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# A Review on Effect of fly ash and silica fume partial Replaced by cement on 70 grade HPC

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**Abstract**

This paper formulates a simplified mix design procedure for HPC by combining BIS and ACI code methods of mix design and available literature on HPC. Based on the above procedure M70 mix are arrived at. These HPC mixes are tested experimentally for compression. This work primarily deals with the compressive strength characteristics such as water absorption super plasticizer used in high performance concrete a set of 23 different concrete mixture were cast and tested with different cement replacement levels (0%, 2.5%, 5%, 7.5%, 10% and 12.5%) of Fly ash (FA) with silica fume (SF) as addition ( 0%,2.5%,5%,7.5% 10 % & 12.5% by wt of Cement and/or each trial super plasticizer has been added at constant values to achieve a constant range of slump for desired work ability with a constant water-binder (w/b) ratio of 0.30.

**Keywords:** High Performance Concrete (HPC), Fly Ash, Silica Fume, Cement Replacement, Compressive Strength

## 1. Introduction

High performance concrete has been used more widely in recent years due to the increasing demand for durable concrete in an attempt to extend in service life and reduce maintenance cost of concrete structures. High Performance Concrete (HPC) has emerged as a vital material in the modern construction industry, particularly for infrastructure requiring high strength, enhanced durability, and extended service life. Traditional concrete, while economical, often falls short in aggressive environmental conditions due to its limitations in tensile strength, permeability, and shrinkage resistance. The evolution of HPC addresses these shortcomings by integrating both chemical and mineral admixtures, particularly supplementary cementitious materials (SCMs), such as fly ash and silica fume. The use of mineral admixture such as a fly ash, silica fume and GGBF slag add strength and durability to concrete.

Fly ash, a by-product of coal combustion in thermal power plants, is widely accepted for its pozzolanic characteristics. It reacts with calcium hydroxide liberated during cement hydration to form additional calcium silicate hydrate (C–S–H), which improves the density and long-term strength of concrete. On the other hand, silica fume, a by-product of silicon and ferrosilicon alloy production, has extremely fine particles that significantly enhance the microstructure of concrete, leading to better strength and impermeability.

The synergy between fly ash and silica fume as partial replacements of cement in HPC is of considerable interest, particularly for higher grades such as M70, where durability and compressive strength are critical. Their simultaneous incorporation could result in improved workability, mechanical properties, and resistance to environmental degradation. However, the proportions and replacement levels must be precisely controlled, as excessive substitution may result in diminished early-age strength and poor setting characteristics.

This study investigates the effect of various combinations of fly ash and silica fume in M70 grade concrete on its compressive strength. The motivation stems from the growing need to design sustainable, high-performance building materials by partially replacing Portland cement—a significant contributor to global $CO_2$ emissions—with more environmentally friendly alternatives.

The experimental program involves 23 concrete mix proportions with varying levels of cement replaced by fly ash and silica fume, either individually or in combination. The compressive strength of each mix is analyzed to determine the optimal proportions for maximum strength gain. The concrete is designed according to IS 10262:2009 guidelines and incorporates super plasticizers to ensure adequate workability at a low water-binder ratio of 0.30.

By combining experimental insights with an in-depth literature review, this study aims to contribute to the broader understanding of sustainable high-performance concrete mix design. It is particularly relevant in the Indian context, where the use of industrial by-products in construction is promoted to reduce environmental impact. The results presented herein serve as valuable guidance for structural engineers and researchers aiming to balance strength, durability, and sustainability in advanced concrete technology.

## 2. Literature Review

### 1. Chinnaraju et al. (2011)

The paper evaluates the effect of fly ash and silica fume on the durability properties of HPC. Durability indicators like water absorption, sorptivity, and chloride ion penetration were analyzed. The authors observed that silica fume significantly reduces permeability and enhances microstructural densification, while fly ash contributes to long-term strength gain. Their combined usage improved durability more than when used separately. The research aligns with sustainable construction practices and emphasizes the synergistic effects of dual mineral admixtures. The relevance to the current study is clear: combining both fly ash and silica fume leads to enhanced compressive and durability properties, a central hypothesis of the current experimental investigation.

### 2. Hariharan et al. (2011)

This study focuses on strength development in high-strength concrete incorporating both fly ash and silica fume. The authors explored various mix ratios and concluded that a combination of 10% fly ash and 10% silica fume yielded superior results in terms of compressive and split tensile strength. They also observed reduced setting times and better workability with proper admixture dosage. Their work demonstrates that using both materials together can help overcome individual limitations—such as the slow pozzolanic reaction of fly ash and the high water demand of silica fume. This insight is directly relevant to the present study's methodology of optimizing hybrid combinations for strength.

**3. Islam Laskar & Talukdar (2008)**

This paper proposes a novel mix design approach for HPC by integrating statistical regression models and performance-based criteria. The methodology incorporates locally available materials and evaluates strength and workability simultaneously. Though not focused specifically on fly ash and silica fume, the research establishes an adaptable and practical framework for designing HPC mixes using supplementary materials. The findings are instrumental in justifying the current study's design approach, which follows Indian standards (IS 10262:2009) but modifies mix proportions based on SCM performance.

**4. Mullick (2007)**

Mullick investigates the mechanical performance of binary and ternary blends in concrete, focusing on combinations of Portland cement with fly ash, silica fume, and slag. The study found that ternary blends (cement + fly ash + silica fume) exhibited better early and long-term compressive strength than binary blends. Moreover, the concrete's resistance to acid attack and sulfate exposure improved with these ternary combinations. These results support the hypothesis that blending multiple mineral admixtures can yield superior concrete, validating the multi-blend design strategy of the present study.

**5. Nataraja & Lelin Das (2010)**

This research compares the concrete mix design codes IS 10262:2009, IS 10262:1982, and ACI 211.1-91. The authors emphasize that the newer IS 10262:2009 allows greater flexibility in incorporating SCMs. Their work confirms the suitability of using IS 10262:2009 for modern HPC design, which is the foundation for this research's mix proportioning. They also advocate for experimental validation when incorporating non-traditional materials such as fly ash and silica fume—precisely the focus of the current study.

6. **Perumal & Sundararajan (2004)**

This study evaluates the partial replacement of cement with silica fume in high-strength concrete. The results showed that even at 10% replacement, silica fume significantly improved compressive strength, water tightness, and resistance to chloride penetration. However, they caution that high replacement percentages can lead to workability issues. The findings support the present work's choice to cap silica fume content at 12.5% and validate the benefit of using it in synergy with fly ash to moderate workability and strength outcomes.

**7. Suryawanshi (2007)**

Suryawanshi emphasizes the structural advantages of using HPC in critical infrastructure. The study underlines how high compressive strength, reduced permeability, and enhanced durability make HPC ideal for marine and high-rise applications. The paper highlights the practical importance of experimental validation and the role of admixtures in achieving targeted performance levels. These themes reinforce the practical motivation of this research to achieve superior M70 grade concrete using industrial by-products.

## 3. Methodology

This study was carried out in a structured manner, combining standard mix design guidelines with a tailored experimental program. The methodology can be categorized into the following phases: material selection, mix proportioning, specimen casting, and testing.

- **Material Selection:**

Materials were selected for their suitability in achieving high strength and durability. Ordinary Portland Cement (OPC) 53 grade was used as the primary binder. Fly ash, sourced from Dirk India Pvt. Ltd., Nashik, was selected for its proven pozzolanic activity. Silica fume, acquired from ELKEM Pvt. Ltd., Mumbai, conformed to ASTM C1240 standards. River sand conforming to IS: 383-1970 Zone II was used as fine aggregate. Crushed granite of 12.5 mm size served as coarse aggregate. Glenium B276 superplasticizer was used to maintain workability at low water-binder ratios.

- **Mix Proportioning:**

Concrete mixes were prepared following IS 10262:2009, maintaining a constant water-binder ratio of 0.30 and total binder content of 474 kg/m³. The control mix (M70 grade) used 100% OPC. Other mixes incorporated fly ash and silica fume at varying proportions, either individually or in combination. Twenty-three trial mixes were developed, with cement replacement levels ranging from 5% to 25%.

- **Mixing and Castig Procedure:**

Each concrete batch was mixed in a pan-type mixer. Dry materials were blended first, followed by gradual addition of water mixed with superplasticizer. Cubes of 150 mm × 150 mm × 150 mm were cast in three layers with tamping and vibration to remove entrapped air. Specimens were demolded after 24 hours and cured in water at 27°C for 28 days.

- **Testing:**

Compressive strength tests were performed as per IS 516:1959 on 28-day cured specimens. A minimum of three specimens per mix were tested, and the average values were recorded. Graphs were plotted to analyze the effect of various replacement levels on compressive strength.

- **Data Recording and Analysis:**

Compressive strength results were tabulated and analyzed to identify trends based on the blend proportions. Particular attention was paid to the synergy between fly ash and silica fume in influencing strength. Graphical comparisons were made between equal and unequal replacement levels of the admixtures.

This robust methodology ensured a reliable evaluation of how mineral admixture combinations affect HPC strength, with real-world relevance for structural engineers and construction professionals.

## 4. Data Collection and Analysis

Using the experimental data:

- **Maximum compressive strength (96.22 MPa)** was achieved with **2.5% Fly Ash + 2.5% Silica Fume** replacement.
- The **control mix strength** was 85.76 MPa.
- Most combinations with higher than 15% total replacement showed a decrease in strength.
- The optimal range lies between **5% and 10% total replacement**.
- Graphs revealed non-linear behavior: moderate levels of silica fume improved strength, but higher levels caused marginal reduction due to poor workability and premature stiffening.

The dataset shows that dual mineral admixture systems can significantly improve M70 grade concrete performance when optimized properly.

Table 1

Physical & chemical Properties of Cement and Admixtures

| Property / Composition | Cement | Fly ash | Silica Fume |
|---|---|---|---|
| Specific Gravity | 3.15 | 2.00 to 2.05 | 2.2 |
| Standard Consistency | 29.00% | --- | --- |
| Initial Setting time (Min) | 165 | --- | --- |
| Final Setting Time (Min) | 245 | --- | --- |
| Physical Form | -- | Powder form | Powder form |
| Class | --- | F | --- |
| Chemical composition | | | |
| Silicon Dioxide (SIO2 ) | 20.78% | Min 35 | 90 – 96 % |
| Aluminium Oxide ( Al2O3 ) | 4.44 % | 25 – 29 % | 0.5- 0.8 % |
| Ferric Oxide (Fe2 O3 ) | 2.88 % | 4.5- 4.8 % | 0.2 – 0.8% |
| Calcium Oxide (CaO) | 63.78% | 0.5 – 1.2 % | 0.1 – 0.5 % |
| Magnesium Oxide ( MgO) | 3.66% | 0.3 – 0.5 % | 0.5 – 1.5 % |

Table 2

Basic Properties of Aggregates

| Property | Fine Aggregate | Coarse Aggregate |
|---|---|---|
| Fineness Modulus | 3.04 | 4.03 |
| Specific Gravity | 2.35 | 2.88 |
| Water Absorption | 2.08 | 3.81 |

- **Mix Proportions**

A total of 23 Concrete Mixtures were designed as per IS 10262 -2009 having a constant water binder ratio of 0.30 and total binder content of 474kg / m3 . The control Mixture of grade M70 included ordinary Portland cement alone as the binder, while remaining mixtures incorporated the fly ash as cement replacement material and silica fume as addition. The replacement levels for FA was 2.5%, 5%,7.5 %,10%, & 12.5%. while those of SF were 2.5%, 5%,7.5 %,10%, & 12.5%.by weight of cement as addition. The mixture proportions are summarized in table 3 in which the mixtures were designated according to the type and the amount of cementitious materials included.

- **Casting & Testing**

For the determination of compressive strength 150mm x 150mm cubes were used. All the specimens were moist cured under water until testing.

Table 3

Proportion of cement materials

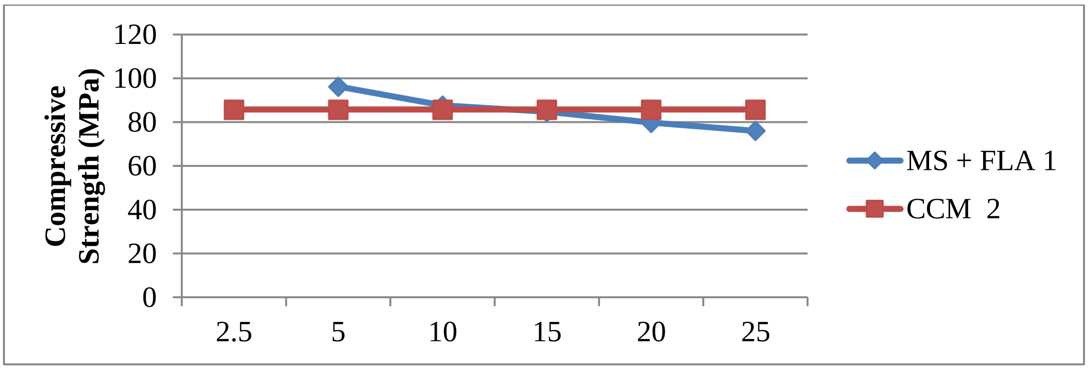
| Sr.No | Mix Description | Cemnt (Kg) | Fly Ash (Kg) | Silica Fume (Kg) |
|---|---|---|---|---|
| 1) | 0 | 5.55 | 0.00 | 0.00 |
| 2) | 2.5% MS + 2.5%FA | 5.275 | 0.137 | 0.137 |
| 3) | 5% MS + 5% FA | 5.00 | 0.275 | 0.275 |
| 4) | 7.5% MS + 7.5%FA | 4.71 | 0.416 | 0.416 |
| 5) | 10 % MS + 10 %FA | 4.44 | 0.55 | 0.55 |
| 6) | 12.5%MS+12.5%FA | 4.16 | 0.69 | 0.69 |
| 7) | 2.5% MS + 7.5%FA | 5.00 | 0.416 | 0.137 |
| 8) | 5% MS + 10%FA | 4.71 | 0.55 | 0.275 |
| 9) | 2.5% MS + 12.5%FA | 4.71 | 0.69 | 0.137 |
| 10) | 0.0% MS + 15%FA | 4.71 | 0.832 | 0.0 |
| 11) | 7.5% MS + 12.5%FA | 4.44 | 0.69 | 0.416 |
| 12) | 5% MS + 15%FA | 4.44 | 0.832 | 0.275 |
| 13) | 5% MS + 20%FA | 4.16 | 1.11 | 0..275 |
| 14) | 10% MS + 15%FA | 4.16 | 0.832 | 0.55 |
| 15) | 5% MS + 0.0%FA | 5.275 | 0 | 0.275 |
| 16) | 0.0% MS + 0.5%FA | 5.275 | 0.275 | 0 |
| 17) | 7.5% MS + 2.5%FA | 5.00 | 0.137 | 0.416 |
| 18) | 10% MS + 5%FA | 4.71 | 0.275 | 0.55 |
| 19) | 12.5% MS + 2.5%FA | 4.71 | 0.137 | 0.69 |
| 20) | 15% MS + 0.0%FA | 4.71 | 0 | 0.832 |
| 21) | 15% MS + 0.5%FA | 4.44 | 0.275 | 0.832 |
| 22) | 20%MS + 5%FA | 4.16 | 0.275 | 1.11 |
| 23) | 15% MS + 10%FA | 4.16 | 0.55 | 0.832 |

Table 4

Test Results

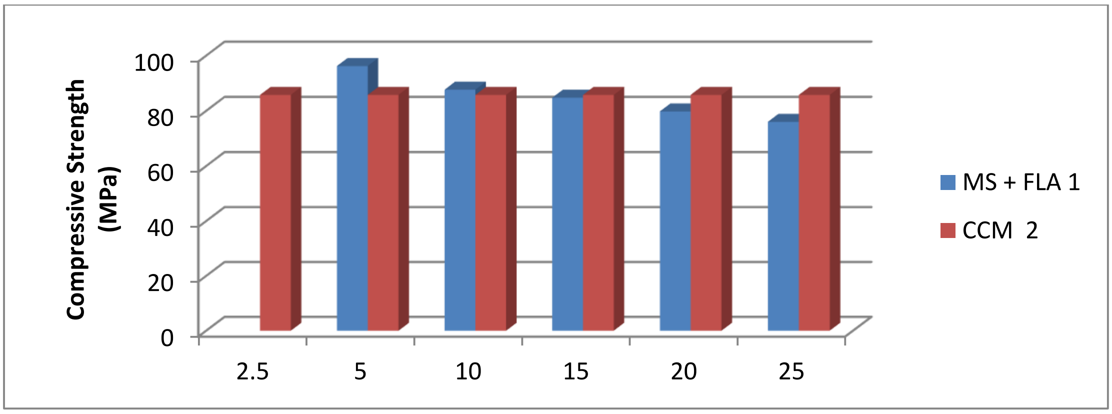
| Sr.No. | Mix Description | Replacement of cement[%] | graph | Compressive Strength [N/MM2] |
|---|---|---|---|---|
| 1 | CCM | 00 | 4.1 | 85.76 |
| 2 | MS 2.5%+FLA 2.5% | 5 | 4.1 | 96.22 |
| 3 | MS 5%+FLA 5% | 10 | 4.1 | 87.66 |
| 4 | MS 7.5%+FLA 7.5% | 15 | 4.1 | 84.74 |
| 5 | MS 10%+FLA 10% | 20 | 4.1 | 79.77 |

| | | | | |
|---|---|---|---|---|
| 6 | MS 12.5%+FLA 12.5% | 25 | 4.1 | 76 |
| 7 | MS 2.5%+FLA 7.5% | 10 | 4.2 | 73.77 |
| 8 | MS 5%+FLA 10% | 15 | 4.2 | 85.11 |
| 9 | MS 2.5%+FLA 12.5% | 15 | 4.2 | 72.29 |
| 10 | MS 0%+FLA 15% | 15 | 4.2 | 71.11 |
| 11 | MS 7.5%+FLA 12.5% | 20 | 4.2 | 70.81 |
| 12 | MS 5%+FLA 15% | 20 | 4.2 | 77.77 |
| 13 | MS 5%+FLA 20% | 25 | 4.2 | 82.66 |
| 14 | MS 10%+FLA 15% | 25 | 4.2 | 92.88 |
| 15 | MS 5%+FLA 0% | 5 | 4.3 | 72.59 |
| 16 | MS 0%+FLA 5% | 5 | 4.3 | 76.88 |
| 17 | MS 7.5%+FLA 2.5% | 10 | 4.3 | 76.22 |
| 18 | MS 10%+FLA 5% | 15 | 4.3 | 83.11 |
| 19 | MS 12.5%+FLA 2.5% | 15 | 4.3 | 70.51 |
| 20 | MS 15%+FLA 0% | 15 | 4.3 | 72.51 |
| 21 | MS 15%+FLA 5% | 20 | 4.3 | 84.88 |
| 22 | MS 20%+FLA 5% | 25 | 4.3 | 75.11 |
| 23 | MS 15%+FLA 10% | 25 | 4.3 | 79.62 |

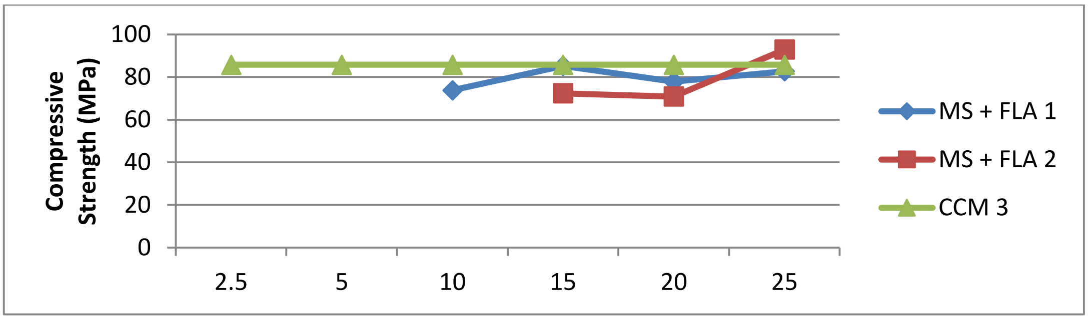



% of Replacement of Cement (with equal percentage of MS & FLA)

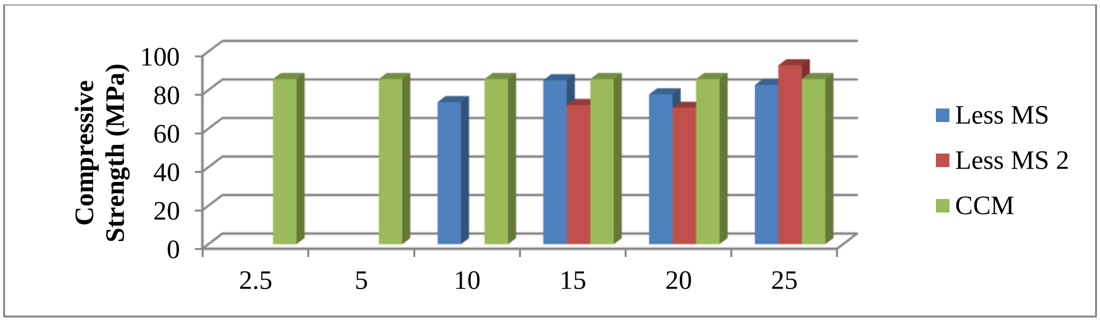
Graph 1- Comparison of compressive strengths of cubes



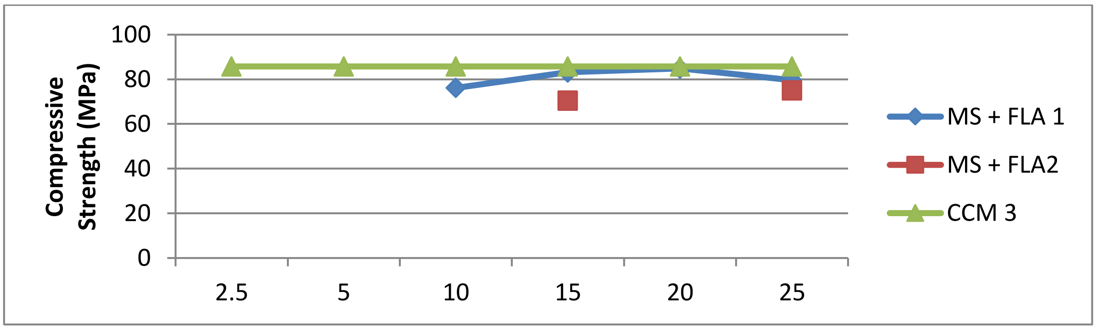

% of Replacement of Cement (with equal percentage of MS & FLA)
Graph 2- Comparison of compressive strengths of cubes



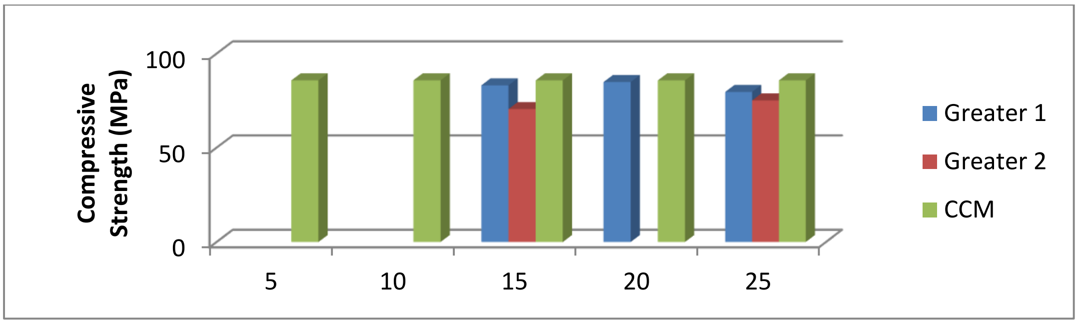

% of Replacement of Cement (with unequal percentage of MS & FLA)
Graph 3- Comparison of compressive strengths of cubes




% of Replacement of Cement (with unequal percentage of MS & FLA)
Graph 4- Comparison of compressive strengths of cubes




% of Replacement of Cement (with unequal percentage of MS & FLA)
Graph 5- Comparison of compressive strengths of cubes




% of Replacement of Cement (with unequal percentage of MS & FLA)

Graph 6- Comparison of compressive strengths of cubes

## 5. Result and Discussion

The results indicate that the partial replacement of cement with fly ash and silica fume has a pronounced effect on the compressive strength of M70 grade concrete. The highest strength gain (96.22 MPa) was observed at a combined replacement level of 5% (2.5% FA + 2.5% SF), an improvement of 12.19% over the control. Beyond 15% replacement, compressive strength began to decline, highlighting a performance threshold.

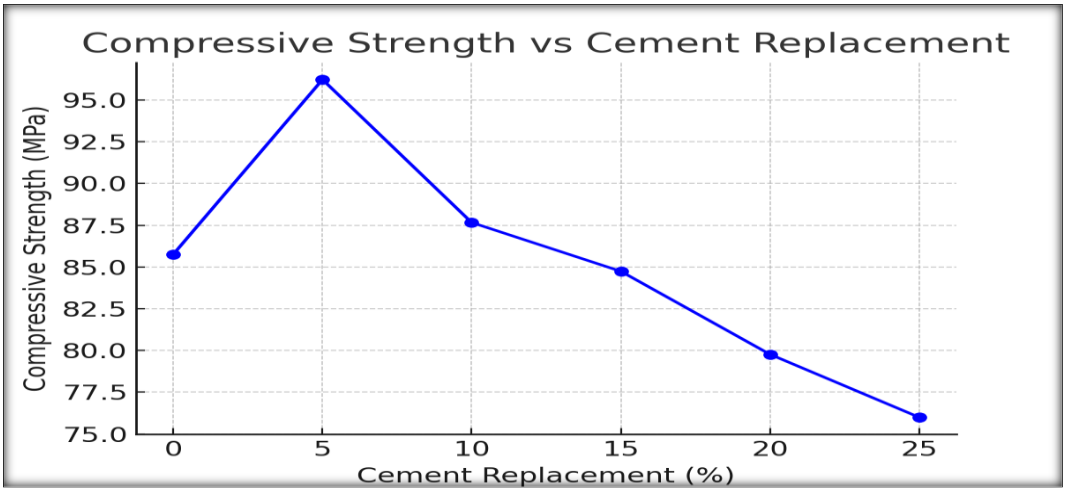
The experimental program involves 23 concrete mix proportions with varying levels of cement replaced by fly ash and silica fume, either individually or in combination. The compressive strength of each mix is analyzed to determine the optimal proportions for maximum strength gain. The concrete is designed according to IS 10262:2009 guidelines and incorporates superplasticizers to ensure adequate workability at a low water-binder ratio of 0.30.

By combining experimental insights with an in-depth literature review, this study aims to contribute to the broader understanding of sustainable high-performance concrete mix design. It is particularly relevant in the Indian context, where the use of industrial by-products in construction is promoted to reduce environmental impact. The results presented herein serve as valuable guidance for structural engineers and researchers aiming to balance strength, durability, and sustainability in advanced concrete technology.

Table : Compressive Strength of Selected Mixes

| Mix Description | Cement Replacement (%) | Compressive Strength (MPa) |
|---|---|---|
| CCM | 0 | 85.76 |
| MS 2.5%+FLA 2.5% | 5 | 96.22 |
| MS 5%+FLA 5% | 10 | 87.66 |
| MS 7.5%+FLA 7.5% | 15 | 84.74 |
| MS 10%+FLA 10% | 20 | 79.77 |
| MS 12.5%+FLA 12.5% | 25 | 76 |

Graph 7: Compressive Strength vs Cement Replacement




Blends with unequal percentages also yielded significant strengths but lacked the uniformity of equal blends. For instance, 10% SF + 5% FA achieved 83.11 MPa, while 7.5% SF + 12.5% FA dropped to 70.81 MPa. The results support the hypothesis that fly ash and silica fume can act synergistically when used in moderate and balanced amounts.

## 6. Conclusion

This study investigated the effect of replacing cement with fly ash and silica fume in M70 grade high performance concrete. The primary objective was to determine an optimal combination that maximizes compressive strength while promoting sustainability in construction materials.

The experimental findings revealed that using fly ash and silica fume together leads to a substantial improvement in compressive strength compared to the control mix. The best-performing mix included 2.5% of each material, achieving a compressive strength of 96.22 MPa, 12.19% higher than the control. This improvement is attributed to the combined pozzolanic reaction of both materials and the refined microstructure due to the ultra-fine nature of silica fume.

It was also observed that higher replacement levels (>15%) led to a decline in strength, possibly due to reduced cementitious content and delayed pozzolanic reaction of fly ash. The use of superplasticizers helped maintain workability even at a low water-binder ratio of 0.30.

The study underscores the importance of proportion optimization when using multiple mineral admixtures. While both fly ash and silica fume individually contribute to enhanced concrete properties, their synergistic effect can lead to superior results if properly balanced.

From a sustainability perspective, this research supports the use of industrial by-products to reduce cement consumption and environmental impact. These findings can inform future HPC mix designs in infrastructure projects where strength and durability are critical.

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