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# Critical Studies on the Influence of Silica Fume and Steel Fiber Enhancing Properties of Concrete

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***Abstract-This paper presents results of concrete containing Portland Pozzolona cement (PPC) containing fly ash with silica fume (SF) and steel fibers. The tests are carried out in laboratory on M30 grade of concrete at 28 and 90 days of age. Mathematical models are proposed to define the cube as well as cylinder compressive strength, dynamic modulus of elasticity, ultrasonic pulse velocity, stress-strain behavior and static modulus of elasticity in compression. As far as the compressive strength is concerned, the replacement of cement by 12% of SF improved performance of concrete. The most significant contribution due to the addition of fibers is to enhance the post peak behavior of concrete and it also resists crack propagation after the first crack, and allow concrete to sustain very high strains than concrete without fibres.***

## I. INTRODUCTION

It is now well established fact that the addition of short, discontinuous fibers plays an important role in the improvement of the mechanical properties of concrete. They increase elastic modulus, decrease brittleness; controls crack initiation, and its subsequent growth and propagation. 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 property of steel fiber reinforced concrete SFRC suggests 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. Silica Fume is a highly effective pozzolanic material. It improves concrete in two ways, the basic pozzolanic reaction, and as micro filler effect, the extreme fineness of the silica fume allows it to fill the microscopic voids between cement particles. This greatly reduces permeability and improves the paste-to-aggregate bond of the resulting in better performance of concrete compared to conventional concrete. 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. Addition of fibers has shown to improve ductility of normal and particularly concrete containing silica fume. A comprehensive review of literature related to Silica Fume and Steel Fiber concrete was presented by ACI Committee 544 [1] and Balaguru and Shah[2].They have included guidelines for design, mixing, placing and finishing steel fiber reinforced concrete, they also 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 N/mm2 to 75 N/mm2, also a statistical model was developed. Steel fiber reinforced concrete under compression and Stress-strain curve for steel fiber reinforced concrete in compression was done by Nataraja C. Dhang, and Gupta, A.P. [5 & 6]. 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 N/mm2, with fiber volume fraction of 0%, 0.5%, 0.75% and 1% and aspect ratio of 55 and 82 were used. Mechanical properties of high-strength steel fiber reinforced concrete was done by Song P.S. and Hwang S.[7].They have marked brittleness with low tensile strength and strain capacities of high strength concrete can be overcome by addition of steel fibers. Steel fibres 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%volumefraction, being 15.3% improvement over the HSC. Investigation on the compressive strength of silica fume concrete using statistical methods was done by Banja and Sengupta [8].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/cm) ratios ranging from 0.3 to 0.42 and silica fume replacement percentages from 5 to 30. They have developed relationship between compressive strength and fiber reinforcing index that predicting 28-day compressive strength at any fiber content in terms of fiber reinforcing parameter and at any water to-cementations material ratios, is quite limited. Influence of silica fume on workability and compressive strength of high performance concrete was done by Duval and Kadri [9].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. Stress-Strain Behavior of Steel Fiber-Reinforced Concrete in Compression was done by Francesco Bencardino, Lidia Rizzuti, Giuseppe Spadea, and Ramnath N. Swamy,[10]. They found post-peak behavior improves due to increase in fiber content. SFRC specimens with fiber content of 1.6 and 3% show, at 0.01 strain, a residual stress of about 74 and 78% of their respective peak stresses. However, there is still incomplete knowledge on the design/analysis of fiber-reinforced concrete 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. Many stress-strain relationships in compression, for FRC materials have been proposed in literature by different authors. With reference to behavior in compression, extensive experimental data and analytical models have been reported during the period from 1989 to 2009, and these are discussed later in this paper. The behavior of a composite material is influenced by the characteristics of each component, their synergistic interaction, and by their proportion in the mixture. In particular, when fibers are added to a concrete mix, fiber characteristics such as their type, shape, aspect ratio Lf/Df, where Lf fiber length and Df fiber diameter and volume content Vf play an important role in modifying the behavior of the material. In addition, it needs to be emphasized that variations in specimen geometry, loading versus casting direction, loading rate, and maximum aggregate size also modify the compression behavior of fiber concrete. Extensive experimental data obtained from tests carried out according to established international standards are then needed to develop and refine models that are rational and reliable, and that will fully reflect the effects of all the different factors discussed above. For this purpose, only the experimental data carried out according to standard procedures have been collected and discussed in this paper in conjunction with the results obtained from a set of compressive strength tests on cube and cylinder specimens.

## II. EXPERIMENTAL SET-UP

The M30 grade of concrete were proportioned using guidelines given in IS: 10262-1999,[11] and ACI Committee 544[12]. The Mix proportions were (1:1.1.42:2.69), the quantity of cement was 420 Kg/ m3 with W/C Ratio 0.42 and ratio of course aggregate A1(20mm) :A2 (10mm) was 70:30; Silica Fume was added as 12% replacement of cement, crimped steel fibers of two diameters (0.5 mm Ø and 1.0 mm Ø with constant aspect ratio of 60) were added. Percentage of fibers was 0%, 0.5 %, 1.0 % and 1.5 % (i.e.0, 39, 78 and 117.5 Kg/m3) by the volume of concrete. Cubes of 150X150X150 mm and cylinders150x300mm were casted. Twenty four hours after casting, the specimens were demolded and placed immediately in water tank for curing for a period of 28 and 90 days. The cubes and cylinders were tested for compressive strength as per guide lines of IS: 516-1959[13] and ACI 544.R [14]. Compress meter equipped with dial gauge was used to record the deformation of the cylinder. Dynamic Modulus of Elasticity and Ultrasonic Pulse Velocity was measured by ultrasonic tester. Three identical specimens were tested in each case.

## III. MATERIALS AND METHODS

### *A. Portland Pozzolona Cement*

IS 1489(part 1):1991 containing 28% fly ash. The properties of cement tested were Fineness (90L Sieve) = 5 %, Normal consistency=31%, Initial & Final setting time =138minute & 216minute and 28 days Compressive strength= 55.63 N/mm2

### *B. 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.

### *C. 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/ m3

### *D. Coarse Aggregate*

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Crushed natural rock stone aggregate (A1) and (A2) were used. The combined specific gravity, Bulk Density and water absorption were 2.69,1612 Kg/ m3 and 0.52 % @ 24 hrs. Fineness modulus of 20 mm &10 mm aggregate were 7.96 & 6.13 respectively.

*E. 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/mm2 to 1250 N/mm2

*F. Super Plasticizer*

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

G. *Water*

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

## IV. TEST RESULTS AND DISCUSSIONS

*A. Workability*

The workability of concrete mixes was maintained with slump up to 20 mm by addition of suitable dosages of super plasticizer.

TableA1.Experimental results of concrete with 8% Silica fume and with and without steel fibers at 28 days of age. (Mean of three specimens)

| SR. NO | Steel Fiber | | Compressive Strength Of Cube N/mm$^2$ | Compressive Strength Cylinder N/mm$^2$ | Static Modulus Of Elasticity $E_s$(Gpa) | Ultrasonic Pulse Velocity m/sec) | Dynamic Modulus of Elasticity $E_d$ (Gpa) |
|---|---|---|---|---|---|---|---|
| | Df mm (Ø) | Vf (%) | | | | | |
| 1 | | 0 | 39.21 | 34.1 | 29.19 | 3813 | 32.71 |
| 2 | | 0 | 40.38 | 34.8 | 29.44 | 3938 | 34.89 |
| 3 | 0.5 | 0.5 | 41.68 | 36.2 | 30.08 | 3946 | 35.03 |
| 4 | | 1 | 42.39 | 37.2 | 30.49 | 4038 | 36.68 |
| 5 | | 1.5 | 42.88 | 37.6 | 31.65 | 4138 | 38.58 |
| 6 | | 2 | 43.58 | 38.9 | 31.18 | 4223 | 40.12 |

TableA2 .Experimental results of concrete with 8% Silica fume and with and without steel fibers at 90 days of age. (Mean of three specimens)

| SR. NO | Steel Fiber | | Compressive Strength Of Cube N/mm$^2$ | Compressive Strength Cylinder N/mm$^2$ | Static Modulus Of Elasticity $E_s$(Gpa) | Ultrasonic Pulse Velocity m/sec) | Dynamic Modulus of Elasticity $E_d$ (Gpa) |
|---|---|---|---|---|---|---|---|
| | Df mm (Ø) | Vf (%) | | | | | |
| 1 | | 0 | 42.39 | 37.6 | 30.65 | 4338 | 42.34 |
| 2 | | 0 | 44.39 | 38.2 | 30.90 | 4523 | 43.39 |
| 3 | 0.5 | 0.5 | 45.6 | 38.6 | 31.06 | 4562 | 44.74 |
| 4 | | 1 | 46.6 | 39.3 | 31.34 | 4638 | 45.58 |
| 5 | | 1.5 | 46.5 | 39.3 | 31.34 | 4636 | 47.37 |
| 6 | | 2 | 47.5 | 39.6 | 31.46 | 4739 | 49.6 |

*B. Compressive Strength*

Compressive strengths at 7 days (cube, fc and cylinder, fcc) are shown in Table A1. Also shown all the values of percentage increase in the strength. Table A2 gives similar details at 28 days of age. Also mathematical model between cylinder compressive strength v/s steel fibers was developed by using graphical method as showed in Figure A1.

1) *Dynamic Modulus Of Elasticity (Ed):* The dynamic modulus of elasticity for different fiber percentages along with the percentage increase are shown in Table A1 (at 28 days of age) and Table A2 (at90 days of age).

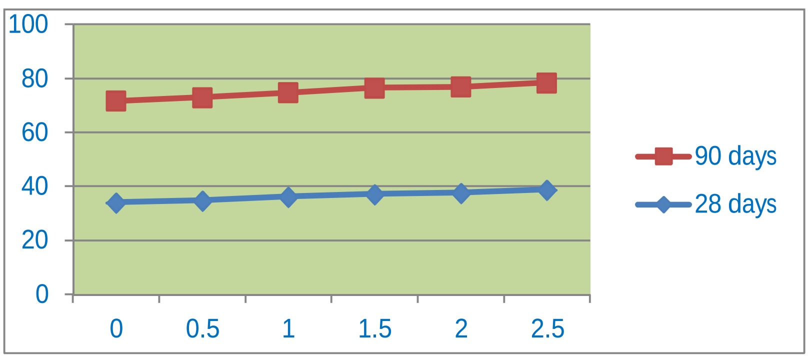
2) *Ultrasonic Pulse Velocity (Upv):* Ultrasonic pulse velocity is one of the most popular non-destructive techniques used in the assessment of concrete properties. However it is very difficult to evaluate the test results since the ultrasonic pulse velocity values are affected by a number of factors. It was observed that in comparison with control concrete the “Upv” marginal increases due to the effect of silica fume with steel fibers are found they are shown in TableA1.and A2.

3) *Static Modulus Of Elasticity (Ed*): Modulus of elasticity (secant modulus) is defined according to ACI Building code (ACI 318-1995), [18], as the slope of the line drawn from a stress of zero to a compressive stress of 0.45fcc. The static modulus of elasticity evaluated from the stress-strain curves are in the range of 29.19x 103 N/mm2 to 31.18x103 N/mm2 at 28 days and 30.65ox 103 N/mm2 to 31..46x103 N/mm2 at 28 days of age. Results of modulus of elasticity obtained have 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 is showed in Table A1and A2.

4) *Dynamic Modulus Of Elasticity (Es):* Dynamic of elasticity (secant modulus) is defined according to ACI Building code (ACI 318-1995), [18], as the slope of the line drawn from a stress of zero to a compressive stress of 0.45fcc. The static modulus of elasticity evaluated from the stress-strain curves are in the range of 32.71x 103 N/mm2 to 40.12x103 N/mm2 at 28 days and 42.34ox 103 N/mm2 to 49.60 x103 N/mm2 at 28 days of age. Results of modulus of elasticity obtained have 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 is showed in Table A1and A2.

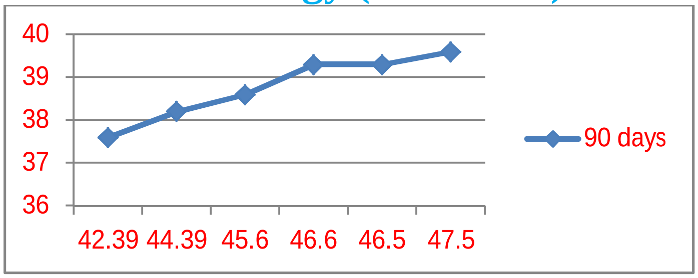
Discussion on Relationship between
Mechanical properties of concrete:

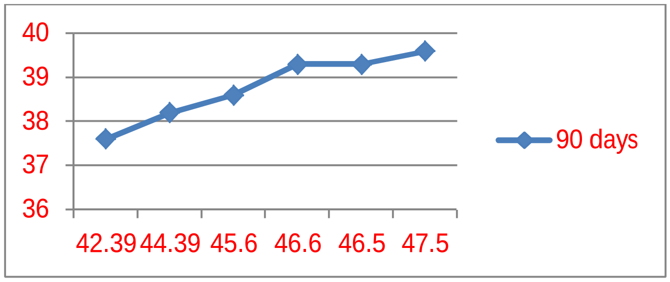
Based on the test results, mathematical model was developed using graphical methods to quantify the effect of silica fume and steel fiber content on interrelationship between compressive strength of cylinder with compressive strength of cube, dynamic modulus of elasticity and ultrasonic pulse velocity of concrete. On examining the validity of the proposedmodel, there exists a good correlation between the predicted values by graphs and the experimental values is shown in Figure A4 to Figure A6.



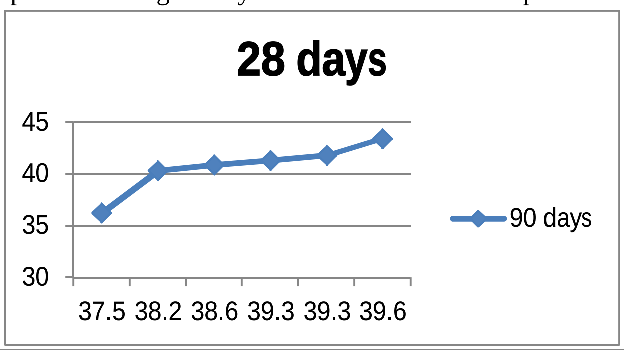

FigureA1.Compressive strength (Cylinder) at 28 days and 90 days of age with 4 % Silica Fume and 0, 0.5, 1.0 & 1.5 % steel fibers and their predicted Models.

28 **days**




FigureA2. Relationship between Compressive strength of cylinder and cube and their predicted Models at 28 days and 90 days of ag



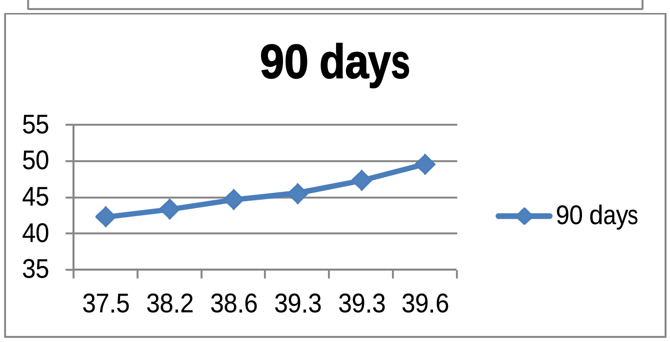
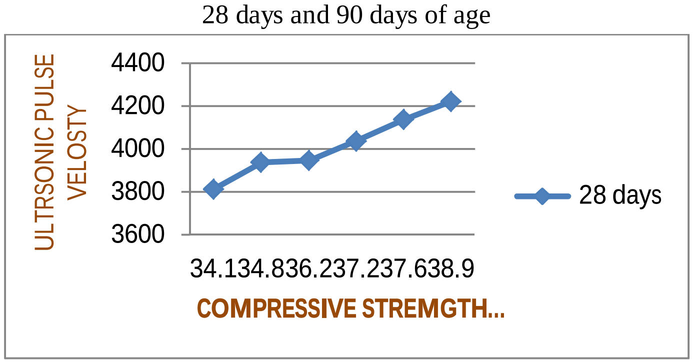




Figure3. Relationship between Compressive strength of cylinder and Dynamic, modulus of elasticity and their predicted Models at 28 days and 90 days of age



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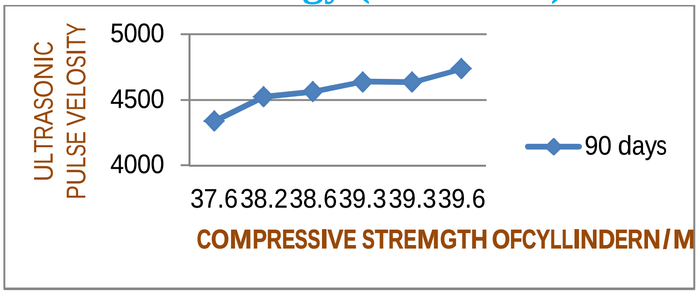


Figure4. Relationship between Compressive strength of cylinder and Ultrasonic pulse velocity And their predicted Models at 28 days and90 days of age.

## V. CONCLUSIONS

Following conclusions are drawn based on the experimental investigations.

Addition of silica fume enhances compressive strength at 28 and 90 days, dynamic modulus of elasticity and static modulus of elasticity.

Additions of steel fibers are found to improve further compressive strength at 28 and 90 days, dynamic modulus of elasticity and static modulus of elasticity. However the enhancement depends upon the percentage of fibers.

The enhancement of compressive strength at 28 and 90 days, dynamic modulus of elasticity and static modulus of elasticity also depends upon the diameter of fibers, for 0.5 mm diameter fibers the enhancement is less as compared to 1.0 mm diameter fiber.

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 ± 2.6 % of the actual values.

Strain at peak stress increases with concrete strength

The slope of the descending branch increases with increasing the volume of steel fibers. The increase of strain at peak stress also showed a good agreement with the increase of [Vf].

The mathematical models developed can predict cylinder compressive strength at 28 and 90 days with reasonable accuracy from the cube compressive strength at 28 and 90 days.

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