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Finite Element Analysis of High Strength Concrete Beams In Shear - Without Web Reinforcement and With Fiber in Shear Predominent Regions

Sudheer Reddy .L[1] , Ramana Rao. N.V[2] , Gunneswara Rao, T.D[3]

Professor, Department of Civil Engineering, Kakatiya Institute of Technology, Warangal, Telengana, India[1].

Professor, Department of Civil Engineering, JNTU, Hyderabad, Telengana. India[2]. and

Associate Professor, Faculty of Civil Engineering, National Institute of Technology, Warangal, Telengana, India[3].

ABSTRACT: In the recent past the use of steel fibers to improve the mechanical properties of concrete has been the prime research area in structural applications. The paper makes an attempt to study the improvement of shear strength of high strength concrete beams (65 MPa) with different shear span to depth ratios (a/d = 1, 2, 3, and 4) and various dosages of fibers (0.4%, 0.8%, and 1.2% by volume of concrete) only in shear predominant regions, without shear reinforcement. The experimental studies were validated analytically by modeling the beams in ANSYS. The investigations revealed an increase in shear capacity with addition of fiber at different shear span to depth ratios (a/d) ratios. Further the test results of the beams with fiber only in critical regions indicated almost the shear capacity similar to that of the beams reinforced with fiber throughout, thus usage of fiber in shear critical regions shall be more cost effective.

KEYWORDS*:* High-strength Concrete, Shear, Steel fiber reinforced concrete, Shear span to Depth Ratio (a/d).

I. INTRODUCTION

Concrete is known for its good compressive strength and low tensile strength. Researchers are continuously striving to improve its tensile capacity, as it is being the most accepted composite used for all structural applications. In this course, usage of steel fiber reinforced concrete (SFRC) emerged and many studies having been undertaken over the past four decades. Numerous research's (e.g. Narayanan. R et al.,[1]; Kwak et al.,[2]) has been conducted on the shear behavior of FRC over the past decades and the general conclusion is that, with proper mixture design FRC is capable of considerably increasing performance in terms of shear strength and ductility when compared to plain concrete. From most of the reviews, it may be concluded that Steel Fiber Reinforced Concrete (SFRC) is a composite material with significantly better tensile strength and higher resistant to crack formation and propagation. Research on the high strength concrete showed that the cube compressive strength has less significance than the fracture energy for the description of the material behavior of structural elements.

Researchers such as, Imam.M. et al[3] and Bukhari.I.A et al[4], reported that high strength SFRC beams possess higher shear capacity than the non fibrous beams. All the research works emphasized the usage of fibers throughout the elements for their study. As the addition of fibers makes the conventional concrete costlier, its usage can be restricted to stress concentrated regions. Research studies with this aspect are almost less. In this paper, shear behavior of high strength concrete beams without web reinforcement, varying shear span to depth ratio and volume fraction of fibers (throughout the beam and only in critical regions) is presented. The experimental studies were validated analytically using ANSYS.

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II. OBJECTIVES OF THE STUDY

To assess the response of high strength concrete (HSC) beams under shear loading, the following studies were carried out both experimentally and analytically.

- Behavior of steel fibrous concrete beams without shear reinforcement, with a/d ratio from one to four and with volume fractions of fiber as 0.4%, 0.8%, and 1.2% of volume of concrete throughout the beam termed as High Strength Fiber reinforced concrete (HSFRC) - (FR series).
- Behavior of steel fibrous concrete beams without shear reinforcement, with a/d ratio from one to four and with volume fractions of fiber as 0.4%, 0.8%, and 1.2% of volume of concrete only in critical regions of the beam (CFR series).

III. EXPERIMENTAL PROGRAMME

The experiments were carried out in two phases by casting and testing the beams in laboratory.

- The first phase involved casting and testing of twelve fibrous HSC beams without shear reinforcement with a/d equal to one, two, three, and four and fiber content of 0.4%, 0.8%, and 1.2% of volume of concrete-FR series.
- The second phase involved casting and testing of twelve fibrous HSC beams without shear reinforcement with a/d equal to one, two, three, and four and fiber content of 0.4%, 0.8%, and 1.2% of volume of concrete only in critical regions- CFR series.

For ensuring the SFRC in critical regions, two stoppers were placed at critical positions. After the first layer of concrete is laid for 50mm the stoppers were removed and concrete was compacted using needle vibrator. Again stoppers were put at the same position and the next layer of concrete was laid. After the second layer was complete, again the stoppers were removed and the concrete is compacted. The same procedure was followed for rest of the beam. In the experimental programme, the parameters viz., designed concrete proportions, aspect ratio of fibers and percentage of longitudinal reinforcement were kept constant. The details are listed in table I and II:

TABLE I

Sl.No	Beam ID	Volume Fraction of Fibers (%)	Length of beam (m)	Remarks
a/d=1				***FR –** With longitudinal Reinforcement and Steel Fibers through out the beam. **0.41:** '0.4' indicate 0.4% Fibers. '1' indicate a/d Ratio.
1	*FR$_{0.41}$	0.4	0.7	
2	FR$_{0.81}$	0.8	1.0	
3	FR$_{1.21}$	1.2	1.3	
a/d=2				
4	FR$_{0.42}$	0.4	0.7	
5	FR$_{0.82}$	0.8	1.0	
6	FR$_{1.22}$	1.2	1.3	
a/d=3				
7	FR$_{0.43}$	0.4	0.7	
8	FR$_{0.83}$	0.8	1.0	
9	FR$_{1.23}$	1.2	1.3	
a/d=4				
10	FR$_{0.44}$	0.4	0.7	
11	FR$_{0.84}$	0.8	1.0	
12	FR$_{1.24}$	1.2	1.3	

TABLE II

Sl.No	Beam ID	Volume Fraction of Fibers (%)	Length of beam (m)	Remarks
a/d=1				
1	*CFR$_{0.41}$	0.4	0.7	***CFR –** With longitudinal Reinforcement and Steel Fibers only in Critical Regions. **0.41:** '0.4' indicate 0.4% Fibers. '1' indicate a/d Ratio.
2	CFR$_{0.81}$	0.8	1.0	
3	CFR$_{1.21}$	1.2	1.3	
a/d=2				
4	CFR$_{0.42}$	0.4	0.7	
5	CFR$_{0.82}$	0.8	1.0	
6	CFR$_{1.22}$	1.2	1.3	
a/d=3				
7	CFR$_{0.43}$	0.4	0.7	
8	CFR$_{0.83}$	0.8	1.0	
9	CFR$_{1.23}$	1.2	1.3	
a/d=4				
10	CFR$_{0.44}$	0.4	0.7	
11	CFR$_{0.84}$	0.8	1.0	
12	CFR$_{1.24}$	1.2	1.3	

A. Materials Used

The ingredient materials physical and mechanical properties used for casting HSFRC beams such as cement, fine aggregate, coarse aggregate and longitudinal reinforcement are taken as per IS code provisions. The type and shape of the steel fibers used for casting was straight and rounded with aspect ratio (l/d) of 75. To improve the workability of fibrous concrete naphthalene based super plasticizer Conplast337 was utilized. Natural pozzolonas such as, fly ash (Class F) acquired from Kothagudam thermal power station and Ground Granulated Blast Furnace Slag (GGBS) with physical requirements confirming to IS 12089 1987 [5] procured from Vizag were utilized.

B. Mix Design:

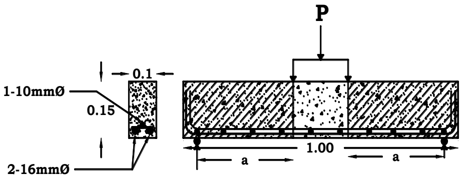
The mix design for high strength concrete has been evaluated using Erntroy H.C. et al [6]. Trial mixes were conducted to achieve the final mix proportions, which are listed in table III. The 28-day compressive strength arrived with the proportion below was 65MPa.

TABLE III

Material	**Unit**	**Quantity**
Cement	Kg/m^3	511
Fine Aggregate	Kg/m^3	568
Coarse Aggregate	Kg/m^3	1138
Water	litre/m^3	132
Fly Ash (By mass of Cement)	**%**	5
GGBS (By mass. of Cement)	%	15

C. Specimen Details

Experimental investigations were carried out on twenty four simply supported beams under two point loading. The cross section of beams was kept constant as 100mm x 150mm. The shear span to depth ratio was varied as one, two, three, and four for each variation of fiber content (0%, 0.4%, 0.8%, and 1.2%). Thus for a/d ratios of one, two, three, and four ,the length of beams were worked out to be 0.7 m, 1.0 m, 1.2 m, and 1.6 m respectively. The 'FR' (Twelve numbers of HSFRC with fiber content 0.4%, 0.8%, and 1.2% - throughout the beams) and 'CFR'(Twelve numbers of HSFRC with fiber content 0.4%, 0.8%, and 1.2% - in critical regions) series of beams were provided with two 16 mm diameter and one 10mm diameter high yield strength deformed bars as longitudinal reinforcement as illustrated in Figure 1.



supports and load was transferred on to the test beam through a rigid spread beam. Based on the a/d ratio, supports of the spread beam were adjusted so as to vary the shear span to depth ratio (as depth of the beam was constant for all beams tested) from one to four. Two LVDT's were used to monitor the deflections at the mid span and at the centre of the shear span. The bend over point in the load displacement diagram of the beam was taken as cracking load and the test was carried out till the load in post peak region reaches 70% of the ultimate load. Crack patterns were marked on the beam. The test set up is presented in Figures 2.

Fig 2: 100 ton loading frame - Arrangement of test specimen

IV. ANALYTICAL PROGRAMME

Finite element method (FEM) models were developed to simulate the behavior of HSC beams from linear through nonlinear response and up to failure, using the ANSYS program. ANSYS is a general purpose finite element modeling package used for analyzing static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. In this context the all the beams are modeled in ANSYS as per their physical condition desired to satisfy the research studies.

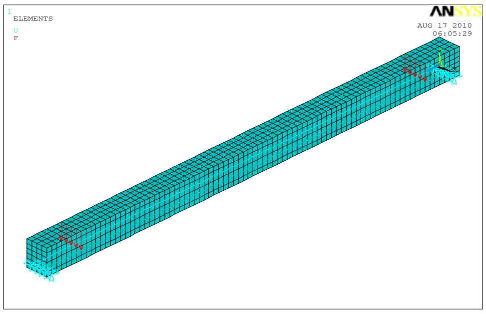
The analytical programme was carried out in three phases by modeling the beams in ANSYS similar to experimental programme.

- Phase -I: Modeling of twelve HSC beams without shear reinforcement with a/d equal to one, two, three, and four varying fiber content as 0.4%, 0.8%, and 1.2% of volume of concrete.
- Phase II: Modeling of twelve HSC beams without shear reinforcement with a/d equal to one, two, three, and four and varying fiber content only in critical regions as 0.4%, 0.8%, and 1.2% of volume of concrete.

A. Modeling of Concrete and Reinforcement in ANSYS*:*

‘SOLID65’ an eight noded brick element capable of simulating the cracking and crushing has been used for modeling concrete. The compressive strength and tensile strength are established based on test data of the specimens cast and tested along with the rectangular beams. The concrete young’s modulus is obtained from the stress-strain behavior of the concerned composite and the Poisson’s ratio is taken as 0.2. The constant mesh size of 25mm is assumed. The meshed solid is presented in figure 3. The compressive strength of concrete was taken as 65Mpa. The compressive uniaxial stress-strain relationship obtained from Hognestad. A et al [7] was used for ‘R’ series beams. The equation proposed by Luiz Álvaro de Oliveira Júnior[8] is adopted to compute the multi-linear isotropic stress-strain for SFRC, which was an input for analysis of FR and CFR beams in ANSYS. For plain concrete, the coefficient for the open crack (βt) was set to 0.25 and the coefficient for closed crack (βc) was set to 0.7. For fiber reinforced concrete, based on the studies of Job Thomas et al [9], βt was set to a value of 0.3, 0.35 and 0.40 and βc as 0.7, 0.73, 0.76 and 0.80 for fiber reinforced concrete V_f = 0.4%,0.8% and 1.2% respectively.

LINK8 3D Spar element was used for modeling the longitudinal reinforcement i.e. the High Yield Strength Deformed (HYSD) bars. The reinforcement was modeled corresponding to experimental studies. The cross sectional area of each element is taken as area equivalent to each rebar. The rebar young’s modulus is taken as 2×10^5 MPa and Poisson’s ratio as 0.3. The mesh size for rebar is taken same as that of concrete element. Perfect bond between concrete and reinforcement is ensured between the two elements in ANSYS. The figure 3 shows a typical beam modeled in ANSYS for a/d =1 with element mesh size of 25mm.



created up to concerned (based on a/d ratio) shear span for SFRC and second volume for normal concrete and the third volume for again SFRC. Later the volumes were glued to form a single entity using Booleans command as displayed in figure 4. In the present analysis the order of material numbers and their purpose is illustrated in the tables IV and V:

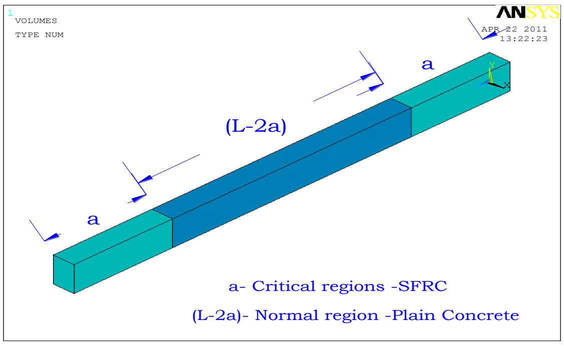


Fig 4: ANSYS modeled beam for typical a/d ratio with fibers in critical regions for CFR. - Series of beams.

TABLE IV

Material Model No.	**Material**	**Element**	**Purpose**
1	SFRC	SOLID65	Concrete with fibers – M65
2	Reinforcement	LINK8	Longitudinal Reinforcement (2-16mm dia)
3	Reinforcement	LINK8	Longitudinal Reinforcement (1-10mm dia)

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TABLE V

Material Model No.	Material	Element	Purpose
1	Plain concrete	SOLID65	Concrete – M65
2	Reinforcement	LINK8	Longitudinal Reinforcement (2-16mm dia)
3	Reinforcement	LINK8	Longitudinal Reinforcement (1-10mm dia)
4	SFRC	SOLID65	Concrete – M65 with fibers in critical regions

B. ANSYS Results

The results of the analysis are listed under General Postprocessor of ANSYS Package. For the present analysis, the load deflection data, load at failure and failure crack patterns are studied. The data from the finite element analysis were collected at the same locations as that of for the load tests for the beams to correlate the results precisely.

V. RESULTS AND DISCUSSION

The load – displacement variation of the tested FR-HSC beams are presented from Figures 5 to 8. It is clear from the graphs that load - deflection variation is linear approximately up to 65% of the ultimate load. The longitudinal reinforcement alone is responsible for the load resistance in the post cracking region. In the shear zone number of secondary cracks has appeared during the post cracking and pre-ultimate stage. Beyond the ultimate load, the load bearing capacity of the member decreased. The ultimate failure occurred with widening of a single potential crack in the shear span. In case of fibrous beams, the post ultimate deflections are found to be more than that of the non fibrous beams. This clearly indicates the post ultimate ductility of the members enhances with the addition of fiber.

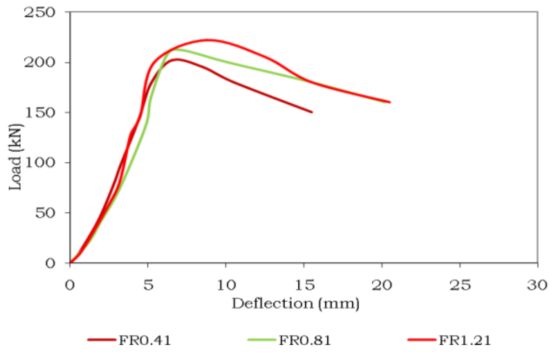

Fig 5: Load - Deflection relation for a/d = 1, with 0.4%, 0.8%, and 1.2% fibers in FR -HSC Beams.

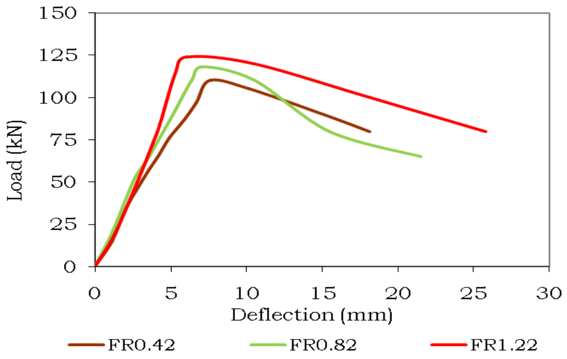

Fig 6: Load - Deflection relation for a/d = 2, with 0.4%, 0.8%, and 1.2% fibers in FR-HSC Beams.

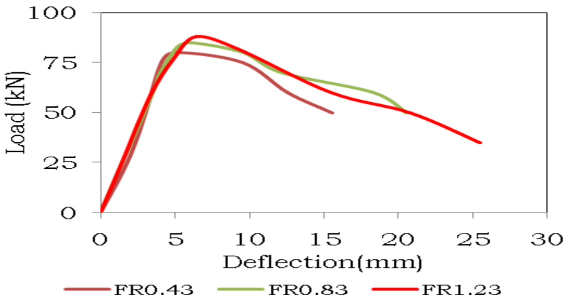

Fig 7: Load - Deflection relation for a/d = 3, with 0.4%, 0.8%, and 1.2% fibers in FR-HSC Beams.

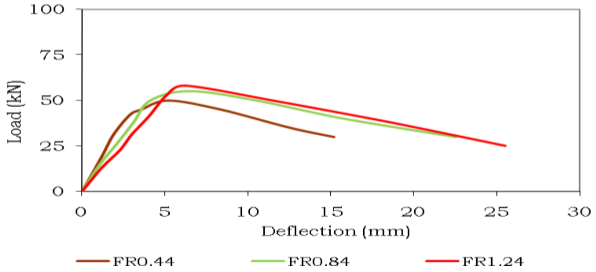

Fig 8: Load - Deflection relation for a/d = 4, with 0%, 0.4%, 0.8%, and 1.2% fibers in FR-HSC Beams.

The load – displacement variation of the tested CFR-HSC beams are presented from Figures 9 to 12. The behavior of the tested beams was found almost similar to that of FR beams at all a/d ratios and different dosages of fibers. The variation in behavior of beams when fiber was dosed through out the beam and only in critical regions is found to be less.

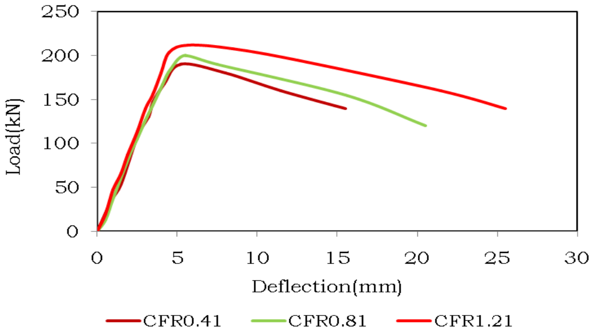

Fig 9: Load - Deflection relation for a/d = 1, with 0.4%, 0.8%, and 1.2% fibers in CFR-HSC Beams.

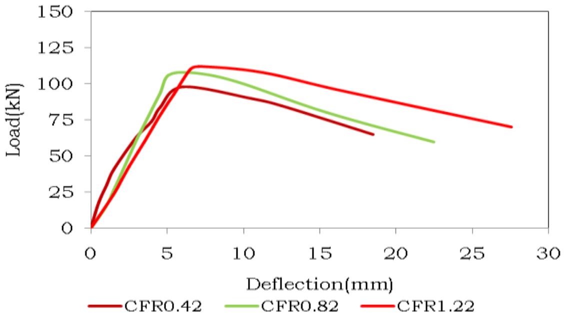

Fig 10: Load - Deflection relation for a/d = 2, with 0.4%, 0.8%, and 1.2% fibers in CFR-HSC Beams.

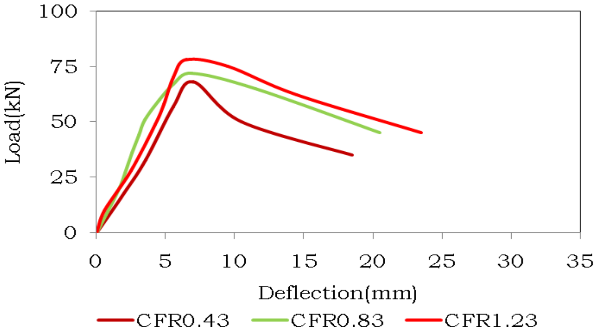

Fig 11: Load - Deflection relation for a/d = 3, with 0.4%, 0.8%, and 1.2% fibers in CFR-HSC Beams.

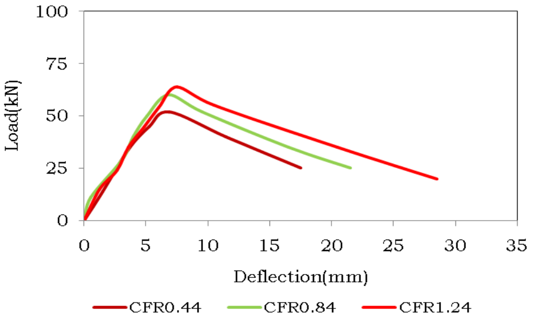

Fig 12: Load - Deflection relation for a/d = 4, with 0.4%, 0.8%, and 1.2% fibers in CFR-HSC Beams.

In the entire load – displacement variations of the tested beams, the increase in shear capacity is 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. The optimum dosage of fibers may be considered as 0.8% for both FR and CFR series of beams.

The ANSYS modeled Load- Deflection response of HSC beams has been compared with the experimental results in figures 13 to 18. The graphs illustrated that the ANSYS model data overlapped with the test data at the initial stage of loading. In the post crack regime the curve was found to be smoother compared to experimental results. Due to the difference in bond characteristics of concrete and reinforcement in the model and the test, the variation in the results may be observed. The ANSYS model could predict the results modestly up to the ultimate load as it assumes perfect bond between the composites. The model could not predict the load-deflection response in the post crack regime as the elements are distorted above the specified limit leading to failure of the specimen.

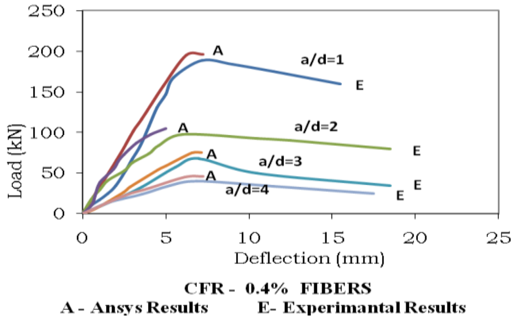

Fig 13: Load - Deflection relation - ANSYS vs Experimental with 0.4% fibers in HSC –CFR Beams

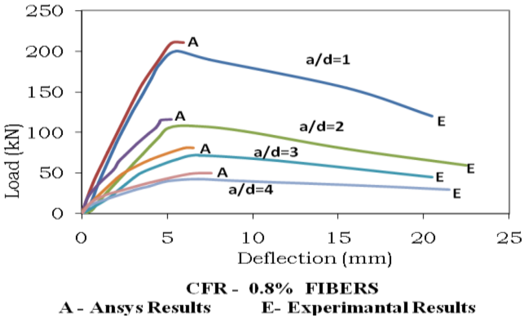

Fig 14: Load - Deflection relation - ANSYS vs Experimental with 0.8% fibers in HSC – CFR Beams.

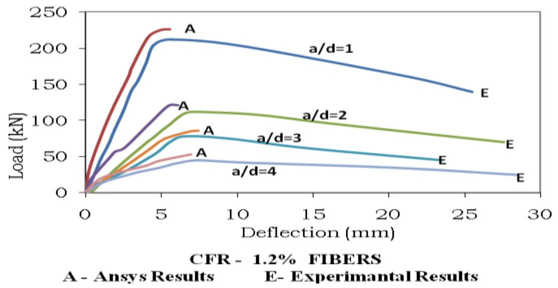

Fig 15: Load - Deflection relation - ANSYS vs Experimental with 1.2% fibers in HSC – CFR Beams

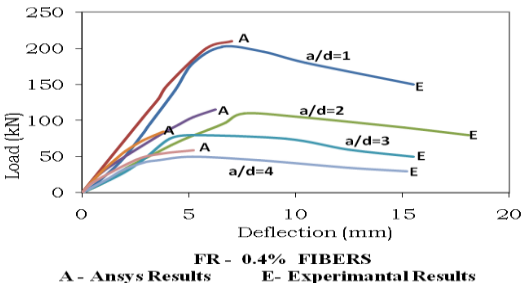

Fig 16: Load - Deflection relation - ANSYS vs Experimental with 0.4% fibers in HSC – FR Beams.

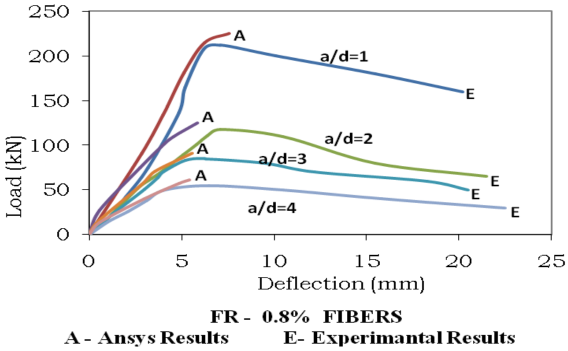

Fig 17: Load - Deflection relation - ANSYS vs Experimental with 0.8% fibers in HSC – FR Beams

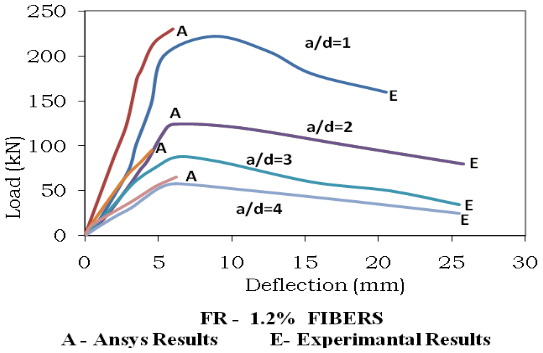

Fig 18: Load - Deflection relation - ANSYS vs Experimental with 1.2% fibers in HSC – FR Beams

Steel fibers are effective in improving the tensile behavior of the HSFRC beams in terms of deformation, cracking strength and energy absorption. Diagonal compression failure was observed in the beams at lower a/d ratios. Therefore the inclusion of fibers has improved deformation, cracking strength and energy absorption moderately for a/d equal to one and two. The failure mode in higher a/d ratios was observed to be diagonal tension type. Therefore the increase in volume fraction of the fiber has shown a better improvement in HSFRC beams for a/d ratios of three and four. From this discussion and comparing the results of FR and CFR beams, it can be inferred that, the addition of fibers in the region where diagonal tension is predominant in HSC beams shall be more effective and economical.

The variation of experimental shear capacity of the members for FR and CFR beams with 0.4%,0.8% and 1.2% fibers for a/d=1,2,3 and 4 are represented in figure 19. Thus, under shear loading it shall be rational to incorporate the a/d ratio in estimating the ultimate as well as cracking shear strength of HSC beams with and without fibers. Further, by comparing the FR and CFR beam behavior with a/d ratio at different dosages of fiber, it can be clearly indicated that the usage of fibers in critical regions shall be cost effective.

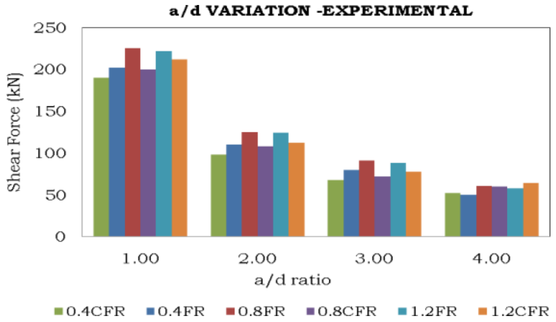

Fig 19: FR- CFR varation for experimental results with 0.4%,0.8% and 1.2% fibers for a/d =1,2,3 & 4.

VI. CONCLUSION

Based on the analytical and experimental studies conducted on HSC, HSFRC (with fiber throughout the beam and only in critical regions) beams without web reinforcement under shear loading, the following conclusions have been drawn**:**

- The influence of fiber influence on both first and ultimate crack loads for HSFRC beams is substantial at lower a/d ratios, i.e. at a/d less than two.
- The influence of fiber on shear capacity of HSFRC beams is less at higher a/d ratios.
- The energy absorption capacity of HSFRC elements at all a/d ratios is high when compared with conventional non fibrous concrete beams.
- The analytical and experimental results revealed that for all a/d ratios, for 0.8% volume fraction of fibers there is a maximum increase in shear capacity of beams.
- As the analytical and experimental results are almost similar, it shall be rational to incorporate the a/d ratio in estimating the ultimate as well as cracking shear strength of HSC beams with and without fibers under shear loading.
- The improvement of the shear capacity of the beams with fiber throughout the beam and fiber in critical regions was found to be almost similar.
- Thus the usage of fiber in shear critical regions shall be more cost effective.

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