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Study on the Strength and Durability Characteristics of High Strength Concrete with Steel Fibers

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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 High Strength steel Fiber Reinforced Concrete. The concrete mix design was done for M40 grade concrete. However the specimens have been tested for different water cement ratio and it is arrived from the slump test. 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 of M40 concrete with steel content 0.5%, 1%, 1.5% and 2% 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. To study the short term durability characteristics such as resistance against acid and sulphate attack, specimens were cast for different steel fiber content and it was compared with the control concrete.
Key words : HSC, HSFRC, 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 40 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. 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[2].This paper evaluates the performance of hybrid fibers in high performance concrete on the fresh and hardened concrete properties[3]. The authors studied 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[4].Based on the experiments to assess the durability factors of high performance concrete with industrial wastes such as GGBFS and copper slag[7]. This paper aims to clarify the effect of steel fiber on the flexural toughness of high performance concrete containing flyash and nano-SiO_2. The flexural toughness were calculated by two methods which are based on ASTM C1018 and DBV 1998. Finally concluded that less than 2% of steel fiber content in volume fractions showed an improvement in flexural toughness[8]. In this paper 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[9]. The paper researched on sulphate resistance of high performance concrete that containing different percentage of natural pozzolana and concluded that the compressive strength was high for different percentage of pozzolana against sulphate attack than control concrete[10].Commonly, aggregate size also an important parameter to improve the ultimate flexural strength of the concrete. The increase in flexural strength for SFRC not only depends on aggregate size, but also the fiber volume fractions and aspect ratio of the fiber[11]. Previous investigation shows the behaviour of SFRC under various strength and durability test shows better performance than control concrete.

II Experimental Programme

Table 1. Materials Used

Specific Gravity of Cement(OPC 53 grade)	3.12
Initial and Final Setting Time of Cement	60 and 450 minutes respectively
Specific Gravity of Sand	2.65
Fineness modulus	3
Specific Gravity of Coarse Aggregate	2.7
Fineness Modulus and Water Absorption(%)	6.5
Hooked end steel fibers (l/d) = (0.5/30)=80 Length and Diameter in mm	Yield strength is 1100-1380 Mpa
Water(Curing and Mixing)	Ordinary portable
Super-Plasticizer (Conplast)	To enhance concrete Workability
Hydro chloric acid and Sulphuric acid	0.1N

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.

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 M40 grade was considered. A nominal mix proportion 1:1.62:2.83 with 0.35 water cement ratio. The water cement ratio arrived from the slump test. W/C was reduced as 0.3 for Super plasticizer concrete. Specimens were prepared based on exact quantity of material for each mix to study the strength characteristics of concrete.

Table 2. Specimen Details

Properties Tested	Size in mm	Number of specimens
7, 14 and 28 days Cube Compressive strength	150x150x150	45
7, 14 and 28 days Split Tensile strength (Cylinder)	300x150ϕ	45
Modulus of Rupture [Prism]	500x100x100	15
Cube Acid and Sulphate resistance	100x100x100	30
Cylinder Sorptivity test	200x100ϕ	15

Table 3. Concrete Mix Proportions - Quantity in kg/m^3

Mix	**A1**	**A2**	**A3**	**A4**	**A5**
Cement	425	425	425	425	425
Fine aggregate	688.5	688.5	688.5	688.5	688.5
Coarse Aggregate	1203	1203	1203	1203	1203
W/C ratio (litre)	0.35 148.75	0.35 148.75	0.35 148.75	0.35 148.75	0.35 148.75
Steelfiber-V_f (%)	0%	0.5%	1%	1.5%	2%
Steel fiber (kg)	0	39.3	78.5	118	157

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 7, 14 and 28 days. The compressive strength values are taken as the average of three values for different mixers are shown in Figure1.

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 days are shown in Figure 4.

Durability characteristics such as sorptivity according to ASTM C 1585, sulphate and chloride resistance were studied by making cylinder and cube specimens for different percentage of steel fiber in volume fractions is done for 28 days curing according to ASTM C 267 and control concrete were compared with concrete specimens with steel fibers.

III Results and Discussion

Compressive strength

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 1.5% caused an increase in compressive strength compared to control concrete at 7, 14 and 28 days and there was a decrease in strength for 2% of fiber content in volume fractions. The test results are reported in Table 2 and figure 3. The percentage increases in compressive strength compared to control concrete at 28 days were 6.49%, 12.98%, 16.82% and 8.6%.The strength improved with steel fibers in volume fractions of 0.5% to 2% compared to HSC. From Table 2. the strength effectiveness shows improvement in strength from 6.49 – 16.82%.

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

$f_c' = AV_f^2 + BV_f + C$ Equ (1)

Applying regression analysis gave

$f_c' = -3.837V_f^2 + 9.984V_f + 41.45$ $R^2 = 0.907$ Equ (2)

For V_f = 0%. A high R-squared value, 0.907, suggests a strong correlation between the regression and test data. Predicted values matching with measurements and prediction error is between 0.51 to 2.41%

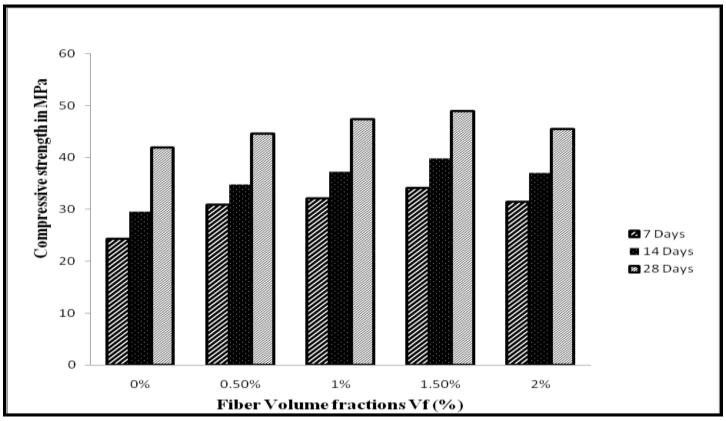

Figure 1. Effect of Steel fiber on compressive strength at different curing ages

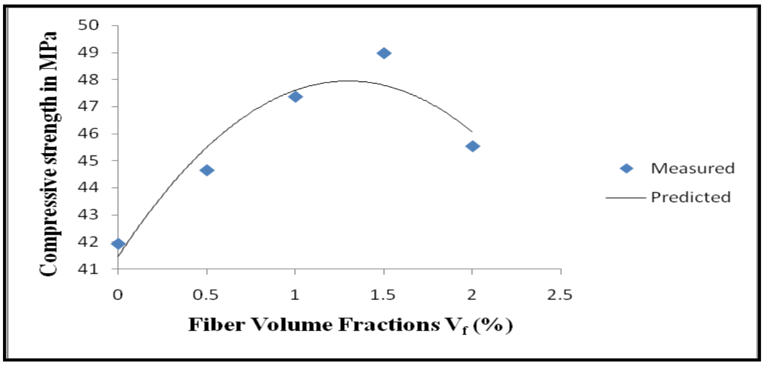

Figure 2. Compressive strength Vs Fiber volume fractions(%), and their predicted models.

Split tensile strength

The tensile strength at various curing ages for concrete with steel fiber (0%, 0.5%, 1%, 1.5% and 2%) are tabulated in Table 2 and figure 3. 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 2% compared to concrete with 1.5 % of steel fiber. The percentage increases in split tensile strength compared to control concrete at 28 days were 14.82%, 34.67%, 59.79% and 73.87%.

The Split tensile strength of HSC and HSFRC was predicted in terms of fiber volume fractions V_f as

$f_{sp}' = AV_f^2 + BV_f + C$ Equ (3)

And applying second order polynomial regression analysis gave

$f_{sp}' = -0.042V_f^2 + 1.448V_f + 3.925$ $R^2 = 0.992$ Equ (4)

For V_f=0%. Equation (4) gives the fsp’ as 3.925 MPa for HSC nearly equal to that given by 0.59Γf’c = 0.59Γ40= 3.73, reported on ACI 363 R-92.The predicted split tensile strength using regression model matching with the measurement values. The prediction error is between 0.56 to 5.66% from Table 4.

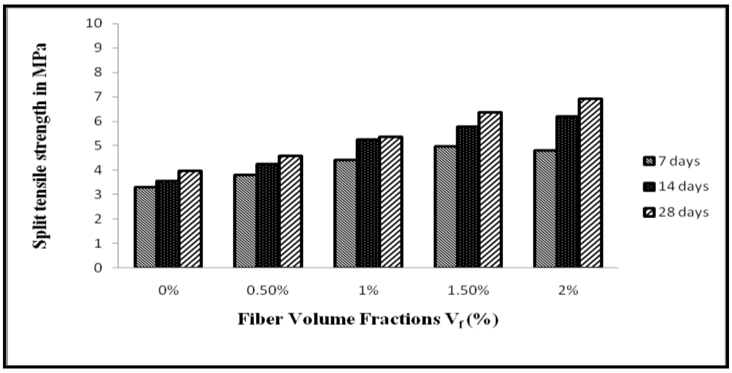

Figure 3. Effect of steel fiber on split tensile strength at different curing ages

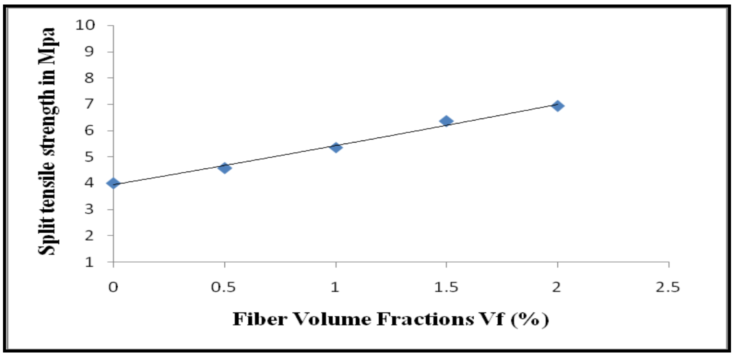

Figure 4. Split tensile strength Vs Fiber volume fractions(%), and their predicted models.

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 5 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 days was 20.98%, 31.80%, 44.12% and 44.31%.

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

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

Applying second order polynomial regression analysis gave the equation

$$f_r' = -0.582V_f^2 + 2.305V_f + 5.108 \qquad R^2 = 0.993 \qquad \text{Equ (6)}$$

for Vf= 0%. Equation (6) gives fr’ as 5.108 MPa for HSC which is nearly equal to 0.94Γfr’ = 0.94Γ40= 5.94, reported on ACI 363 R-92.The MOR prediction values using regression equation more or less identical with measurements. The prediction error is between 0.20 to 4.1% from Table 4.

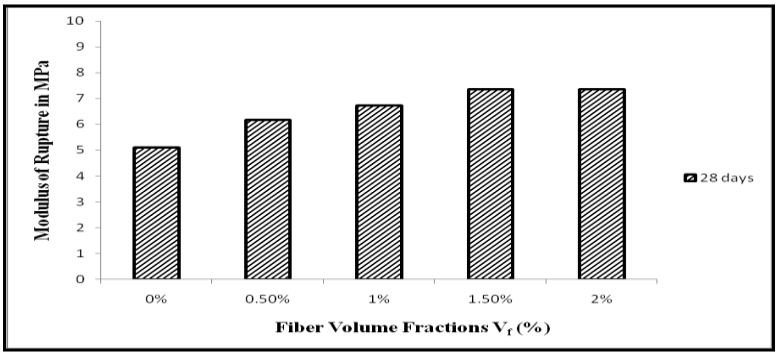

Figure 5. Effect of steel fiber on Modulus of rupture at different curing ages

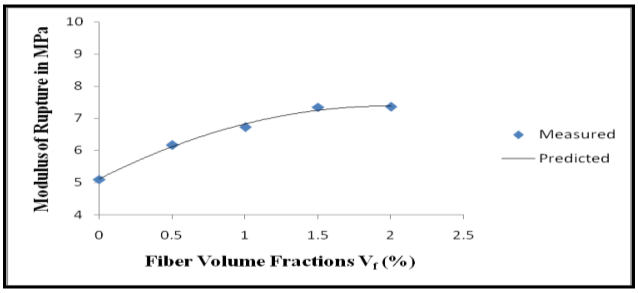

Figure 6. Flexural strength Vs Fiber volume fractions(%), and their predicted models.

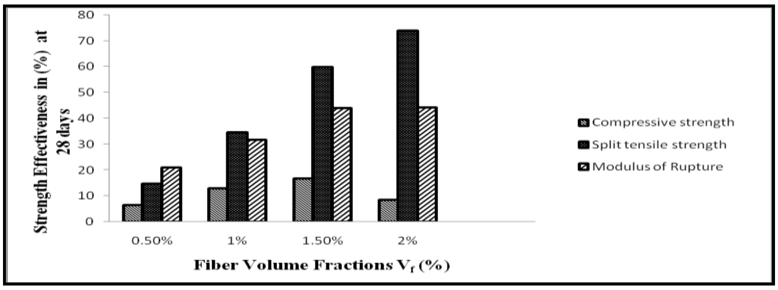

Figure.7 Strength Effectiveness and Steel Fiber volume fractions(%) at 28 days

Table 3 Strength and Strength Effectiveness of concrete without and with steel fibers at 28 days

Fiber Volume(%)	Compressive strength (MPa)		Split tensile strength (MPa)		Modulus of Rupture (MPa)	
	Measured Value	Strength Effectiveness (%)	Measured value	Strength Effectiveness (%)	Measured Value	Strength Effectiveness (%)
0	41.92	0	3.98	0	5.10	0
0.5	44.64	6.49	4.57	14.82	6.17	20.98
1	47.36	12.98	5.36	34.67	6.72	31.80
1.5	48.97	16.82	6.36	59.79	7.35	44.12
2	45.53	8.6	6.92	73.87	7.36	44.31

Table 4. Comparison of measurements and predictions for various strength at 28 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(%)
0	41.92	41.45	-1.12	3.98	3.93	-1.26	5.10	5.11	0.20
0.5	44.64	45.48	1.88	4.57	4.64	1.53	6.17	6.12	-0.81
1	47.36	47.60	0.51	5.36	5.33	-0.56	6.72	6.83	1.64
1.5	48.97	47.79	-2.41	6.36	6.00	-5.66	7.35	7.26	-1.22
2	45.53	46.07	1.19	6.92	6.65	-3.90	7.36	7.39	-4.1

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 5. 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 5. Flexural Toughness indices.

Steel Fiber Content V_f(%)	Toughness index		
	I5	I10	I30
0	2.7	4.12	7.95
0.5	3.5	6.75	14.80
1	4.32	8.75	18.50
1.5	5.23	9.75	19.4
2	6.75	12.85	23.50

Resistance to acid attack

The test was conducted to study the concrete specimens with different percentage of steel fiber in volume fractions on the resistance against acid attack. The cube specimens of size 100x100x100 mm were cast and cured in water for 28 days. After 28 days curing the specimens were taken out to measure the initial weights, and then transferred to 0.1N solution of Hydro chloric acis and 0.1N solution of Sulphuric acid. After 28 days of acid curing the final weights of the specimens were measured. The measurements of weight loss of the specimens at the age of 28 days were identified. Three specimens were used for each data. Based on the percentage of weight loss the specimen with steel fibers shows better resistance against corrosion than control concrete comparatively from Figure 8.

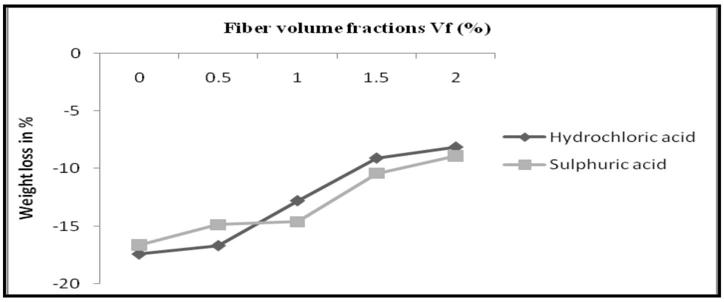

Figure 8. Percentage of weight loss under HCL and H_2SO_4

Sorptivity test

The sorptivity of concrete is a quantity that measures the unsaturated flow of fluids in to the concrete. Sorptivity is a measure of the capillary forces exerted by the pore pressure causing fluids to be drawn in to the body of the material. Determining the sortivity of a sample in the lab is a simple, low technology technique illustrated.The graph for the square root of time versus the parameter Q/A was plotted. Based on Figure 9.It was found out that the sorption co-efficient of steel fiber concrete specimen gives the highest value than control specimen. The function of the steel fiber is to fill the void spaces with air bubbles, so as to reduce the permeability of concrete by locking the air spaces and so, when these air bubbles get filled permeability of concrete is greatly reduced.

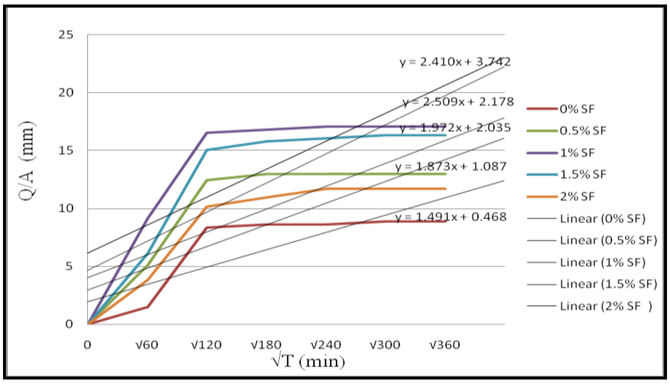

Figure 9. SQRT (T) Vs Q/A for with and without steel fibers

IV Conclusions

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

1. 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 days.
2. The strength effectiveness was calculated for 28 days, at all volume fractions exhibited superior strength improvement for split tensile strength than modulus of rupture and compressive strength.
3. The flexural toughness for three indices shows highest at 2% of steel fiber content in volume fractions as 6.75, 12.85 and 23.50.
4. 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 days based on prediction more or less identical with measurements.
5. On the durability test, the specimen with 1.5% of steel fibre was found to have more sorption co-efficient**.** Though the graph is found to be curved at the initial stage, in the later stage linearity is achieved**.**
6. 5.After 28 days curing in sulphuric and Hydro chloric acids, the percentage of weight loss is minimum for different percentage of steel fiber when compared to control concrete.

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