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# An Experimental Investigation on Mechanical and Durability Properties of High Strength Fiber Reinforced Concrete

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***ABSTRACT:*** *At present a large scale production of cement is useful for construction which causes global warming on one side and depletion of natural resources on other side. So that different pozzolanic materials like silica fume, Fly ash, are used in concrete as admixtures. The present study was to evaluate the mechanical and durability properties of M60 grade concrete by replacing 10%, 15% of silica fume and 10%, 20%, 30% of fly ash to cement. 0.5% steel hook fibers are used by volume fraction as admixture for all proportions of HSFRC. The main objective of the present work is to develop M60 grade concrete and to find the effective dosage of silica fume and fly ash. This paper presents the detailed experimental study on compressive strength at different ages i.e. 3 days, 7 days, 28 days, 56 days, 90 days and split tensile test and flexural strength at the age of 28 days. Durability tests like Rapid Chloride Permeability test and Water Absorption test were conducted on casted specimens.*

**Key wards:** Silica Fume (SF), Fly Ash (FA), Steel Hook Fibers (SHF), High Strength Concrete (HSC), High Strength Fiber Reinforced Concrete (HSFRC), Compressive Strength, Split Tensile Strength, Flexural Strength, RCPT.

## I. Introduction

With the passage of time to meet the demand, there was a continual search in human being for the development of high strength and durable concrete. The history of high strength concrete (HSC) is about 35 years old, in late 1960s the invention of water reducing admixtures lead to the high strength precast products and structural elements were cast in situ using high strength concrete (HSC). The primary difference between high-strength concrete (HSC) and normal-strength concrete (NSC) relates to the compressive strength that shows the maximum resistance to concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute (ACI) defines high-strength concrete as concrete with a compressive strength greater than 60MPa.

. The utilization of fine Pozzolanic materials in high-strength concrete (HSC) like silica fume and fly ash leads to reduction in size of the crystalline compounds, particularly, calcium hydroxide. Consequently, there is a reduction of the thickness of the interfacial transition zone in high-strength concrete. Applications of mineral admixtures such as silica fume (SF), fly ash (FA) in concrete are effective and easy to future increase in the strength and make durable for high strength concrete. The addition of admixtures to the concrete mixture increases the strength by pozzolanic action and filling the small voids and that are created between cement particles. Almost all these concretes have mineral additives involve for a variety of reasons including strength improvement, reduction of permeability, higher crack resistance and durability factors.

This study describes the development of high strength fiber reinforced concrete (HSFRC) with f'ck in the range of 60-100 N/mm$^2$. The objective of present study was mainly to increase the compressive strength, split tensile strength and flexural strength, with the aim of producing a concrete requiring less steel for use in the construction of prestressed concrete bridge superstructures. In addition to increasing compressive strength of the concrete and using fiber reinforcement to improve compressive strength, another development objective was to increase versatility by producing HSFRC that does not requiring special materials or special curing methods. The addition of high strength steel fibers to the concrete increases flexural strength and ductility properties of concrete. This residual strength also tends to reduce crack sizes and spacing's. The use of steel fibers is particularly attractive for high-strength concrete, which can be relatively brittle without fibers.

In the present study, the different admixtures were used to study their combined effect on the resistance of concrete in addition to their effects on durability, compressive strength, split tensile strength and flexural strength by partial replacement of mineral admixtures by 10%, 15% of silica fume &10%, 20% and 30% of fly ash by the weight of cement with a constant amount of 0.5% steel hook fibers are added by volume fraction of concrete, throughout the study.

## 2.0 Experimental Program

## 2.1 Materials

### 2.1.1 Cement

Ordinary Portland cement of (Zuari brand) 53 grades was selected for the experimental investigation. The characteristics of cement were tested as per IS: 4031-1988 and IS: 12269-1987(9). The experiments such as fineness, standard consistency, initial setting time, final setting time and specific gravity of cement are conducted on ordinary Portland cement shown in table 1.

**Table-2.1: properties of opc**

| S. No | Characteristic of cement | Value |
|---|---|---|
| 1 | Fineness of cement | 6% |
| 2 | Normal consistency | 33% |
| 3 | Initial setting Time | 40 minutes |
| 4 | Final setting time | 350 minutes |
| 5 | Specific gravity | 3.14 |

**2.1.2 fine aggregates**

Sand is a naturally occurring material from Rock and Minerals by weathering and is composed of majorly $sio_2$, and Calcium carbonate. The specific particle size composition of the sand as per the **IS 650:1966 and IS 383:1970** was used. River sand was used for the experimental work. The properties of fine aggregate are shown in Table 2.

**Table-2.2: Properties Of Fine Aggregates**

| S.no | Properties | Results |
|---|---|---|
| 1. | Specific gravity | 2.583 |
| 2. | Bulking of sand | 4% |
| 4 | Water absorption | 1% |
| 5 | Bulk Density | 1460 kg/m$^3$ |
| 6 | Fineness modulus | 2.8 |

### 2.1.3 Coarse Aggregate

Gravels are popularly used as Coarse aggregates, which are free from organic impurities and silt. Locally available aggregates of passing through 20 mm sieve and retained on 10 mm sieve are taken. As per **Indian standard specifications IS 383-1987** the coarse aggregates were tested and mentioned in table 3.

**Table-2.3: Coarse Aggregate Properties**

| S.No | Properties | Results |
|---|---|---|
| 1. | Specific gravity | 2.68 |
| 3 | Fineness Modulus | 6.26 |
| 4 | Water Absorption | 0.5% |
| 5 | Bulk Density | 1469.8 kg/m$^3$ |
| 6 | Elongation index | 20.49% |
| 7 | Flakiness index | 13.19% |

### 2.1.4 Silica Fume

Silica fume is a waste by-product of the production of silicon and silicon alloys. It is available in different forms, of which the most commonly used is in a dandified form. Silica fume used was conforming to IS: 1331(PART-1) 1992 and also ASTM C (1240-2000). Silica fume was also referred as micro silica or condensed silica fume, is a byproduct material that is used as a pozzolanic. This by product is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. In this project silica fume is used as partial replacement to cement and its properties are mentioned in table 4.

**Table-2.4: Properties Of Silica Fume**

| Property | Results |
|---|---|
| Color | Dark grey |
| Practical size | <1μm |
| Specific surface | 15,000 to 30,000 m$^2$/kg |
| Bulk density | 695 g/cm$^3$ |
| Specific gravity | 2.2 |
| Moisture content | 0.78% |
| $Sio_2$ | 92.83% |
| Al2o3 | 0.69% |

***As per manufacturers manual

### 2.1.5 Fly Ash

For this project Fly ash is taken from Rayalaseema thermal power plant (RTPP), Kadapa. Fly ash conforms to the requirements of **IS: 3812 part-I and also ASTMC-618 type-F** were used**.**

**Table 2.5 Properties Of Fly Ash**

| Sl. No. | Characteristics | Percentage |
|---|---|---|
| 1 | Silica,$SiO_2$ | 49-67 |

| | | |
|---|---|---|
| 2 | Alumina, $Al_2O_3$ | 16-28 |
| 3 | Iron oxide, $Fe_2O_3$ | 4-10 |
| 4 | Lime, CaO | 0.7-3.6 |
| 5 | Magnesia, MgO | 0.3-2.6 |
| 6 | Sulphur trioxide, $SO_3$ | 0.1-2.1 |
| 7 | Loss of ignition | 0.4-0.9 |
| 8 | Surface area, ($m^2$/kg) | 230-600 |
| 9 | Specific gravity | 2.3 |

## 2.1.6 Steel Hook Fibers

Steel fibres make significant improvements in flexure, impact and fatigue strength of concrete. These fibres are used in concrete as crack arrester and would substantially improve its static and dynamic properties. Compressive strength of fibre reinforced concrete increased with increase in steel fibre content. The additions of steel fibres shear strength increases significantly. Steel hook fibers compliance to the requirements of **ASTM A 820** (type-1 cold drawn wire)

**Table-2.6: Properties Of Steel Hook Fibres**

| 1 | Type | Hooked end |
|---|---|---|
| 2 | Diameter of fibers | 0.60 mm |
| 3 | Length of fibers | 30 mm |
| 4 | Aspect ratio (L/D) | 50 |

As per ASTM Yield Strength of Wire : > 1000 MPa

**Wire Mechanical Properties**

Tensile strength of the wire : 1450 Mpa

Strain at failure : < 4 %

**Shape**

The ending shapes of Hooked End Steel Fiber are very important to grant adhesion between fiber and concrete.

**3.0 MIX-PROPORTIONS**

**3.1 Mix Proportions:**

| | Water | Cement | Fine aggregate | Coarse aggregate |
|---|---|---|---|---|
| Proportion by Weight (kg/$m^3$) | 147 | 420 | 650.916 | 1254.24 |
| Proportion by Ratio | 0.35 | 1 | 1.55 | 2.985 |

**3.2 Experimental Procedure**

The specimen of standard cube of (150mm x 150mm x 150mm) and standard cylinders of (300mm x150mm) and Prisms of (100mm x100mm x 500mm) were used to determine the compressive strength, split Tensile strength and flexural strength of concrete. For each proportion of silica fume replacement, 10%, 20% and 30% fly ash is replaced to cement and a constant amount of 0.5% steel hook fibers are added for all proportions HSFRC. The constituents were weighed and the materials were mixed by hand mixing. The water binder ratio (W/B) (Binder = Cement + Partial replacement with silica fume and fly ash) adopted was 0.35. The casted specimens were cured in water at room temperature and then tested for its compressive strength, split tensile and flexural strength as per Indian Standards.

**TABLE-3.2: MIX-PROPORTIONS FOR M60 GRADE CONCRETE THAT ARE USED IN HSFRC**

| Silica fume (%) | Fly Ash (%) | F.A (kg/$m^3$) | C.A (kg/$m^3$) | W/C Ratio | Water (liters) | Steel fibers (% by volume of concrete) |
|---|---|---|---|---|---|---|
| 0% | 0% | 651 | 1254 | 0.35 | 147 | 0.5% |
| 10% | 10% | 651 | 1254 | 0.35 | 147 | 0.5% |
| | 20% | 651 | 1254 | 0.35 | 147 | 0.5% |
| | 30% | 651 | 1254 | 0.35 | 147 | 0.5% |
| 15% | 10% | 651 | 1254 | 0.35 | 147 | 0.5% |
| | 20% | 651 | 1254 | 0.35 | 147 | 0.5% |
| | 30% | 651 | 1254 | 0.35 | 147 | 0.5% |

**3.3.0 TEST METHODS**

**3.31 Mechanical Properties**

Mechanical properties such as compressive strength, split tensile strength and flexural strength tests are evaluated.

**3.3.2 Compressive Strength Test**

Compressive strength test usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. The compression test is an important concrete test to determine the strength development of the concrete specimens. Compressive strength tests were performed on the cube specimens at the ages of 3, 7, 28, 56 and 90 days. The compressive strength test results are mentioned in table 4.1.

**3.3.3 Splitting Tensile Strength**

The indirect method of applying tension in the form of splitting was conducted to evaluate the effect of silica fume and fly ash on tensile properties of concrete. The split tensile strength is a more reliable technique to evaluate tensile strength of concrete (lower coefficient of variation) compared to other methods. The split tensile strength of 150 mm diameter and 300 mm high concrete cylindrical specimens was determined to assess the effect of silica fume and fly ash on the tensile properties of the concrete. The split tensile strength test results are mentioned in table 4.2.

**3.3.4 Flexural Strength**

The ultimate flexural strength analysis presented in this paper is based on the conventional compatibility and equilibrium conditions used for normal reinforced concrete except that the contribution of the fibers in the tension is recognized. . The Flexural strength test results are mentioned in table 4.2.

**3.4.0 DURABILITY TESTS**

**3.4.1 Rapid Chloride Permeability Test**

The rapid chloride penetration test is carried out as **per AASHTO T277, (ASTM C1202)** test. In this a water-saturated, 50-mm thick, 100-mm diameter concrete specimen is subjected to a 60 V applied DC voltage for 6 hours using the apparatus. In one reservoir is a 3.0 % NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete.

The procedure of this test method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a test method. The method relies on the results from a test in which electrical current passes through a concrete sample during a six-hour exposure period. The interpretation is that the larger the Coulomb number or the charge transferred during the test, the greater the permeability of the sample. The more permeable the concrete, the higher the coulombs the less permeable the concrete, the lower the coulombs. The method has shown good correlation with chloride tests [10]. The following formula, based on the trapezoidal rule can be used to calculate the average current flowing through one cell.

$$Q = 900(I0+2I30+2I60+2I90+2I120+\ldots+2I300+2I330+I360)$$

Where,

Q = current flowing through one cell (coulombs)

I0 = Current reading in amperes immediately after voltage is applied, and

It = Current reading in amperes at t minutes after voltage is applied

The table 3-2 shows the rating of chloride permeability according to ASTM C 1202-97[10].

| Charge Passed (Coulombs) | Chloride Ion Penetrability |
|---|---|
| > 4000 | High |
| 2000 – 4000 | Moderate |
| 1000 – 2000 | Low |
| 100 – 1000 | Very Low |
| < 100 | Negligible |

The main objective of this test was to evaluate the performance of mixes and compared with each other. Chloride ion penetrability test were conducted on 100mm diameter and 50mm thick cylinder specimens for each concrete mixture 28 days for M60 grade of concrete. The results of chloride permeability in coulombs for different proportions of concrete are given in Table 4.3.

**3.4.2 Water Absorption Test**

One of the most important properties of a good quality concrete is low-permeability, especially one resistant to freezing and thawing. The water absorption test is carried out at the age of 28 day according to standard procedure **ASTM C 642-11**. For the water absorption test, 100 x 200mm size of cylinder is cut into three parts (top, middle, bottom) of 50mm thickness and 100mm diameter, then specimens are dried in an oven at $100^{O}$ to $110^{O}$ C for not less than 24 hours. After removing each specimen from the oven, allow it to cool in dry air to a temperature of $20^{O}$ to $25^{O}$ C and determine the mass. . The percentage water absorption test results are mentioned in table 4.4.

## 4.0 Results and Discussion

Results of hardened concrete with partial replacement of silica fume and fly ash with 0.5% steel hook fibers are discussed in Comparison with normal concrete.

## 4.1 Compression Test

**Table-4.1: compressive strength of high strength frc concrete with 0.5% steel hook fibres as admixture:**

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| S.NO | SAMPLES | AVERAGE COMPRESSIVE STRENGTH ($N/mm^2$) | | | | |
|---|---|---|---|---|---|---|
| | | 3 days | 7 days | 28 days | 56 days | 90 days |
| **1** | **Controlled mix** | 27.62 | 44.23 | 68.07 | 75.18 | 78.74 |
| **2** | **10%SF+10%FA+0.5%SHF** | 36.96 | 49.40 | 75.33 | 79.77 | 81.11 |
| **3** | **10%SF+20%FA+0.5%SHF** | 40.18 | 50.07 | 81.92 | 82.67 | 83.40 |
| **4** | **10%SF+30%FA+0.5%SHF** | 39.33 | 49.63 | 76.60 | 81.06 | 82.00 |
| **5** | **15%SF+10%FA+0.5%SHF** | 39.18 | 49.48 | 74.88 | 80.51 | 81.55 |
| **6** | **15%SF+20%FA+0.5%SHF** | 36.96 | 48.67 | 74.67 | 79.11 | 80.66 |
| **7** | **15%SF+30%FA+0.5%SHF** | 36.41 | 47.33 | 71.55 | 73.55 | 78.00 |

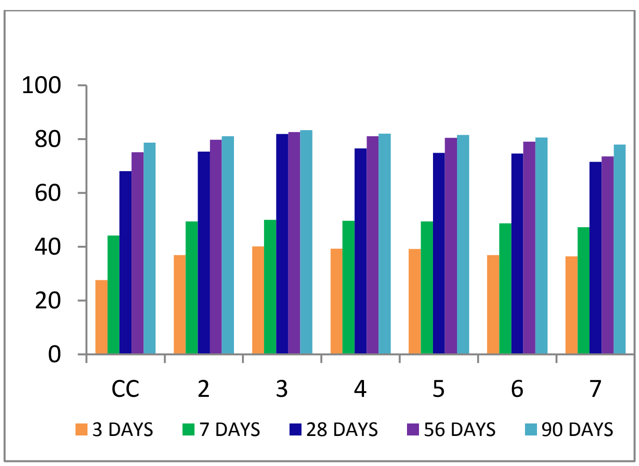


Fig N0 4.1: Compressive Strength Comparison of All Proportions of Concrete

## 4.2 Split Tensile Test

**Table-4.2: split and flexural test results**

| Days | Cases | Average split tensile strength (Mpa) | Flexural strength (MPa) |
|---|---|---|---|
| | Controlled mix | 13.27 | 14.06 |
| 28 days | 10% SF+10% FA+ 0.5% steel fibres | 14.5 | 15.60 |
| | 10% SF+20% FA+ 0.5% steel fibres | 15.2 | 19.50 |
| | 10% SF+30% FA+ 0.5% steel fibres | 14.8 | 15.60 |
| | 15% SF+10% FA+ 0.5% steel fibres | 14.2 | 19.46 |
| | 15% SF+20% FA+ 0.5% steel fibres | 14.4 | 15.52 |
| | 15% SF+30% FA+ 0.5% steel fibres | 13.8 | 15.30 |


**Fig:** Tensile strength at 28 days for various percentages of Silica Fume and Fly Ash

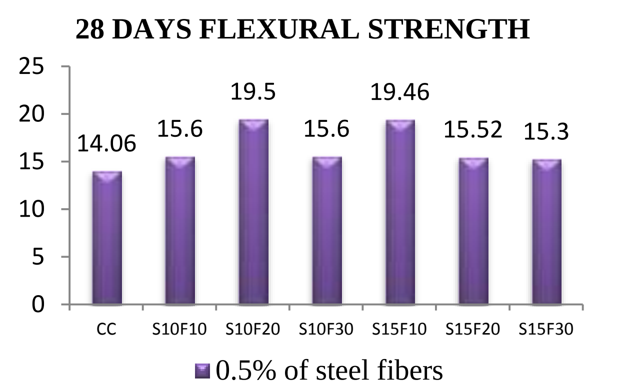


**Fig 6.11:** Flexural strength at 28 days for various percentages of Silica Fume and Fly Ash

From above graphs it has been seen that, the comparison of flexural strength results of concrete for various replacements of silica fume and fly ash with 0.5% steel hook fibers as admixture. At 10% silica fume and 20% fly ash gives maximum 28 days split strength as 5.2N/mm2, next higher value occurs at 15% silica fume and 10% fly ash with 0.5% steel hook fibers as 12.97 N/mm2.

### 4.4 Durability Tests

**Table 4.3: rapid chloride penetration test:**

| S.no | SAMPLE | I cumulative in mA | I average in coulombs | Penetrability of chloride |
|---|---|---|---|---|
| 1 | CC | 2.26 | 2034 | Medium |
| 2 | 10%SF+10%FA+0.5%SHF | 2.02 | 1818 | Low |
| 3 | 10%SF+20%FA+0.5%SHF | 0.31 | 279 | Very Low |
| 4 | 10%SF+30%FA+0.5%SHF | 2.01 | 1809 | Low |
| 5 | 15%SF+10%FA+0.5%SHF | I.02 | 918 | Very Low |
| 6 | 15%SF+20%FA+0.5%SHF | 1.23 | 1107 | Low |
| 7 | 15%SF+30%FA+0.5%SHF | 0.58 | 522 | Very Low |

**Table4.4: water absorption test results:**

| S.no | Sample | Wet weight (kgs) | Dry weight (kgs) | Water absorption in % |
|---|---|---|---|---|
| 1 | CC | 0.956 | 0.940 | 1.70 |
| 2 | S10F10 | 0.952 | 0.942 | 1.06 |
| 3 | S10F20 | 0.953 | 0.945 | 0.84 |
| 4 | S10F30 | 0.944 | 0.939 | 0.53 |
| 5 | S15F10 | 0.944 | 0.935 | 0.96 |
| 6 | S15F20 | 0.946 | 0.940 | 0.63 |
| 7 | S15F30 | 0.949 | 0.944 | 0.53 |

## Conclusions

Based on the results obtained from the present investigation the following conclusions were made;

1. By the addition of steel hook fibers in concrete leads to increase in compressive strength and makes concrete into ductile.
2. In split tensile and flexural tests, we notices that crack width reduced due to the presence of steel fibers when compared with conventional specimen.
3. When the cement is replaced with 10% silica fume and 20% fly ash gives the optimum compressive strength, split tensile strength and flexural strength.
4. At 10% silica fume and 20% fly ash replacement to cement, compressive strength were increased up to 20.34% when compared with conventional concrete for 28 days.
5. At 10% silica fume and 20% fly ash replacement to cement, split tensile strength were increased up to 60.85% when compared with conventional concrete for 28 days.
6. At 10% silica fume and 20% fly ash replacement to cement, flexural strength were increased up to 38.74% when compared with conventional concrete for 28 days
7. The addition of silica fume and fly ash as replacement to cement, its normal consistency and initial setting time increases with increase in percentage and final setting time decreases with increase in percentage.
8. The use of mineral admixtures in concrete causes considerable reduction in the volume of large pores at all ages and thereby reduces the permeability of concrete mixes because of its high fineness and formation of C-S-H gel

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