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Strength Predictions of Admixed High Performance Steel Fiber Concrete

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Abstract: High strength Steel-fiber reinforced concrete is being used increasing day by day as a structural material. The study was conducted to evaluate the mechanical characteristics of the Admixed High Performance steel Fiber Concrete. The concrete mix design was done for M60 grade concrete. However the specimens have been tested for different water binder ratio and it is arrived from the slump test and chemical admixture Super-plasticizer are added.The concrete specimens cubes, cylinders and prisms were casted and evaluate the strength properties such as compressive strength, splitting tensile strength and modulus of rupture for M60 concrete with optimum dosage of Super-Plasticizer, steel content 0.5, 1, 1.5 and 2 per cent has been tested, analysed and it has been compared in the control mix. Strength predictions were established using regression models to predict the strength such as compressive, splitting tensile and modulus of rupture of High strength and High strength fiber reinforced concrete containing steel fibers in different volume fractions. The second order polynomial regression models give prediction strength matching with the actual strength.
Key words- HPC, HPFRC, Super- Plasticizer, Steel Fiber content.

I. Introduction

The study of high strength concrete has become interesting as concrete structures grow taller and larger. The usage of high strength concrete in structures has been increasingly worldwide and has begun to make an impact in India. “High strength concrete” explained on the basis of its compressive strength measured at a given age. In 1970’s, any concrete mix that shows a characteristics compressive strength of 60 MPa would have been considered high but now it has become normal phenomena. Later, concrete mixes with characteristic compressive strength of 60 MPa and above will be considered as high strength concrete were commercially developed and used in high-rise buildings and long span bridges construction. Such high strength has been achieved through the introduction of such mineral and chemical admixtures. Fiber reinforced concrete may be defined as the composite materials made with Portland cement, aggregate , and incorporating short discrete discontinuous fibers. Plain reinforced concrete is a brittle material due to this the structure having low ductility, low tensile strength and a low strain capacity. The addition of steel fibers in concrete considerably improves the tensile strength, static flexural strength, durability, Impact strength, Shear and fatigue strength, shock resistance ductility and failure toughness. However the degree of these improvements depends on the type, size, shape and aspect ratio of the steel fibers. Deformed steel fibers perform better in fresh concrete than straight fibers and also more efficient than straight steel fibers in improving the desired hardened concrete properties. Fibers reinforced concrete has been found more economical for use in air port and highway pavements. It is also used for thin sections concrete applications such as sewer pipes, bridges overlays and curtain walls. It is also rapidly gaining acceptance as a suitable material for repair and rehabilitation of concrete structures. The properties were assessed for fresh as well as hardened concrete. Previous investigation shows the behavior of SFRC under various strength test shows better performance than control concrete. This paper elaborates the mechanical characteristics of hydrid fiber in high performance concrete[2]. The effect of steel fibers content, high range water reducing admixture and the combined effect of rice husk ash and (HRWRA) in ultra high strength fiber reinforced concrete. From the tests, control concrete with 2%, 2.5% and 3% volume fractions of steel fibers showed a minimum- reduction in compressive strength at early period of curing[3]. The investigation was done on the mechanical behavior of HSC. The compressive strength, stress- strain curve and crack pattern also identified based on the size and shape effect for cubes and cylinder[6.] The mechanical properties of normal and high strength concrete with and without steel fibers in volume fractions. From the experimental results, showed that an improvement in compressive, split tensile strength and modulus of rupture improved to 1.0% steel fiber in volume fractions[7]. In this study inferred that the strength improvement of HSC containing steel fibers in volume fractions. The study result showed the strength improvement with addition of steel fibers and it lengthen the time elapsed before cracking and it can renders the brittleness and strain capacities of HSC. Here the concrete with 0.5%, 1%, 1.5% and 2% volume fractions of steel fibers, shows marginal increase in strength and toughness of concrete[8]. In this paper did a study on the compression & impact strength test on Glass Fibre Reinforced Concrete with various combinations of Admixtures like (Super-Plasticizer + Accelerator + Air-Entraining Agent, Super-Plasticizer + Retarder + Air-Entraining Agent and Super-Plasticizer + Water-proofing compound + Air-Entraining Agent). The result showed that different combinations of admixtures increase the Compressive and Impact strength considerably particularly the “SP+R+AEA” combination showed good result both in compression and impact test[9].

Experimental Programme

Concrete Mixing, Casting and Curing Procedure

For concrete preparation, the constituent materials were mixed thoroughly and the fibers were then fed continuously to avoid balling. Finally, the exact quantity of super plasticizer was diluted with remaining water was added and the mixing was continued for an additional 2 minute. Before use, the molds were properly coated with mineral oil, casting was carried out in three different layers and each layer was compacted well manually to avoid air bubbles and voids. Based on the quantity of mix the specimens were casted. The casted specimens were demolded after giving a minimum period of 24 hours and kept in water curing for different curing ages and the specimens were taken out from the tank and allowed for surface drying for few hours before testing.

Table 1.Materials and the properties used

Property of Cement	Value	Grade/Type/ Source
Specific Gravity	3.12	OPC-53
Initial and Final setting time	60 and 450 minutes	
Property of Fine aggregate		
Specific Gravity	2.65	Locally available river sand passing through 4.75 mm and retained on 2.36 mm sieve was used .
Fineness Modulus	3	
Coarse aggregate		
Specific Gravity	2.7	Locally available 20 mm size was used
Fineness modulus	6.5	
Water Absorption (%)	3	
Water	Ordinary portable water was used for mixing and curing purposes	-
Silica Fume		Elkem India pvt Ltd. Navi Mumbai. As per Manufacturer’s Manual
Specific Gravity	2.2	
Bulk density	576 kg/m^3	
Size (Micron)	0.1	
SiO_2	90-96%	
Al_2O_3	0.5 – 0.8%	
Steel Fibers (Dramix)		Hooked and Baekert India Pvt. Ltd. Mumbai
Aspect ratio (l/d)	80	
Yield strength Elastic Modulus	1100- 1380 MPa 2.1×10^5 MPa	

Super plasticizer (HRWRA)	Specific gravity- 1.220-1.225 pH ≥6 Aspect Light Brown Liquid Relative Density 1.08 ± 0.01 at 25°c	Master Glenium Sky 8233, BASF Chemical Company Limited, Mumbai. As per Manufacturer's Manual

Table 2. Specimen Details

Properties Tested	Size in mm	Number of specimens
28, 90 and 180 days Cube Compressive strength	150x150x150	45
28, 90 and 180 days Split Tensile strength (Cylinder)	300x150ϕ	45
28, 90 and 180 days Modulus of Rupture [Prism]	500x100x100	45

Concrete Mix Design and Methods

Mix design can be designed as the process of selecting suitable concrete ingredients and determining their relative quantities economically with the objective of producing notable strength and durability . In this work, a HSC of M60 grade was considered. A nominal mix proportion of materials used are Cement: Fine Aggregate: Coarse Aggregate: Silica fume 1:0.62:2.09:0.11 with 0.3 water binder ratio. The water binder ratio arrived from the slump test (100 mm Slump). To obtain the effective dosage of admixtures on High Performance Concrete, the admixture are added in three different dosages — 5ml/kg of cement, 10ml/kg of cement, 15ml/kg of cement depending upon the quantity used. In case of super-plasticizer, the water-binder ratio was reduced by 10 percent (from 0.3 → 0.27) for Super-plasticizer concrete without steel fiber then added with three different dosages as mentioned above.Specimens were prepared based on exact quantity of material for each mix to study the strength characteristics of concrete.

Effect of Super-plasticizer on High Performance Concrete.

The compressive strength of concrete cubes made with various dosages of super-plasticizers is plotted against different days of curing considered as preliminary test to identify the optimum dosage of Super-plasticer to study the mechanical properties of concrete. The average value of three cubes tested on all three directions. It was found that the compressive strength on 3-days and 7-days gives a good result, whereas for 28-days it gives a moderate result. This is due to the fact that, when super-plasticizers are added to the concrete mix with a small reduction in w/b ratio, it provides flocculation and flow-ability to the concrete mix. But for a smaller quantity, it gives a poor dry mix and as a result the strength is increased, but workability is decreased. Furthermore for greater quantity it gives a flowing concrete which in-turn causing segregation of concrete. For Super-plasticizer- 10 ml/kg of cement, though the mix was little dry, desired workability and strength was achieved at the end. This is evident from the plot which shows a good result for Super-plasticizer- 10 ml/kg of cement.

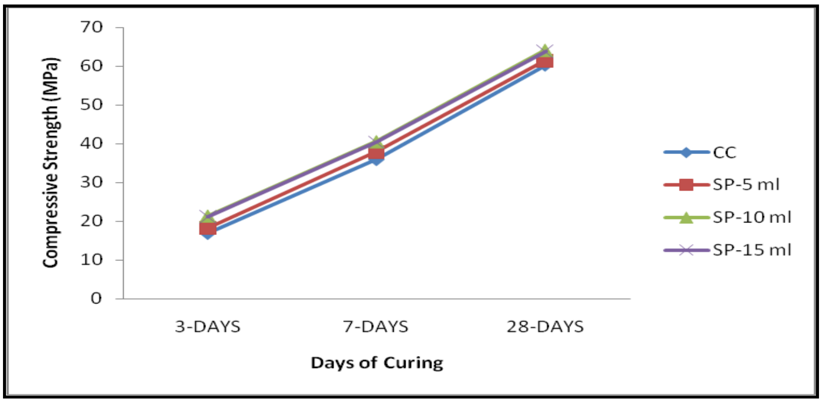

Figure. 1 Compressive strength Vs Days of curing for control and Super-plasticizer specimens.

Tests on Hardened Concrete Specimens

Compression and Split Tensile Strength Test

A total of 45 cubes for compression test and 45 cylinders for split tensile test were tested in ASTM Compression testing machine of 3000 kN capacity in according to ASTM C39, the load was applied at the rate of 2.9 kN/sec. The test was conducted on 28, 90 and 180 days. The compressive strength and Split tensile strength values are taken as the average of three values for different mixers are shown in Table 3.

Flexural Strength Test

The Beams (Prism) was tested in Flexural strength testing machine of 100 kN capacity accordance with ASTM C 78 to determine the flexural strength of concrete with and without steel fiber under three point loading. The centre distance between supporting rollers for Beams (prism) as 400 mm and centre distance between loading rollers as 133 mm. The strength values at 28, 90 and 180 days are shown in Table 3.

Results and Discussion

Compressive Strength

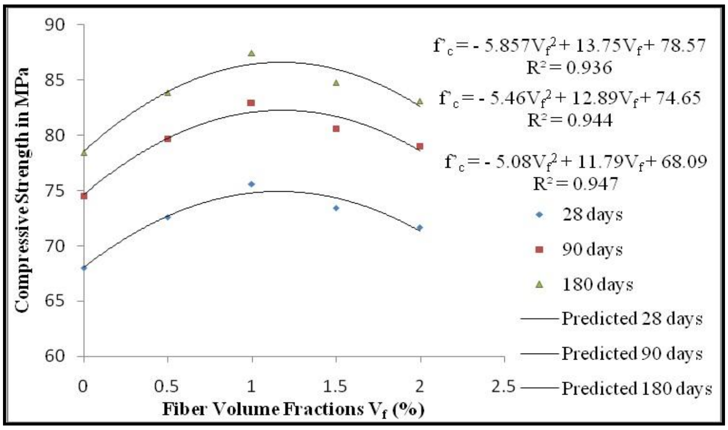

Figure 2. Compressive strength Vs Fiber volume fractions(%), and their predicted models.

Three specimens were tested to assess the cube compressive strength with steel fiber content (0%, 0.5%, 1%, 1.5% and 2%) in volume fractions. There is an increase in compressive strength of concrete with the increase in fiber content. The addition of steel fiber to HSC up to volume fractions of 1% caused an increase in compressive strength compared to control concrete at 28, 90 and 180 days and there was a decrease in strength after 1% of fiber content in volume fractions. The test results are reported in Table 3 and figure 2. The percentage increases in compressive strength compared to control concrete were 6.67 – 11.13%, 6.03- 11.29% and 6.92 – 11.48% at 28, 90 and 180 days respectively. The strength improved with steel fibers in volume fractions of 0.5% to 2% compared to HSC. From Figure 5-7. the strength effectiveness shows percentage improvement in strength.

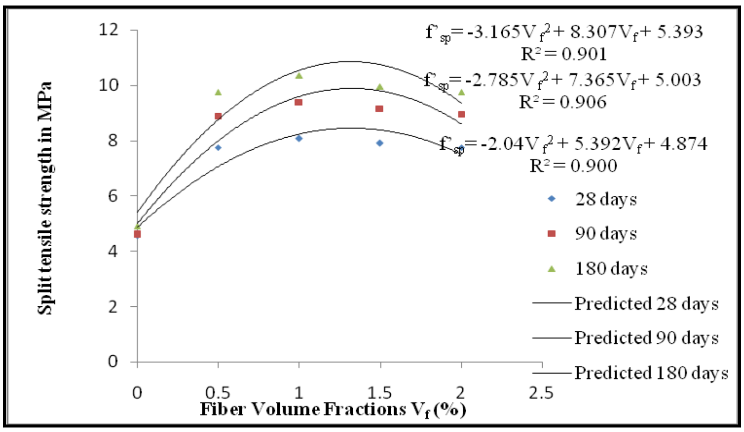

Figure 3. Split tensile strength Vs Fiber volume fractions(%), and their predicted models

From the compressive strength test results, a second order polynomial equation (1) was used to regress the compressive strength f'c value based on fiber volume fractions V_f

$$f_c' = AV_f^2 + BV_f + C \qquad \text{Equ (1)}$$

Applying regression analysis gave

$$f_c' = -5.08V_f^2 + 11.79V_f + 68.09 \qquad R^2 = 0.947 \qquad \text{Equ (2)}$$

$$f_c' = -5.46V_f^2 + 12.89V_f + 74.65 \qquad R^2 = 0.944 \qquad \text{Equ (3)}$$

$$f_c' = -5.85V_f^2 + 13.75V_f + 78.57 \qquad R^2 = 0.936 \qquad \text{Equ (4)}$$

For V_f = 0%. A high R-squared value, suggests a strong correlation between the regression and test data. Predicted values matching with measurements and prediction error is shown in Table 3.

Split Tensile Strength

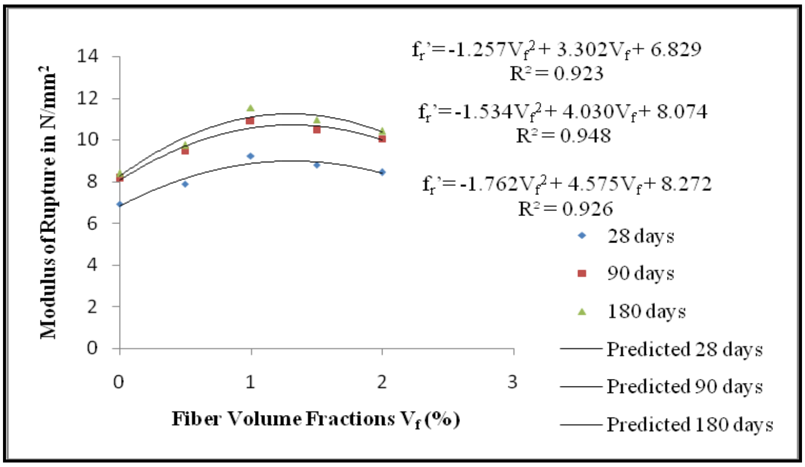

Figure 4. Flexural strength Vs Fiber volume fractions(%), and their predicted models.

The tensile strength at various curing ages for concrete with steel fiber (0%, 0.5%, 1%, 1.5% and 2%) are tabulated in Table 3 and figure 4. Results demonstrated that in general, all concrete specimens up to volume fractions of 2% of steel fiber shows an considerable increase in strength than control concrete and there was a minimum decrease in strength at 1.5% compared to concrete with 1% of steel fiber. The percentage improvement in split tensile strength compared to control concrete at 28, 90 and 180 days were 69.74 to 76.97 %, 93.46 to 104.57 % and 98.37 to 110.57 % respectively. The Split tensile strength of HSC and HSFRC was predicted in terms of fiber volume fractions V_f as

$$f_{sp}' = AV_f^2 + BV_f + C \qquad \text{Equ (5)}$$

And applying second order polynomial regression analysis gave

$$f_{sp}' = -2.04V_f^2 + 5.392V_f + 4.874 \qquad R^2 = 0.900 \qquad \text{Equ (6)}$$

$$f_{sp}' = -2.785 + 7.365V_f + 5.003 \qquad R^2 = 0.906 \qquad \text{Equ (7)}$$

$$f_{sp}' = -3.165 + 8.307V_f + 5.393 \qquad R^2 = 0.901 \qquad \text{Equ (8)}$$

For V_f = 0%. Equation (6) gives the fsp' as 4.874 MPa for HSC nearly equal to that given by 0.59Γf'c = 0.59Γ60= 4.57 MPa, reported on ACI 363 R-92. The predicted split tensile strength using regression model matching with the measurement values. The prediction error is represented in Table 3.

Table 3. Comparison of Measurements and Predictions for Compressive strength, Split tensile strength and Modulus of Rupture at three different curing days.

Fiber Volume (%)	Compressive Strength (MPa)			Split tensile strength (MPa)			Modulus of Rupture (MPa)		
	Measured Value	Predicted Value	Prediction error(%)	Measured Value	Predicted Value	Prediction error(%)	Measured Value	Predicted Value	Prediction error(%)
At 28 days									
0	68.02	68.09	0.103	4.56	4.87	6.8	6.92	6.83	-1.3
0.5	72.62	72.72	0.138	7.74	7.06	-8.78	7.87	8.17	3.81
1	75.59	74.8	-1.045	8.07	8.23	1.98	9.22	8.87	-3.8
1.5	73.42	74.35	1.26	7.90	8.37	5.95	8.79	8.95	1.82
2	71.70	71.35	-0.49	7.76	7.5	-3.35	8.43	8.41	-0.24
At 90 days									
0	74.52	74.65	0.17	4.59	5.00	8.93	8.15	8.074	-0.98
0.5	79.71	79.75	0.044	8.88	8.0	-9.91	9.44	9.71	2.86
1	82.93	82.14	-0.96	9.39	9.58	2.02	10.92	10.57	-3.21
1.5	80.60	81.84	1.54	9.15	9.78	6.88	10.47	10.67	1.91
2	79.01	78.83	-0.23	8.94	8.59	-3.9	10.04	10	-3.94
At 180 days									
0	78.46	78.57	0.14	4.92	5.39	9.55	8.39	8.27	-1.43
0.5	83.89	83.98	0.11	9.76	8.76	-10.2	9.73	10.12	4.01
1	87.47	86.46	-1.15	10.36	10.54	1.73	11.55	11.09	-3.9
1.5	84.79	86.02	1.45	9.96	10.73	7.73	10.94	11.17	2.1
2	83.10	82.64	-0.55	9.76	9.35	-4.2	10.41	10.37	-0.38

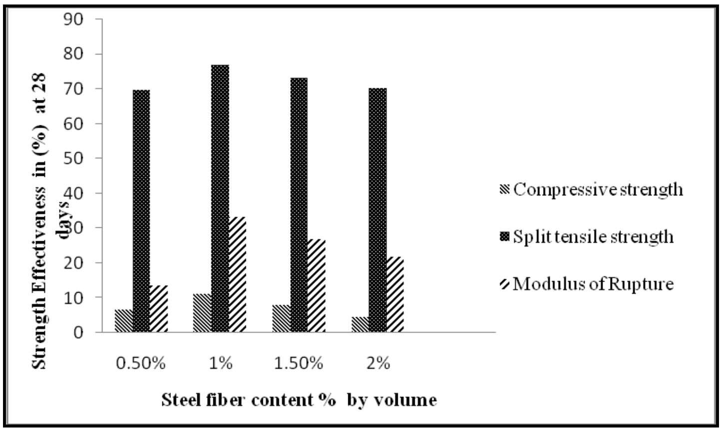

Figure.5 Strength Effectiveness and Steel Fiber content in volume fractions(%) at 28 days

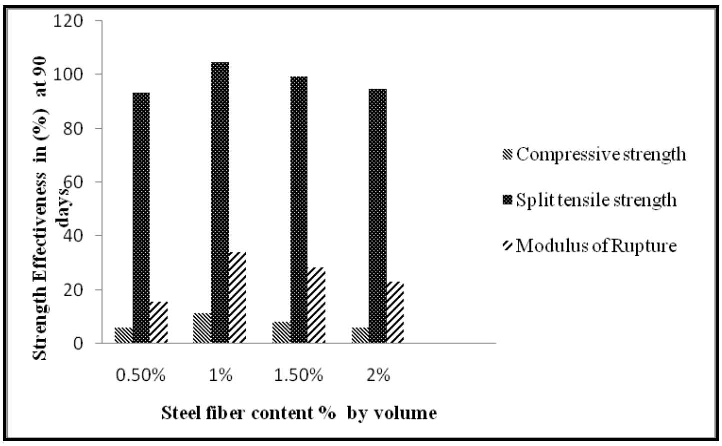

Figure 6. Strength Effectiveness and Steel Fiber content in volume fractions(%) at 90 days

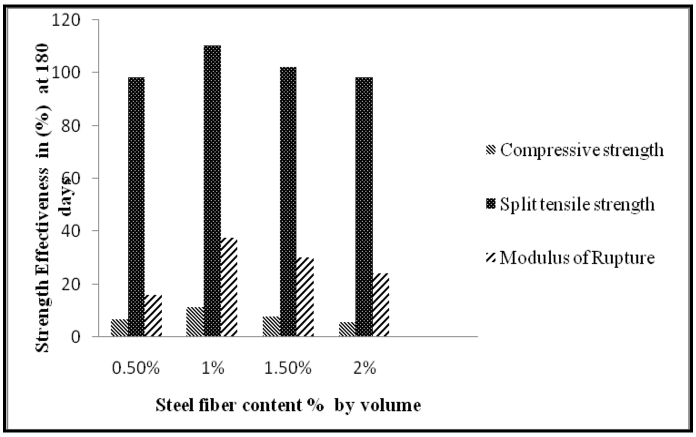

Figure 7. Strength Effectiveness and Steel Fiber content in volume fractions(%) at 90 days Modulus of Rupture

The flexural strength (MOR)were studied at different curing ages for concrete with different percentage of steel fiber in volume fractions are shown in figure 4 and Table 3. A results show that, all concrete specimens with steel fiber shows an increase in flexural strength compared to control concrete. There was a reduction in strength of concrete with increase of steel fiber content in volume. The strength effectiveness of steel fiber concrete compared to control concrete at 28, 90 and 180 days were 15.83 – 33.99%, 15.97 – 37.66 % and 13.73 – 33.24 %.

The flexural strength of HSC and HSFRC was predicted from measured strength and percentage of fibre in volume fractions.

$$f_r' = AV_f^2 + BV_f + C \qquad \text{Equ (9)}$$

Applying second order polynomial regression analysis gave the equation

$$f_r' = -1.25V_f^2 + 3.302V_f + 6.829 \qquad R^2 = 0.923 \qquad \text{Equ (10)}$$

$$f_r' = -1.53V_f^2 + 4.030V_f + 8.074 \qquad R^2 = 0.948 \qquad \text{Equ (11)}$$

$$f_r' = -1.762V_f^2 + 4.575V_f + 8.272 \qquad R^2 = 0.926 \qquad \text{Equ (12)}$$

for V_f = 0%. Equation (4) gives the f_r' as 6.829 MPa for HSC nearly equal to that given by 0.94Γf'c = 0.59Γ60= 7.28 MPa, reported on ACI 363 R-92The MOR prediction values using regression equation more or less identical with measurements. The prediction error is presented in Table 3.

Flexural Toughness

The flexural toughness of HSFRC is the energy absorption capacity of a prismatic beam of size 100 x 100 x 500 mm under three point loading. The toughness of HSC and HSFRC were estimated based on some portion of area under the load- deflection curve. The different toughness indices are obtained as per ACI 544.1R-96 (Reapproved 2002) based on first crack deflection δ during flexure test (ASTM C 1018). The indices I_5, I_{10} and I_{30} represents the 3δ, 5.5δ and 15.5δ, where δ represents the first crack deflection. The toughness index values are tabulated in the Table 4. From the obtained values inferred that the toughness values increases due to increase of steel fiber content in concrete than concrete without steel fiber.

Table 4. Flexural Toughness Indices

Fiber Volume (%)	Flexural Toughness indices at 28 days			Flexural Toughness indices at 90 days			Flexural Toughness indices at 180 days		
	I_5	I_{10}	I_{30}	I_5	I_{10}	I_{30}	I_5	I_{10}	I_{30}
0	3.24	4.94	9.94	4.21	5.93	11.93	5.05	8.90	13.35
0.5	6.65	8.78	12.5	8.64	11.41	27.0	12.1	14.83	32.40
1	5.18	9.01	18.56	6.73	13.5	23.45	8.41	18.90	29.35
1.5	6.47	10.92	27.50	9.71	15.3	31.75	12.15	22.95	39.68
2	10.53	14.65	35.65	14.75	20.51	42.40	19.18	24.64	56.85

Conclusions

From the results of this experimental investigation, the following conclusions were drawn on concrete without and with steel fibers.

1. The optimum dosage of Super-Plasticizer for this High Performance Concrete was found to be 10ml per kg of cement. However adding the next higher quantity (upto 15ml), the strength was not greatly affected. But excess quantity has made the concrete increase its flow-ability, leading to segregation of constituent particles
2. With the addition of hooked end steel fibers leads to increase in compressive strength, Split tensile strength and modulus of rupture with age and with the increase of steel fiber content in volume fractions (0.5%, 1%, 1.5% and 2%) compared to control concrete at 28, 90 and 180 days.
3. The strength effectiveness was calculated for three different curing ages, at all volume fractions exhibited superior strength improvement for split tensile strength than modulus of rupture and compressive strength.
4. The flexural toughness for three indices shows highest at 2% of steel fiber content in volume fractions as 10.53, 14.65 and 35.65 at 28 days, 14.75, 20.51 and 42.40 at 90 days, 19.18, 24.64 and 56.85 at 180 days.
5. On the basis of regression analysis, strength model has been developed using experimental results. The proposed model was found to have good accuracy in estimating the various strength at 28, 90 and 180 days based on prediction more or less identical with measurements.

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