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Effect of Dosage, Aspect Ratio and End Shape of Steel Fibers on the Flexural Toughness Performance of Steel Fiber Reinforced Concrete- A Performance Study

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Abstract:- The usefulness of fiber reinforced concrete in the civil engineering field is indisputable. Fiber reinforced concrete (FRC) has been a solution for the engineers in arresting and preventing crack propagation. FRC has been a part of the construction of bridges, offshore and hydraulic structures, structural elements to be built in seismically prone areas, precast products and so on. This paper presented herein provides an experimental report on the flexural performance and durability parameters of fiber reinforced concrete. We broadly classify Steel Fiber Reinforced Concrete (SFRC) based on a few parameters such as dosage, shape and aspect ratio of steel fibers. In particular, issues related to the post cracking behaviour , the load carrying capacity and the fresh concrete properties of fiber reinforced concrete is briefly explained.

Keywords:- fiber reinforced concrete, SFRC, flexural performance, post cracking behaviour, fresh concrete properties, dosage, shape and aspect ratio of steel fibers.

I. INTRODUCTION

Concrete is a stone like material which is strong in Compression, favourable in Flexure, but very weak in Tension. Attempts which have been done to do away with this negative characteristic of concrete through various reinforcing techniques have not been successful. Recent years have observed in researches concentrating on making concrete itself ductile/semi-ductile instead of totally relying upon reinforcing steel at tension zones through various means such as reactive powder concrete or fiber reinforced composites, etc. Fiber reinforced concrete (FRC) can be defined as a composite material of cement concrete or mortar along with certain discontinuous discrete and uniformly dispersed fiber. These fibers act as crack arrestors and increase the structural integrity of the concrete. By their incorporation there will be a shift from the usual limitation of concrete restricted to pre cracking behaviour to a definite and measurable post-cracking behaviour. This forms an interface between the first cracks of concrete – stress transfer on the reinforcing steel and visibly extends the duration between the same, giving sufficient warning and breathing time, as well as in reducing the ill-effects on the RC structure due to sudden release of energy at the first crack level. This also results in optimizing the load carrying/moment capacities of the entire RC structure, when properly modelled, analyzed and designed.

Some of the most commonly used fibers are;

- Steel
- Glass
- Natural
- Carbon
- Polypropylene
- Polyethylene etc…

There are currently around 3 lakh metric tons of fibers used for concrete reinforcement. Steel fiber remains the most used fiber of all (50% of total tonnage used) followed by polypropylene (20%), glass (5%) and other fibers (25%).

The most techno-commercially viable proposition of all these would be incorporating three-dimensionally reinforcing steel fibers into concrete matrix. Steel fibers are the most widely used fibers for both structural and non-structural components.

SFRC is broadly used in areas where determination of actual loads on structures is almost impossible, such as in tunnel linings and also where the actual layout of structures is indefinite. Fiber incorporation in concretes is also widely known for its property of significantly reducing the plastic/drying shrinkage of concretes compared to non fiber reinforced concretes. It has got high modulus of elasticity and makes significant improvements in flexure, impact and fatigue strength of concrete. In the hardened state, when fibers are properly bonded, they interact with the matrix at the level of micro-cracks and effectively bridge these cracks thereby providing stress transfer media that delays their coalescence and unstable growth. The most important aspects controlling the performance of steel fibers in concrete are the;

. Aspect ratio
. Volume concentration
. Geometrical shape.

The higher the dosage and aspect ratio of the fiber provided the tensile strength is high, performance of the SFRC will be better with respect to flexural strength, impact resistance, toughness, ductility, crack resistance.

Unfortunately, the higher dosage and aspect ratio of the fiber, the more difficult the concrete becomes to mix and convey. Thus there are practical limits to the amount of fibers, which can be added to SFRC, with the amount varying with the different geometrical characteristics of the several fiber types. Loose steel fibers with a high l/d aspect ratio, which is essential for good reinforcement, are difficult to incorporate in the concrete and to spread evenly in the mixture.

II. EXPERIMENTAL PROGRAM

M50 grade of concrete having mix proportions developed as per IS 10262:2009 was used throughout the experimental investigation. Following are the variations in parameters that were tested;

A. Dosage variation: The volume fraction of steel fibers for 30, 40 and 50 kg/m3 by the volume of cement content is varied by keeping hooked shape steel fibers and aspect ratio of 60 as constant.
B. Shape variation: Different shapes such as hooked and crimped steel fibers are investigated by maintaining the dosage of 40 kg/m3 and 60 aspect ratio as constant.
C. Aspect ratio variation: By using hooked shape steel fibers with 40 kg/m3 dosage as the constant parameters four different aspect ratio of steel fibers such as 50, 60, 70 and 80 were used in the mix and their effect was studied.

Cubes of 150mm size was used for compressive test, cylinders of 150mm diameter and 300mm length for split tensile test and prisms of 100x100x500mm for both flexural strength and flexural toughness evaluation were casted. All the specimens were water cured for 28 days at ambient room temperature and were tested in surface dry condition. Each value of the results presented in this paper is the average of three test samples.

Table I: Casted Specimens Details

Variations of parameters	**Number of specimens casted**		
	Cubes	Cylinders	Prisms
1. Dosage variation			
a. 0 kg/m³	6	3	3
b. 30 kg/m³	6	3	3
c. 40 kg/m³	6	3	3
d. 50 kg/m³	6	3	3
2. Shape variation			
a. Hooked	6	3	3
b. Crimped	6	3	3
3. Aspect ratio variation			
a. 50	6	3	3
b. 60	6	3	3
c. 70	6	3	3
d. 80	6	3	3

III. MATERIALS

This section will present the chemical and physical properties of the ingredients. Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) procedures were followed for determining the properties of the ingredients in this investigation.

A. Cement: Ordinary Portland cement 53 grade of Ultratech Birla Super brand was used corresponding to the IS standards. The specific gravity of cement was 2.95.

B. Coarse aggregate: Crushed granite stones of size 20mm and 12.5mm with equal proportions were used as coarse aggregate.

C. Fine aggregate: Manufactured sand is used as fine aggregate.
The materials finer than 75µ IS sieve was 1.2%. Based on fineness modulus and grain size distribution the sand we used comes under Zone-II according to IS: 383-1970.
As per IS: 2386 (Part-3)-1963 the following properties are determined.

Table II: Properties Of Aggregates

Sl no	Properties	Material	
		Fine aggregate	Coarse aggregate
1.	Bulk specific gravity	2.62	2.70
2.	Water absorption	4.50%	0.4%
3.	Moisture content	1.60%	0.2%

D. Water: Potable water is used for mixing and curing of the fiber reinforced concrete mixes. The properties of water are tabulated below;

Table III: Water Properties

Sl no	Properties	Readings
1	pH	7.72
2	Acidity	Nil
3	Specific conductance	835 micro/mhos
4	Total hardness	274 mg/litre
5	Chloride	105 mg/litre
6	Turbidity	1NTU
7	Sulphate	63 mg/litre
8	Calcium	109 mg/litre
9	Magnesium	17 mg/litre
10	Na	10 mg/litre
11	K	2 mg/litre
12	Alkalinity	260 mg/litre
13	TDS	500 mg/litre
14	Iron	0.04 mg/litre
15	Fluoride	0.7 mg/litre
16	nitrate	7 mg/litre

E. Chemical admixture: Super plasticizer of type BASF Glenium Sky B8233, was used to increase the workability. Optimum dosage of super plasticizer was around 40-45% of the cement content which has been determined using trial mixes.

Table IV: Specifications of Master Glenium Sky 8233

Aspect	Light brown liquid
Relative density	1.08 ± 0.01at 25˚c
pH	≥6
Chloride ion content	<0.2%

F. Steel fibers: Five types of steel fibers were used in the project;

Table V: Specifications Of Steel Fibers

Sl no	Shape	Aspect ratio	Length	Diameter
1	HOOKED	50	30	0.60
2	HOOKED	60	35	0.60
3	HOOKED	70	50	0.70
4	HOOKED	80	60	0.75
5	CRIMPED	60	35	0.60

IV. MIX PROPORTIONS

For M50 grade designation, the quantities obtained per cum of concrete as per IS 10262:2009 are tabulated below;

Table VI: Mix Proportions

Sl no	Material		Quantity
1	Cement		410 kg/m^3
2	Fine aggregate		710 kg/m^3
3	Coarse aggregate	20 mm down	548.5 kg/m^3
		12.5 mm down	548.5 kg/m^3
4	Water		164 kg/m^3
5	Admixture		1.64 kg/m^3

V. DISCUSSION ON RESULTS

The tests on hardened concrete were carried out according to the relevant standards wherever applicable. Experimental results obtained are tabulated and are used for discussions.

A. Dosage Variation:

Steel fibers: Hooked shape; Aspect ratio: 60

Table VII (A): Consolidated Test Results

Fiber content (kg/m³)	Compressive strength (MPa)		Split tensile strength(MPa)	Flexural strength (MPa)
	7 days	28 days	28 days	28 days
0	47.41	62.05	3.96	5.91
30	53.10	65.42	4.74	6.79
40	56.25	66.16	5.41	7.14
50	58.05	68.76	5.61	7.45

B. Shape Variation:

Steel fibers: Aspect ratio: 60; Dosage: 40 kg/m^3

Table VII (B): Consolidated Test Results

Fiber shapes	Compressive strength (MPa)		Split tensile strength(MPa)	Flexural strength (MPa)
	7 days	28 days	28 days	28 days
Hooked	56.25	66.16	5.41	7.14
Crimped	52.62	63.11	4.71	6.83

C. Aspect Ratio Variation:

Steel fibers: Hooked shape; Dosage: 40 kg/m^3

Table VII(C): Consolidated Test Results

Aspect ratio	Compressive strength (MPa)		Split tensile strength(MPa)	Flexural strength (MPa)
	7 days	28 days	28 days	28 days
50	48.3	62.25	4.28	8.38
60	56.25	66.16	5.41	7.14
70	54.47	65.72	4.85	7.36
80	49.26	64.96	4.42	7.76

VI. FLEXURAL TOUGHNESS

Apart from the compression, tensile and flexural strength properties fiber reinforced concrete has been widely implemented because of its post cracking behavior i.e., after the sudden release of energy at the first crack level. Toughness is defined as the area under a load-deflection (or stress-strain) curve. Adding fibres to concrete greatly increases the toughness of the material. That is, fibre-reinforced concrete is able to sustain load at deflections or strains much greater than those at which cracking first appears in the matrix.

Flexural toughness test is hence carried out as a major of this research work and the procedure to be followed as follows according to ASTM C1609;

1. This test method evaluates the flexural performance of fiber-reinforced concrete using parameters derived from the load-deflection curve obtained by testing a simply supported beam under third-point loading using a closed-loop, servo controlled testing system.
2. This test method utilizes preferred specimen size of 100 by 100 by 500 mm prism tested on a 450 mm [18 in.] span as shown in figure below.
3. The rate of loading is kept as slow as possible and the deflection of the specimen for every 20μ on the dial gauge is observed.
4. This test method provides for the determination of first-peak and peak loads and the corresponding stresses calculated by inserting them in the formula for modulus of rupture given in Eq (1). It also requires determination of residual loads at specified deflections i.e., at 0.5mm and 3.2mm, the corresponding residual strengths calculated by inserting them in the formula for modulus of rupture given in Eq (1). It provides for determination of specimen toughness based on the area under the load-deflection curve up to a prescribed deflection.

$$f = \frac{Pl}{bd^2} \qquad \text{.............. (1)}$$

The first peak strength is the flexural strength of that particular specimen and the residual strengths at 0.5mm and 3.2mm deflection are tabulated along with graphs for different variations carried out in this performance study.

A. Residual Strength Evaluation

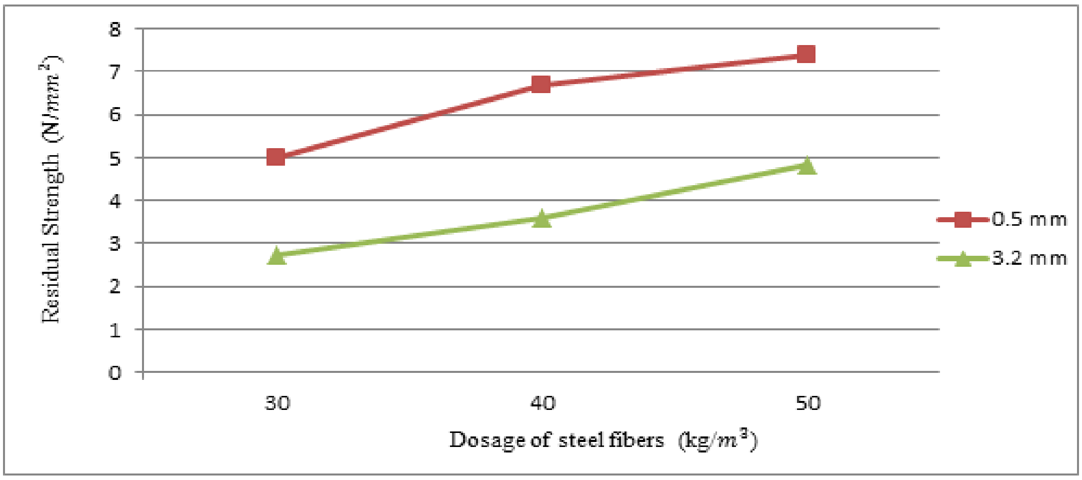
1) *Dosage variation:*

Steel fibers: Hooked shape; Aspect ratio: 60

Table VIII (A): Residual Strength Results

DOSAGE	Residual strength (N/mm²)	
	0.5mm	**3.2mm**
30	**5**	**2.73**
40	**6.68**	**3.61**
50	**7.39**	**4.83**

Fig I (A): Residual Strength At 0.5 And 3.2mm Deflections



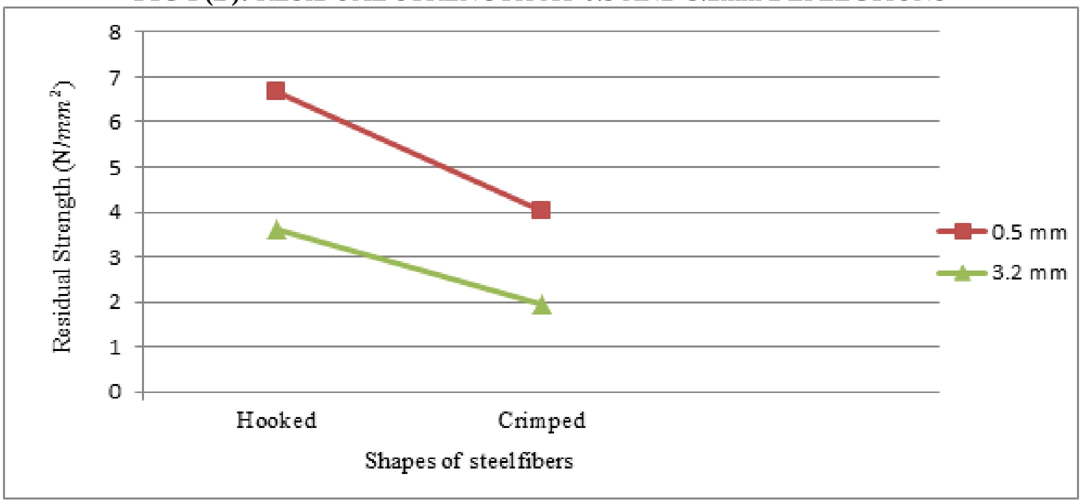
2) Shape variation:

Steel fibers: Aspect ratio: 60; Dosage:40 kg/m^3

Table VIII (B): Residual Strength Results

SHAPES	Residual strength (N/mm²)	
	0.5mm	3.2mm
Hooked	6.68	3.61
Crimped	7.03	1.93

FIG I (B): RESIDUAL STRENGTH AT 0.5 AND 3.2mm DEFLECTIONS



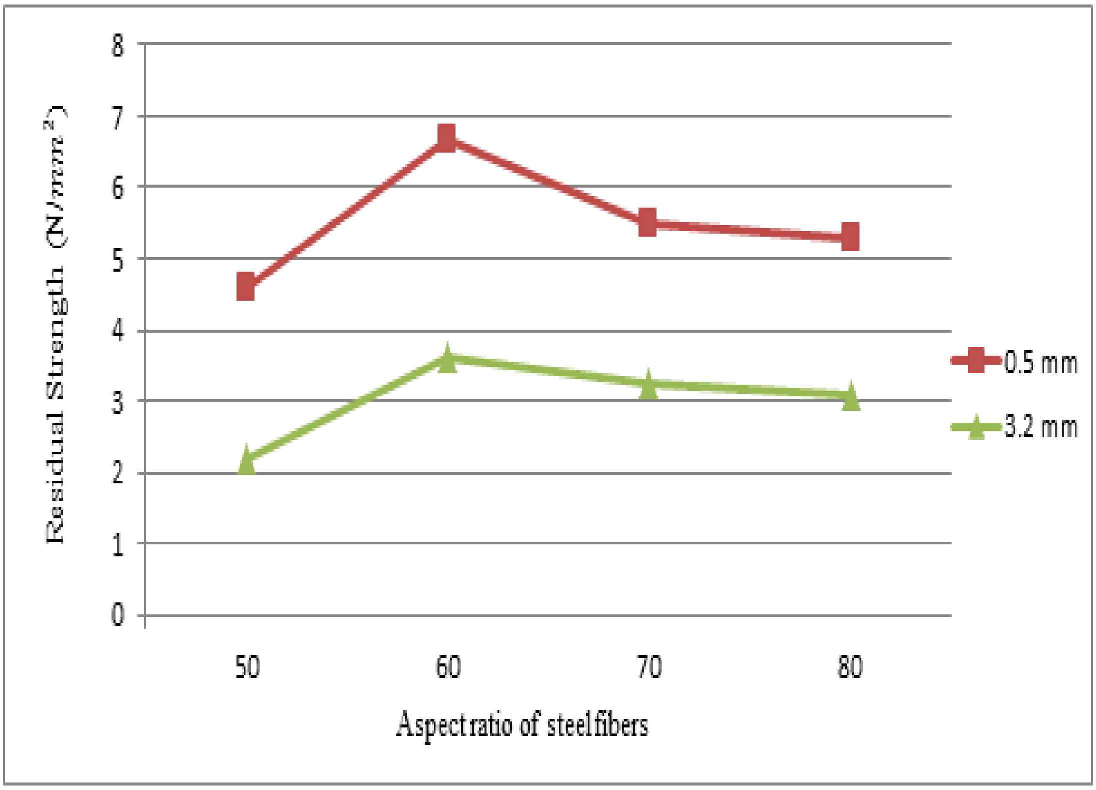
3) Aspect ratio variation:

Steel fibers: Hooked shape; Dosage: 40 kg/m^3

TABLE VIII(C): RESIDUAL STRENGTH RESULTS

ASPECT RATIO	Residual strength (N/mm^2)	
	0.5mm	3.2mm
50	4.59	2.18
60	6.68	3.61
70	5.48	3.25
80	5.30	3.10

FIG I (C): RESIDUAL STRENGTH AT 0.5 AND 3.2mm DEFLECTIONS



VII. FRESH CONCRETE PROPERTIES

The fresh concrete properties such as slump and the fresh density of each mix has been determined as a part of this experimental work in order to investigate the effect of fiber inclusion on the workability of the steel fiber reinforced concrete. As a matter of fact it was observed that the presence of fibers considerably alters the fresh concrete properties when compared to that of conventional one. The properties of SFRC in a green state are mainly influenced by the aspect ratio of the fibers, geometry of fibers, volume fraction and fiber-matrix bond.

A. Slump:

Slump is a measure of consistency or workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works. Unsupported fresh concrete, flows to the sides and a sinking of height takes place. This vertical settlement is known as slump. It is the most important and basic test carried to determine the fresh concrete properties of desired concrete mix.

In the project the slump is being maintained constant so as to allow the other parameters like dosage, shape and aspect ratio to have their influence on the flexural property.

Hence the slump value is maintained as 100±10 for each mix so that the effect of fibers on the concrete by varying the above mentioned parameters can be obtained to the precision.

B. Fresh Density:

The density of concrete of the desired mix is determined to visualize the effect of different types of fibers on the normal concrete. The following graphs gives a wide knowledge on the variation of densities for different volume, shape and aspect ratio of steel fibers.

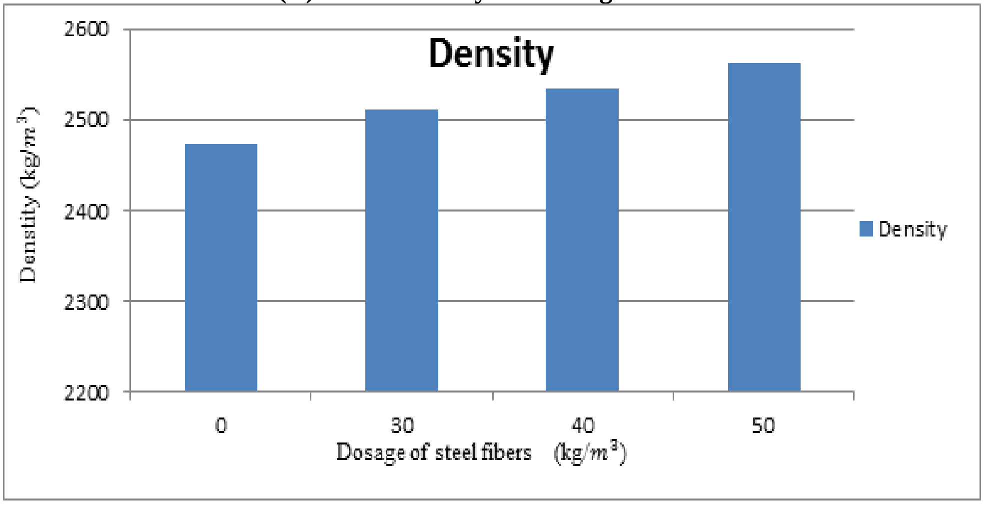
1) For different dosage:

Steel fibers: Hooked shape; Aspect ratio: 60

TABLE IX (A): Fresh Density Results

Dosage(kg/m^3)	Density(kg/m^3)
0	2473.07
30	2511.73
40	2535.7
50	2562.96

FIG II (A): Fresh Density For Dosage Variation



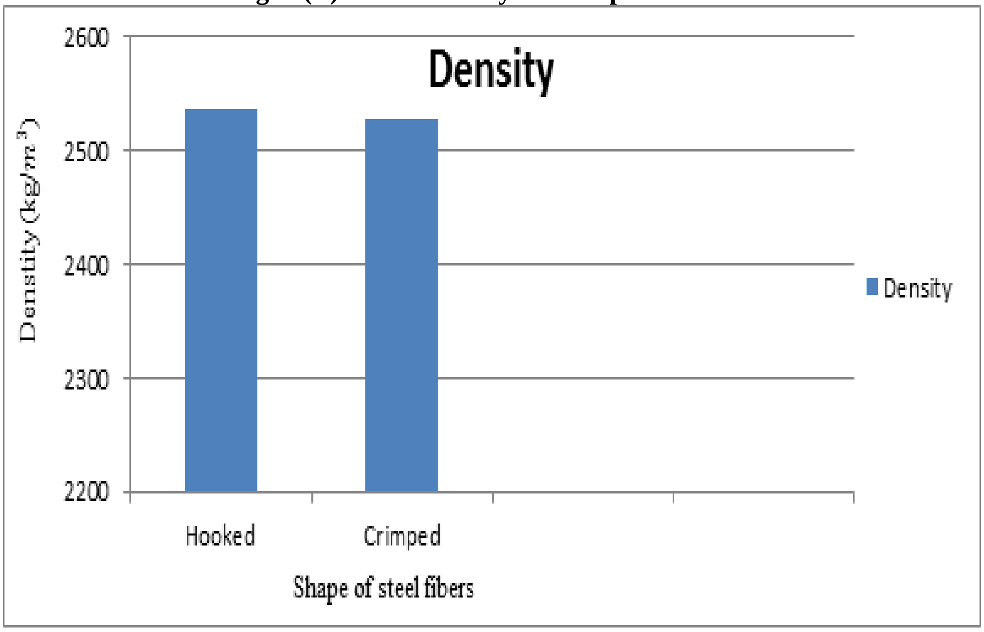
2) For different Shapes:

Steel fibers: Aspect ratio: 60; Dosage: 40 kg/m^3

TABLE IX (B): Fresh Density Results

Shape	Density(kg/m^3)
Hooked	**2535.70**
Crimped	**2528.59**

Fig II (B): Fresh Density For Shape Variation



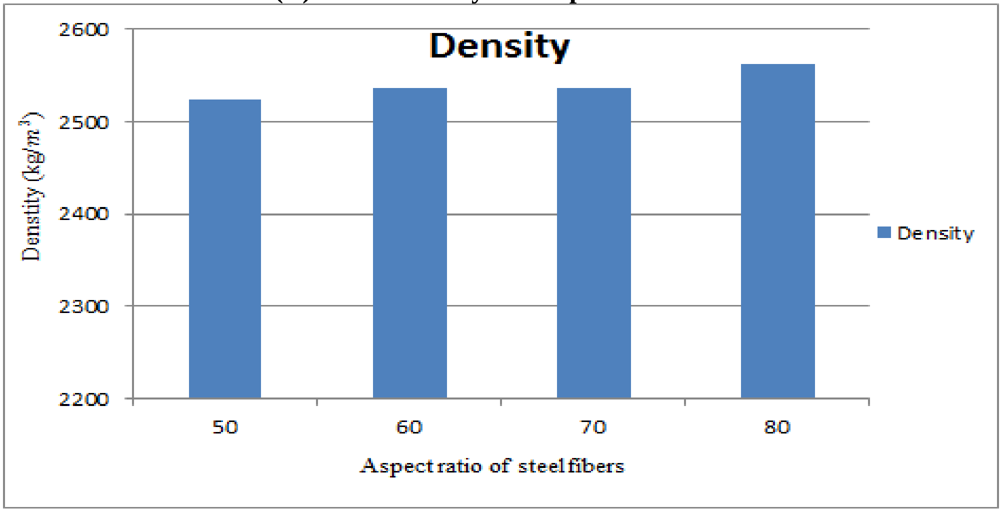
3) ***For different aspect ratio:***

Steel fibers: Hooked shape; Dosage: 40 kg/m^3

Table IX(C): Fresh Density Results

Aspect ratio	Density(kg/m^3)
50	**2523.85**
60	**2535.7**
70	**2536.29**
80	**2563.55**

FIG II(C): Fresh Density For Aspect Ratio Variation



VIII. CONCLUSION

Based on the experiment conducted on steel fiber reinforced concrete using the local materials, we have arrived at following conclusions;

A. Dosage variation:

1. As the fiber volume increases the tensile and flexural strength increases. But the incorporation of steel fibers in concrete had a small effect on the compressive strength. Overall from the observations it can be said that increase in strength is directly proportional to the fiber content in the specimen. Refer Table[VII(A)]
2. The flexural toughness results show that the specimen with higher dosage of steel fibers is capable of withstanding the load even after the failure.
3. The fresh density of concrete increases gradually by increasing the dosage of steel fibers. Refer Table[IX(A)] and Fig [II(A)]
4. The residual strength increases with increase in the dosage of steel fibers. Refer Table[VIII(A)] and Fig [I(A)]

B. Shape variation:

1. For the same volume fraction of 40 kg/m^3 and aspect ratio of 60 hooked shape steel fibers responds better than the crimped shape steel fibers under compression, tensile and flexure. Refer Table[VII(B)]
2. The residual strength at 0.5mm and 3.2mm deflection of hooked fibers is more than the crimped fibers. Hence the shape of post crack load-deflection curve did strongly depend on the geometry of the fibers. Table[VIII(B)] and Fig [I(B)]

C. Aspect ratio variation:

1. By considering dosage of 40 kg/m^3 and hooked shape the fibers with aspect ratio 60 has shown more compression, tensile and residual strength than the fibers with other aspect ratio such as 50, 70 and 80. Refer Table[VI(C)]
2. In the case of flexural strength the fibers with aspect ratio 50 absorbs more load before leading to failure.

D. From the test performed it can be stated that;

1. Fibers incorporated have shown an ability to pull-out rather that disintegrating into pieces. This gives enough precautionary measure for taking up repair and rehabilitations.
2. The most important point greatly influencing the hardened concrete properties of FRC is the distribution of fibers which has to be even throughout the entire specimen.
3. Plain concrete specimens fail catastrophically by the existence of first crack and get separated into two pieces on the other hand the specimen with even a small volume of steel fibers has an ability to withstand the load in the post cracking session.

REFERENCES

[1] D. V. Soulioti, N. M. Barkoula, A. Paipetis and T. E. Matikas" Effects of Fibre Geometry and Volume Fraction on the Flexural Behavior of Steel-Fibre Reinforced Concrete"-strain-An International Journal for Experimental Mechanics" Volume 47, Issue1, June 2011, PP 535-541.

[2] P.Balaguru, Ramesh Narahari and Mehendra Patel "Flexural Toughness of Steel Fiber Reinforced Concrete" -ACI Journal, November-1992, Volume 89, Issue-6, Pages 541-546.

[3] D.B.Mohite, S.B.Shinde "Experimental investigation on effect of different shaped steel fibers on compressive strength of high strength concrete"-IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Volume 6, Issue 4, May - Jun. 2013, PP 24-26.

[4] J.A.O.Barros, J.A.Figueiras "Flexural Behavior Of Steel Fiber Reinforced Concrete:Testing And Modeling"- ASCE Journal , Volume 11, No 4, Nov 1999, PP 331-339.

[5] B.Setti, M.Taazount, S. Hammoudi, F.Setti, M.Achit-Henni "Compressive, flexural and abrasive performances of steel fiber reinforced concrete elements"-International Journal of Mechanical Engineering and Applications Volume 1, No. 3, August 2013, PP 69-77.

[6] Klaus Holschemacher, Torsten Muller "Influence Of Fibre Type On Hardened Properties Of Steel Fibrereinforced Concrete".

[7] B. Miloud "Permeability And Porosity Characteristics Of Steel Fiber Reinforced Concrete"-Asian Journal Of Civil Engineering (Building And Housing) Volume. 6, NO. 4 (2005), PAGES 317-330.

[8] Jimmy Susetyo, Paul Gauvreau, and Frank J. Vecchio "Effectiveness of Steel Fiber as Minimum Shear Reinforcement"-ACI Journal,Volume 108,Issue 4, July 2011,Pages 488-496.

[9] Amit Rana- "Some Studies on Steel Fiber Reinforced Concrete" International Journal of Emerging Technology and Advanced Engineering (IJETAE), Volume 3, Issue 1, January 2013.

[10] Merve Acikgenc, Kursat Esat Alyamac, Zulfu Cinar Ulucan- "Fresh and hardened properties of steel fiber reinforced concrete produced with fibers of different lengths and diameters" 2nd International Balkans Conference on Challenges of Civil Engineering", BCCCE, 23-25, May 2013, Epoka University, Tirana, Albania.

[11] ASTM C1609/C1609M Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete.