Effect of different aspect ratio of steel fiber on mechanical properties of high strength concrete

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In this paper, the effect of different aspect ratio (65 and 80) of steel fiber on mechanical properties of high strength concrete are addressed. Mechanical properties of high strength concrete investigated by varying positions of steel fiber in concrete cubes and beams. Percentage of steel fiber by volume was 0.5%, 1.0% and 1.5%. A series of 78 specimens (39 cubes and 39 beams) of different aspect ratio and varying positions of steel fibers were cast. Experimental findings addressed that as volume of fiber increases, there will be increase in flexural strength. More flexural strength was observed at aspect ratio 80. In flexural strength test more displacement was observed at one third depth than randomly reinforced fibers. Steel fiber reinforced concrete can be used for construction of pavement, industrial floors, bridge deck slabs satisfactorily. For aspect ratio 80 it was found that compressive strength increases in both positions of steel fiber. Empirical equations for predicting basic strength properties of concrete were presented based on regression analysis.

1. INTRODUCTION

As compared to conventional flexible pavement, rigid pavements were found to be more sustainable and durable. It was well designed that steel fibers in concrete are effective in bridging the cracks [1]. Fibers in a concrete helps to reduce propagation of cracks. It was found that performance of CRCP with steel reinforcement suggests the best performance has resulted when the reinforcement is placed at about one third the depth of slab measured from pavement surface. At this location reinforcement is most effective in holding the cracks together [2].

This paper presents the effect of different aspect ratio of steel fiber and position of steel fiber on rigid pavement construction. Various experimental tests are carried out on concrete specimens to obtain compressive strength, flexural strength, maximum deflection of beam under the applied loads. Fly ash enhances the strength and shrinkage of the concrete and reduces the heat of permeability and porosity [3, 4]. Compressive strength and flexural strength of concrete increases for HPSFRC compared to HPC [5]. Steel fiber enhances post cracking behavior, ductility, load bearing capacity after cracking of concrete [6-11]. Abrasive resistance, impact strength, flexural strength of rigid pavement is increased due to addition of steel scrap fiber [12]. In the concluding section validation of strength results were carried out with regression technique.

2. MATERIALS AND MIX DESIGN

Sand passing through IS sieve 4.75 mm and retaining on IS sieve 150 micron is used in the investigation. The sample shall be brought to an air dry condition before weighting and sieving. This may be achieved either by drying at room temperature or by heating at a temperature of 100 to 110°C. The air dried sample was weighed. It was sieved with a sieves arranged in descending order of the openings of the sieve. Sieve should clean before use (IS 2386: Part-I 1963) [13]. In this experimental programme crushed aggregates were used. For this study 12.5 mm coarse aggregates were used. The physical properties of coarse aggregate like specific gravity, impact value, bulk density, gradation and fineness modulus are tested in accordance with IS 2386. Steel

Table 1. Steel fiber properties

Type	Length (mm)	Diameter (mm)	Aspect ratio	Tensile strength (MPa)	Young's modulus (GPa)
Dramix	35	0.55	65	1000	210
Dramix	60	0.75	80	1000	210

Ordinary portland cement of 53 grade confirming IS 4031:1988 used for experimental work.

Figure 1. Steel fibers

fibres with properties as shown in Table 1 used for steel fibre reinforced concrete having aspect ratio 65 and 80. It is hooked end in shape and circular in cross section as shown in Figure 1.

A high strength concrete was prepared to obtain cube compressive strength higher than 60 N/mm^2 after 28 days. ACI method was used to prepare high strength concrete mixture [14]. The mixture were prepared with proper selection of cement, fine aggregate, coarse aggregate, W/C ratio and admixture [15, 16]. Ordinary Portland cement of 53 grade confirming IS 4031:1988 used for experimental work. The proportion of different ingredients are shown in Table 2.

3. TEST PROCEDURE

3.1 Workability

Workability is the measure of lubrication required for handling the concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish easily. The results of workability test as shown in Table 3.

It was observed that as percentage of fiber increases workability reduces. The reduction in workability is due to more water required to lubricate more amount of fiber. As amount of fiber increases less space is available for movement of fiber.

3.2 Test for compressive strength of concrete (IS 516:1959)

In this investigation plain cement concrete cubes and fiber reinforced concrete cubes (with randomly reinforced and 1/3rd reinforced from top of the surface) were tested on compression testing machine of capacity 3000 KN. The load

Table 2. Mix design

Components	Mixtures					
	65SF0.5	65SF1.0	65SF1.5	80SF0.5	80SF1.0	80SF1.5
Cement (Kg/M^3)	588	588	588	588	588	588
Fly ash (Kg/M^3)	65	65	65	65	65	65
Coarse aggregate (Kg/M^3)	1159	1159	1159	1159	1159	1159
Fine aggregate (Kg/M^3)	527	527	527	527	527	527
Steel fiber (Kg/M^3)	39	78	118	39	78	118
Water (Lit/M^3)	183	183	183	183	183	183
Superplasticizer (Lit/M^3)	5.23	5.23	5.23	5.23	5.23	5.23
W/C ratio	0.31	0.31	0.31	0.31	0.31	0.31

Table 3. Workability test

Mixtures	Controlled concrete	65SF0.5	65SF1.0	65SF1.5	80SF0.5	80SF1.0	80SF1.5
Slump in mm	55	50	40	35	35	33	30

Table 4. Compressive strength test

Type	Test	Position	Mixture	Average compressive strength (N/mm^2)
Cube	Compressive	--	Controlled concrete	64.89
Cube	Compressive	Random	65SF0.5	63.77
Cube	Compressive	Random	65SF1.0	64.00
Cube	Compressive	Random	65SF1.5	75.55
Cube	Compressive	One third	65SF0.5	63.55
Cube	Compressive	One third	65SF1.0	64.22
Cube	Compressive	One third	65SF1.5	66.66
Cube	Compressive	Random	80SF0.5	71.92
Cube	Compressive	Random	80SF1.0	74.29
Cube	Compressive	Random	80SF1.5	71.33
Cube	Compressive	One third	80SF0.5	67.11
Cube	Compressive	One third	80SF1.0	73.55
Cube	Compressive	One third	80SF1.5	74.22

Figure 2. Compressive strength test

is applied to opposite sides of specimen. The load at which concrete cube was failed, considered as ultimate load and noted as shown in Figure 2. The compressive strength was obtained by formula

$$\text{Compressive strength} = \frac{P}{A}$$

Here, P = Cube compressive load causing failure in N, A = Cross sectional area of cube in mm. The average of number of specimen strength is calculated and it was taken as compressive strength of one set [14] as shown in Table 4.

3.3 Test for flexural strength of concrete (IS 516:1959)

This test is carried out for finding out flexural strength of concrete. The number of beams tested for different percentage of fiber content. The specimens were tested by using universal testing machine and results were obtained as shown in Table 5. The load at which control specimen ultimately fails is noted. The displacement at maximum

Table 5. Flexural strength test

Type	Test	Position	Mixture	Average displacement at failure (mm)	Average maximum displacement (mm)	Average flexural strength (N/mm^2)
Beam	Flexural	---	Controlled concrete	1.15	1.26	6.71
Beam	Flexural	Random	65SF0.5	1.75	6.70	4.64
Beam	Flexural	Random	65SF1.0	1.05	8.75	7.15
Beam	Flexural	Random	65SF1.5	2.80	12.35	7.79
Beam	Flexural	One third	65SF0.5	1.15	13.75	5.40
Beam	Flexural	One third	65SF1.0	1.60	2.80	6.51
Beam	Flexural	One third	65SF1.5	1.60	7.75	6.80
Beam	Flexural	Random	80SF0.5	1.20	21.25	5.25
Beam	Flexural	Random	80SF1.0	2.20	16.60	6.08
Beam	Flexural	Random	80SF1.5	2.45	16.30	8.57
Beam	Flexural	One third	80SF0.5	1.20	25.35	5.43
Beam	Flexural	One third	80SF1.0	2.90	25.25	6.18
Beam	Flexural	One third	80SF1.5	5.60	25.40	7.87

load and maximum displacement at ultimate failure was measured with the help of computer connected to UTM. Displacement was measured on electronic universal testing machine of capacity 1000 KN with straining speed at no load is 0-150 mm per minute. This UTM can be hooked to any PC using communication port. Load is applied by hydrostatically lubricated ram. Main cylinder pressure is transmitted to the pressure transducer housed in the control panel. The transducer gives the signal to the electronic display unit corresponding to the load exerted by the main ram. Simultaneously the digital electronic fitted on the straining unit gives mechanical displacement to the electronic display unit. Both signals are processed by microprocessor and load and displacement are displayed on the digital readouts simultaneously as shown in Figure 3. The flexural strength is calculated by formula

$$\text{flexural strength} = \frac{P\,l}{bd^2}$$

Here, P = maximum load in N, l = Length between the support in mm, d = Depth of specimen in mm, b = Width of specimen in mm [17].

Figure 3. Flexural strength test

4. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results and discussions are given in Figures 2 to 13 and Tables 4 to 7.

5. REGRESSION TECHNIQUE

It is statistical technique used to explore linear relationship between predictor and criterion variable. The equations obtained from linear regression technique for compressive strength test and flexural strength test are as shown in Table 6 and 7 respectively.

Table 6. Linear regression equations for compressive strength

Sr. no.	Figure no.	Linear regression equation	Explanation
01	4	$y = 6.312x+61.93$, $R^2=0.524$	The curves as shown in Figure 4, 5, 6 and 7 follows linear regression type equation in the form $y = ax+b$. where, y = compressive strength as dependent variable, x = percentage of fiber as a independent variable, a and b are constants. The above equations holds good for steel fiber range from 0.5% to 1.5%.
02	5	$y = 1.172x+63.92$, $R^2=0.311$	
03	6	$y = 4.310x+67.37$, $R^2=0.482$	
04	7	$y = 6.886x+64.77$, $R^2=0.913$	

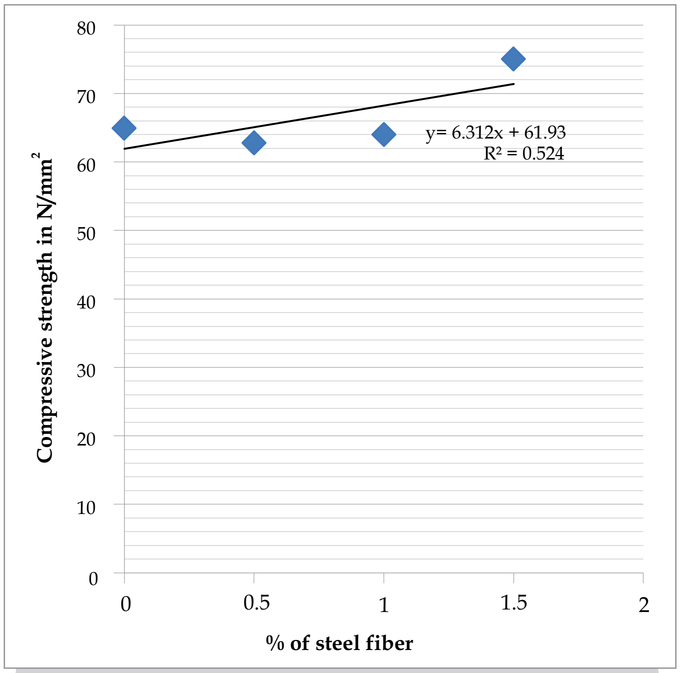

Figure 4. Compressive strength-% of steel fiber randomly reinforced (AR65)

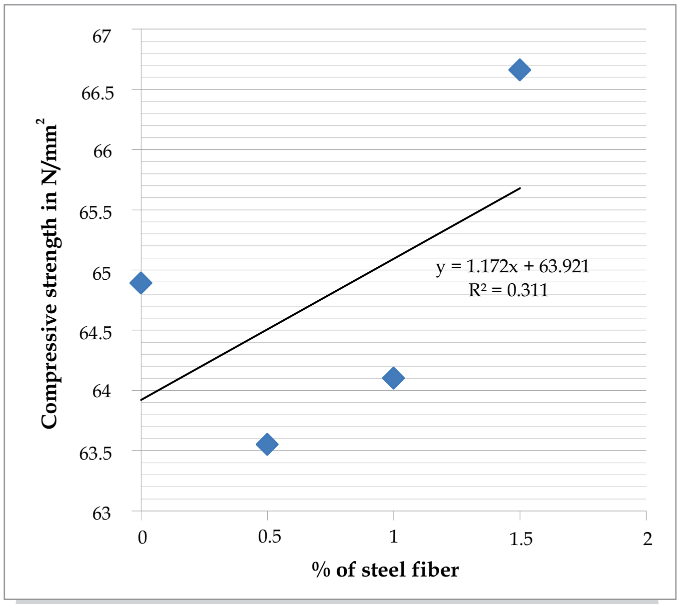

Figure 5. Compressive strength-% of steel fiber 1/3rd reinforced (AR65)

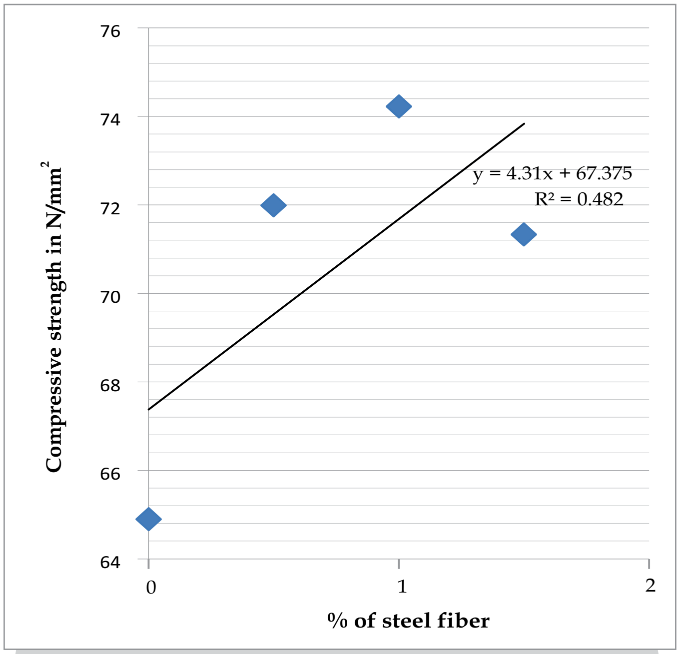

Figure 6. Compressive strength-% of steel fiber randomly reinforced (AR80)

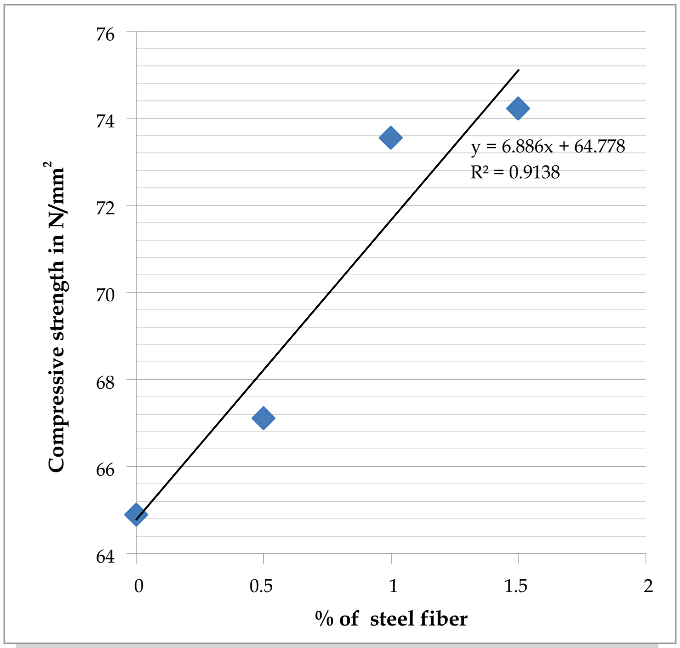

Figure 7. Compressive strength-% of steel fiber 1/3rd reinforced (AR80)

Table 7. Linear regression equations for flexural strength

Sr. no.	Figure no.	Linear regression equation	Explanation
01	8	$y=1.654x+5.122$, $R^2=0.582$	The curves as shown in Figure 8, 9, 10 and 11 follows linear regression type equation in the form y = ax+b. Where, y = flexural strength as a dependent variable, x = percentage of fiber as a independent variable, a and b are constants. The above equation holds good for steel fiber range from 0.5% to 1.5%.
02	9	$y=0.780x+5.560$, $R^2=0.637$	
03	10	$y=1.786x+5.103$, $R^2=0.622$	
04	11	$y=1.350x+5.325$, $R^2=0.667$	

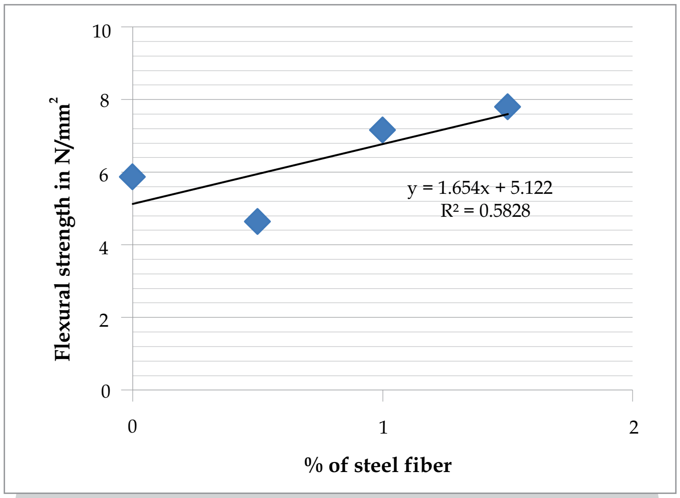

Figure 8. Flexural strength-% of steel fiber randomly reinforced (AR65)

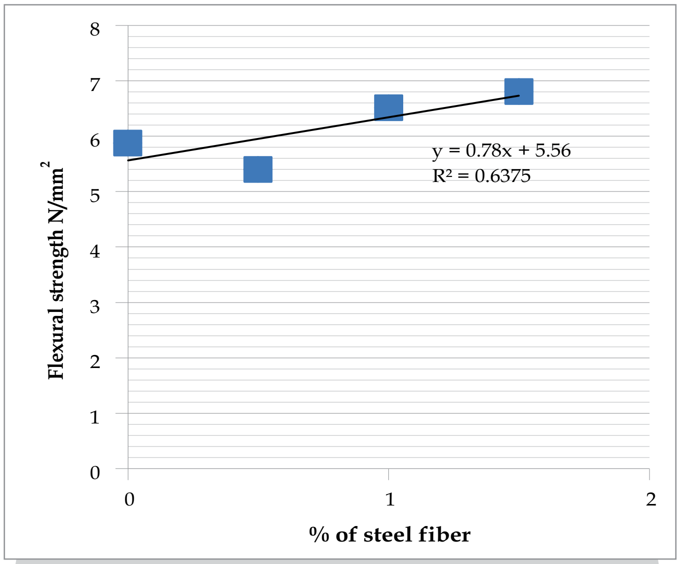

Figure 9. Flexural strength-% of steel fiber 1/3rd reinforced (AR65)

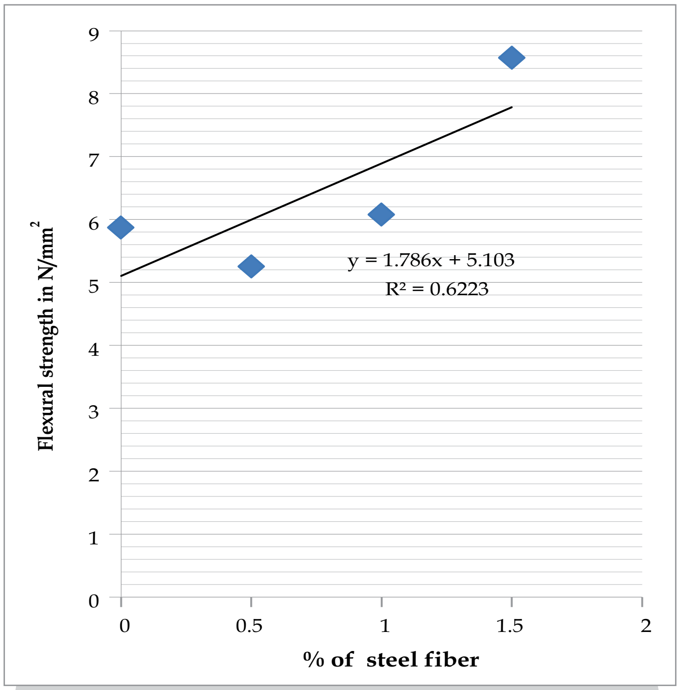

Figure 10. Flexural strength-% of steel fiber randomly reinforced (AR80)

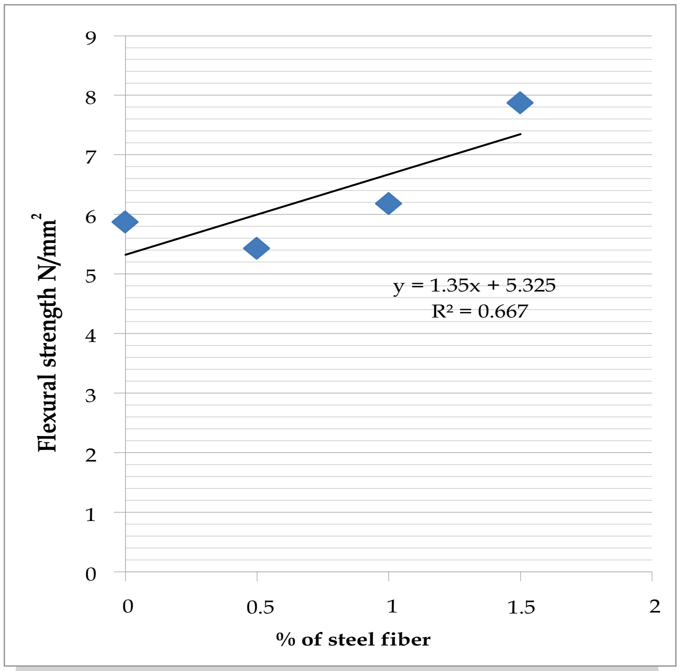

Figure 11. Flexural strength-% of steel fiber 1/3rd reinforced (AR80)

Table 8. Comparison between experimental results and regression technique result for compressive strength

Mixture	Position	Experimental results (N/mm^2)	Regression technique (N/mm^2)	Experimental results / Regression technique
65SF0.5	Random	63.77	65.086	0.979
65SF1.0	Random	64.00	68.240	0.937
65SF1.5	Random	75.55	71.390	1.058
65SF0.5	One third	63.55	64.506	0.985
65SF1.0	One third	64.10	65.092	0.984
65SF1.5	One third	66.66	65.678	1.014
80SF0.5	Random	71.99	69.525	1.035
80SF1.0	Random	74.22	71.680	1.035
80SF1.5	Random	71.33	73.835	0.966
80SF0.5	One third	67.11	68.213	0.983
80SF1.0	One third	73.55	71.656	1.026
80SF1.5	One third	74.22	75.099	0.988

Table 9. Comparison between experimental results and regression technique result for flexural strength

Mixture	Position	Experimental results (N/mm^2)	Regression technique (N/mm^2)	Experimental results / Regression technique
65SF0.5	Random	4.64	5.949	0.779
65SF1.0	Random	7.15	6.776	1.055
65SF1.5	Random	7.79	7.603	1.024
65SF0.5	One third	5.40	5.950	0.907
65SF1.0	One third	6.51	6.340	1.026
65SF1.5	One third	6.80	6.730	1.010
80SF0.5	Random	5.25	5.996	0.875
80SF1.0	Random	6.08	6.889	0.882
80SF1.5	Random	8.57	7.782	1.101
80SF0.5	One third	5.43	6.000	0.905
80SF1.0	One third	6.18	6.675	0.925
80SF1.5	One third	7.87	7.350	1.070

Comparison made between experimentally obtained results and regression technique results are presented in Tables 8 and 9 respectively.

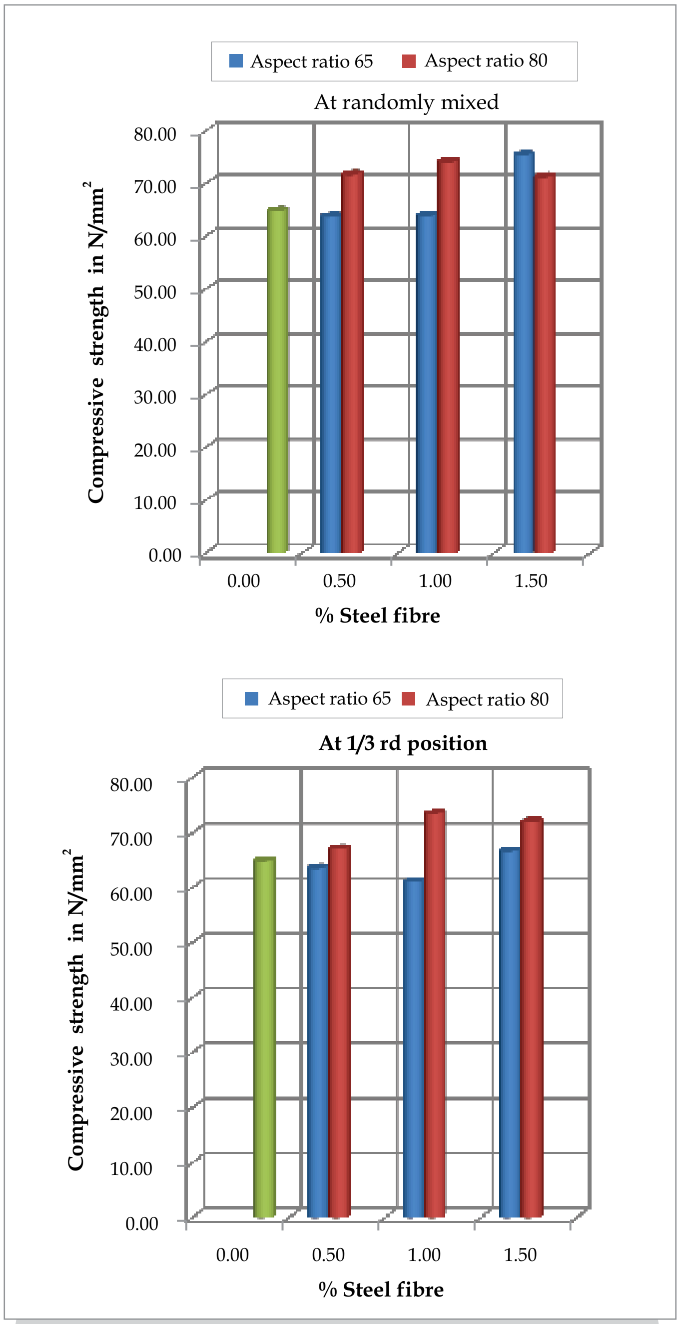

Figure 12. Comparison of compressive strength between different aspect ratio of steel fiber with varying position

6. CONCLUSION

1. Increase in compressive strength for steel fiber reinforced concrete with aspect ratio 80 in both position than with aspect ratio 65 and controlled concrete as shown in Figure 12 except 1.5 % steel fiber randomly reinforced case.

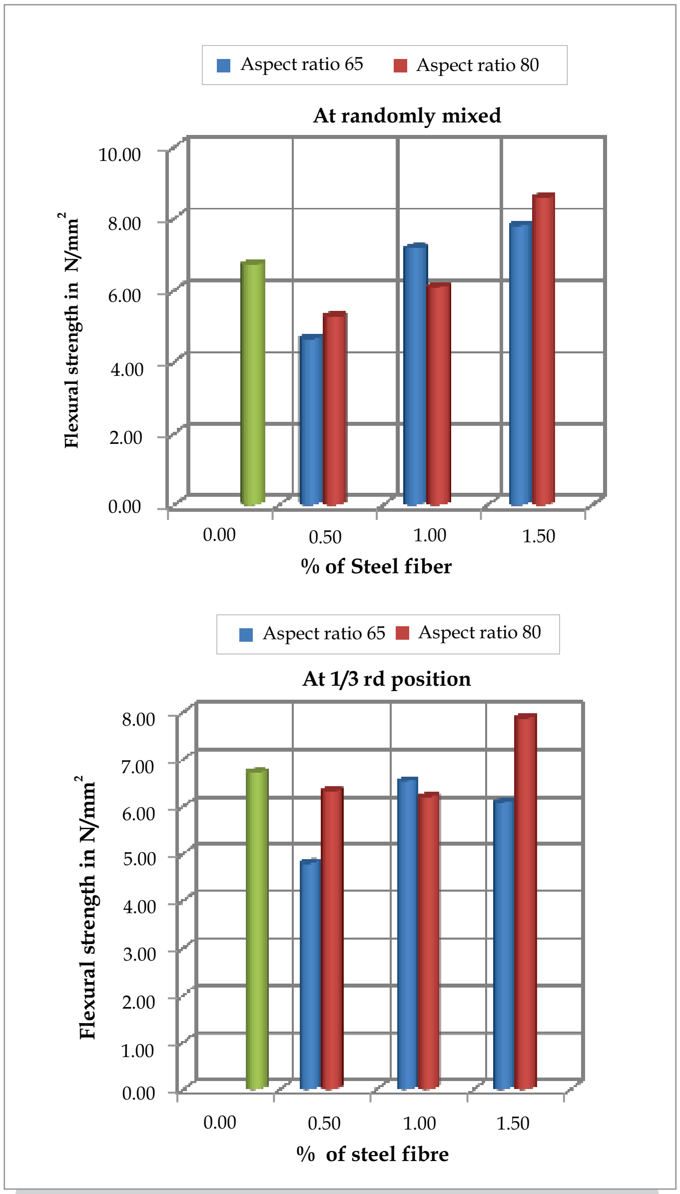

Figure 13. Comparison of flexural strength between different aspect ratio of steel fiber with varying position

2. Increase in flexural strength of concrete for 80 aspect ratio steel fiber concrete than 65 aspect ratio steel fiber concrete and controlled concrete was observed as shown in Figure 13 except 1 % steel fiber in randomly reinforced case. For mixture 80SF1.5 flexural strength was increased by 27.71% and 16.09% than the controlled concrete and mixture 65SF1.5 respectively in randomly reinforced steel fiber case. As compare to fibers with aspect ratio 65, fibers with aspect ratio 80 are longer, so more fibers are available for bridging the crack. There is delaying in crack formation which helps to increase the strength of concrete.

3. In flexural strength test maximum displacement was observed for mixture 80SF1.5 with fibers placed at 1/3rd- position.

4. As percentage of fiber increases flexural strength also increases in both the position that is at randomly reinforced fiber concrete and fibers reinforced at 1/3rd depth from top of the surface.

5. Maximum displacement without fiber was 1.26 mm and with fiber having aspect ratio 80 maximum displacement was 25.40 mm at 1/3rd depth condition. It indicate that post cracking behavior was affected by fiber length. Therefore an increment in ductility was observed.

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