Investigation on Steel Fiber Composite Beam Using Fracture Mechanics Approach

Sk.Amreen, P.Poluraju

Abstract: Fracture mechanics is the field of mechanics based on energy principles. The crack propagates in a material when energy dissipation is more. The existence of pores and cracks which are stable are not considered while designing a structure under ultimate load in stress-strain criteria, but their presence is included in energy based principles i.e., fracture mechanics. The fracture mechanics study determines the ductile behavior of a particular structure under loading conditions using following parameters such as fracture energy, stress intensity factor, fracture process zone etc., The ductile and toughness nature of a concrete elements will be increased by incorporation of steel fiber in a normal concrete defined as steel fiber reinforced concrete (SFRC). In this present study, the experimental work has been carried out on steel fiber reinforced concrete notched beams by varying notch to depth ratio as recommended by RILEM (fracture test) tested under three point bending test (TPBT). The behavior of notched beams has been assessed through load-deflection curve, crack pattern resulted from three point bending test which are required to find the fracture parameters such as fracture energy and stress intensity factor. It is been observed from the experimental study, the energy dissipation produced by the crack was shortened by the usage of steel fiber.

Index Terms: Fracture Energy, Notch to Depth ratio,Stress Intensity Factor,Steel Fiber Reinforced Concrete.

I. INTRODUCTION

Concrete is most commonly used material in construction industry due to its load bearing capacity, longerserviceability, ease of construction and economical. In addition to these properties, stillmicro cracks and flaws are present in a concrete structure which progressinto a structural failure under the action of forces acting on the structure.

Failure of a structure occurs only when energy released by a crack is greater than the energy it observes. So, to avoid this failure it is necessary to express an outcome in advance by quantifying the amount of energy absorbed in crack propagation and for the formation of other new cracks. All these energy criteria have not been stated in stress-strain criteria which are basically conducted for all the RC structures. This mechanism can only be stated underfracture mechanics.

Fracture Mechanics is defined as "***The field of mechanics based on energy principles***", because the crack propagates only when energy dissipation is higher. Many researchers [1] have developed experimental and analytical studies to examine the structure under fracture mechanics. The classification of fracture mechanics is defined based on its deformation behaviour, failure behaviour and type of loading [2]. According to deformation behaviour, it is classified a Linear elastic fracture mechanics (LEFM), elastic plastic fracture mechanics (EPFM) and dynamic fracture mechanics. EPFM approach is more feasible and accurate then LEFM.

Rate of crack propagation and formation of crack surface depends on fracture parameters like fracture energy and stress intensity factor for concrete material can be analysed using EPFM approach. They are two methods to find fracture parameters according to EPFM approach like direct method and indirect method [3]. Direct method is dependent on material behaviour and indirect method is size dependent. The fracture parameters discussed are material dependent.

A. Work of fracture method

The most commonly used method for finding out the fracture parameters in direct method is "Work of Fracture" Method developed by RILEM in 1985. The concept used behind this method is "Fictitious Crack model [4]". According to RILEM, this test method considers the specimens of specified geometry and size with central edge notch testing under three point bending as shown in Fig. 1.

Fig. 1: Schematic diagram of Three Point Bending test

B. Fracture parameter

Fracture energy (G_f): It is defined as the energy obtained for the crack extension under unit area.Fracture energy is calculated by area under the load-deflection curve divided by total cracked area. Fracture energy depends on size and geometry of the specimen. The formula for calculating$G_f$presented below is according to RILEM. The behavior of crack can be described using G and R where R is crack resistance depends on material behavior. The failure of structure depends on following condition

a. If the energy necessary for a crack to grow is equal to its resistance (G=R) then Crack grows.

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b. If the energy necessary for a crack to grow is less than its resistance(G<R) thenCrack will not grow
c. If the energy necessary for a crack to grow is more than its resistance (G>R) then Crack grows up to failure.

At pre-peak of load:
When crack is inclined,

$$G_f = \frac{U - 0.5mg\delta_0}{bh\left[1 - \left(\frac{a_0}{h}\right)\right]/\cos\alpha} \qquad (1)$$

As the inclined section has rough crack area, G_f is as follows

$$G_f = \frac{U - 0.5mg\delta_0}{1.15bh\left[1 - \left(\frac{a_0}{h}\right)\right]/\cos\alpha} \qquad (2)$$

When crack is normal to the section, $\alpha = 0$

Where U is the area under load-deflection curve up to the point of instability,$\delta_0$is the vertical deflection at that point(mm),$\alpha$is the angle between crack plane formed and vertical plane of section(in degree), mg is the unit weight of the section(N/mm),a_0 is the initial notch depth(mm), b and h are the width and height of the section respectively**.**

- At post-peak of load i.e., after the fracture occurs. according to RILEM 89,1990.

$$G_f = \frac{Wo + 2mg\delta_0}{t(b - a)} \qquad (3)$$

$W_0$is the area under the load-deflection curve, t is thickness of section, mm; a is initial notch depth, mm.

Stress intensity factor (K): It is defined to evaluate the amount of stress concentration present at the crack. This parameter also depends on the behavior of material resistance to form into crack defined as Critical Stress Intensity Factor K_C. The crack grows only when $K=K_C$. The formulation for K is taken from RILEM.

$K=\sqrt{(G_f * E)}$ (**4**)

Where G_f is Energy Release Rate or Fracture Energy,N/mm

E is Modulus of Elasticity, N/mm^2

E=[1+3.15(d/l)+8(d/l)g(a/d)]*(1/4b)(l/d)3(df/dδ)]**(4(i))**

Where l= span length, mm

d=depth of beam, mm

b=width of beam, mm

(df/dδ) =initial slope of F-δ curve

$g(a/d)=\frac{0.15}{[1-\left(\frac{a}{d}\right)]^3}$ **(4(ii))**

C. Modes of Failure

The failure modes can be classified as:
Mode-1: Opening Mode/tensile mode
Mode-2: Sliding Mode /shearing mode
Mode-3: Tearing Mode/out-of-plane.

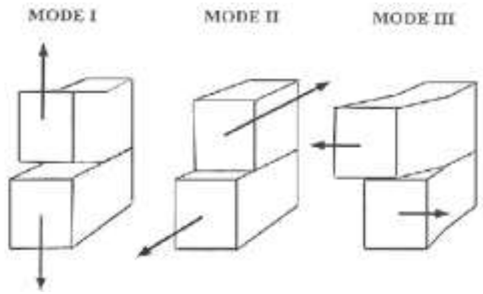

Fig. 2(a): Modes of Failure

From Fig. 2(a) & 2(b) Defining of modes of failure is easier.

- Mode-1 is observed when displacement of crack surfaces is perpendicular to the plane of crack.
- Mode-2 is observed when displacement of crack surfaces is parallel to the plane of crack and perpendicular to crack front.
- Mode-3 is observed when displacement of crack surface is parallel to plane of crack and parallel to crack front.
- Sometimes, Mixed mode also occurs i.e., combination of Mode-1 and Mode-3.

D. Behavior of fracture parameters due to change in cementitious material

Fracture parameters which are defined above get influenced by the change in cementitious material. The main parameters

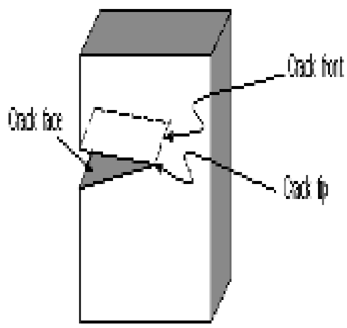

Fig. 2(b): Crack tip and Crack plane

are Compressive strength, Maximum aggregate size, Water to cement ratio, Aggregate type. The increase of compressive strength of concrete is altered by the addition of admixtures like fly ash, GGBS, silica fume, reinforcing material and can also be differed by the size of aggregate which simultaneously reduces the fracture energy [5-6]. From the reference [6], the only parameter which increases the fracture energy is the aggregate type(change of crack pattern within the crack size). The fracture energy even decreases with increase of water to cement ratio [7].

II. RESEARCH SIGNIFICANCE

The main objective of this current study is to determine the behavior of steel fiber reinforced concrete notched beam by varying the notch to depth ratio of which results are

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validated through experimental work. The research work is focused on the fracture parameters whose result is expected to vary by notch to depth ratio. From the reference [8], it can be stated that Addition of steel fibers increases the energy absorption capacity, ductile nature, shear and flexural toughness

The experimental study is conducted on the plain concrete reinforced beams mixed up with hooked end steel fiber which completely changes the property of concrete. Steel fiber has the property to increase the ductile nature, compressive strength, arrest crack width. So, Steel fibers are added in a plain cement concrete at 0.5% by volume of concrete as per ACI-544. R-93 [9] recommendation. To find the fracture parameters, the steel fiber reinforced concrete beams are initially cracked by varying the crack depth from 60-150mm of overall depth of concrete and keeping crack width as 5mm constant. The beams were tested under three point bending test [10] using force controlled machine. After testing, load-displacement curve can be observed. The following observation made from the analyses is that the energy dissipated from a crack had taken more time to form into a failure and crack width has been reduced.

III. EXPERIMENTAL WORK

The experimental work includes program of works like collection of materials, casting of cubes to find the compressive strength, casting of notched fiber reinforced beams under flexure loading to find fracture parameters.

A. Materials Used in the Work

Ordinary Portland cement of 53 grade was used confining to IS12269-1987 [11]. Specific gravity of cement was tested as per IS 2720-Part-3 and was found to be 3.12.The aggregate which passes through 4.75mm sieve is used. Specific gravity of fine aggregate of Zone-2 was tested as per IS 2386-Part-3 and resulted as 2.62.The aggregate was taken as a combination of 20mm (60%)and 10mm (40%) as per IS code. Specific gravity of coarse aggregate test was conducted as per IS 2386 -Part-3[12] and resulted as 2.73.Portable water is used for casting and curing work of beams and cubes. Steel fibre has been used as reinforcing material and plays a key role in this research work. So, steel fibre concept is explained below

Steel Fibre: Steel fibers are most commonly used types of fiber in concrete industry in comparison with other type of fiber because they take the role of rebar. These fibers are available of different lengths. The tensile strength of steel fibers is 1700 N/mm^2 referred from paper [13]. The diameter of steel fiber usually varies from 0.25mm to 0.75mm. Table I shows the properties of steel fibre and Fig. 3 indicates the steel fibre.

Table I: Properties of steel fiber

Properties of Steel fiber	
Shape of fiber	Hooked end
Length of fiber	60 mm
Diameter of fiber	0.75 mm
Tensile strength	1025

Fig. 3: Steel fiber

B. Mix proportion

The mix design for concrete was conducted as per IS 10262:2009[14]. The mix designation of concrete was done for M30 grade whose target strength is 38.25N/mm^2. Water to

Table II: Mix proportion details

Cement kg/m3	F.A kg/m^3	C.A kg/m^3		Water kg/m^3	Steel fiber
		20mm	10mm		
377.77	685.36	729.54	486.36	170	2.06g

10262:2009 [14]. The mix designation of concrete was done for M30 grade whose target strength is 38.25N/mm^2. Water to cement ratio was taken as 0.45. The material quantities were listed in the below Table II and were mixed in the proportion shown as below.

Mix proportion for 1m^3 of concrete: **1:1.814:3.218**

C. Compressive Strength

Normal concrete has the low compressive and tensile strength of concrete. So, the steel fibers are added in order to increase the compressive and tensile strength of concrete. Concrete cubes of standard dimension (150mm×150mm×150mm) of both normal and SFRC cubes (Addition of 0.5% steel fiber) were casted as per mix design. These cubes were tested for 7 days and 28 days. Compressive strength of cubes was tested under compression testing machine after completion of curing process and the obtained results are as shown in Table III.

Table III: Compressive Strength of Cubes

Name of the work	No of cubes	Compressive strength (7 days) N/mm^2	Compressive strength (28 days) N/mm^2
Normal Concrete Cubes	3	28.2	35.8
SFRC Cubes	3	45.3	59.5

D. Three Point Bending Test

A Steel Fiber Reinforced notched beam of dimension 1000 mm × 230 mm × 300mm were cast by varying notch to

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depth ratio as per RILEM recommendation (a_0/D=0.2 to 0.5) where a_0 is notch height and D is depth of overall beam and notch width of 5mm can be seen as shown inFig.3. The casted beams were undergone curing process for 28 days. After completion of curing work, the beams were tested under three point bending test refer to [15] using force controlled machine (loading frame). Fig.4 is the work view done in this research. The outcome of the test would be Load-Deflection curve refer to Fig. 5. Referring to load-deflection curve flexure strength, fracture parameters (G_f and K) values are presented in the Table IV.

Fig. 4: Test setup of a 120 mm notched SFRC beam under three point loading

For Fracture energy calculation refer to "(1),"
Stress intensity calculation refer to "(4),"

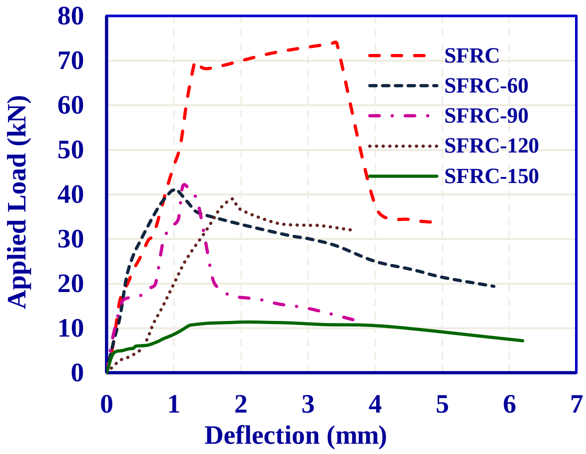

Fig. 5: Load *vs.* deflection curve all the SFRC beam

Table IV: Result of Fracture Parameter from Three Point Bending Test

S. No	Name of the work	G_f (N/mm)	E (N/mm^2)	K (N/mm)
1.	SFRC	0.507	1.033	0.723
2.	SFRC- 60mm	0.424	1.593	0.821
3.	SFRC- 90 mm	0.381	2.8167	1.036
4.	SFRC- 120 mm	0.2178	2.6843	0.764
5.	SFRC- 150 mm	0.216	4.637	1.008

E. Fracture Toughness

It can be considered as a term to quantify the energy absorbing capacity of a reinforced concrete beam under loading. In this research work, plain concrete beams are required to find fracture parameters whose energy absorbing capacity is less. So, the steel fibers are added to increase the strength and ductile nature of concrete beams. Toughness index is the number obtained by dividing the area upto a specified point of deflection to area upto the first crack. First crack deflection is the deflection value at the point where point of instability occurs in load-deflection curve.

The toughness index values are expressed in the form of I_5, I_{10}, I_{30} and the corresponding Index values formula presented in the below section are taken from the code ASTM C 1018[16]. Table V indicates toughness index of SFRC.

Index values are explained in terms of I_5, I_{10}, I_{30}

- Toughness Index I_5 = 3(first crack deflection)
- Toughness Index I_{10} = 5.5(first crack deflection)
- Toughness Index I_{30} = 15.5(first crack deflection)

Table V: Toughness Index of SFRC.

S. No	Name of the work	I_5	I_{10}	I_{30}
1.	SFRC	10.29	18.865	20.46
2.	SFRC-60mm	3	5.5	15.5
3.	SFRC-90mm	5.49	10.065	28.365
4.	SFRC-120mm	5.76	10.56	29.76
5.	SFRC-150mm	6.3	11.55	32.55

F. Fracture Strength

It is also known as flexural strength/modulus of rupture/bending strength. It can be defined as the strength used to resist the forces/stresses coming on an unreinforced concrete element under bending. It is expressed in MPa or Psi. They are two basic tests that are conducted basically to find the Fracture strength. They are center point loading and third point loading test. In this research, centre point loading test has been carried out on all the beams. The formula presented below is for flexural strength from ASTM C 293[17] and the result of the tested beam are presented in Table VI.

$$\sigma = \frac{3PL}{2bd^2} \qquad (5)$$

Where σ is the fracture strength, N/mm^2
P is the load at the fracture point, N
L is length of the specimen, mm
b is width of the specimen, mm
d is depth of the specimen, mm

Table VI: Fracture Strength of SFRC

S. NO	Name of the work	σ (N/mm^2)
1	SFRC	SFRC-150mm
2	SFRC-60mm	2.985
3	SFRC-90mm	2.826
4	SFRC-120mm	1.630
5	SFRC-150mm	0.826

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IV. RESULTS AND DISCUSSION

All the SFRC beams were tested under flexure loading (centre point loading). The variation is made in the notch depth keeping notch width as constant. From the basic test i.e., Compressive strength of Steel fiber concrete cubes is more when compared with Normal cubes. So, Steel fiber can be used as a reinforcing material. Secondly, referring to Load vs. deflection curve of all test result of SFRC Notched beams and Un-notched beam.

From the experiment point of view, the crack pattern has been observed at the mid span of the beam at an angle of nearly 80 degree i.e., where initial notch(crack) is provided and can be seen in Fig.5, No other cracks like flexural has appeared. Under loading, the notch width which has been kept constant (5mm) has increased to nearly 20mm because of the steel fiber which is arresting the new crack to initiate. From "Fig.6" it can be discussed that increase of notch depth, the fracture energy that is the energy required for a crack to extend has been decreased. Fracture toughness and fracture strength of SFRC un-notched beam is more than the SFRC notched beam

V. CONCLUSION

From the experimental work where the beams were tested under three point using loading frame and referring to all the results the following conclusions points can be made**:**

- Steel fibers can be used as a reinforcing material because of its higher compressive strength compared to PCC.
- The steel fiber has increased the ductile nature of concrete.
- Fracture energy of steel fiber reinforced concrete (SFRC) notched beams is decreased, but in comparison to PCC it has acquired more time to initiate a crack
- The cracking behavior (first crack deflection) of SFRC beams is slightly higher compared to PCC beam
- Fracture toughness of SFRC notched beams has reduced when compared to Un-notched SFRC beams.
- Fracture strength of SFRC notched beams is higher in comparison with Un-notched SFRC beam.

REFERENCES

1. A. Hillerborg, M. Modeer, P-E Peterson, "Analysis of Crack Formation and Crack Growth in Concrete by means of Fracture Mechanics and Finite Elements," *Cement and Concrete Research*, Vol.6, Issue 6, 1976, pp.773-782.
2. P.E.Petersson "Fracture Energy of Concrete: method of determination", *Cement and Concrete Research*.Vol.1, Issue 10, 1980, pp-79-89.
3. R. Brincker, H. Dahl, "Fictitious crack model of concrete fracture," *Magazine of Concrete Research*, Vol. 147, Issue 41, 1989, pp.79-86.
4. T.S. Arjun, K. K. Divya, "Fracture Study On Steel Fiber Reinforced Concrete," 2016, pp 26-31
5. Rozalija Kozul, David Darwin, "Effects of Aggregate Type, Size and Content on Concrete Strength and Fracture Energy,". Structural Engineering and Engineering Materials SM Report No.43.
6. D.Rohini Kumar, M. Mallikarjun Reddy, "Effect of Fiber and Aggregate Size on Fracture Parameters of High Strength Concrete," *IOP Conf. Series: Material Science and Engineering*, vol. 225, Issue 1, 2017, pp. 1-23.
7. Sreenivasa Rao A, Appa Rao G, (2014)." Comparison of Mode I and Mode II Fracture Energies of Latex Modified Steel Fiber Reinforced Concrete," *International Journal of Civil and Structural Engg.*,Volume 5, Issue 1, pp.
8. 9.ACI 544.3 R-93,(1998). "Guidelines for specifying, placing, mixing and finishing steel fiber reinforced concrete," reported by ACI committee.
9. Lennart Osteraard, John Forbes Olesen, "Comparative Study on Fracture Mechanical Test Methods for Concrete,"
10. IS: 12269-1987, Indian standards ordinary Portland cement,53 grade, specification.
11. IS 2386-PART-3,method of test for aggregate for concrete,part-3:specific gravity, density, voids, absorption and bulking [CED 2:Cement and Concrete].
12. P. Polu Raju, S. Ghouse Basha, (2017). "Comparative study on effect of steel and glass fibers on compressive and flexural strength of concrete." *IJCIET*, Volume 8, Issue 4, 2017, pp. 141–155.
13. IS: 10262(2009), Guidelines for concrete mix design
14. Yi-Cheng Chiu, ParthPanchmatia, AswathySivaram, (2011). "Analysis of Fracture Energy by Comparative Study of PCC & FRC".
15. ASTM C 1018.,(1987), "Standard test method for flexure toughness and first crack strength of fiber reinforced concrete(using beam with three-point loading)".
16. ASTM C293,standard test method for flexural strength(using simple beam with centre point loading)

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