EXPERIMENTAL INVESTIGATION ON THE FRACTURE BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE

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Abstract- *Concrete is a composite material used for construction worldwide. The presence of cracks and pores inside concrete material is inevitable and it is necessary to investigate if they are stable or not. Hence problems related to fracture are vital in concrete. Fracture study assesses the ductile behavior of concrete structures under loading using various fracture parameters. Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Addition of closely spaced and uniformly dispersed fibers to concrete acts as crack arrestor and substantially improves its static and dynamic properties. As a result of this ability to arrest cracks, fiber composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibers are able to hold the matrix together even after extensive cracking. The present study aims at finding out how far the ductility of concrete can be improved by the addition of steel fibers in terms of fracture parameters by varying the fiber content. The fiber content was varied from 0% to 1.2% with an increment of 0.2%. The mechanical properties such as cube compressive strength, flexural strength, split tensile strength and modulus of elasticity were studied. From that results the optimum percentage of fiber was decided. Three-point bending test on notched beams (fracture tests) were conducted for determination of fracture parameters. The tests were done as per the guidelines of International Union of Laboratories and Experts in Construction Materials, Systems and Structures(RILEM)*

Keywords*: Notched beams, Three-point bending tests, Ductility, Fracture Parameters*

1.INTRODUCTION

Concrete is the most versatile material used in the field of civil engineering. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure. Usually, normal strength concrete is employed for common purposes and high strength concrete for tall and important structures only. Since concrete is a composite material, the presence of cracks and pores inside concrete cannot be controlled. So it becomes necessary to investigate whether these cracks are stable or not. Fracture mechanics is a valuable method for studying concrete behavior under static loading. Fracture is a common but important problem in construction industry. The severity of problem varies with the type and importance of the structure.

Fracture is defined as the separation of a component into, atleast, two parts. Fractures of a material occur when sufficient stress and work are applied on the atomic level to break the bonds that hold atoms together. The fracture behaviour in concrete is more complicated due to its heterogenous nature and the presence of large size fracture process zone (FPZ) at the crack tip. Failure occurs for many reasons, including uncertainties in the loading or environment, defects in materials, inadequacies in design and deficiencies in construction and maintenance. Failure of a structure usually occurs due to catastrophic growth of cracks resulting in localization of stresses and there by affects the serviceability of the structure. Here an attempt is made to study the fracture behavior of normal concrete when characteristics is modified by adding steel fibers in varying volume fractions.

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. Now a days the fibers are used as a secondary reinforcement, which act as a crack arrester improves toughness and mechanical properties. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers which are commonly used include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. Besides that, the character of fiber reinforced concrete changes with type of concrete, fiber materials, geometries, distribution, orientation and volume fraction. The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of concrete termed as "volume fraction" (Vf). Vf, typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing the fiber length (l) by its diameter (d). The stitching action of the fibers across the cracks reduces the development of macro cracks from micro cracks. They also reduce the permeability of concrete and thus reduce bleeding of water. Steel fibers are cheap and easily available when compared to other types of fibers. It is available in different forms such as straight, crimped and hooked end type steel fibers.

Steel Fiber Reinforced Concrete (SFRC) offers a solution to the problem of cracking by making concrete tougher and more ductile. The randomly oriented steel fibers assist in controlling the propagation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix itself, and later by bridging across even smaller cracks formed after the application of load on the member, thereby preventing their widening in to major cracks.

2. EXPERIMENTAL DETAILS

2.1 Materials

The materials used in this study included ordinary Portland cement, fine aggregate (manufactured sand), coarse aggregate, mixing water, super plasticizers and steel fiber (hooked end). Ordinary Portland cement of grade 53 conforming to IS: 12269 was used. Laboratory test were conducted on cement to determine specific gravity, standard consistency and initial setting time and final setting time. The results of laboratory tests on cement are shown in Table 1. Manufactured sand (M sand) passing through 4.75 mm IS sieve was used for the experiments as fine aggregate. Laboratory tests were conducted to determine different physical properties. The results shown that the fine aggregate conforms to Zone II. The properties of fine aggregates are shown in Table 2. Crushed granite stone obtained from local quarries were used as coarse aggregate. Aggregates with particle size of 20mm were used for this investigation. Laboratory tests were conducted on coarse aggregate to determine the different physical properties. The properties of coarse aggregates and tests are shown in Table 3. Steel fiber (hooked end) was purchased from Precision drawell pvt ltd. Properties of fibers are shown in Table 4. The view of steel (hooked end) fiber is shown in Fig 1. The super plasticizer used Cementone Conflo. The properties of cementone Conflo is shown in Table 5.

Table 1 Properties of cement

SL NO	PROPERTIES	VALUES
1	Fineness (%)	3
2	Specific gravity	3.13
3	Standard consistency (%)	30.25
4	Initial setting time (minutes)	85
5	Final setting time (minutes)	260
6	3rd day Compressive Strength, N/mm^2	25
7	7th day Compressive Strength, N/mm^2	31

Table 2 Properties of fine aggregates

SL NO	PROPERTIES	VALUES
1	Fineness modulus	3.11
2	Specific gravity	2.6
3	Bulk density (Kg/m^3)	1.65
4	Void ratio	0.57
5	Porosity (%)	36
6	Grading zone	II

Table 3 Properties of coarse aggregates and tests

SL NO	PROPERTIES	VALUE
1	Fineness modulus	7.06
2	Specific gravity	2.74
3	Bulk density (Kg/m^3)	1.58
4	Void ratio	0.73
5	Porosity (%)	42.25

Table 4 Properties of fibers

PROPERTIES	STEEL (HOOKED END)
Diameter (mm)	0.5
Aspect ratio	60
Specific gravity	7.80
Water absorption (%)	33.33
Density (kg/m^3)	7850

Fig 1 Steel fiber (Hooked end)

Table 5 Properties of Cementone Conflo

Supply form	Liquid
Color	Black
Specific gravity	1.09
Dosage	0.3% to 0.4% by weight of cement

2.2 MIX DESIGN

All the mixes were prepared corresponding to M30 grade concrete. The code IS 10262-2009 is followed for cement concrete mix designs. The obtained mix design is presented in Table 6.

Table 6 Mix proportions

Cement (kg/m³)	Water kg/m³	Fine aggregate kg/m³	Coarse aggregate kg/m³	Water cement ratio	Mix proportion
436	191.58	635.88	1141.018	0.44	1 : 1.45 : 2.6

2.3 WORKABILITY OF FRESH CONCRETE

Slump test is the most commonly used method of measuring consistency of concrete. It is performed with the help of a vessel, shaped in form of a frustum of a cone opened at both ends. It was observed that the workability reduced as the fiber dosage increased. This may be due to the presence of fibers which causes obstruction to the free flow of concrete. The Fig 2 show the slump variation with fiber content

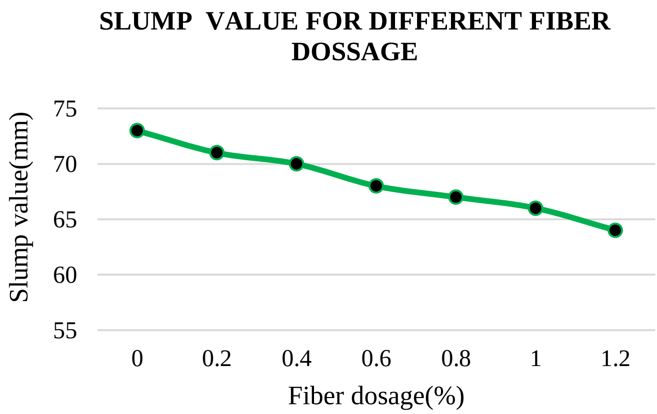

Fig 2 Slump variation with fiber content

2.3 TEST RESULT ON HARDENED CONCRETE

For compressive strength test , cube size of 150 x 150 x 150 mm was adopted and the 7 and 28 days strength was calculated. Results for compressive strength was based on the average values of three test data for all mixtures. Based on the results, the optimum fiber content was determined. The compressive strength was observed to be increasing with the increase of fiber dosage. Because when the percentage of fiber increased, the fiber content in the matrix was enough to bridge the micro cracks developed. An increase in compressive strength was found to be obtained when the fiber content was increased up to 1% for steel, which can be taken as optimum dosage. The reduction in compressive strength for the mixes with the increased fiber content beyond the optimum dosage is justified as the extra amount of fiber reduced the free flow of concrete and the compaction achieved. Compressive strength variation with steel dosage at 7days and 28days are shown in Fig 3 and Fig 4.

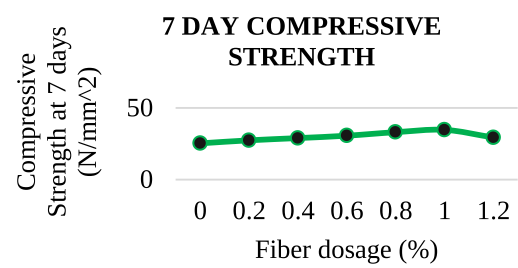

Fig 3 Compressive strength variation with steel dosage at 7days

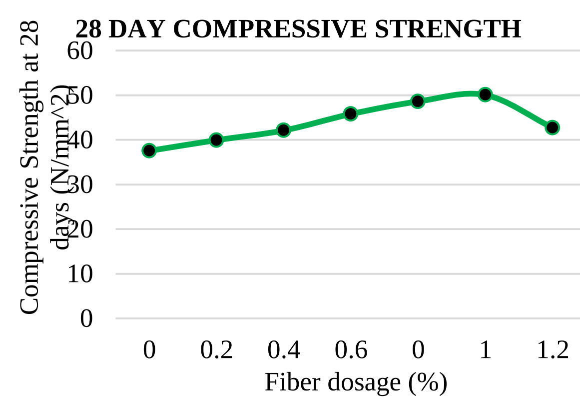

Fig 4 Compressive strength variation with steel dosage at 28 days

In splitting tensile test the cylindrical specimen of size 150 X 300mm was adopted. The split tensile strength is the tensile strength of concrete determined indirectly by splitting a concrete cylinder specimen across its vertical diameter. The Split tensile strength was observed to be increasing with the increase of fiber dosage. An increase in Split tensile strength was found to be obtained when the fiber content was increased up to 1% for steel. Because by the inclusion of steel fibers into plain concrete, the brittle mode of failure is changed to a ductile mode as fibers increase the energy absorption capacity and enhance lateral stiffness to the section. After occurrence of cracks, the specimen did not fail suddenly. The drop in split tensile strength fiber can be justified as the increased fiber content reduced the free flow of concrete there by reducing the compaction achieved. Fig 5 shows variation of split tensile strength with fiber dosage.

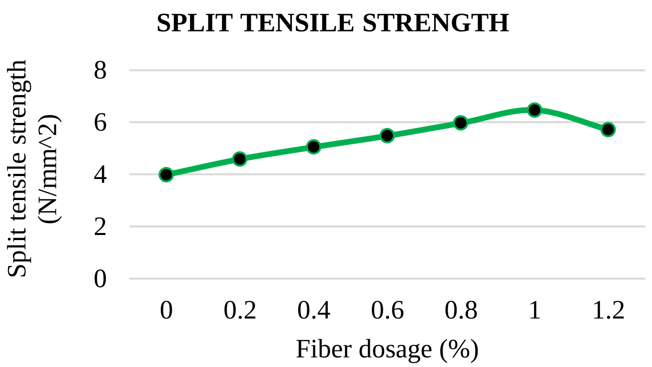

Fig 5 Split tensile strength varying with fiber dosage

The flexural tensile strength test is performed to determine the tensile load, at which the concrete cracks. This is an indirect test for assessing the tensile strength at failure or modulus of rupture. The test was carried out on beam having 100X100X500mm size and the total load was applied continuously until it fails. The results showed that there was an increase in flexural strength as the fiber content increased. At an optimum dosage of fibers by volume of concrete indicated the maximum flexural strength. This clearly indicates that the added fiber in the matrix act as a crack arresting mechanism and improve the tensile strength of concrete. Beyond the optimum dosage the flexural strength was reduced. This can be justified as the extra amount of fiber reduced the free flow of concrete and the compaction achieved. Fig 6 shows variation of flexural strength varying with fiber dosage.

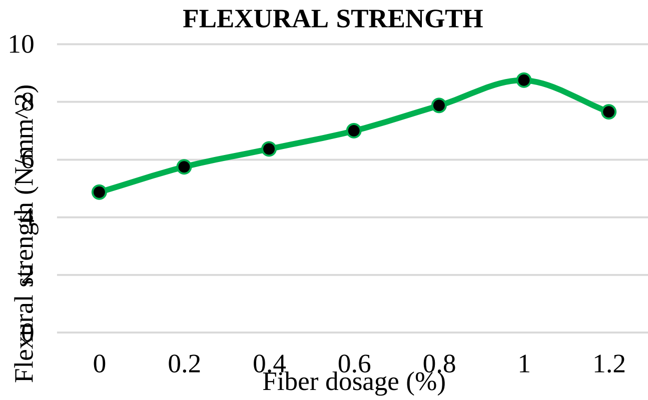

Fig 6 Flexural strength varying with fiber dosage

Modulus of elasticity is also known as young's modulus. It was found from. The young's modulus values are obtained from stress strain diagram obtained by compression test on cylindrical specimens of diameter 150 mm and height 300 mm. From the figure it is seen that the modulus of elasticity is found to be maximum in the mix without fiber. The modulus of elasticity decreases when fiber content increases. The plasticity and workability should be less when fiber content increases. So compaction is not effective thus there is more voids in the concrete. Therefore, increase in the strain occurs and thus modulus of elasticity decreases. Fig 7 shows variation of modulus of elasticity with fiber dosage.

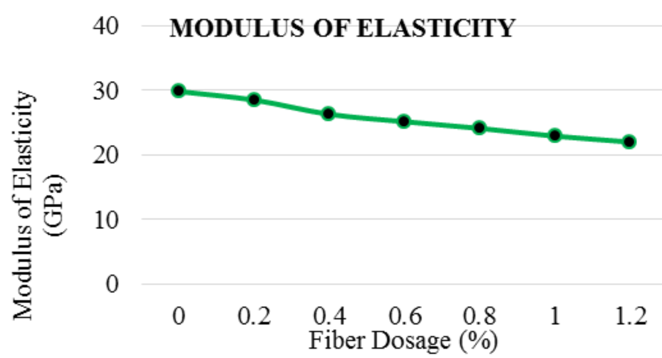

Fig 7 Modulus of elasticity varying with fiber dosage

2.4 FRACTURE TEST

For the fracture study, three-point bending tests is performed on Single Edge Notched Beam (SENB) specimens. One can apply the recommendation of the technical committee RILEM to perform three-point bend tests in notched beams. RILEM is International Union of

Laboratories and Experts in Construction Materials, systems and structures.

Test conducted on the beam specimens of size of beam is 1000 x 200 x 300mm with an initial notch size of 25 mm for all the mixes with a span of 800 mm. Beams were provided with two 16 mm diameter high yield strength deformed bars at bottom and two 12 mm diameter bars at top. Two legged stirrups of 8 mm diameter @150 mm c/c have been used as shear reinforcement. The reinforcement details of the specimen for the fracture test are shown in Fig 8. Casted beams demolded after 24 hours and were cured in a water curing tank. After 28 days, the large beams were white washed for easy detection of cracks. Fig 9 shows white washed beam specimens. Beam designation details are shown in Table 7.

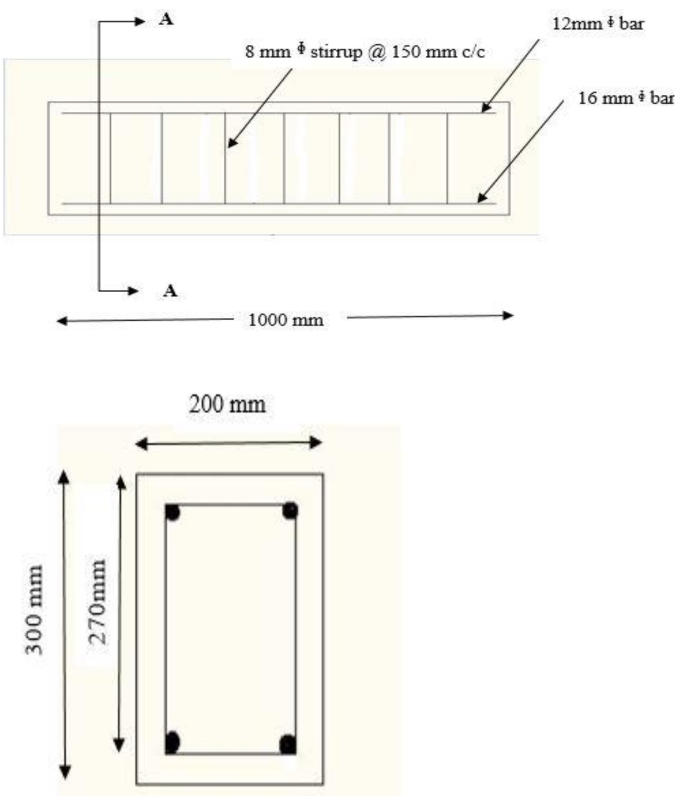

Fig 8 Reinforcement details

Fig 9 White washed specimens

Table 7 Beam designation details

Sl No	Details	Beam designation
1	Normal concrete(without notch)	NC0
2	Normal concrete (with notch)	NC1
3	Notched steel fiber reinforced concrete (Optimum dosage)	SF

2.4.1 Test setup

Three point bending system is adopted for the fracture tests. Fracture test was conducted on notched beams of size 1000x200x300 mm.. Specimens are tested in a four legged loading frame of 1000KN (100t) capacity with an effective span of 800mm. Load cell of 100kN capacity with a least count of 1KN and load was applied to the beams through hydraulic jack. The measured load is displayed in the digital indicator and further it is connected to data acquisition system. The load is increased in stages till the failure of the specimen occur. After the each increment of load the deflection at the mid span was noted. At each stage, the deflection at mid span is found out using an LVDT (Linear Variable Differential Transducer).The measured displacement is displayed in the digital indicator and further it is connected to the data acquisition system. First crack load, displacement at mid span and ultimate load was noted. The actual test set up and loading arrangement are shown in Fig 10,12,14 and crack appearing on beam specimen are shown in Fig 11,13,15.

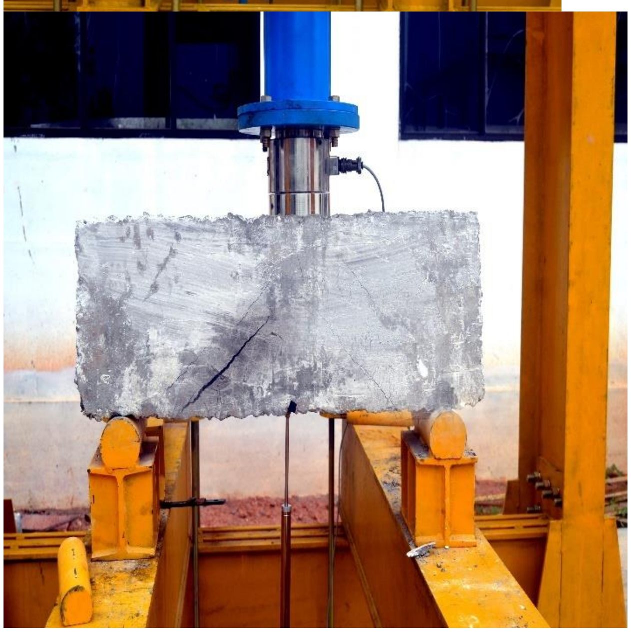

Fig 10 Fracture test set up

Fig 11 Crack appearing on un-notched beam of on un-notched beam

Fig 12 Fracture test set up of notched beam
Fig 13 Crack appearing on notched beam

Fig 14 Fracture test set up of notched steel

Fig 15 Crack appearing on notched steel fiber reinforced concrete beam
reinforced concrete beam

2.4.2 Fracture parameters

The analysis of fracture mechanics problem is done through different approaches and each method has its own parameters. All of them are well accepted to measure the potency of a crack. The parameter Fracture Energy is energy based and is applied to brittle or less ductile materials. Stress Intensity Factor (K) is stress based, also developed for brittle or less ductile materials. The critical stress intensity factor (K_{IC}), has been used to represent the fracture toughness.

i. Fracture Energy

The fracture energy is defined as the amount of energy necessary to create a crack of unit surface area projected in a plane parallel to the crack direction. As the beam is split in to two halves, the fracture energy can be determined by dividing the total dissipated energy by the total surface area of the crack. According to the RILEM fracture energy can be calculated as,

$$G_F = \frac{W_o + 2mg\delta_o}{b(d-a)} \quad (1)$$

Where,

GF = Fracture energy (N/m)

Wo = Area under the load-deflection curve (Nm)

δ0 = Displacement corresponding to the ultimate load (m)

m = Weight of the beam between supports (N)

b = Width of the beam (m)

d = Depth of the beam (m)

a = Initial notch of the beam (m)

ii. Fracture toughness

Fracture toughness (stress intensity factor) is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for many design applications. It is denoted as KIC and has the units MPa√m According to the RILEM, the fracture toughness KIC is calculated using the equation.

$$KIC = \frac{3PS\sqrt{\pi a}}{2bd^2} f(\alpha) \quad (2)$$

Where,

KIC = Fracture toughness (MPa√m)

Pmax = Ultimate load + self-weight of the beam (N)

S = Span (mm)

d= Depth (mm)

b = Width (mm)

f(α) is geometry factor, which depends on the ratio of the initial crack length/notch depth to the depth of the beam , f(α) can be written as follows.

$$f(\alpha) = \frac{[1.99-\alpha(1-\alpha)(2.15-3.93\alpha+2.7\alpha^2)]}{\sqrt{\pi}(1+2\alpha)(1-\alpha)^{\frac{3}{2}}} \quad (3)$$

Where,
$\alpha = \frac{a}{d}$
a = initial notch of the beam (m)

2.4.3 THREE POINT BENDING TEST RESULTS

Three point bending test were carried out on beams having dimension 1000x200x300mm cross section with an initial notch 25mm and an effective span of 800 mm. Beams with and without notch has been considered for this test. In all cases flexural cracks formed in the pure bending zone. As the load increased, the existing cracks propagated and new cracks developed in the span. All the beams are failed in flexural mode.

Load-Deflection Characteristics

Mid span deflection was noted at every load increment. Deflections of all specimens were found to be increased considerably after the first crack was observed. Deformations corresponding to each increment of load for all specimens were noted. In general, the load-deflection curve will consist of three regions, the first region is a linear region that indicates the response till the concrete cracks, the second region is also a linear region that shows the response till the steel reinforcement yields and the third region indicates the response after the yielding of reinforcement where there is an enormous rate of increase in deflection for subsequent loads. Fig 16 shows load deflection curve for flexural beam specimens.

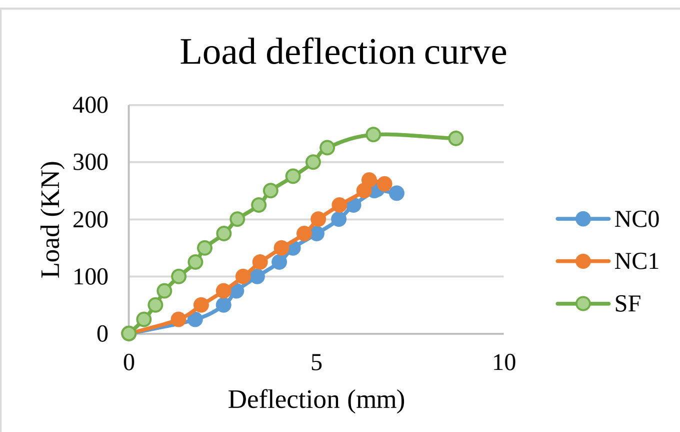

Fig 16 Load deflection curve

As the load increases, beam starts to deflect and flexural cracks were developed along the span of the beams. In notched beams the crack appeared from the end of the notch and started propagate fast to the ligment when the load reached its peak value. Eventually, all beams were failed in a typical flexure mode. From the load deflection curve, it can be observed that the load carrying capacity of beams were found to be increases with the addition of steel fibers as compared with the load carrying capacity of normal concrete beam. When fibers are added to concrete, crack propagation gets arrested which results in requirement of more energy. This improves the load carrying capacity. The rate of increase in deflection of beams without fiber is higher than that of beams with fiber. In the case of specimens without fibers a sudden drop in the load was noticed beyond the ultimate load. Addition of fibers produced an increase in the ultimate load and a more ductile softening behaviour.

First crack load and ultimate load

From the test results it can be seen that the addition of fibers increases the load carrying capacity for all the beams. The ultimate load is higher for SFRC beams. This is due to the steel fibers bridging the micro cracks effectively. Fig 17 shows variation in the first crack load and ultimate load values of beam specimen and Fig 18 shows variation of ductility factor.

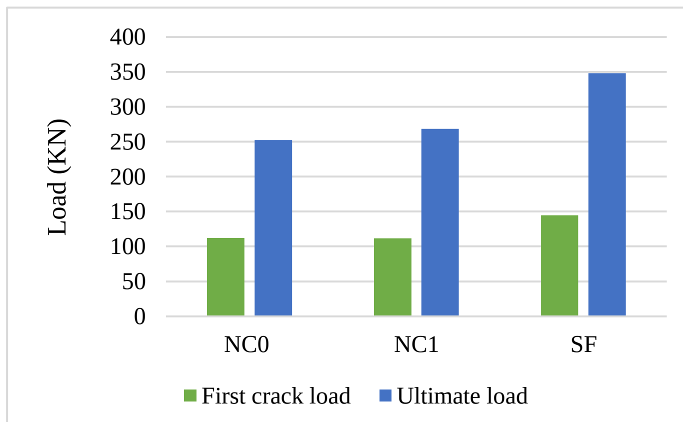

Fig 17 Variation in the first crack load and ultimate load values of beam specimen

It was not able to predict the first crack load exactly from the experimentally obtained load deflection curve. Hence the first crack load was noticed only through the visual observations made during testing. From the table 5.5 it can be observed that there is an increase in first crack load and ultimate load with the increase in fiber content. The ultimate load carrying capacity of steel fiber reinforced concrete is 38 % higher when compared with normal concrete. The increase of first crack load and ultimate load carrying capacity of steel fiber reinforced concrete may be due to the increase in tensile strain carrying capacity of concrete in the neighborhood of fibers. The ductility was found to be increased with addition of steel fiber. The increase in ductility was due to the effective bond and confinement between the particles.

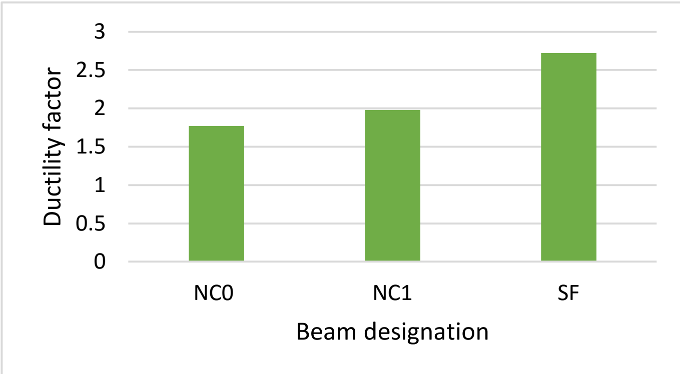

Fig 18 Variation of ductility factor

Fracture parameters

The fracture parameters studied for concrete are fracture energy and fracture toughness. The fracture energy was determined by the work of fracture method using load deflection curves. And the critical stress intensity factor or fracture toughness was determined from the peak load and geometry of the specimen.

The fracture energy is the amount of energy necessary to create a crack of unit surface area projected in the plane parallel to the crack direction. The variation of fracture energy of beam specimens are plotted in Fig 19

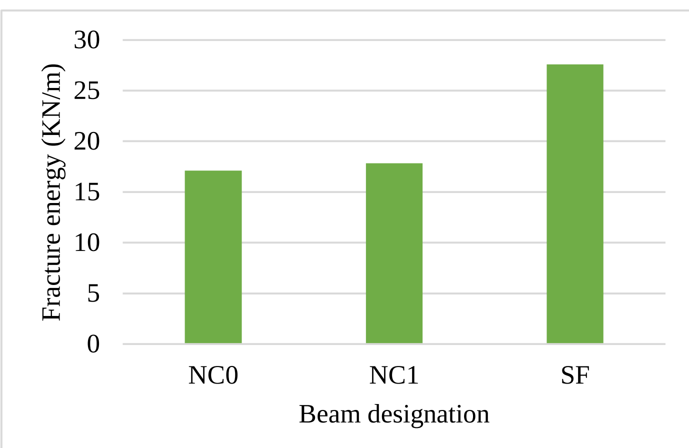

Fig 19 The variation of fracture energy of beam specimens

The results shown that the fracture energy of steel fiber reinforced concrete is 68 % higher when compared with normal concrete. The SFRC has high tensile strength and ductility due to the pullout-resistant mechanism of steel fiber and the steel fiber in the concrete controls the crack propagation due to the tensile stress and resists the tensile stress across the crack. So the fracture energy for the steel fiber reinforced concrete specimens are higher than those of the normal concrete specimens.

The value of fracture toughness or stress intensity factor indicate the magnitude of the stress concentration in front of the crack tip when the crack starts to propagate. The variation of fracture toughness of beam specimens are plotted in Fig 20.

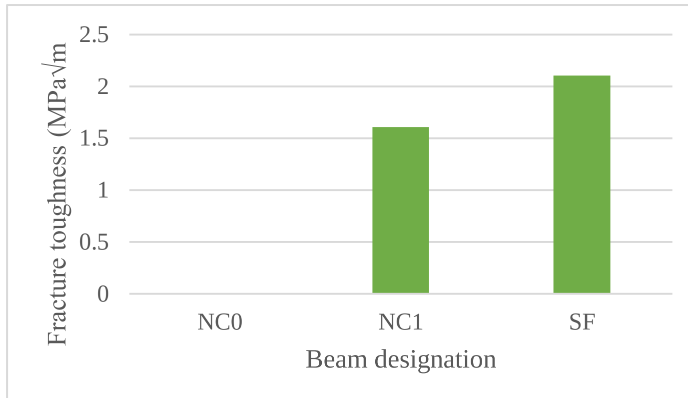

Fig 20 The variation of fracture toughness of beam specimens

When compared to normal concrete, steel fiber reinforced concrete has higher fracture toughness. The results show that the fracture toughness of beam specimens improves with the addition of fiber content. This shows that the critical stress at which cracking occurs is higher in steel fiber reinforced concrete than in normal concrete. Steel fiber reinforced concrete needs a higher stress than normal concrete for the formation of cracks. Therefore, the crack resistance of steel fiber reinforced concrete is higher than that of normal concrete.

CONCLUSIONS

- The optimum dosage of steel fiber was obtained as 1%.
- It was observed that addition of steel fibers in concrete mix affects the fresh properties of concrete and demand dosage of 0.3% superplasticizer to maintain the fresh properties within workable limits.
- Compressive strength, split tensile strength and flexural strength, was observed to be increasing up to optimum dosage.
- At optimum dosage, increment of compressive strength, flexural strength and split tensile

strength were 33.34%, 79.67%, 62.15% as compared to normal mix.
- Modulus of elasticity is found to be maximum in the mix without fiber and decreases with increase in fiber content.
- The rate of increase in deflection of beams without fiber is higher than that of beams with fiber
- The ultimate load carrying capacity of steel fiber reinforced concrete is 38 % higher when compared with normal mix.
- Fracture energy of steel fiber reinforced concrete is 68 % higher when compared with normal concrete.
- The fracture toughness of beam specimens improves with the addition of fiber content.

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