

# Effect of Silica Fume and Fly Ash as Partial Replacement of Cement on Strength of Concrete

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**ABSTRACT:** Concrete is the most versatile construction material because it can be designed to withstand harshest environments while taking on the most inspirational forms. Nowadays, most concrete mixture contains supplementary cementitious material which forms part of the cementitious component. The main benefits of SCMs are their ability to replace certain amount of cement and still be able to display cementitious property, thus reducing the cost of using Portland cement. The fast growth in industrialisation has resulted in tons and tons of by-product or waste materials, which can be used as SCMs such as Fly Ash, Silica Fume, Ground Granulated Blast Furnace Slag, Steel Slag, etc. The use of these by-products not only helps to utilise these waste materials but also enhances the properties of concrete in fresh and hardened states. Perhaps the most successful SCM is silica fume because it improves both strength and durability of concrete to such extent that modern design rules call for the addition of silica fume for design of high strength concrete. To design high strength concrete good quality aggregates is also required.

In the present work a series of tests were carried out to make comparative studies of various mechanical properties of concrete mixes prepared by using Reliance OPC 43 grade cement. The mixes are modified by 7.5%, 10% and 12.5% of silica fume in replacement. After optimizing the percentage of silica fume, the silica fume is then blended with fly ash, keeping the percentage of cement fixed. The optimum percentage of silica fume comes out to be 10%. The fine aggregate used is natural sand comply to zone III as per IS: 383-1982. The properties studied are 7 days and 28 days compressive strength; 28 days split tensile strength and 28 days flexural strength.

**KEYWORDS:** Supplementary cementitious materials, fly ash, silica fumes, strengths of concrete.

## I. INTRODUCTION

Concrete is a mixture of cement, sand, coarse aggregate and water. Its success lies in its versatility as can be designed to withstand harshest environments while taking on the most inspirational forms. Any construction activity requires several materials such as concrete, steel, brick, stone, clay, mud, glass, wood and many more. However, the cement concrete remains the main construction material used in construction industry. For its suitability and adaptability with respect to the changing environment, the concrete must be such that it can conserve resources, protect the environment and at the same time be economic too. To achieve this, major emphasis must be laid on the reuse of by-products or waste materials from industrial processes. The cement industry is held responsible for some of the carbon dioxide emission, because in the production of one ton of Portland cement, approximately one ton of carbon dioxide gas is emitted into the atmosphere. The emission of carbon dioxide will increase the effect of global warming due to the emission of greenhouse gases. Among the greenhouse gases, carbon dioxide contributes about 65% of global warming. The usage of silica fumes and fly ash to partially replace the cement is because the production of cement emits carbon dioxide gas to the atmosphere. Engineers and scientists are further trying to increase its limits with the help of innovative chemical admixtures and various supplementary cementitious materials SCMs.

More recently, strict environmental – pollution controls and regulations have produced an increase in the industrial wastes and sub graded by-products which can be used as SCMs such as fly ash, silica fumes, ground granulated blast furnace slag etc. The use of SCMs in concrete constructions not only prevents these materials to check the pollution but also to enhance the properties of concrete in fresh and hydrated states.

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Early SCMs consisted of natural, readily available materials like volcanic ash or diatomaceous earth. The engineering marvels like Roman aqueducts, the Coliseum are examples of this technique used by Greeks and Romans. Nowadays, most concrete mixture contains SCMs which are mainly by-products or waste materials from other industrial processes. Sustainability was a big issue that being concern in making a development. This is because sustainable development has become a key aspect in society, economics and development. Sustainable development shall meet the needs of the present without compromising ability of future generations to meet their own needs. It also shows that the development that is going to be made to sustain the planetary resources by using them effectively without making unnecessary wastage.

## II. EXPERIMENTAL PROGRAM AND APPROACH

### A. MATERIAL OF SPECIMEN

To obtain the best percentages of mix proportions, separate castings of test specimens were conducted. Concrete materials were mixed as per standards of IS: 10262. OPC was used and its physical and chemical properties are tabulated in table 1. River sand passing through IS 4.75 mm sieve confirming to grading zone III as per IS: 383 – 1970 was used as fine aggregate which were free from organic chemicals and unwanted clay. Crushed granite stone with a maximum size of 20 mm was used as coarse aggregate. The water available from laboratory tap water was used in the production of concrete. The same water was used for the subsequent curing of the test specimens. Silica fume was supplied by Krishna Glass Udyog, Bardhaman, West Bengal. The physical and chemical analysis of the constituents of silica fume is tabulated in table 1. Finely ground fly ash was obtained from Maithon Power Ltd., Maithon. The physical and chemical analysis of the constituents of fly ash is tabulated in table 1.

**Table 1: Physical and Chemical Properties of OPC, Silica Fume and Fly Ash**

Properties	Ordinary Portland Cement	Silica Fume	Fly Ash
Specific Gravity	3.12	2.24	2.85
Fineness	370 m <sup>2</sup> /kg	20400 m <sup>2</sup> /kg	423 m <sup>2</sup> /kg
Consistency	26 %	-	42 %
Initial Setting Time (min.)	27	-	-
Final Setting Time (min.)	529	-	-
Bulk Density	-	240 kg/m <sup>3</sup>	-
SiO <sub>2</sub>	21.02 %	91.4 %	53.92 %
Al <sub>2</sub> O <sub>3</sub>	5.68 %	1.1 %	21.0 %
Fe <sub>2</sub> O <sub>3</sub>	3.53 %	0.3 – 0.5 %	3.9 – 4.3 %
MgO	1.1 %	1.3 %	2.2 %
CaO	62.25 %	0.7 %	4.0 %
SO <sub>3</sub>	3.0 %	-	0.6 %
Na <sub>2</sub> O	0.15 %	0.8 %	-
K <sub>2</sub> O	0.35 %	0.5 %	-
TiO	-	-	0.98 %
C	-	0.9 %	18.92 %
S	-	1.8 %	-
Loss of Ignition	1.05 %	2.4 %	1.9 %

### B. MIX PROPORTIONS OF SPECIMEN

The mixture proportions of all specimens for replacement of cement with silica fume and fly ash are tabulated in table 2. The replacement levels of cement by weight with silica fume were

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selected as 7.5%, 10% and 12.5%. At 10% replacement level, maximum compressive strength, split tensile strength and flexural strength is obtained. Now keeping cement fixed at 90%, blending of silica fume and fly ash is done in different percentages (SF 8% + FA 2%, SF 6% + FA 4%, SF 5% + FA 5%, SF 4% + FA 6% and SF 2% + FA 8%). For all specimens, the w/c ratio is kept constant at 0.43.

### C. CASTING OF SPECIMEN AND CURING

Three types of specimens were casted to conduct all sort of test regarding strength. Standard cube specimen of dimension 150mm x 150mm x 150mm for compressive strength test, cylinder specimen of 150mm dia. with 300mm length for splitting tensile strength test, and beam specimen of dimension 100mm x 100mm x 500mm for flexural strength test were casted. During curing period, the samples were stored in a place free from vibrations and in relatively moist air at temperature range from 25 – 27°C. After 24 hours the mould is removed and marked with symbol to identify later and finally cured under clean fresh water.

**Table 2: Mix Proportions**

Specimen ID	w/c Ratio	Cement (Kg/m <sup>3</sup> )	Silica Fume		Fly Ash		Aggregates (Kg/m <sup>3</sup> )		Water (Kg/m <sup>3</sup> )
			%	Kg/m <sup>3</sup>	%	Kg/m <sup>3</sup>	Fine	Coarse	
M <sub>1</sub>	0.43	433	0	0	0	0	625	1164	195.80
M <sub>2</sub>	0.43	400.53	7.5	32.47	0	0	625	1164	195.80
M <sub>3</sub>	0.43	389.70	10.0	43.30	0	0	625	1164	195.80
M <sub>4</sub>	0.43	378.86	12.5	54.14	0	0	625	1164	195.80
M <sub>5</sub>	0.43	389.70	8.0	34.64	2.0	8.66	625	1164	195.80
M <sub>6</sub>	0.43	389.70	6.0	25.98	4.0	17.32	625	1164	195.80
M <sub>7</sub>	0.43	389.70	5.0	21.65	5.0	21.65	625	1164	195.80
M <sub>8</sub>	0.43	389.70	4.0	17.32	6.0	25.98	625	1164	195.80
M <sub>9</sub>	0.43	389.70	2.0	8.66	8.0	34.64	625	1164	195.80

### D. TESTING OF SPECIMEN

To measure the workability of concrete, slump test was conducted. Compressive strength of cube specimen as per Indian Standards was conducted by UTM for 7 and 28 days, splitting tensile strength for cylinder specimen and flexural strength for beam specimen were also observed for 28 days.

## III. RESULTS AND DISCUSSIONS

### A. WORKABILITY

The slump value for all the mixes doesn't show any specific trend towards determination of workability. However, it is observed that when cement is partially replaced with Silica Fume in different percentages, the slump values recorded were found to be in accordance with the design mix. But when silica fume was blended with fly ash, the workability gets affected. A fluctuation in the slump values is recorded.

### B. COMPRESSIVE STRENGTH

*For replacement of OPC by Silica Fume*

Silica Fume has strong effects on compressive strength of concrete after 7 and 28 days of curing. The variation of compressive strength for different replacement levels of OPC by silica fume for 7 and 28 days is shown in fig. 1. For 7 days concrete it was observed that maximum compressive strength (31.11 N/mm<sup>2</sup>) was exhibited when cement was

replaced with 10% silica fume by weight. For 28 days concrete the maximum compressive strength (45.33 N/mm<sup>2</sup>) was obtained when cement was replaced with 10% silica fume by weight.

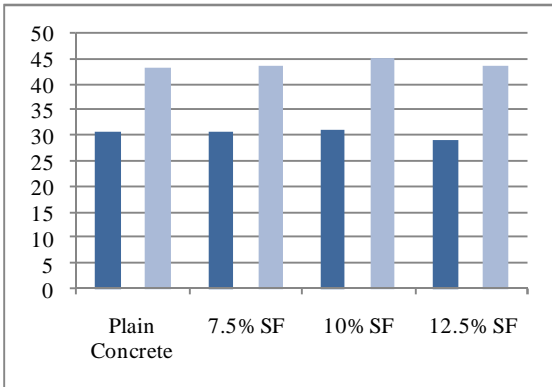


Fig. 1: Variation of Compressive Strength for different levels of Silica Fume for 7 & 28 days

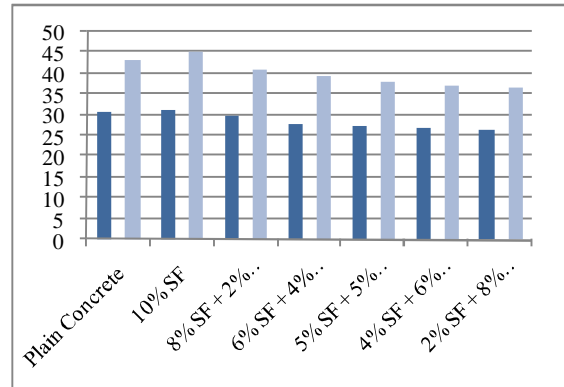


Fig. 2: Variation of Compressive Strength for different levels of Silica Fume & Fly Ash for 7 & 28 days

*For replacement of OPC by Silica Fume and Fly Ash*

Fly Ash also has strong effects on compressive strength of concrete. Keeping the percentage of cement fixed at 90%, when silica fume is partially replaced with fly ash, it was observed that the compressive strength continuously decreases for different percentage mixes of silica fume and fly ash for both 7 & 28 days respectively as shown in fig. 2.

### C. SPLIT TENSILE STRENGTH

*For replacement of OPC by Silica Fume*

Optimum percentage of silica fume can play a great role in increasing the split tensile strength. The split tensile strength for different replacement levels of OPC by silica fume for 28 days aged concrete is shown in fig. 3. Maximum split tensile strength (4.61 N/mm<sup>2</sup>) for 28 days aged concrete is obtained when cement is replaced with 10% silica fume by weight.

*For replacement of OPC by Silica Fume and Fly Ash*

The split tensile strength for different replacement levels of OPC by silica fume and fly ash for 28 days aged concrete is shown in fig. 4. Keeping the percentage of cement fixed at 90%, when silica fume is partially replaced with fly ash, it was observed that the split tensile strength continuously decreases for different percentage mixes of silica fume and fly ash for both 28 days curing.

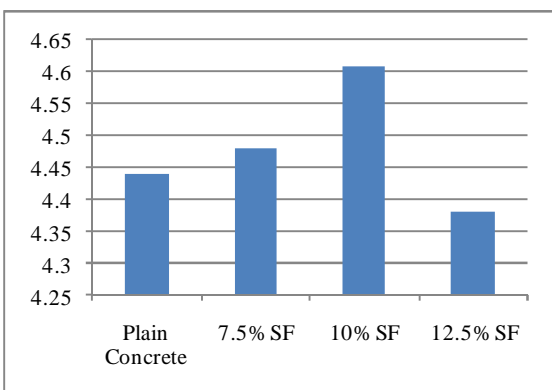


Fig. 3: Variation of Split Tensile Strength for different levels of Silica Fume for 28 days

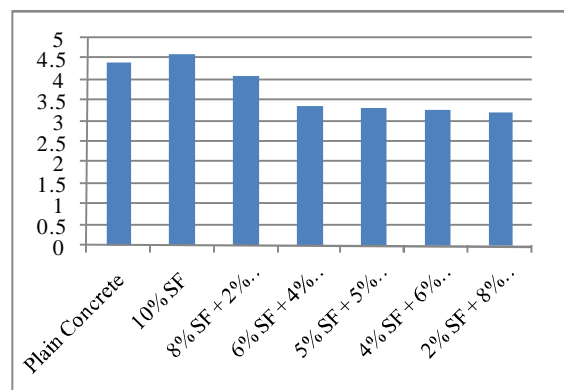


Fig. 4: Variation of Split Tensile Strength for different levels of Silica Fume & Fly Ash for 28 days

### D. FLEXURAL STRENGTH

#### For replacement of OPC by Silica Fume

Silica fume has strong effects in flexural strength of concrete for 28 days curing. The variation of flexural strength for different replacement levels of OPC by silica fume for 28 days aged concrete are shown in fig. 5. Maximum flexural strength (4.55 N/mm<sup>2</sup>) for 28 days aged concrete is obtained when cement is replaced with 10% silica fume by weight. So ultimately it can be decided that the partial replacement of 10% OPC by silica fume was found to be optimum.

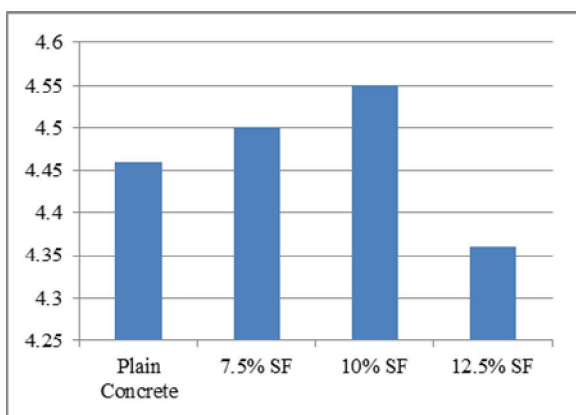


Fig. 5: Variation of Flexural Strength for different levels of Silica Fume for 28 days

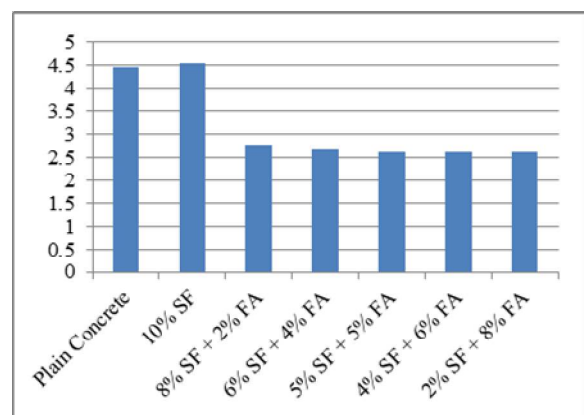


Fig. 6: Variation of Flexural Strength for different levels of Silica Fume & Fly Ash for 28 days

#### For replacement of OPC by Silica Fume and Fly Ash

Fly Ash has strong effects in flexural strength of concrete for 28 days aged concrete. The variation of flexural strength for different replacement levels of OPC by silica fume for 28 days aged concrete are shown in fig. 6. Keeping the percentage of cement fixed at 90%, when silica fume is partially replaced with fly ash, it was observed that the flexural strength continuously decreases for different percentage mixes of silica fume and fly ash for both 28 days curing. So it is clear that the replacement of silica fume with fly ash in different percentages adversely affects the flexural strength of concrete for 28 days aged concrete.

### E. COST ANALYSIS

The constituent materials for this experimental investigation were procured locally. Hence local market rates are considered for cost – benefit analysis.

For 1m<sup>3</sup> of concrete,

Cement	= 433 kg @ Rs. 7.00 per kg	= Rs. 3031.00
Coarse aggregate	= 0.43 m <sup>3</sup> @ Rs. 1600.00 per m <sup>3</sup>	= Rs. 688.00
Fine aggregate	= 0.25 m <sup>3</sup> @ Rs. 700.00 per m <sup>3</sup>	= Rs. 175.00
<b>Total cost of 1 m<sup>3</sup> concrete</b>	<b>= Rs. (3031.00 + 688.00 + 175.00)</b>	<b>= Rs. 3894.00</b>

When cement is replaced with 10 % silica fume by weight

Cement	= 389.7 kg @ Rs. 7.00 per kg	= Rs. 2728.00
Silica Fume	= 43.3 kg @ Rs. 4.00 per kg	= Rs. 173.00
Coarse aggregate	= 0.43 m <sup>3</sup> @ Rs. 1600.00 per m <sup>3</sup>	= Rs. 688.00
Fine aggregate	= 0.25 m <sup>3</sup> @ Rs. 700.00 per m <sup>3</sup>	= Rs. 175.00
<b>Total cost of 1 m<sup>3</sup> concrete</b>	<b>= Rs. (2728.00 + 173.00 + 688.00 + 175.00)</b>	<b>= Rs. 3764.00</b>
<b>Different in total cost per m<sup>3</sup> of concrete</b>	<b>= Rs. (3894.00 – 3764.00)</b>	<b>= Rs. 130.00</b>

$$\text{Percentage savings} = \frac{130}{3894} \times 100 = 3.34\%$$

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## IV. CONCLUSION

From the whole investigations and research, the following conclusions can be drawn:

1. Pozzolanic materials have significant influence on mechanical properties of concrete.
2. The maximum compressive strength increased by 1.43% after 7 days and 4.42% after 28 days at 10% replacement of cement by weight with silica fume. However when silica fume was blended with fly ash in different percentages, a continuous decrease in compressive strength was recorded.
3. The maximum split tensile strength increased by 3.83% after 28 days at 10% replacement of cement by weight with silica fume. However when silica fume was blended with fly ash in different percentages, a continuous decrease in splitting tensile strength was recorded.
4. The maximum flexural strength increased by 1.79% after 28 days at 10% replacement of cement by weight with silica fume. However when silica fume was blended with fly ash in different percentages, a continuous decrease in flexural strength was recorded.
5. The strength characteristics of high performance concrete can be improved considerably by replacing the Ordinary Portland Cement with silica fume. However blending of silica fume with fly ash results in a decrease in strength of concrete.
6. In terms of economy, replacement of cement with silica fume results in cost reduction considerably for large projects. About 3 – 3.5 % of the total concreting cost could be saved.
7. The replacement of cement with silica fume is environment friendly in nature. One of the biggest benefits of using silica fume is reduction in CO<sub>2</sub> emissions, which is the main cause of Green – house effect.

From the complete investigation and the results of this work, it may be recommended that blending of silica fume and fly ash should not be done to increase the strength characteristics of concrete. Silica fume alone is enough to enhance the quality. Use of silica fume is economical and also eco – friendly in nature.

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