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A STUDY ON EFFECT OF STEEL FIBER IN SHEAR CRITICAL REGIONS OF HSC BEAMS - VARIAITON WITH a/d RATIO

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Abstract— *To improve the mechanical properties of concrete the steel fibers are being used in different structural applications. In this paper an effort is made to use steel fiber in an optimistic way i.e. in stress concentrated regions. Thus investigations were carried out for the improvement of shear strength of high strength concrete beams (65 MPa) with various dosages of fibers (0.4%, 0.8%, and 1.2% by volume of concrete) only in shear predominant regions, without shear reinforcement varying shear span to depth ratios (a/d = 1, 2, 3, and 4). The results were compared with similar beams cast with shear reinforcement and dosing the fibers throughout the beam to quantify the effect of shear reinforcement and fiber in stress concentrated regions. To validate the experimental studies, the beams for modeled and loaded analytically using ANSYS. The validation results revealed that there was an increase in shear capacity with addition of fiber at different shear span to depth ratios (a/d) ratios. The shear capacity of beams with shear reinforcement was almost equivalent to beams reinforced with fiber through out the beam and fiber only in shear critical regions.*

Index Terms— High-strength Concrete, Shear, Steel fiber reinforced concrete, Shear span to Depth Ratio (a/d).

1 INTRODUCTION

Concrete is more versatile material with good compressive strength and low tensile strength. The low tensile strength is compensated with steel. Most of the researchers have emphasized their study on improving the tensile strength of concrete inherently. The Steel Fiber Reinforced Concrete (SFRC) emerged as a promising composite. **Julia Sauer et al [1] (2010)** have investigated on shear capacity of steel fiber reinforced concrete beams without stirrups. The research checked the effectiveness of steel fibers on the shear capacity of beams without stirrups. A comparison between the ultimate shear force and the calculated shear force showed that the German guideline estimates the shear capacity on the safe side. **Guray Arslan [2] (2008)** has investigated on Cracking shear strength of RC slender beams without stirrups. The author has made an attempt to predict a simplified equation of cracking shear strength of RC beams and to compare test results reported in the literature with the current ACI Code provisions. **Remigijus Salna and Gediminas Marciukaitis [3] (2007)** have reported on "The influence of shear span ratio on load capacity of fiber reinforced concrete elements with various steel fiber volumes"**.** Test results suggest that steel fiber volume and shear span can increase load capacity, plasticity and cracking.

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Most of the research on SFRC is emphasized on use steel fibers through out the structural element. The paper makes an attempt to study the behavior of high strength SFRC beams in shear with fiber only in stress concentrated regions, by varying a/d ratio and volume fraction of fibers. A rational formula has been proposed for estimating the shear resistance of high strength fiber reinforced concrete (HSFRC) members in terms of shear span to depth ratio, tensile strength of the composite and percentage longitudinal tensile reinforcement.

2. EXPERIMENTAL PROGRAMME:

The response of HSFRC beams under shear loading was evaluated by studying the behavior of

- Concrete beams with out fiber and with shear reinforcement varying shear span to depth ratio (a/d) from 1 to 4
- Steel fiber concrete beams with shear reinforcement varying a/d ratio 1 to 4 and with volume fractions of fibre as 0.4%, 0.8% and 1.2% of volume of concrete.
- Steel fiber concrete beams with shear reinforcement varying a/d ratio 1 to 4 and with volume fractions of fibre as 0.4%, 0.8% and 1.2% of volume of concrete only in shear critical regions.

To study the behavior of the above said phenomenon the beams were caste and tested under shear loading in three batches. In the first batch four high strength concrete beams (HSCB) were cast with shear reinforcement by varying a/d ratio as 1, 2, 3 & 4(named as 'SR' batch). The second batch involved casting of twelve SFRC beams with shear reinforcement for a/d = 1, 2, 3 & 4 and varying the fibre content as 0.4%, 0.8% and 1.2% of volume of concrete through out the

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beam(named as 'SFR' batch). Similar to second batch beams, in the third batch, twelve beams were cast with same parameters, but the fiber was dispensed only in shear predominant regions(named as 'CFSR' batch). For all the batches, the parameters viz., concrete proportions, aspect ratio of fibres and percentage of longitudinal reinforcement were kept constant.

Table 1: Details of beams:

S.No	Batch	No of Beams	Parameters varied		
			a/d	% of fibers	Fiber dosage
1	SR	4	1,2,3 & 4	0	NA
2	SFR	12	1,2,3 & 4	0.4,0.8 & 1.2	Full
3	CFSR	12	1,2,3 & 4	0.4,0.8 & 1.2	Critical regions

Table 2 :Experimental Details:

Materials Used	Cement, Flyash, GGBS,Fine and Coarse Aggregate,Superplasticizer, Steel fibers(l/d=75), Logitudinal reinforcement(2-16mmΦ + 1-10mmΦ), Shear Reinforcement (6mmΦ @ 100mm c/c)
Specimen size	100mm x 175mm
Beam Length(m)	0.7, 1.0, 1.3 and 1.6 as per a/d ratio 1, 2, 3 and 4 respectively.

2.1 Mix Design:

The high strength concrete mix design for M65 was done using Erntroy and Shacklock method [4]. After few trail mixes the mix design proportions were finalized.

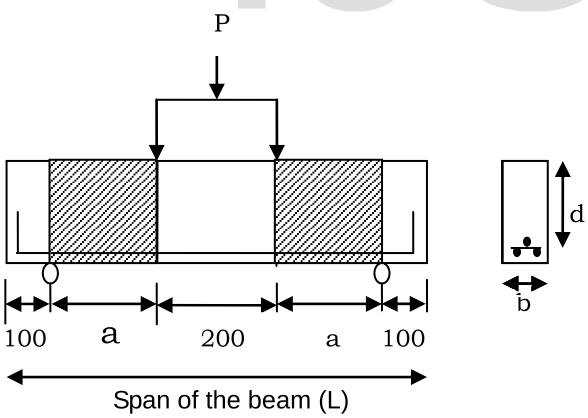

Figure 1: Specimen Details

2.2 Test Procedure:

A loading frame of 100 ton capacity was used to test the beam which is shown in figure 2 where the ends of the beam were simply supported. The load was transferred through a rigid spread beam on to the top of thetest specimen. Corresponding to the a/d ratio, the supports of the spread beam were adjusted so as to vary the shear span to depth ratio (as depth of the beam is constant for all beams tested) from 1 to 4. The deflection was monitored using LVDT's at the mid span and at the centre of the shear span. The data from test was interpeted in form of load displacement diagram, the bend over point in the graph was taken as cracking load.

Figure 2: Photo showing 100 ton loading frame - Arrangement of test specimen

3. Discussion of Test Results:

The load – displacement variation of the tested beams are presented in Fig 3 to 6. From these variations, it is clear that the load deflection variation is linear up to 65% of ultimate load. The load resistance in the post cracking region is due to longitudinal reinforcement alone and the variation is approximately linear. The secondary cracks were seen in shear span in during the post cracking and pre-ultimate stage of loading the beam. Eventually load bearing capacity of the member decreased beyond the ultimate load and the widening of a single potential crack in the shear span lead the ultimate failure. The deflects in fibrous beams were found to be more in the post ultimate stage of loading, which infers that fiber addition in members improved the ductility.

In all the graphs there was a gradual rate of increase in shear capacity up to 0.8% dosage of fibers and decreased a little at 1.2% dosage of fibers. The shear capacity reduction is attribueted to poor workability at 1.2% dosage of fibers.The details of percentage increase in shear capacity and energy absorption id stated in table no 3.

Table 3: Details of shear and energy absorption capacities:

a/d ratio	% of Fibers	% increase in shear capacity	% increase in Energy absoption capacity
1	0.4	12	39
	0.8	16	55
	1.2	24	69
2	0.4	23	54
	0.8	28	76
	1.2	30	85
3	0.4	30	69
	0.8	35	89
	1.2	39	122
4	0.4	24	76
	0.8	30	117
	1.2	33	146

The energy absorption capacity is observed to be incresing with increase in volume fraction of fibers. The strut and arch action in the beam for lower a/d ratios (1 and 2) resulted in lower energy absorption capacity. As compressive strength of concrete plays vital role in strut mode of failure and the fiber is poor in increasing the compressive strength of the concrete, the energy absorption for strut action is found to be low. For higher a/d ratios (3 and 4), beam action prevails and the load carrying capacity is governed by the diagonal tensile strength of concrete. The failure pattern of the beams for a/d 1 and 2 was a compression failure which occurred adjacent to the load which may be designated as a shear compression failure. For shear span to depth ratio 3 and 4 the diagonal crack started from the last flexural crack and turned gradually into a shear crack more and more inclined under the shear loading. The failure may be designated as diagonal tension failure. The pattern of cracks of fibrous beams is similar to that of non fibrous beams, but the crack width at ultimate failure is less in fibrous beams compared to non fibrous beams.

As steel fibers are effective in improving the tensile behavior of the concrete in terms of deformation, cracking strength and energy absorption, volume fraction of the fiber shows better behaviour in beams with higher a/d ratios. From this d ffective if pla redominant.

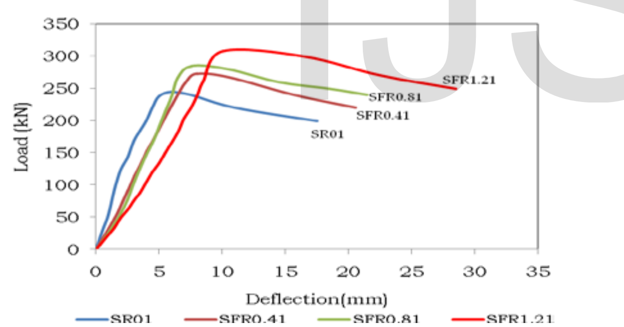

Figure 3: Load (kN) vs Deflection (mm) for a/d = 1, with 0%, 0.4%, 0.8% and 1.2% fibers in HSCB.

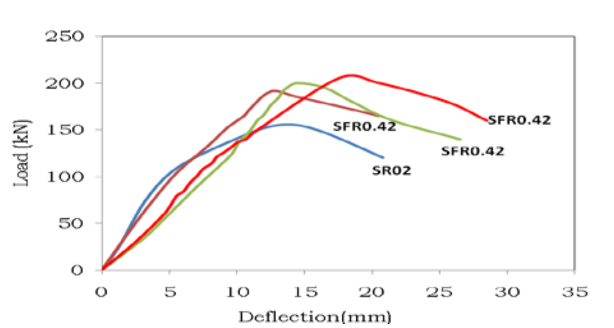

Figure 4: Load (kN) vs Deflection (mm) for a/d = 2, with 0%, 0.4%, 0.8% and 1.2% fibers in HSCB.

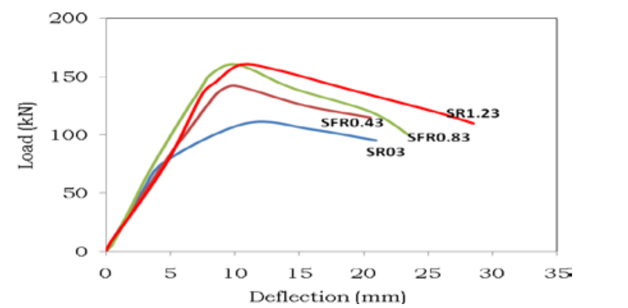

Figure 5: Load (kN) vs Deflection (mm) for a/d = 3, with 0%, 0.4%, 0.8% and 1.2% fibers in HSCB.

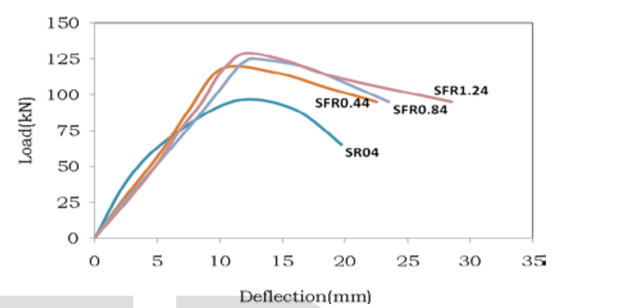

Figure 6: Load (kN) vs Deflection (mm) for a/d = 4, with 0%, 0.4%, 0.8% and 1.2% fibers in HSCB.

4. FINITE ELEMENT ANALYSIS OF HSC BEAM USING 'ANSYS':

For obtaining approximate solutions to a wide variety of engineering problems a numerical analysis technique the finite element method is used widely. For numerically solving a wide variety of problems which include static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems ANSYS a general purpose finite element modeling package is used. The HSC beams with tensile reinforcement, shear reinforcement and fiber have been modeled and analyzed using a finite element (FE) model in ANSYS.

5. MODELLING OF BEAMS:

The concrete has been modeled using 'SOLID65' defined as eight node brick element capable of simulating the cracking and crushing of brittle materials. The compressive strength and tensile strength are established based on test data of the specimens cast and tested along with the rectangular beams. The data was used for defining concrete ('CONCR') properties in 'ANSYS'. In the present analysis a constant mesh size of 50mm was assumed. The mesh solid is presented in Figure 3. The longitudinal reinforcement i.e. the High Yield strength deformed (HYSD) have been modeled using LINK8 3D Spar element. The cross sectional area of each element is given as area equivalent to each rebar. For the rebar the same mesh size as that of concrete element is adopted. Perfect bond between concrete and reinforcement is ensured between the two elements in ANSYS. The figure 7 shows a typical beam modeled in ANSYS for a/d =1 with element mesh size of 25mm.

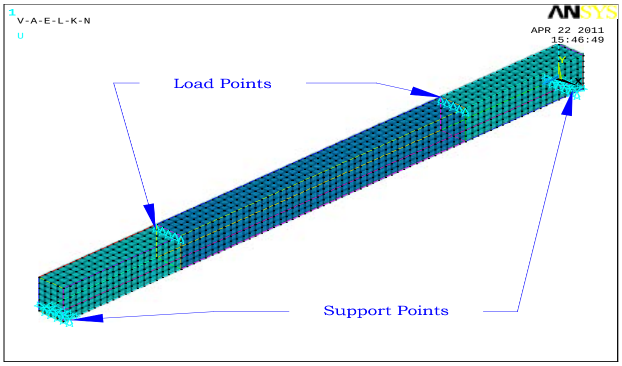

Figure 7: ANSYS modeled beam for typical a/d ratio after meshing with boundary conditions and load points.

6. COMPARITIVE ANALYSIS OF EXPERIMENTAL AND ANALYTICAL RESULTS VARYING a/d RATIO:

The variation of experimental and analytical shear capacity of the members with increase in a/d ratio is represented from figure 18 to 23. The experimental results almost matched with ANSYS results at all a/d ratios. Thus, to estimate theultimate as well as cracking shear strength of HSC beams with and without fibers under shear loading it shall be rational to incorporate the a/d ratio. Further, from figures 8-16 it is clear that, by comparing the SFR and CFSR beam behavior with a/d ratio at 0.4, 0.8 and 1.2% of dosages of fibersignifies that the dosage of fibers in critical regions shall be economical.

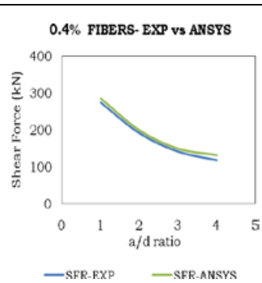

Figure 8: Shear Force Vs a/d ratio for 0.4% volume fraction of fibers throughout the beam.

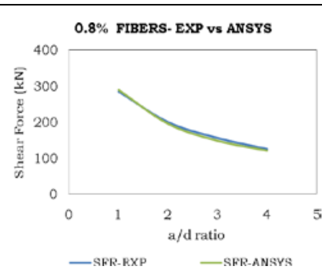

Figure 9: Shear Force Vs a/d ratio for 0.8% volume fraction of fibers throughout the beam.

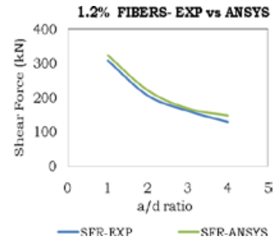

Figure 10: Shear Force Vs a/d ratio for 1.2% volume fraction of fibers throughout the beam.

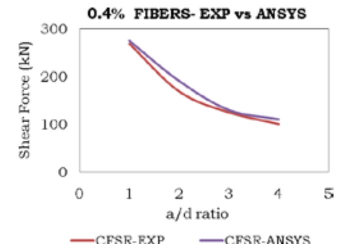

Figure 11: Shear Force Vs a/d ratio for 0.4% volume fraction of fibers in critical regions.

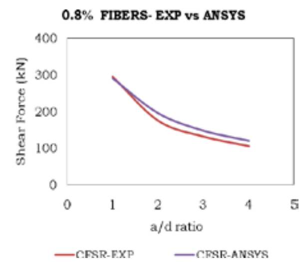

Figure 12: Shear Force Vs a/d ratio for 0.8% volume fraction of fibers in critical regions.

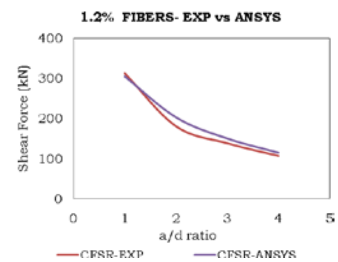

Figure 13: Shear Force Vs a/d ratio for 1.2% volume fraction of fibers in critical regions.

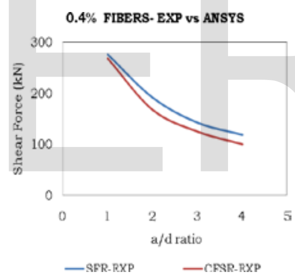

Figure 14: Shear Force Vs a/d ratio for 0.4% volume fraction of fibers throughout the beam and in critical regions.

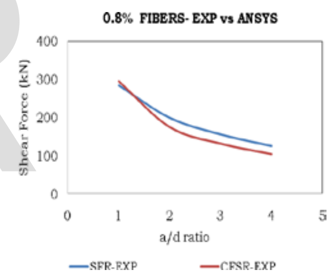

Figure 15: Shear Force Vs a/d ratio for 0.8% volume fraction of fibers throughout the beam and in critical regions.

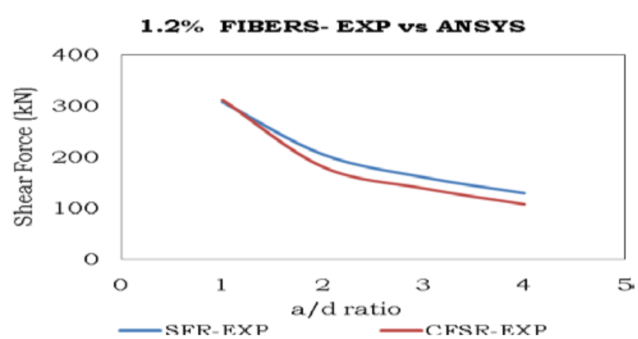

Figure 16: Shear Force Vs a/d ratio for 1.2% volume fraction of fibers throughout the beam and in critical regions.

In the present paper as we are more particular on improvement of shear capacity of HSCB with web reinforcement, the tensile strength of concrete plays a vital role. The shear equations proposed by different codes cited in shear resistance models clearly disclose that shear resistance is factor of tensile strength of concrete, shear span to depth ratio (a/d) and tensile reinforcement ratio, the tensile strength of concrete and tensile reinforcement ratio has a direct proportionality relation and shear span to depth ratio (a/d) has a inverse proportionality relation. Therefore to estimate the shear capacity of HSC beams, the parameters viz.., tensile strength of concrete, shear span to depth ratio (a/d) and tensile reinforcement ratio were taken into account in form of Shear Influencing Parameter (SIP).

$$SIP = \left(f_t \Big/ \left(a/d \right) \right) \rho \quad \text{.....................} \ (1)$$

f_t - Tensile strength of concrete in Mpa.
a/d – Shear Span to Depth Ratio.
ρ – Tensile Reinforcement Ratio.
The shear resistance obtained by testing the specimens, is used to caluculate the shear strength.The variation of the shaer strength with SIP's calculated using equation 1 is presented in Figure 5.40. Thus to estimate the shear resistance (V_c) a linear regression equation was set in power series as equation 2. However the total shear capacity is combination of that resisted by concrete and shear reinforcement given by equation 4.

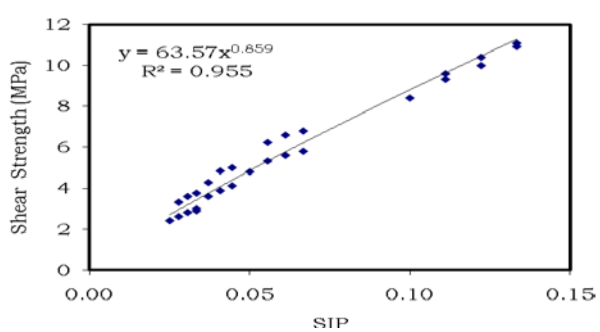

Figure 17: Variation of Shear stress with SIP for beams without Shear Reinforcement.

$$\tau = 63.57(SIP)^{0.86} \quad \text{.............} \ (2)$$

$$V_c = \tau b_w d \quad \text{.............................} \ (3)$$

The shear capacity contributed by stirrups is given by:

$$V_{s} = \frac{f_y A_{sv} d \cot\theta}{s_v} \quad \text{.........................} \ (3)$$

Therefore

$$V = V_c + V_s \quad \text{.............................} \ (4)$$

To authenticate the proposed equation HSSFRC beams with shear reinforcement, the experimental and empirical results are compared.The variations of experimental and empirical results are in range of 10% for beams without shear reinforcement. The variations are presented in the figure 18.

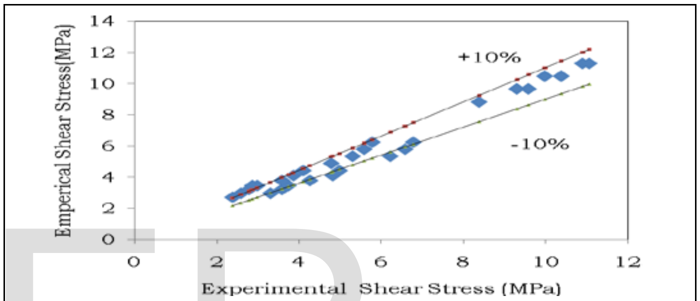

Figure 18: Variation of Experimental and Empirical Shear stress with shear reinforcement.

7. CONCLUSIONS:

1. The shear capacity of the HSSFRC beams shear reinforcement increased with increase in fiber content.
2. It was observed that the cracking shear resistance decreased with increasing a/d ratio. The fibers appeared to be effective in delaying the formation of cracks and in arresting initial growth of the crack.
3. The increase in shear capacity was remarkable up to 0.8% dosage of fibers but decreased slightly at 1.2% dosage of fibers. This decrease in shear capacity for 1.2% fiber content may be due to less workability observed during casting.
4. The shear capacities of beams with fiber in critical regions are convincing with results of beams provided with fiber throughout the beams at all a/d ratios and all dosages of fibers. This indicates that use of steel fibers in the critical regions is better than using the steel fiber throughout the length of the beam.
5. A simplified equation is proposed to predict the shear capacity of HSSFRC specimens with shear reinforcement which fairly estimates the shear capacity of the members.

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