Experimental Study on Engineered Fiber Reinforced Concrete under Axial Compression

Dr. Kookutla Ramesh
Professor in Civil Engineering Department
K.L.University
Vaddeswaram – 522 502.
Andhra Pradesh state, India

Abstract - **An Experimental Investigation on the behavior of engineered fiber reinforced Concrete (EFRC) has been carried out. A common parameter reinforcing index (RI) which is the product of Volume fraction (V_f) and aspect ratio (l/d) of fibers is used to assess the behavior of Fiber reinforced Concrete. The variables considered are Confinement index (C_i) and reinforcing index (RI). A total of 60 specimens of concrete prisms of size 150mm x 150mm x 300mm were cast and tested under strain controlled rate of loading. The test results reveal that the ductile characteristics of Fiber reinforced Concrete are further improved due to the passive confinement of the fiber and also improved the peak stress and strain at the peak and ductility of concrete. The improvement is in proportion to the Reinforcing Index (RI) of the fiber for a given confinement index (C_i).**

Key Words – Reinforcing Index, Confinement Index, Ductility, Peak Strength, Strain at peak strength, Strain Rate of Loading.

I. INTRODUCTION

Earthquake resistant design of structures demands high ductility. At present the ductility of concrete is being improved by confining it in steel binders, as ties in compression members and as stirrups in beams. It has been reported [7] that concrete strain of 0.01 is sufficient to give full redistribution of moments, which results in the use of procedures of plastic analysis for the analysis of concrete structures also. However it can be seen that the higher the degree of indeterminacy of the structure the more will be the concrete strain at failure and consequently the rotation capacity required at the first plastic hinge which will form in the structure. The critical sections in statically indeterminate structures, at which first hinge forms are incidentally also the sections having maximum shear force. The stirrup reinforcement which is provided has to take care of shear at that section and simultaneously provide confinement. It has been established by previous researchers [7] that only the stirrup reinforcement provided beyond what is required for resisting shear failure will only provide confinement. Hence with practical minimum spacing that can be provided at the critical sections there is limitation to the quantity of confinement, which can be Provided by the stirrups. Moreover, confinement of a column using a sophisticated arrangement of closely spaced stirrups not only interrupts the continuity and creates plane of weakness between the core and the concrete cover, but also adds to the problem of steel congestion. Thus it may not be possible to sufficiently confine the structure by providing the laterals alone. Hence it would be useful if a supplementary or indirect confinement, in addition to laterals, can be provided at the critical sections or a better alternative to confinement can be devised. Many investigations have revealed that the inclusion of steel fibers to concrete enhances several of its engineering properties such as tensile strength, ductility and fracture toughness. When short, randomly distributed fibers are added to concrete, fibers improve the integrity of the material. In addition to the tensile properties of concrete, Recently few investigations [1,7,8] were made to confine the concrete using fibers in addition to the laterals. The conclusions drawn were qualitative in nature but highlighted that fibers can give some confinement. Such type of Concrete can be termed as ENGINEERED FIBER REINFORCED CONCRETE (EFRC). The present study is an attempt to investigate the stress-strain characteristics of EFRC.

II. EXPERIMENTAL PROGRAMME

A. *Scheme of Experimental Work*

The experimental program was designed to study the behavior of engineered steel fiber reinforced concrete under axial compression by testing prisms of size 150mm X 150mm X 300mm. The variables in the study are reinforcing index (RI) of the steel fiber, which controls the behavior of the FRC and confinement index (C_i) of lateral steel reinforcement, which indicates the degree of confinement provided by laterals. The reinforcing index (RI) of steel fiber is the product of weight fraction of fiber and aspect ratio of fiber. The weight fraction is the ratio of weight of fiber added to the weight of concrete.

Table.1. Details of Prisms

Sl. No.	Designation	Long. Steel (G.I.wire) No.	Long. Steel (G.I.wire) Dia. (mm)	Lateral steel Dia. (mm)	Lateral steel Spa. (mm)	V_f %	RI	Cube Str. f_{ck} (Mpa)	Pl. Prism Str. f_c' (Mpa)	No. of Prisms
1.	P11 - P13	-	3.00	--	--	--	--	52.57	36.8	3
2.	A11 - A13	4	3.00	7.00	290	0	0			3
3.	B11 - B13	4	3.00	7.00	88	0	0			3
4.	C11 - C13	4	3.00	7.00	57	0	0			3
5.	P21 - P23	-	3.00	--	--	--	--	51.68	37.0	3
6.	A21 - A23	4	3.00	7.00	290	0.3	0.74			3
7.	B21 - B23	4	3.00	7.00	88	0.3	0.74			3
8.	C21 - C23	4	3.00	7.00	57	0.3	0.74			3
9.	P31 - P33	-	3.00	--	--	--	--	50.69	37.2	3
10.	A31 - A33	4	3.00	7.00	290	0.6	1.48			3
11.	B31 - B33	4	3.00	7.00	88	0.6	1.48			3
12.	C31 - C33	4	3.00	7.00	57	0.6	1.48			3
13.	P41 - P43	-	3.00	--	--	--	--	49.98	36.5	3
14.	A41 - A43	4	3.00	7.00	290	0.9	2.22			3
15.	B41 - B43	4	3.00	7.00	88	0.9	2.22			3
16.	C41 - C43	4	3.00	7.00	57	0.9	2.22			3
17.	P51 - P53	-	3.00	--	--	--	--	49.88	36.9	3
18.	A51 - A53	4	3.00	7.00	290	1.2	2.96			3
19.	B51 - B53	4	3.00	7.00	88	1.2	2.96			3
20.	C51 - C53	4	3.00	7.00	57	1.2	2.96			3
TOTAL										60

Table.2. Mechanical Properties of Longitudinal steel, Lateral steel and Fiber

S.No.	Designation	Diameter (mm)	Yield Strength (Mpa)	Ultimate strength (Mpa)	Breaking Strength (Mpa)	Percentage Elongation
1.	3mm G.I	3.00	350	500	333	19.2
2.	7mm MS	7.00	448	637	430	16.5
3.	0.5 mm Fiber	0.55	225	430	272	17.50

The program consisted of casting and testing 60 prisms, which were cast with M25 grade of concrete. This group was cast in five batches. The prisms in this batch were divided into three sets. In each set three identical specimens were cast and tested and the average behavior was taken to represent the behavior for that set of three specimens. Hence in each batch the total number of prisms amounted to nine.

Out of three sets of this group I category (A, B and C) in each batch, the first set consisted of two lateral ties (C_i= 0.0), second set consisted of four lateral ties (C_i = 0.08) and third set consisted of seven lateral ties (C_i= 0.19).

Each group, out of five batches, the first batch with 0% (RI = 0.00) fiber, second batch with 0.30% (RI = 0.74) fiber, third batch with 0.6% (RI=1.48) fiber, fourth batch with 0.9% (RI = 2.22) fiber and fifth batch with 1.20% (RI = 2.96) fiber were cast. Proper designation was given for each specimen. The details of prisms were given in Table. 1

B. MATERIALS USED

i. Longitudinal Steel

. The 3mm diameter G.I. wire are used as longitudinal reinforcement in prisms. Three wires cut from different parts of the roll, were tested on the Hounsfield Tensometer for G.I. Wires and the mechanical properties are given in Table .2.

ii. Lateral Steel (Ties)

The steel used as lateral reinforcement was 7mm nominal diameter mild steel obtained from single lots. Three test specimens of required length were cut and tested on Universal testing machine. Mechanical properties are given in Table .2.

iii. Cement

The cement used Ordinary Portland Cement of 43 grade conforming to IS: 8112-1989. The cement for each phase of work was procured in a single consignment and properly stored.

iv. Coarse Aggregate

Machine crushed hard granite chips passing through 12.5 mm IS sieve and retained on 4.75 mm IS sieve No. 480 was used as coarse aggregate throughout the work.

v. Fine Aggregate

River sand procured locally was used for fine aggregate.

vi. Fiber

0.55 mm diameter steel fibers with aspect ratio of 75 were used in the entire work. Three samples collected were tested on the Hounsfield tensometer for mechanical properties and mechanical properties given in Table.2.

vii. Water

Potable water was used in the work both for mixing and curing.

C. MIX PROPORTION

The grade of concrete M25 was selected for the investigation. The mix proportions adopted was 1:1.65:2.20 with water cement ratio 0.5.

D. MOULDS AND EQUIPMENT

i. Moulds

The specimens used in this work are of size 150 mm x 150 mm x 300 mm. Specially fabricated moulds were used for this casting. The moulds are shown in Fig.1.

Fig.1. Typical Moulds used for Prisms

ii. Vibrator

The compaction was done by a needle vibrator working at 2860 rpm.

E. PREPARATION OF SPECIMENS

i. Fabrication Process

3 mm diameter galvanized iron wire, to be used as longitudinal steel and 7 mm diameter mild steel to be used as lateral steel was cut to the required length and made straight. The lateral ties were made on a bar bending bench with a hand tool. The size of lateral tie was such that there is a cover of 15 mm to the tie. The ties were made to the four longitudinal bars at the required pitch in such a manner that the hooks were distributed evenly at all the four corners. Fig. 2 shows the reinforcement details of the tie confined fiber reinforced concrete specimens.

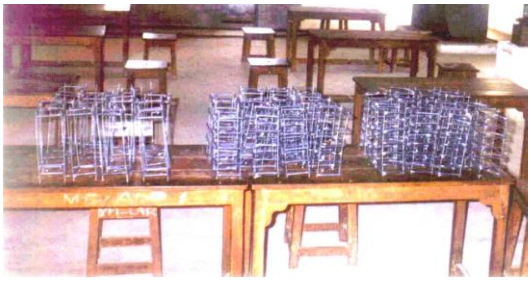

Fig.2 Reinforcement Cages for Prisms

ii. Casting of the specimen

The inner side of the cast iron mould was lubricated thoroughly using lubricating oil. Special care has been taken at the joints to make them leak proof and smooth. The prisms are to be cast in the vertical position. The prepared cage of reinforcement was kept in the moulds vertically. The required quantities of materials for one batch of specimens were weighed and mixed in a mixer. Coarse aggregate, fine aggregate and cement were put into the mixer and water was added to the mix during mixing. The required weighed quantity of fiber was added to the concrete during mixing. The concrete heap was kept under moist gunny bags to prevent the evaporation of water as concreting of the 18 specimens in a batch took about 30 minutes. Each mould was filled in three layers and each layer was thoroughly compacted using a needle vibrator. Precautions were taken to see that the reinforcement is not disturbed. Three concrete cubes were cast both before and after the concreting of prisms, to account for variation of the strength of the mix during the period of casting. The top face of the prism specimen was capped with a rich cement paste. The cement paste was prepared after one hour of casting of all the specimens i.e., one and a half hours after the casting of the first specimen. This paste was spread on the top of the prism after a gap of five hours, so that the top face of the prism becomes plane and normal to the longitudinal axis of the mould. The specimens were demoulded 24 hours after casting. The designation of the specimens was done with indelible waterproof ink. The specimens were kept under water for curing.

iii. Curing

The specimens were cured for 28 days in the curing pond. After the completion of curing period the specimens were kept under shade.

F. TESTING

i. Preparation of test specimens

The cured specimens were capped with plaster of Paris before testing, to provide a smooth loading surface. The capping is done with the help of glass plate and spirit level. The paste was prepared each time, and was placed uniformly on the top surface. A plane paper was kept over the paste and glass plate was pressed over the paper to level the surface perfectly with the help of spirit level. The excess paste on the sides was removed using cutting edge.

ii. Testing Machine

Tinius - Olsen Testing Machine of 1810 KN capacity was used for testing. The machine has two ranges of loading viz., 274 KN and 1810 KN, with a sensitivity of 0.454 KN and 4.54 KN respectively. The 1810 KN range was selected for testing the specimens.

iii. Strain Measurement

From the studies of previous investigators[15] who worked on concrete confined with ties, it was observed that the cover concrete spalling off at about 90 percent of the ultimate load. Along the concrete, the resistance strain gauges and demec points fixed to the concrete surface usually came off. Also, the compressometer designed to measure the strains in standard concrete cylinders could not be fitted to the square prisms. To overcome above-mentioned difficulties, compressometers suitable for prisms, which were fabricated by the earlier investigators at National Institute of Technology, Warangal on confined concrete, were adopted. Each compressometer consisted of two square frames; a top frame and a bottom frame made of 12mm square mild steel bars. Two diametrically opposite pairs of screws at four points attached each frame to the concrete specimen. The two frames were attached to the specimen symmetrically at the required gauge length, i.e.150mm apart. Two pairs of diametrically opposite dial gauges with a minimum count of 0.002mm and travel of 12mm were attached to vertical hanger bars fixed to the top frame. The movable spindles of the dial gauges rested on the plane circular heads of the adjustable screws, which were positioned in mild steel plates projecting horizontally from the bottom frame. The frames were attached to the specimen by means of screws, which would fit snugly to the concrete. The gauge length over which the strains measured was 150 mm. Fig. 3.shows the details of the compressometer attached to the specimen. Fig. 4. shows the photograph of the same arrangement.

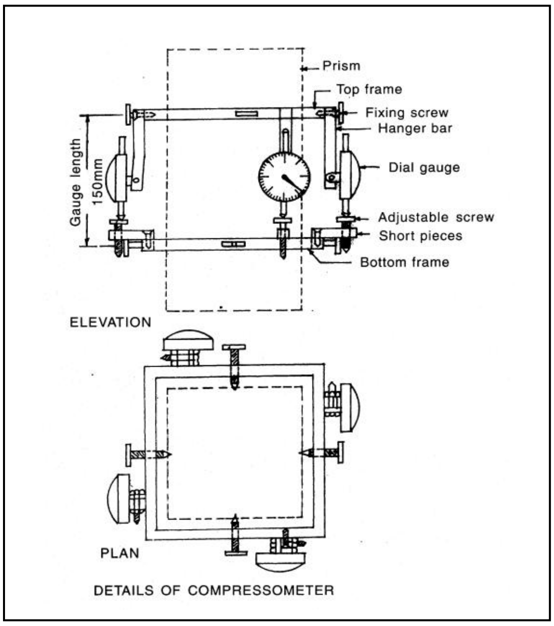

Fig.3.Details of Comressometer

iv. Testing Procedure

The capped specimen with the compressometer attached was placed on the movable cross head of the testing machine and centered correctly. A dial gauge with a run of 50 mm and a least count of 0.01 mm with a magnetic base arrangement was used to control the movement of the cross head. After applying a small initial load the control dial gauge and other four dial gauges attached to the compressometer were adjusted to their zero readings. Strain rate control was adopted to get the

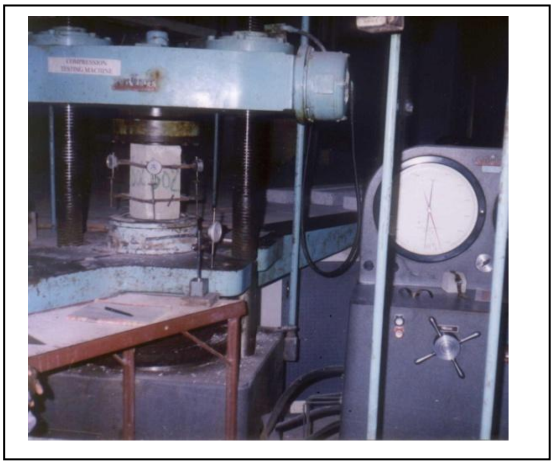

Fig.4.Test Arrangement

Complete stress - strain diagram including the post ultimate descending portion. Load control will not be useful to get the stress-strain diagram beyond the ultimate load. A uniform movement of cross head was achieved by adjusting the inlet valve throughout the period of testing with the help of control dial gauge and a stopwatch. For a satisfactory recording of strains the crosshead movement of 0.1 mm per minute was suggested by the previous investigators on the subject. Fig.4 shows the test arrangement.

The loading was applied continuously with a uniform movement of the crosshead. The four compressometer dial gauges readings were recorded at every half a minute interval. The test was continued until the load dropped to about 75 to 80 percent of the ultimate loads in the post ultimate region for all the specimens.

G. INTERPRETATION AND DISCUSSION OF TEST RESULTS

i. General

The test results of all 60 prisms are presented. The experimental stress-strain curves were drawn for each set of the prisms, taking the average of three values. The relationship between the reinforcing index of the fiber and the increase in stress and also the increase in strain are established. The experimental results are gven in Table.3.

ii. Behavior of test specimens under load

a) General

As already mentioned, all the specimens were tested under a strain control of 0.1 mm / minute. The load increased rapidly in the initial stage up to about 75 to 80 percent of the peak load and increased at a slower rate

Table.3.Test Results of Prisms

S.No.	Specimen designation	C_i	RI	P(KN)	ε_u ($x10^{-5}$)	$\varepsilon_{0.85u}$ ($x10^{-5}$)
	(2)	(3)	(4)	(5)	(7)	(9)
1.	D11 - D13	0.0	0.0	866.25	160	210
2.	D21 - D23	0.0	0.74	929.25	180	270
3.	D31 - D33	0.0	1.48	1012.5	220	330
4.	D41 - D43	0.0	2.22	1048.5	225	365
5.	D51 - D53	0.0	2.96	1118.3	250	395
6.	E11 - E13	0.08	0.0	960.75	210	375
7.	E21 - E23	0.08	0.74	1014.8	230	435
8.	E31 - E33	0.08	1.48	1077.8	270	510
9.	E41 - E43	0.08	2.22	1109.3	275	645
10.	E51 - E53	0.08	2.96	1140.8	280	690
11.	F11 - F13	0.194	0.0	983.25	295	580
12.	F21 - F23	0.194	0.74	1077.8	320	630
13.	F31 - F33	0.194	1.48	1140.8	340	760
14.	F41 - F43	0.194	2.22	1172.3	380	820
15.	F51 - F53	0.194	2.96	1228.5	410	850
16.	P11 - P13	--	--	828	202	349
17.	P21 - P23	---	---	832.5	198	335
18.	P31 - P33	--	--	837	201	325
19.	P41 - P43	--	--	821.25	197	315
20.	P51 - P53	--	--	830.25	199	345

until the peak load was reached. Tests were continued until the peak load dropped to about 0.75 to 0.8 times the peak load. Beyond the peak load the strains increased at a rapid rate and were accompanied with a decrease in the load carrying capacity of the specimen.

b) Plain Concrete Specimens

In the case of plain concrete prisms also, the load increased rapidly up to about 70 to 80 percent of the peak load and later, the rate of increase became slow. The failure was sudden and explosive in nature, which occurred as soon as the visible cracks appeared on the surface. Since the failure occurred suddenly, it was not possible to record the strains beyond the ultimate load.

c) Reinforced concrete (RC) specimens

In the case of RC specimens, vertical cracks appeared in the cover region at about half of the peak load. As the load increased, the number of cracks increased and the width of cracks widened. The spalling of concrete cover was noticed before the peak load (i.e., at about 90% of peak load) was reached. But was severe after passing the peak load.

d) Engineered Fiber Reinforced concrete specimens (EFRC)

In the case of EFRC specimens, fine vertical cracks appeared on the surface of the specimen at about 75% to 80% of the peak load with increase of load, the number of cracks increased at reduced rate compared to that of the confined reinforced concrete specimens was about the same. Beyond the peak load, the fine vertical cracks were widened. The extent of the cracking and rate of decrease of the load after peak (in the descending portion of stress strain curve) depended upon the reinforcing index (RI) of the fiber if the tie confinement indicated by confinement index (Ci) is same. The higher the RI, the lower is the rate of decrease of load and the extent of spalling. This may be due to the improvement of internal crack arresting mechanism, dimensional stability as well as integrity of the material caused by the presence of large volume fraction of the fiber present in the concrete. Also the presence of fibers might have enhanced the core concrete failure strain and resulted in an improvement in the strength and ductility of EFRC.

e) The Reinforcing Index

The factors which influence the behaviour of fiber reinforced concrete are (i) Volume fraction of the fibers (ii) length of the fibers and (iii) diameter of the fibers. A common parameter that combines these factors is used in the form of reinforcing index, RI (product of weight fraction and aspect ratio). Here, the reinforcing index is defined in terms of weight fraction W_f. Weight fraction (ratio of weight of fibers to weight of concrete) is approximately equal to 3.2 times the volume fraction.

f) Experimental Stress-Strain Curves

From the observations recorded for each specimen, as shown in table.3, the axial loads and strains were calculated. The stresses were calculated using the overall dimensions of the specimens as there was no cover spalling and dimensional stability is obtained. The longitudinal deformations were calculated from the average readings of the four dial gauges of the compressometer. The strains were obtained by dividing the longitudinal deformation by the gauge length, which was 150 mm. Using the above values the stress-strain curves for three companion specimens of a set were drawn with the same origin and the mean curve was taken to represent the set. Such mean curves for all the sets of a batch with a common origin and the same scale were drawn as shown Fig. 5. The strains ε_u at the maximum stress of engineered fiber reinforced concrete prism and the strain ε_{ct} at the maximum stress of the companion tie confined concrete prism given by [S.R.Reddy., 1974] were obtained. The strain at 0.85 times the peak stress in the descending portion of stress curve ($\varepsilon_{0.85u}$) was also recorded for each curve. The ratio of strains at 0.85 times the peak stress in the descending portion of stress strain curve and the strain at peak stress (ε_u) were also calculated. The results indicate that the additional indirect or passive confinement due to steel fiber improved the ultimate strength, strain at ultimate strength and the ductility of the concrete expressed by strain at 85 percent of ultimate strength in the descending portion of the stress strain diagram. The improvement is in proportion to the reinforcing index (RI) of steel fiber for a given confinement index (C_i) of the lateral reinforcement.

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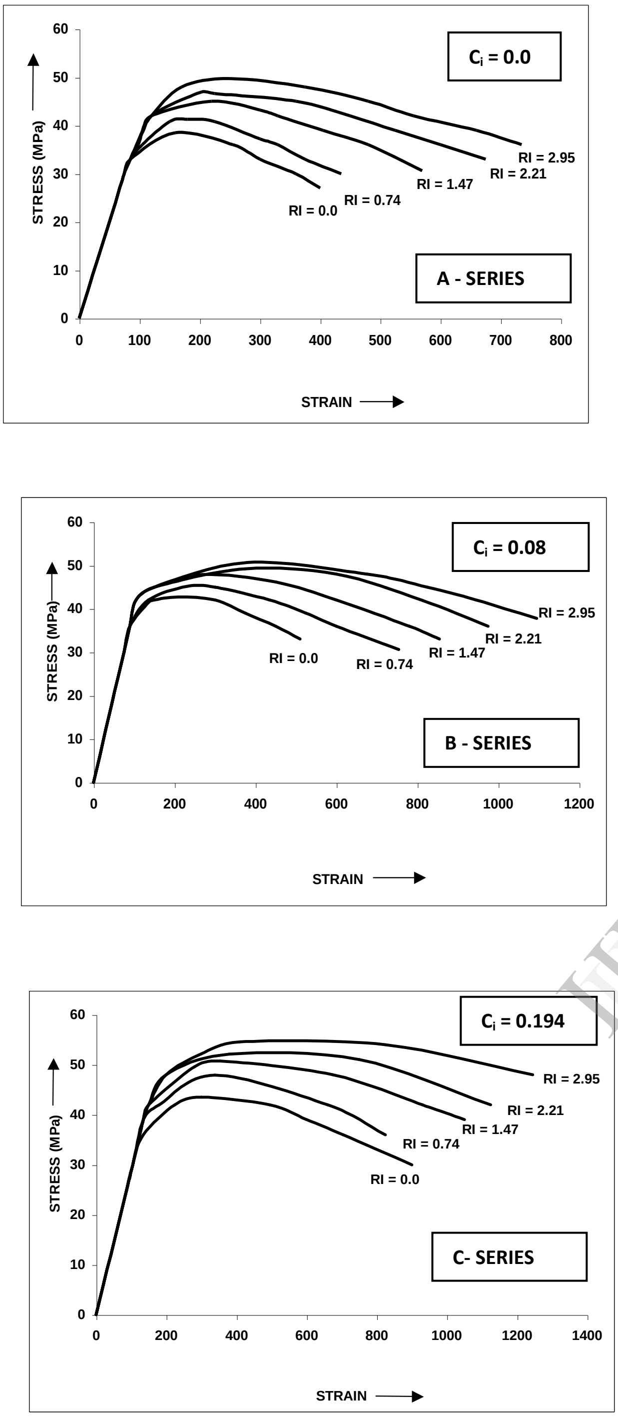

Fig.5.Stress – Strain Curves of EFFC Prisms

CONCLUSIONS

1. The Engineered Fiber reinforced Concrete (EFRC) has improved the peak strength and strain at peak strength.
2. The increase in volume fraction of increased the ductility represented by area under stress – strain curve for the same level of tie confinement.
3. The improvement in strain is more pronounced compared to the improvement in the strength.
4. For higher levels of confinement in reinforced concrete, there exists equivalent lower levels of confinement in EFRC. Hence some amount of confining transverse reinforcement can be replaced by introducing steel fiber in concrete. This will ease the situation like seismic resistant beam column junctions where high confinement requirement leads to congestion of steel.

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