Experimental study on Strength Attainment of concrete containing silica fume and fly ash

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Abstract Increased utilization of cement in recent construction techniques leads to the global gas emission and involves high cost. Many researchers investigated the incorporation of pozzolanic materials in the cement in order to reduce its notorious effects on the environment which directed this research in order to develop high strength concrete by partially replacing supplementary cementitious materials with the cement. This study represents the experimental investigation on concrete which is blended with class F fly ash and silica fume in order to obtain high strength concrete. For this purpose, silica fume is used in 6%, 9% fly ash is replaced with 30%, 40% and 50% by weight of cement. The specimens were subjected to curing up to 90 days and conducted tests in order to determine the mechanical properties like compressive strength, flexural strength and durability properties like RCPT and UPV. Based on the experimental results, addition of 6% silica fume and fly ash at 30% replacement is high strength attainment as well as durability in the concrete.

Key words: Silica fume, fly ash, durability, flexural strength

1. Introduction
With the recent developments in the concrete technology, many researchers focused towards producing the cementitious binder by the amalgamation of various mineral additives. Thus, the concrete mix having binary and ternary systems are being produced predominantly [1]. In developing high strength and high performance concrete different cement replacing materials are being used out of which silica fume and fly ash are the most abundantly used pozzolanic materials because of its potential to consume portlandite during the process of hydration [2]. By conducting experimental studies on fresh concrete with ternary amalgamation, concrete with ternary mixture containing cement, silica fume and fly ash relatively resulted in attainment of high compressive strength when compared to the binary mixture [3]. Silica fume which is also termed as micro silica is the byproduct of Ferro silicon alloy comprises of amorphous silica and fly ash is the byproduct of thermal power plants consisting of amorphous silica particles that are relatively larger than that of present in the silica fume [4]. After the addition of pozzolanic materials in the cementitious binder system, these particles originate sites of nucleation for the precipitation of hydration products which result in the achievement of homogenous binder system. From the research investigation performed on silica fume concrete, it was reported that the strong bond between the phases and micro structure development of the binder system is due to the presence of finer particles and dense packing with cement [5, 6].

Utilization of silica fume and fly ash combination in order to replace cement is the trending research recent days and from the investigation it was reported that utilization of GGBS and silica fume
resulted in high strength attainment [7]. From the research investigations carried in order to determine the effect of using fly ash in the concrete, it was reported that utilization of fly ash at high volume resulted in the alteration of microstructure of the cementitious system and enhanced Young’s modulus, lower shrinkage and creep when compared to the conventional concrete because the unreacted particles of fly ash comprises of high modulus of elasticity compared to hydrated binder products and reported that incorporation of fly ash in concrete at 45% resulted in larger crack tip opening displacement [8]. Filler effect plays a vital role in the enhancement of engineering properties because of its fineness, these particles accommodate the space among the coarse aggregate and cement grains. Chemically, silica fume id rich in amorphous silica which has pozzolanic nature and reacts quickly compared to the normal pozzolans [9]. Effect of incorporating silica fume and fly ash in C3A cement was determined using X-ray diffraction. From the research investigation, it was reported that samples with fly ash and silica fume was observed with a rift of diffraction peaks and enhanced Silica to aluminum ratio in aluminosilicates. The samleswith20%, #0% and 50% silica fume along with 50% fly ash resulted in the formation of gelhenite and laumonite in the form of aluminosilicates [10].

From the research investigations carried out to determine physical properties, sulphate attack resistance and freeze thaw effect on blended concrete, it was reported that maximum compressive strength attainment at 28 days occurred at 15% replacement [11]. Research investigations were carried to determine the effect of silica fume incorporation on the mechanical properties of hardened concrete for M40 and M50 grades of concrete and reported that incorporation up to 12% silica fume resulted in enhancement of compressive strength, flexural strength as well as spilt tensile strength and found that beyond 15% replacement there is decrease of mechanical properties at curing age of 28 days [12]. Based on the experimental investigation and micro level study of silica fume blended concrete, it was investigated that addition of silica fume enhanced the microstructure by densifying cementitious matrix. By the incorporation of 15% silica fume in to the concrete, porosity was declined and beyond 15% replacement it initiated in an increase. From the micro level studies, it was observed that at 7, 28, 90 days, consumption of CH gel decreased by 31%, 32%, 65% for15% replacement respectively [13].

2. Experimental Program

2.1 Materials

Ordinary Portland cement of 53 grade according to the specifications confirming to IS: 12269-1987 along with the class F fly ash which was collected from Narla Tata Rao Vijayawada Thermal Power Plant (NTVTPS) and silica fume were used as mineral additives in order to replace with the cement content. Coarse aggregate of size 12, 20mm were used and locally available river sand which confirming to the specifications of IS 383 (1970) was used in order to cast the concrete. Fly ash was replaced with cement at 30%, 40% and 50% and silica fume was incorporated at 6% and 9% with the cement content. Cement binder ratio (C/B) of 0.45 was used and cement content of 400 kg/m³ was utilized in order to determine the mechanical as well as durability properties of the blended concrete.

Figure 1 and figure 2 represents the X-ray diffraction pattern obtained by performing micro level analysis using PAN analytical X’pert diffractometer. The test set up comprises of X- ray tubes with copper (Cu) anode as reference anode. The test was performed at scanning speed being 5° per minute with at an interval of 0.5° and scan range was 3 to 90° with the 40kv voltage and current being 15mA. Silica fume is a waste obtained from metallurgical which comprises of high amounts of Quartz (SiO₂) and fly ash consists of mainly silica (SiO₂), aluminum oxide (Al₂O₃) and ferric oxide (Fe₂O₃). From the test performed on both the additives, the XRD patterns show that silica fume consists of silica in higher amounts along with some compounds like calcium dioxide and silicon carbide as well as fly ash comprises of crystalline components like Mullite, Quartz and Hematite. The chemical composition of fly ash and silica fume were tabulated in Table 1. Table 2 demonstrates the properties
of fly ash as well as silica fume.

![Figure 1. XRD pattern of Silica fume](image1)

![Figure 2. XRD pattern of fly ash](image2)

The properties of coarse and fine aggregates were tabulated in the Table 3 and the mix proportions were demonstrated from Table 4 respectively.

### Table 1. Chemical composition

| Compound | OPC (%) | Fly ash (%) | Silica fume (%) |
|----------|---------|-------------|-----------------|
| SiO2     | 18.9    | 63          | 94              |
| Al2O3    | 4.6     | 32          | 2.1             |
| Fe2O3    | 4.7     | 0.8         | 0.7             |
| CaO      | 63.5    | 0.9         | 0.1             |
| Mgo      | 2.4     | 0.5         | 0.15            |
| SO3      | 2.1     | -           | -               |
| Na2O     | 0.7     | -           | 0.1             |
| P2O5     | 0.3     | 0.16        | 0.3             |
| S        | 2.3     | 1.9         | 1.9             |
Table 2. Physical properties of pozzolanic materials

| Property                          | OPC   | Fly ash | Silica fume |
|-----------------------------------|-------|---------|-------------|
| Specific gravity                  | 3.12  | 2.4     | 2.2         |
| Average grain size (µm)           | 22.6  | 20      | 2           |
| Specific surface area (cm²/g)     | 3245  | 3500    | 200000      |
| Normal consistency                | 28    | 37      | 33          |
| Initial setting time (min)        | 30    | 190     | 155         |
| Final setting time (min)          | 210   | 300     | 260         |

Table 3. Properties of fine and coarse aggregates

| Physical property     | Fine aggregates | Coarse aggregates |
|-----------------------|-----------------|-------------------|
| Specific gravity      | 2.67            | 3.72              |
| Fineness modulus      | 2.34            | 6.5               |
| Unit weight (kg/m³)   | 1705            | 1670              |

For the purpose of determining mechanical as well as durability properties of blended concrete at various curing ages like 7 days, 28, 56- and 90-days specimens of 100x100x100 mm size were cast in order to determine the compressive strength of the hardened concrete. Cylindrical specimens of 150mm diameter and 300mm height were cast in order to evaluate the flexural strength of the concrete. For the determination of Rapid Chloride ion permeability (RCPT) test, 50mm diameter and 50mm height specimens were made.

Table 4. Mix quantities of cement and cement substitutes

| Mix Designation | Cement (kg) | Fly ash (kg) | Silica fume (kg) | Water (kg) |
|-----------------|-------------|--------------|------------------|------------|
| F-0 SF-0        | 400         | 0            | 0                | 180        |
| F-30 SF-6       | 256         | 120          | 24               | 180        |
| F30 SF-9        | 244         | 120          | 36               | 180        |
| F40 SF-6        | 216         | 160          | 24               | 180        |
| F40 SF-9        | 204         | 160          | 36               | 180        |
| F50 SF-6        | 176         | 200          | 24               | 180        |
| FS0 SF-9        | 164         | 200          | 36               | 180        |

2.2 Testing

2.2.1 Compressive strength

One of the predominant characteristics of the hardened concrete is the compressive strength. It is termed as the resistance offered by the hardened concrete before its failure when the loading is applied
on the specimen. The test was performed as per the codal provisions of IS 516: 1959 with the help of a Universal testing machine (UTM) with the rate of loading being 30kN per minute. Compressive strength is the ratio of failure load of the specimen to cross sectional area of the specimen.

2.2.2 Flexural strength

This test is also termed as standard beam test as per the codal specifications of IS: 516 – 2002 which was performed on prisms of 100x100x500mm size. The span of the beam to be placed while testing was 400mm and the loading is applied on the specimen. The rate of loading was 1.8kN per minute and continued up to the failure of the specimen.

![Figure 3. Flexural strength test set up](image)

2.2.3 Acid Attack test

The specimens were subjected to acid attack for various curing ages like 7, 28, 56 and 90 days in encased tanks filled with 5% concentrated sulphuric acid (H₂SO₄) and Ph of 2 was maintained thoroughly. This test was performed as per the codal specifications of ASTM C1898–20. The specimens were tested for weight loss as well as strength loss after the completion of required immersion in the acid.

2.2.4 Rapid Chloride Permeability test

This test is also termed as RCP test. This test is performed in order to determine the resistance of the chloride ion in order to dissolve in to the fly ash blended concrete and it was performed according to the codal specifications of ASTM C 1202. This test involves in the potential of electric conductivity among the blended cementitious system and the indication of resistance offered for passing through the cylindrical specimen of 50mm diameter and 100mm height was evaluated over a particular period of time. This is a measure of predicting the impermeability of concrete to the chloride ions into it. This test was performed by clamping the specimen between cells out of which one cell is negative and the other cell is positive end. The negative end of the cells connected to 3% NaCl solution and the other end of the cell is connected to 0.3M NaOH solution. The specimen was encased with sealant and the current was supplied at the voltage of 60V.

2.2.5 Ultrasonic Pulse Velocity test

This test is also termed as UPV test in which waves of ultrasonic pulse were transmitted through the cubical specimen. The time taken for initiation as well as exit of the wave which is often considered as transmitting time was measured with the specifications confirming to BIS 13311-92 Part (1). In this
test the waves were transmitted through the cubes at curing ages of 7, 28, 56 and 90 days respectively. As per the codal provisions of BIS 13311-92 part 1, the criteria of grading concrete quality is tabulated in table 4.

![Figure 4. RCP test setup](image)

**Table 5. Grading concrete quality**

| Pulse velocity (km/s) | Grading concrete quality |
|-----------------------|--------------------------|
| Greater than 4.5      | Excellent                |
| 3.5 - 4.5             | Good                     |
| 3.0 - 3.5             | Medium                   |
| Less than 3.5         | Doubtful                 |

3. Results

3.1. Compressive Strength

Compressive strength of the specimens at 7, 28, 56 and 90 days was performed using Universal Testing Machine (UTM) at rate of loading being 30kN/minute. Figure 5 represents the compressive strength of blended concrete. From the figure 5, mix F30SF6 resulted in the high strength attainment. Beyond that replacement, compressive strength was declined from 67.8 to 61.4 for 90 days curing age. Retardation of compressive strength was occurred due to the addition of fly ash which was counteracted by the incorporation of silica fume resulted in continuation of the strength attainment in early and later stages of hydration as well. Fly ash and silica fume both performed as fillers and resulted in the strength attainment during its life.

3.2. Flexural Strength

Flexural strength is also termed as standard beam test which is used to determine the flexural strength of the specimen. In order to perform the test, prism of 100x100x500 mm was marked by leaving 100 mm on both sides from the ends. The flexural strength is ratio of flexural load to the area of the specimen.

\[
\text{Flexural strength} = \frac{P \times L}{b \times d^2}
\]

Where P is the flexural load acting on specimen L is the length of the specimen B is the width of beam and d is the depth of beam in mm. Figure 6 represents the flexural testing when prism is loaded and figure 7 represents the failure specimen after the application of failure load on the specimen. F30SF6 mix resulted in high flexural strength. Incorporation of fly ash at 30% and silica
fume at 6% resulted in maximum flexural strength when compared to the other replacements.

![Figure 5. Compressive strength](image)

3.3 Acid attack Test

After the casting and final setting, the specimens were subjected to acid attack by immersing the sulfuric acid of 5% concentration. The period of immersion depends on the curing age like 7, 28, 56 and 90 days. After the successful completion of immersion period, the specimens were tested for strength loss using Universal testing machine and weight loss using weighing machine. The loss percentage of strength and weight determines the vulnerability of pozzolans in the acidic environment which were added in the concrete. Figure 9 represents the specimens after immersing in acid for 28 days respectively. Figure 10 represents the percentage loss of compressive strength from 56.2% for control mix to 30.5% for F50SF9 mix. Figure 11 represents the percentage of weight loss when the specimens were subjected to acid attack. There was a decline of 8.45% to 2.65% for the F50SF9 mix.

![Figure 6. Flexural strength testing](image)  ![Figure 7. Failure specimen](image)
Reactive salts may be precipitated when the sulfuric acid react with the concrete specimen. These salts are responsible for the deterioration of the concrete. Because of the addition of fly ash and silica fume in the concrete, the reactive salts precipitation is reduced. As a result, durability of the concrete incorporated with fly ash and silica fume at 50% and 9% was increased relatively.

3.4 Ultrasonic Pulse velocity test

This test is performed in order to assess the presence of voids by emitting ultrasonic pulse waves from source in to the specimen from one end. Time taken by the wave for transmission in to the specimen is calculated. Using the speed of the wave along with time taken, velocity of the wave was evaluated. Figure 11 represents the testing of specimen which corresponds to F40SF6 mix. The velocity of wave is inversely proportional to presence of voids. From the figure 12, it was evident that presence of voids was decreasing with respect to curing age. The velocity for F0SF0 was 5.3km/s which was increased to 5.5km/s for F30SF6 mix relatively. Due to the filling of pores by the tiny particles of fly ash as well as silica fume, presence of voids gets reduced and yielded in pulse wave with high velocity. After optimum percentage replacement of fly ash and silica fume, due the filled voids and excess presence...
of additives there was formation of tiny suspended particles. These are responsible for the lower velocity beyond the F30SF6 mix.

![Figure 11. Loss of percentage of strength due to acid attack.](image1)

![Figure 12. Loss of percentage of weight due to acid attack.](image2)

![Figure 13. UPV testing](image3)

![Figure 14. UPV test Results](image4)
3.5 **RCP test**

The resistance to chloride ion permeability was measured using RCPT apparatus. The specimen of size 100 mm diameter and 50 mm height was fitted between two cells with 0.3M NaOH solution and 3% NaCl solution. Figure 13 represents the RCP test specimen and figure 14 represents the test readings respectively. The formula to measure the total electric charge passed through the specimen is

\[ Q = (900(I_0 + 2I_{30} + 2I_{60} + \cdots + 2I_{300} + 2I_{330} + I_{360})) \]

Where \( Q \) = current in amperes immediately through one cell (Coulombs), \( I_0 \) = current reading in amperes immediately after voltage is applied, \( I_t \) = current reading in amperes at \( t \) minutes after voltage is applied.

Figure 15 represents the charge passed through the specimens for 7, 28, 56 and 90 days respectively. From the figure it was evident that the control mix is having high current conductivity which in another way less resistance to permeability of chloride ion when compared to other concrete mixes. Due to the dissolution of ions and transferring through the specimen, resistance to chloride ion permeability decreases. Mix of F30SF6 possess high resistance to chloride ion permeability due to the eradication of dissolution of ions.

![Figure 15.RCP test specimen](image1)

![Figure 16.RCP test readings](image2)

Figure 17. RCPT Test Results

4. **Conclusions**

- Silica fume and fly ash act as fillers and fill the pores and has positive effect on high compressive strength attainment.
Addition of silica fume and fly ash resulted in the reduction of CH gel and enhance the CSH gel as well as its hydration products. Amorphous content was slowly transformed to crystalline microstructure.

Microstructure of concrete was increased due to filling and pozzolanicity.

Presence of silica in the form of Quartz and Mullite was observed at high amounts in silica fume and fly ash.

Silica fume compensated the drawback of late strength attainment with class F fly ash and fly ash reduced the water demand required due to the presence of silica fume.

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