Effect of Steel Fiber on Mechanical Properties of Standard Strength Concrete Using Portland Pozzolana Cement and Their Relationship

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Abstract -- **In this investigation a series of tests were conducted on 150mm, cube and 150mm x 300mm, cylindrical and 100x100x500mm beam specimens using a modified test method that gave the complete compressive strength, static, dynamic modulus of elasticity, and flexure strength using silica fume with and without steel fiber of volume fractions 0, 0.5, 1.0, and 1.5 %, of 0.5mm Ø of aspect ratio of 60 on Portland Pozzolona cement on standard strength concrete. As a result the incorporation of steel fibers, silica fume and cement has produced a strong composite with superior crack resistance, improved ductility and strength behavior prior to failure. Addition of fibers provided better performance for the cement-based composites, while silica fume in the composites may adjust the fiber dispersion and strength losses caused by fibers, and improve strength and the bond between fiber and matrix with dense calcium-silicate-hydrate gel. The results predicted by mathematically modeled expressions are in excellent agreement with experimental results. On the basis of regression analysis of large number of experimental results, the statistical model has been developed. The proposed model was found to have good accuracy in estimating interrelationship at 28 and 90 days age of curing. On examining the validity of the proposed model, there exists a good correlation between the predicted values and the experimental values as showed in figures.**

Index Terms-- **Portland Pozzolona Cement, Silica Fume, Steel Fibers, Compressive Strength, Modulus of elasticity, Flexural Strength.**

I. INTRODUCTION

It is necessary to develop the concrete of special properties. Portland Pozzolona cement concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro-cracks are inherently present in the concrete and its poor tensile strength is due to propagation of such micro-cracks, leading to brittle failure of concrete. Development of such type of concrete that has to meet special requirements. As strength of concrete increases brittleness of concrete also increases. This weakness and brittleness can be reduced by inclusion of steel Fiber in the concrete mix. These Fiber help to transfer loads at internal micro cracks which called Fiber reinforced concrete. Steel fiber reinforced concrete (SFRC) has gained acceptance for a variety of applications, namely industrial floors, bridge decks, pavements, hydraulic and marine structures, precast elements, nuclear vessels, repair and rehabilitation works, blast resistance structures It has been reported that the addition of steel fibers into concrete improves all engineering properties of concrete such as tensile strength, Compressive strength, impact strength, ductility and toughness. The basic requirements of fibers for improving strength , high modulus of elasticity , adequate extensibility , good bond at the interface , chemical stability and durability The mechanical properties of steel fibers reinforced concrete are influenced by the type of fiber aspect ratio amount of fiber, strength of matrix ,size, shape and method of specimen preparation and size of aggregate Addition of short, discontinuous fibers plays an important role in the improvement of the mechanical properties of concrete. It increases elastic modulus, decreases brittleness; controls crack initiation, and its subsequent growth and propagation. Deboning and pull out of the fibers require more energy absorption, resulting in a substantial increase in the toughness and fracture resistance of the material to cyclic and dynamic loads. In particular, the unique properties of steel fiber reinforced concrete SFRC suggest the use of such material for many structural applications, with and without traditional internal reinforcement. The use of SFRC is, thus, particularly suitable for structures when they are subjected to loads over the serviceability limit state in bending and shear, and when exposed to impact or dynamic forces, as they occur under seismic or cyclic action. However, there is still incomplete knowledge on the design/analysis of fiber-reinforced concrete FRC structural members. The analysis of structural sections requires, as a basic prerequisite, the definition of a suitable stress-strain relationship for each material to relate its behavior to the structural response.

Silica Fume is a highly effective pozzolanic material. Silica fume improves concrete in two ways the basic pozzolanic reaction, and a micro filler effect. Addition of silica fume improves bonding within the concrete and helps reduce permeability, it also combines with the calcium hydroxide produced in the hydration of Portland cement to improve concrete durability. Silica Fume is used in concrete to improve its properties. It has been found that Silica Fume improves compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore helps in protecting reinforcing steel from corrosion.

A comprehensive review of literature related to Silica Fume and Steel Fiber concrete was presented by ACI Committee 544 [1], Balaguru and Shah [2]. It includes guidelines for design, mixing, placing and finishing steel fiber reinforced concrete, reported that the addition of steel fibers in concrete matrix improves all mechanical properties of concrete.

Toughness of steel fiber reinforced silica fume concrete under compression and Dynamic mechanical performance of high-performance fiber reinforced concrete was done by Ramadoss P.and Nagamani K.[3 & 4]. They have studied the effect of crimped steel fibers with aspect ratio of 80 with 0%,0.5%,1.0% and 1.5% and silica fume of 10 % replacement by variation in w/c 0.25 to 0.40. The compressive strength was found to be in the range of 52 to 75 Mpa. The ultrasonic pulse velocity test was conducted to study the uniformity of composite including fiber distribution and from the experimental results, the statistical model has been developed, for predicting the compressive strength of high performance fiber reinforced concrete over a wide range of w/c ratios, Fiber and silica fume.

Investigation on the compressive strength of silica fume concrete using statistical methods was done by Banja and Sengupta [5]. They studied the effect of silica fume on the tensile and compressive strength of high performance concrete (HPC); they developed mathematical model using statistical methods to predict the 28-day Compressive strength of silica fume concrete with water-to cementations material (w/c) ratios ranging from 0.3 to 0.42 and silica fume replacement percentages from 5 to 30.

Influence of silica fume on workability and compressive strength of high performance concrete was done by Duval and Kadri [6]. They have reported that the optimum silica fume replacement level for 28-day compressive strength is 10% for a w/cm ratios ranging from 0.25 to 0.45 with varying dosages of a high-range of water-reducing admixture was used to maintain a fluid consistency, SF plays a positive part up to approximately 20% content and has the most important effect when reaching 10 to 15% content.

Steel fiber reinforced concrete under compression and Stress-strain curve for steel fiber reinforced concrete in compression was done by Nataraja.C. Dhang, N.and Gupta,A.P.[7 & 8]. They have proposed an equation to quantify the effect of fiber on compressive strength of concrete in terms of fiber reinforcing parameter. In their model the compressive strength ranging from 30 to 50 MPa, with fiber volume fraction of 0%, 0.5%, 0.75% and 1% and aspect ratio of 55 and 82 were used. In all the models only a particular w/cm ratio with varying fiber content was used. The absolute strength values have been dealt with in all the models and thus are valid for a particular w/cm ratio and specimen parameter. Mechanical properties of high-strength steel fiber-reinforced concrete was done by Song P.S. and Hwang S.[9].They have marked brittleness with low tensile strength and strain capacities of high strength concrete can be overcome by addition of steel fibers. The steel were added at the volume of 0.5%, 1.0%, 1.5% and 2.0%.The compressive strength of fiber concrete reached a maximum at 1.5%volume fraction, being 15.3%improvement over the HSC. The split tensile and Flexural Strength improved 98.3% and 126.6% at 2.0% volume fraction. Strength models were developed to predict the compressive strength with split and flexural Strength of the fiber reinforced concrete. Effect of GGBS and Silica Fume on mechanical Properties of Concrete Composites was done by Palanisamay T and Meenambal T [10]. Carried out on 70 Mpa concrete with partial replacement of silica fume of 5, 10, 15, and 20% were investigated. The compressive strength, split tensile and Flexural Strength were carried out on 25 concrete mixes at the age of 28 days and compared with conventional concrete. The optimum replacement of silica fume was at 10 % that showed compressive, split tensile and Flexural Strength increased by 8%, 22% and 4.1% than control concrete.

Research Significance

Concrete is, from a structural point of view, assumed to be a no-tension material. This characteristic influences the structural performance of reinforced concrete structures because the mechanical behavior of plain concrete is essentially brittle. The negative effects of the brittle behavior of the material can be reduced by improving the no-tension behavior of concrete with the addition of fibers on in built Portland pozzolana cement (containing 28% fly ash) based standard concrete.

II. EXPERIMENTAL PROGRAM

This section describes the experimental program planned for investigating the influence of various parameters of crimped steel fiber on the Mechanical properties of standard grade concrete under compression and Flexure.

III. MIX DESIGN AND MATERIAL PROPERTIES:

The M30 grade of concrete were proportioned using guidelines given in IS: 10262-1999,[11] and ACI Committee 544[12]. The Mix proportions were (1:1.62:2.88), the quantity of cement was 400 Kg/ m^3 with W/C Ratio 0.42 and ratio of course aggregate A1(20mm) **:**A2 (10mm) was 70**:**30; Silica Fume was added as 4% replacement of cement, crimped steel fibers of diameters (0.5 mm Ø and with aspect ratio of 60) were added. Percentage of fibres was 0%, 0.5 %, 1.0 % and 1.5 % (i.e.0, 39, 78 and 117.5 Kg/m^3) by the volume of concrete. Cubes of 150X150X150 mm and cylinders 150x300mm were casted.

3.1. Portland Pozzolona Cement: IS 1489(part 1):1991 containing 28% fly ash. The properties of cement tested were Fineness (90μ Sieve) = 5 %, Normal consistency=31%, Initial & Final setting time =138minute & 216minute and 28 days Compressive strength= 55.63 N/mm^2

3.2. Silica Fume: Silica fume having fineness by residue on 45 micron sieve = 0.8 %, specific gravity = 2.2, Moisture Content =0.7% was used. The chemical analysis of silica fume (Grade 920-D): silicon dioxide = 89.2%, LOI at 975[degrees]C = 1.7% and carbon = 0.92%, are conforming to ASTM C1240-1999 standards.

3.3. Fine aggregate**:** Locally available river sand passing through 4.75 mm IS sieve, conforming to grading zone-II of IS: 383-1970 [15] was used. The physical Properties of sand like Fineness Modulus, Specific Gravity, water absorption, Bulk Density, as per IS: 2386-1963[16] were 2.69, 2.61, 0.98% and 1536 Kg/ m^3

3.4. Coarse aggregate: Crushed natural rock stone aggregate (A1) and (A2) were used. The combined specific gravity, Bulk Density and water absorption were 2.69,1612 Kg/ m^3

and 0.52 % @ 24 hrs. Fineness modulus of 20 mm &10 mm aggregate were 7.96 & 6.13 respectively.

3.5. Steel Fiber: Crimped steel fibers conforming to ASTM A820-2001 was used in this investigation. 1) Length = 30 mm, diameter = 0.50 mm, and 2) Length = 60 mm, diameter = 1.00 mm, with a constant aspect ratio = 60, ultimate tensile strength, = 910 N/mm^2 to 1250 N/mm^2

3.6. Super Plasticizer**:** CONPLAST SP 430 super plasticizer was used. It conforms to IS: 9103-1999 and has a specific gravity of 1.20.

3.7. Water: Water conforming IS: 456-2000 [17] was used for mixing as well as curing of Concrete.

IV. SAMPLE PREPARATIONS

Aiming to obtain a cohesive and flow able mixture and uniform fiber distribution, gap-grading of the aggregates was avoided. The mixtures were prepared using a conventional mixer. The mixing procedure was as follows: sand and coarse aggregates were homogenized together and mixed with half the total water content to reach a saturated surface-dry condition. Cement, silica fume, and the remaining mixing water were then added. Finally, the superplasticizer was added and thoroughly mixed. The fibers were gradually sprinkled by hand, and care was taken to obtain homogeneous and workable mixtures. The concrete batch was introduced into each mold and compacted on a vibrating table. The initial curing was carried out by spreading wet gunny bags over the mould about 24 hours after casting, the specimens were remolded and placed immediately in water tank for further curing for a period of 28 and 90 days.

4.1Compression Test Details

The cubes and cylinders were tested for compressive strength on compressive testing machine of 2000KN capacity was used. As per guide lines of IS: 516-1959[13] and ACI 544.R [14].

The cylinder attached with compressometer equipped with dial gauges 150mm in length was used to record the deformation of the Cylinder Static Modulus of Elasticity, Dynamic Modulus of Elasticity measured by ultrasonic tester. The flexural strength was carried out on 100 mm x 100 mm x 500 mmsize prisms under two point load condition at 28 days & 90days of curing. Three identical specimens were tested in all the mixtures and the entire test.

V. TEST RESULTS AND DISCUSSIONS

5.1 Workability

The workability of silica fume with steel fiber concrete has found to decrease with increase in silica & steel replacement so, It appeared that the addition of super plasticizer might improve the workability. Super plasticizer was added range of 0.75 to 1.80% by weight of cementations materials for maintaining the slump up to 20mm.

5.2 Compressive strength (f_c) (Cube).

In comparison with control concrete the maximum increase in the compressive strength at 8% silica fume was 11.17% and 12.00%at 28 & 90 days of age. And the combine effect of silica fume with steel fiber 0.5 mm Ø at 0.5%, 1.0% and 1.5% by weight of concrete for was 13.50%, 14.74% and 15.38% at 28 days. And 14.35%, 15.61% and 16.18%at 90 days increases in compressive strength and the predicated values as shown in Table1

5.3 Test result of concrete Cylinder.

A) Compressive Strength (f_{cc}):

In comparison with control concrete the maximum increase in the compressive strength at 8% silica fume was 7.64% and 7.69% at 28and 90 days of age. And the combine effect of silica fume with steel fiberof 0.5%, 1.0% and 1.5% by weight of concrete for was 11.46%, 14.51% and 15.96% at 28 days. And 11.50%, 14.19% and 15.57% at 90 days increases in compressive strength and the predicated values as shown in Table 1

B) Dynamic Modulus of Elasticity (Ed):

In comparison with control concrete the "Ed" increases due to the combine effect of silica fume with steel fiber of 0.5%, 1.0% and 1.5% by weight of concrete for 0.5mm ø diameter as shown in Table 2.

C) Static Modulus of Elasticity (E_s): Modulus of elasticity (secant modulus) was defined according to ACI Building code (ACI318-1995) as the slope of the line drawn from a stress of zero to a compressive stress of $0.45f_{cc}$.The static modulus of elasticity evaluated from the stress-strain curves are in the range of 29.489x 10^3 Mpa to 33.442x10^3 MPa (Table 2). Results of modulus of elasticity obtained are shown that modulus of elasticity increases with increase in fiber volume fraction or fiber reinforcing index.

Based on the experimental results, using least square regression analysis, the expression obtained for the elastic modulus as a function of compressive stress was showed in Table2. and the predicated values are close agreement with obtained values but IS456 formula under estimates with both the result. Where secant modulus, [E_s] and compressive strength, [f_{cc}] are all expressed in megapascals. IS: 456-2000, recommended equations, on comparing the predicted model for modulus of elasticity, gives the upper bound values.

5.4 Flexural Strength

In comparison with control concrete, the flexural strength increase by replacement of 8% silica fume showed 6.30% at 28 days of curing and 6.84% increase in flexural strength at 90 days of curing.And the combine effect of silica fume with steel fiber 0.5 mm Ø at 0.5%, 1.0% and 1.5% by weight of concrete for was 12.0%, 15.75% and 17.91% at 28 days. And 14.42%, 17.93% and 20.52% at 90 days increases in flexural strength and the predicated values are close agreement with obtained values but IS456 formula under estimates with both the result as shown in Table2.

5.5 Discussion on Relationship between Mechanical properties of concrete:

Based on the test results, mathematical model was developed using graphical methods to quantify the effect of silica fume and steel fiber content on interrelationship between cylinder compressive strength with cube compressive strength and cylinder static, dynamic modulus of elasticity and Cube compressive strength with flexural strength of concrete, at 8% silica fume with steel fiber of 0%, 0.5%, 1.0%, and 1.5% at 28and 90 days of curing. And On the basis of regression analysis, the statistical model has been developed. The proposed model was found to have good accuracy in estimating interrelationship at 28 & 90 days age of curing. On examining the validity of the proposed model, there exists a good correlation between the predicted values and the experimental values was showed in Figure.1 to Figure 6.

Table1. Experimental results, Strengths and their predicated values of concrete at 28 & 90 days of age.

S.NO.	Age of Curing	Steel Fiber V_f (%)	Comp. Strength of Cube (Mpa)	% increase in cube strength w.r.t. normal concrete	Predicated strength of cube (Mpa)	Comp. Strength Cylinder (Mpa)	% increase in cylinder strength	Predicated strength of cylinder (Mpa
1	28	0	40.37	0.00	40.94	33.77	0.00	33.49
2		0	44.88	11.17	43.88	36.35	7.64	37.17
3		0.5	45.82	13.50	45.36	37.64	11.46	37.93
4		1.0	46.32	14.74	46.53	38.67	14.51	38.34
5		1.5	46.58	15.38	47.09	39.16	15.96	38.55
6	90	0	42.16	0.00	42.76	35.65	0.00	35.37
7		0	47.22	12.00	46.12	38.39	7.69	39.22
8		0.5	48.21	14.35	47.78	39.75	11.50	39.98
9		1.0	48.74	15.61	48.96	40.71	14.19	40.38
10		1.5	48.98	16.18	49.56	41.20	15.57	40.56

Table2. Experimental results, Strengths and their predicated values of concrete at 28 & 90 days of age.

S.NO.	Age of Curing	Steel Fiber $\mathbf{V_f}$ (%)	Static Modulus of Elasticity $\mathbf{E_s}$ (Gpa)	$\mathbf{E_s}$ (Gpa) As per IS456-2000 $(5000\sqrt{fc}$	Predicated $\mathbf{E_s}$ (Gpa)	Dynamic Modul of Elasticity, E_d (Gpa)	Predicated, $\mathbf{E_d}$ (Gpa)	Flexural Strength Beam fcr (Mpa)	fcr As per IS456-2000 $(0.7\sqrt{fck})$	Predicated Flexural Strength Beam (Mpa)
1	28	0	29.49	29.06	29.67	41.81	41.952	5.08	4.45	4.98
2		0	31.35	30.15	30.88	44.20	43.918	5.40	4.69	5.58
3		0.5	31.51	30.68	31.49	45.08	44.901	5.69	4.74	5.71
4		1.0	31.88	31.09	31.97	45.57	45.686	5.88	4.76	5.77
5		1.5	32.16	31.29	32.20	45.98	46.059	5.99	4.78	5.81
6	90	0	30.63	29.85	30.63	43.06	43.213	5.41	4.55	5.29
7		0	32.03	30.98	32.02	45.66	45.359	5.78	4.81	6.04
8		0.5	32.79	31.52	32.71	46.78	46.421	6.19	4.86	6.18
9		1.0	33.16	31.90	33.19	47.02	47.175	6.38	4.89	6.26
10		1.5	33.44	32.09	33.44	47.43	47.559	6.52	4.90	6.30

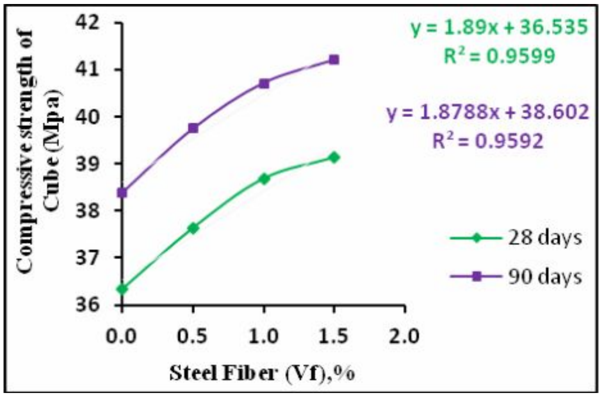

Figure1.Compressive strength (Cube) at 28, days of age at 8 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fiber, and their predicted Models.

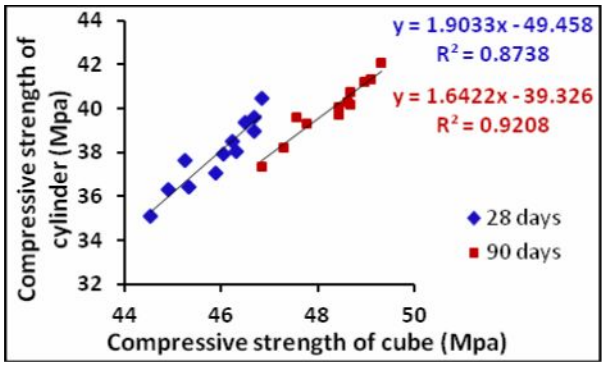

Figure2.Relationship between Compressive strength of cylinder and cube at 8 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fiber, and their predicted Models.

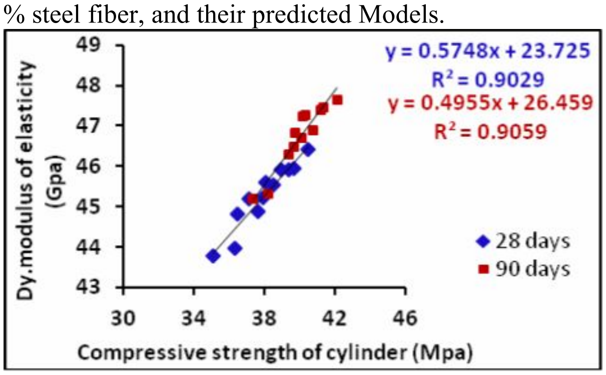

Figure3.Relationship between Compressive strength of cylinder (f_{cc}) and Dynamic modulus of elasticity (Ed) at 8 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fiber, and their predicted Models

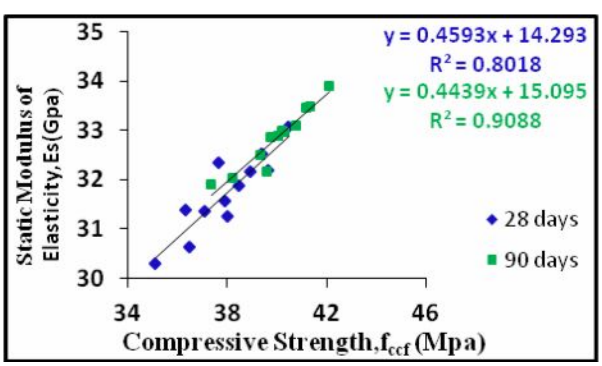

Figure4.Relationship between Compressive strength of cylinder (f_{cc}) and Static modulus of elasticity (Ed) at 8 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fiber, and their predicted Models.

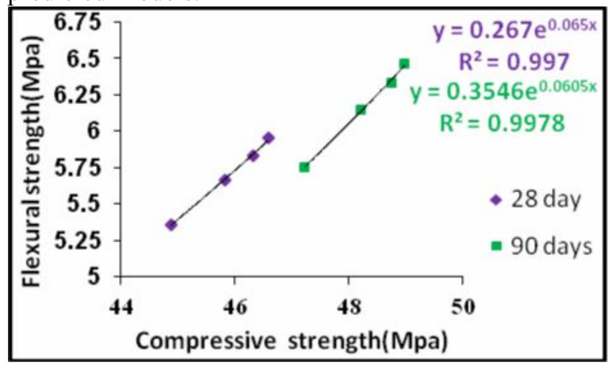

Figure5.Relationship between Compressive strength of Cube (f_{ck}) and Flexural strength at 8 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fiber, and their predicted Models.

VI. CONCLUSIONS

Following conclusions were obtained base on the experimental investigations.

1. The weight density of concrete increase with increase in the steel fiber content.
2. Super plasticizer with dosage range of 0.75 to 1.40% by weight of cementations materials (Cm = PPC + SF) has been used to maintain the adequate workability of silica fume concrete and silica fume with steel fiber concrete mixes.
3. The compressive strength increases with the increase in silica fume compared with normal concrete.
4. The compressive strength increases with the addition of steel fiber was marginal as compared with silica fume concrete.
5. All the properties of concrete, compressive strength (Cube & cylinder) and Modulus of Elasticity increases by addition of steel fiber.
6. On the basis of regression analysis of large number of experimental results, the statistical model showed in figures has been developed. The proposed model was found to have good accuracy in estimating the 28 and 90 days Compressive strength of cube with cylinder. Compressive strength of cylinder with static and dynamic modulus of elasticity with their inter relationship at 8% Silica Fume & 0%, 0.5%, 1.0%, 1.5% Steel Fibers have good correlation.
7. In general, the significant improvement in various strengths is observed with the inclusion of steel fibers in the plain concrete with high volume fractions.
8. The flexural strength increases with the addition of steel fiber was more as compared with silica fume concrete. It was observed that the increases in flexural strength is directly proportional to the fiber content and also the flexural deflection decreases with increase in steel fiber than that of normal concrete.

9. First crack development in case of steel fiber concrete was late than plain concrete.
10. The proposed model is found to have good accuracy in estimating the 28 and 90 days Compressive strength of fiber reinforced concrete, where 100% of the estimated values are within ± 2.3 % of the actual values.

VII. ACKNOWLEDGEMENT

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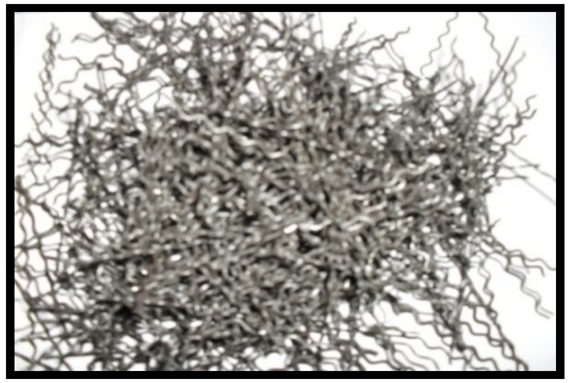

Figure6. Showed 0.5 mmØ Steel Fiber.

Figure 7. Cylinder Compressive Strength and Compressometer with dial gauge (strain measurment)Test.

Figure 8. Showed Compressive Strength Test

Figure 9. Showed Flextural Strength Test