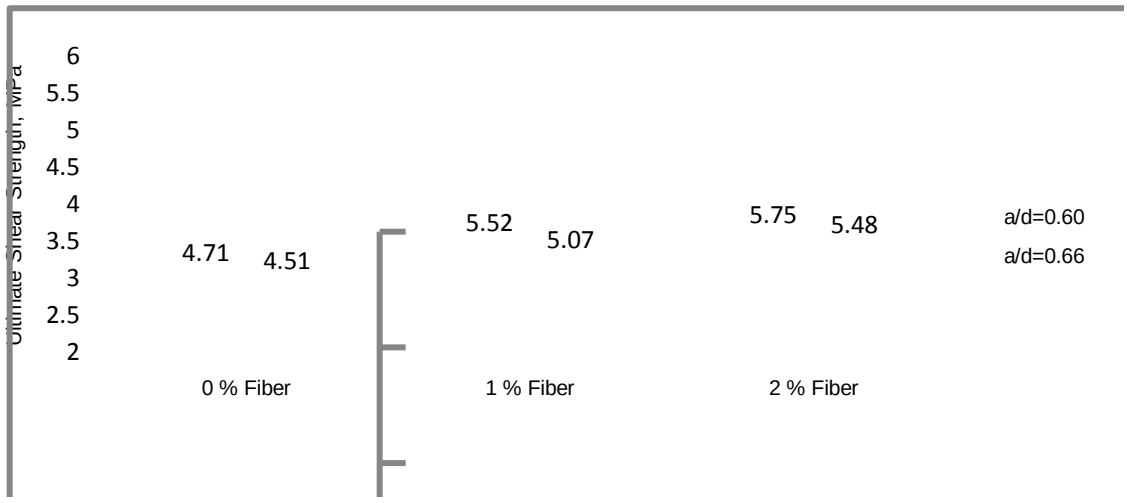


Figure 2.Ultimate shear strength of beam with respect to a/d ratio and fiber content.

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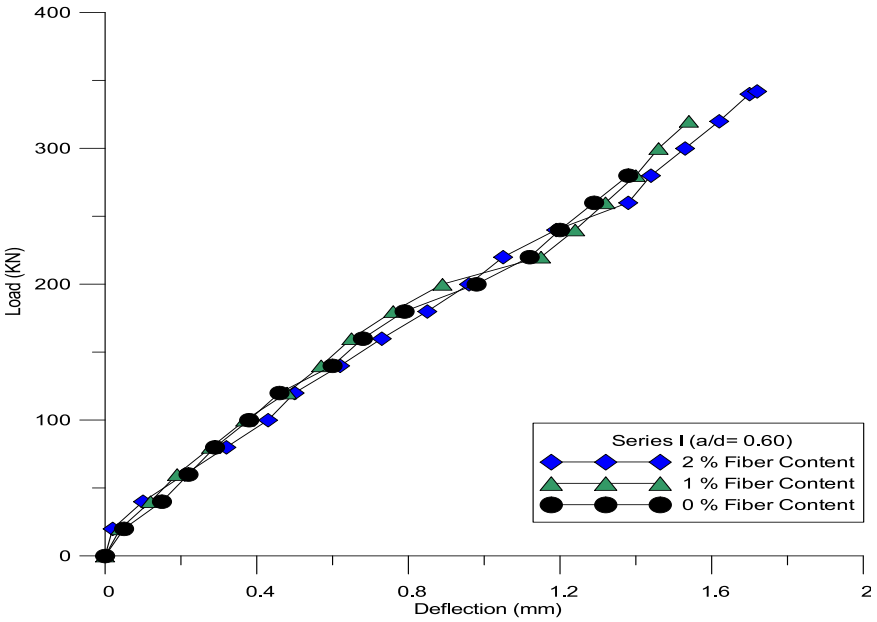


Figure 3 The graph of central deflection with respect to load, series-I

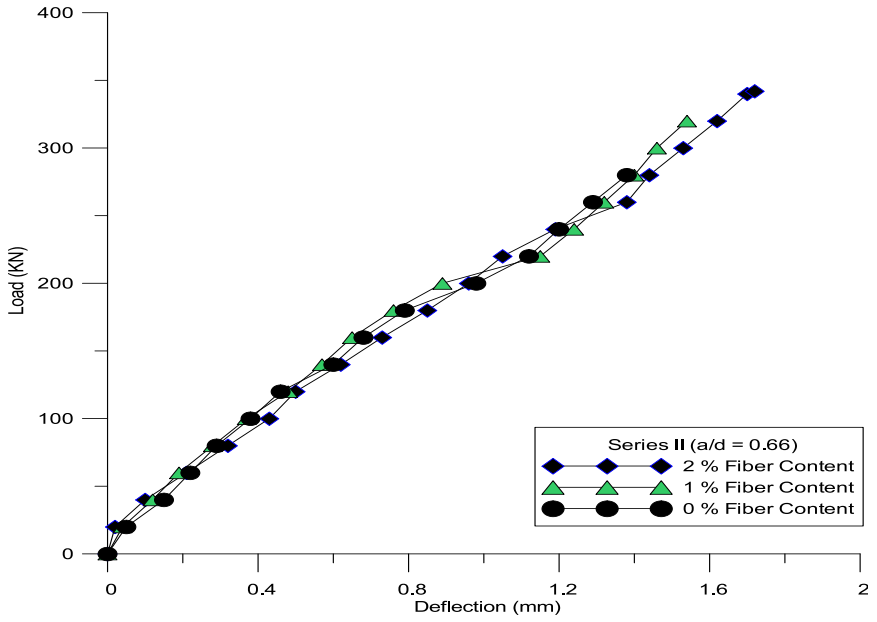


Figure 4 The graph of central deflection with respect to load, series-II

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E. Comparison of Test Results with Shear Design Equation:

Four design equations, namely, the ACI code, CIRIA Guide code, Khuntia and Mansur are used to estimate ultimate shear capacity. Comparison of test results with shear design is provided in Table IV.

Table IV Comparison of Test Results with Shear Design Equations

Beam Designation	Shear Strength (KN)					Shear Strength Ratio			
	V_{ACI}	V_{CIRIA}	$V_{KHUNTIA}$	V_{MANSUR}	V_{TEST}	V_{TEST}/V_{ACI}	V_{TEST}/V_{CIRIA}	$V_{TEST}/V_{KHUNTIA}$	V_{TEST}/V_{MANSUR}
I-0%	104.71	79.82	152.32	53.09	140	1.337	1.753	0.919	2.630
I-1%	108.92	82.14	171.07	84.93	164	1.505	1.505	0.958	1.931
I-2%	108.60	84.23	190.00	118.22	171	1.574	2.030	0.900	1.446
II-0%	86.6	70.96	125.93	47.49	122	1.408	1.719	0.968	2.568
II-1%	88.32	73.04	142.56	76.44	137	1.551	1.875	0.960	1.798
II-2%	89.36	74.90	159.44	106.71	148	1.656	1.975	0.928	1.386

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Shear strength obtained from ACI 318-05 Design Model and CIRIA Guide-2 Design Model is lower compared with test results, since contribution of fibers toward shear strength is not considered in above two equations. Thus, ACI 318-05 Design Model and CIRIA Guide-2 Design Model are not applicable to compute shear strength of fiber reinforced concrete deep beams. Results obtained from Khuntia's equation are approximately similar to test results, since contribution of fibers toward shear strength is considered. Mansur's equation gives approximate shear strength as obtained in test for higher volume fractions. From Table IV, it is evident that, Khuntia's equation holds good to calculate shear strength of fiber reinforced concrete deep beams.

CONCLUSION

Based on the test results following conclusions can be drawn,

1) Hybrid (Crimped steel-Polypropylene) fibers in concrete deep beams provides better crack control and deformation characteristic of beams.

2) Both the first crack strength and ultimate strength in shear increased with increase in fiber content because of their increased resistance to propagation of cracks.

3) Maximum increase of 52.71% in ultimate shear stressfor beam (Series-I) containing 2 % fibers was observed when compared it with beam without fibers.

4) Maximum increase of 22.08% in cracking shear stressfor beam (Series-I) containing 2 % fibers was observed when compared it with beam without fibers.

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