Approach of Silica Fume in Civil Engineering

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Abstract - *Cement is one of the most essential materials in the construction industry. However, continuous efforts are being made to enhance its performance and sustainability to fulfill the increasing demands. Cement is becoming a scarce commodity globally due to its rapid consumption and also contributes significantly to CO_2 emissions. To reduce environmental impact and improve concrete properties, supplementary cementitious materials such as silica fume are used. This study investigates the utilization of silica fume as a partial replacement of cement in M30 grade concrete using OPC 53 grade cement. The replacement levels considered are 0%, 5%, 10%, and 15% by weight of cement. Artificial sand is used as a complete replacement for natural river sand to promote eco-friendly construction practices. The experimental work includes mix design, casting of concrete cubes, and testing at curing periods of 7, 14, and 28 days. The study focuses on evaluating compressive strength, workability, and overall performance of concrete. Silica fume, being an ultrafine material rich in silicon dioxide (SiO_2), reacts pozzolanically with calcium hydroxide to form additional calcium silicate hydrate (C–S–H), resulting in improved strength and dense microstructure.*
The results aim to determine the optimum percentage of silica fume that provides maximum strength without compromising workability. This study contributes to the development of high-performance, durable, and sustainable concrete for modern civil engineering applications.

***Key Words*: Silica Fume, High Performance Concrete, Artificial Sand, Pozzolanic Reaction, Durability, Workability, Strength performance, Modern civil engineering applications**

1.INTRODUCTION

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and versatility. However, the increasing demand for construction has led to excessive use of natural resources such as cement and river sand, causing environmental concerns and resource depletion. To address these issues, the use of alternative and sustainable materials has become essential.

Silica fume, a by-product of silicon and ferrosilicon industries, is a highly reactive pozzolanic material used as a partial replacement for cement. It improves the strength, durability, and impermeability of concrete. At the same time, manufactured sand (M-sand) is emerging as a suitable alternative to river sand due to its consistent quality, better bonding properties, and eco-friendly nature.

The combined use of silica fume and manufactured sand helps in producing high-performance and sustainable concrete. This study focuses on evaluating their effects on the strength and durability characteristics of concrete.

1.1 MATERIALS USED IN CONCRETE

Concrete is composed of several essential materials including cement, fine aggregate, coarse aggregate, water, and mineral admixtures like silica fume. Each material plays a crucial role in determining the strength and durability of concrete.

1.1.1 Cement

Cement is a fine grey powder made from limestone and clay. When mixed with water, it undergoes hydration and forms a strong binding material. It contains compounds such as lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), which contribute to strength and durability.Ordinary Portland Cement (OPC) 53 grade was selected for this study due to its superior strength characteristics and widespread application in high-performance concrete. A comprehensive evaluation of cement quality was carried out through both field and laboratory testing methods. Preliminary identification tests such as colour, lump, float, and temperature assessment confirmed that the cement was fresh, free from moisture contamination, and in satisfactory condition for construction use. Advanced laboratory tests including fineness, specific gravity, standard consistency, and soundness were performed in accordance with IS 4031 specifications to ensure compliance with standard requirements. The fineness of cement was determined as 3%, indicating adequate particle size for effective hydration. The specific gravity value of 3.12 falls within the acceptable range for OPC, confirming its density characteristics. The standard consistency was found to be 32%, ensuring proper water demand for achieving desired workability. Furthermore, the soundness test showed an average expansion of 2.0 mm, which is significantly lower than the permissible limit, indicating volumetric stability of the cement. Overall, the test results demonstrate that the OPC 53 grade cement used in this investigation satisfies all relevant IS code provisions and is highly suitable for producing durable and high-strength concrete.

1.1.2 Silica Fume

Silica fume is an ultra-fine by-product obtained during the production of silicon metal. It consists mainly of amorphous silicon dioxide (SiO_2). Due to its very fine particles, it reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H), which enhances concrete strength and durability. Silica fume is an ultrafine by-product obtained from the production of silicon and ferrosilicon alloys. It is mainly composed of amorphous silicon dioxide (SiO_2) and is widely used as a pozzolanic material in concrete. In this study, silica fume was tested for its suitability through laboratory tests such as specific gravity, fineness, and chemical composition. The specific gravity was found to be within the standard range, while the fineness test confirmed its extremely fine particle size. The high silica content ensures strong pozzolanic activity, which reacts with calcium hydroxide to form additional calcium silicate hydrate (C–S–H). This improves the strength, durability, and density of concrete. Due to its micro-filling ability and high reactivity, silica fume enhances particle packing, reduces porosity, and increases bonding in the cement matrix, making it highly useful in high-performance and sustainable concrete.

Fig -1: Silica fume

1.1.2.1 Properties of Silica Fume

Appearance: Very fine powdered form

- Colour: Dark grey
- Texture: Extremely fine and smooth
- Silicon Dioxide (SiO_2): Minimum 89%
- Specific Gravity: 2.20
- Particle Size: ~0.1 micron (100 times finer than cement)
- Surface Area: 15,000–30,000 m^2/kg
- Nature: Highly pozzolanic
- Particle Shape: Spherical
- Reactivity: Very high

1.1.3 FINE AGGREGATE

Fine aggregate used in this study was manufactured sand (M-Sand), obtained by crushing hard granite stones and used as a complete replacement for natural river sand. The material was light brownish grey in colour, clean, and free from organic impurities, making it suitable for concrete production. The silt content test showed a value of 1.2%, which is within the permissible limit of 3%, indicating that the sand is clean. The float test confirmed the absence of clay and organic impurities, ensuring good quality material. Sieve analysis was conducted to determine grading, and the sand was found to fall under Zone II, indicating well-graded sand suitable for concrete. The fineness modulus was calculated as 2.13, confirming appropriate particle size distribution. The specific gravity test yielded an average value of 2.46, which lies within the permissible IS range, indicating good density characteristics. The water absorption test showed a value of 3.54%, which is within acceptable limits for fine aggregate. Overall, all test results satisfy IS 383:2016 and IS 2386 standards, confirming that the M-Sand is clean, well-graded, and suitable for use as fine aggregate in concrete

1.1.4 River Sand

River sand is naturally obtained from riverbeds. It has smooth and rounded particles but may contain impurities like silt and clay.

1.1.5 Manufactured Sand (M-Sand)

Manufactured sand is produced by crushing hard stones like granite. It has angular particles, better bonding properties, and consistent quality. It is more economical and environmentally friendly compared to river sand.

1.1.6 COARSE AGGREGATE

Coarse aggregates are large-sized materials such as gravel or crushed stones retained on a 4.75 mm sieve. They provide strength and stability to concrete. The coarse aggregate used in this study was 20 mm size crushed angular stone obtained from a local quarry. The aggregates were hard, clean, and free from dust, clay, and organic impurities, ensuring good quality. Sieve analysis confirmed that the aggregate is well graded and suitable for concrete work. The specific gravity was found to be 2.68, which lies within the permissible range, indicating good density characteristics. The water absorption was observed as 3.86%, which is slightly higher than the recommended limit, indicating porous nature but acceptable with proper mix design adjustments. The aggregate crushing value was 27%, which is within the permissible limit, confirming adequate strength. Overall, all test results satisfy IS 383:2016 and IS 2386 standards, indicating that the coarse aggregate is suitable for concrete production.

1.1.7 WATER

Water available on the college campus was used for mixing and curing concrete. The water was clear, colourless, and free from visible impurities and odour, indicating good quality. Various tests were conducted to assess its suitability as per IS 456:2000 standards. Visual inspection and odour tests confirmed that the water was clean and free from harmful substances. The taste test indicated slight hardness due to dissolved salts; however, it was within acceptable limits. The pH value was found to be 7.2, which lies within the permissible range for concrete use. No floating impurities were observed during the standing water test, confirming its cleanliness. Although the water was slightly hard in nature, all test results satisfy IS code requirements, indicating that it is suitable for use in concrete.

1.2 ADVANTAGES OF SILICA FUME

- High compressive strength
- Low permeability
- Improved durability
- Better bonding with reinforcement
- High resistance to chemical attack
- Reduced water permeability
- Increased abrasion resistance
- 1.3 ADVANTAGES OF MANUFACTURED SAND
- Eco-friendly alternative to river sand
- Better strength due to angular particles
- Consistent quality and grading
- Cost-effective
- Reduced environmental impact
- Improved durability of concrete paper.

2. OBJECTIVES

● To analyze the workability of silica fume concrete mixes.

● To determine the optimum replacement percentage of silica fume.

● To study the effect of silica fume on the strength of concrete.

● To completely replace river sand with artificial sand (M-Sand) and evaluate its

effect on workability and strength.

● To understand the role of silica fume in improving durability.

3. LITERATURE REVIEW

Kaci Chalah, Aghiles Hammas, and Abdelbaki Benmounah [2024]they have studied Improvement of Physical and Mechanical Properties of High-Performance Sand Concrete with Different Silica Fume Content. Advances in Civil and Architectural Engineering, 15(29), 19–32. The study examined high-performance sand concrete with 0%, 4%, 6%, and 8% silica fume replacement at a water–cement ratio of 0.35. Results indicated that 6% silica fume content was optimal, improving compressive strength by 6.19% and flexural strength by 10.03%, while reducing water absorption by 8.8% and capillary absorption by 8.57%. Beyond this level, further improvement was minimal. The authors concluded that moderate silica fume (≈6%) effectively enhances the strength and durability of high-performance sand concrete.

Judita Gražulytė, Audrius Vaitkus, Ovidijus Šernas, and Donatas Čygas [2020].

In this paper they have studied Effect of Silica Fume on High-Strength Concrete Performance. In Proceedings of the International Conference on Sustainable Engineering and Concrete Technology (ICSECT). The research analyzed silica fume as a partial replacement for cement at 0%, 7%, and 10% levels with a constant w/c ratio of 0.4. Results revealed that 7% silica fume gave the best performance, improving compressive strength by 12–15%, tensile strength by 10%, and flexural strength by 9%. The authors concluded that silica fume enhances compactness, reduces microcracks, and refines the concrete matrix due to its pozzolanic and micro-filling properties.

Kumar, R., & Dhaka, J. [2016]. Review Paper on Partial Replacement of Cement with Silica Fume and Its Effects on Concrete Properties. International Journal for Technological Research in Engineering, 4(1), 83–85. They investigated M35 grade concrete with 0%, 5%, 10%, and 15% silica fume replacement. They observed that partial cement replacement enhanced compressive strength significantly at 7, 14, and 28 days, with optimum results around 10% replacement.

Mehta, P. K., & Monteiro, P. J. M. [2014]. Concrete: Microstructure, Properties and Materials (3rd ed.). McGraw-Hill Education. They discussed that silica fume particles, being extremely fine (about 100 times smaller than cement), fill voids and refine pore structure, resulting in increased strength and lower permeability. They highlighted improved resistance against chloride and sulfate attacks.

Neville, A. M. [2011]. Properties of Concrete (5th ed.). Pearson Education. Silica fume enhances the interfacial transition zone (ITZ), the weakest region in normal concrete, leading to improved bond and strength properties.

Pradhan, D., & Dutta, D. [2013]. Effects of Silica Fume in Conventional Concrete. International Journal of Engineering Research and Applications, 3(5), 24–30.Replacing 20% of cement with silica fume yielded the highest compressive strength at all curing ages (24 hours, 7, 14, and 28 days).

Ajileye, F. V. [2012]. Investigations on Microsilica (Silica Fume) as Partial Cement Replacement in Concrete. Global Journal of Research in Engineering: Civil and Structural Engineering, 12(1), 17–23. Studied M35 grade concrete with silica fume replacement up to 15%. The results showed that up to 10% replacement increased compressive strength by 16.15–29.24%, while at 15% replacement, the strength decreased, suggesting an optimal limit at 10%.

Amudhavalli, N. K., & Mathew, J. [2012]. Effect of Silica Fume on Strength and Durability Parameters of Concrete. International Journal of Engineering Sciences & Emerging Technologies, 3(1), 28–35. Investigated M40–M50 grade concrete with silica fume at 0%, 5%, 10%, and 15%. The results showed that silica fume improved compressive strength and durability parameters at all levels, with the best results around 10%.

Roy, D., & Sil, S. [2012]. Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete. International Journal of Emerging Technology and Advanced Engineering, 2(8), 472–475. Observed that 10% silica fume replacement achieved maximum compressive strength, about 19.65% and 16.82% higher than that of normal concrete.

Siddique, R. [2011]. Utilization of Industrial By-products in Concrete. Resources, Conservation and Recycling, 55(4), 459–467. Reviewed the use of silica fume, fly ash, and GGBS as supplementary cementitious materials. Silica fume enhanced compressive strength, reduced permeability, and improved chemical resistance, supporting sustainable concrete production.

Tahir Gonen, & S. Yazıcıoğlu [2007]. The Influence of Mineral Admixtures on the Short and Long-Term Performance of Concrete. Building and Environment, 42(8), 2980–2985. Investigated silica fume, fly ash, and GGBS. Silica fumes showed the highest early compressive strength and lowest permeability, though it reduced workability, making it suitable for high-performance concrete.

4.METHODOLGY

Step-1: Collection and Testing of Materials

Step-2: Primary Test on Materials

Step-3: Preparation of Mix Design

Step-4: Batching & Mixing of Concrete:

Step-5: Test on Fresh Concrete

Step-6: Casting & curing of Specimens

Step-7: Testing of Specimens

Step-8: Analysis of Results

Step-9: Conclusion & Report Preparation

1.Collection and Testing of Materials: The materials used in this study were carefully selected and tested to ensure their suitability for preparing concrete with silica fume and artificial sand. Each material was examined through basic field tests and laboratory tests according to the Indian Standard codes.

2.Primary Test on Materials: Primary tests were conducted on all construction materials to evaluate their basic properties and suitability for concrete production. Cement was tested for fineness, specific gravity, standard consistency, and soundness, and the results were found within permissible IS limits. Fine aggregate (M-sand) was tested for silt content, grading, specific gravity, and water absorption, confirming that it is clean and well graded. Coarse aggregate was examined for shape, grading, specific gravity, and crushing strength, indicating good quality and adequate strength. Silica fume was tested for fineness, specific gravity, and chemical composition, confirming its high pozzolanic reactivity. Water was tested for pH, impurities, and hardness, and was found suitable for mixing and curing. Overall, all materials satisfied relevant IS code requirements, confirming their suitability for use in concrete.

3.Preparation of Mix Design: The mix design for M30 grade concrete was carried out in accordance with IS 10262:2009 and IS 456:2000 guidelines. The design was done to achieve the required strength and workability with proper proportioning of materials. Based on the calculations, the final mix proportions for 1 m^3 of concrete were obtained as follows:

Table: 1-Mix Proportion for 1 m^3 Concrete

Material	Quantity
Grade	M30
Cement	371 kg/m^3
Fine Aggregate	640 kg/m^3
Coarse Aggregate	1325 kg/m^3
Water	156 kg/m3
Water-cement Ratio	0.42

Table: 2-Material Requirement for 36 Cubes (M30 Mix)

Silica fume %	0%	5%	10%	15%
Cement (kg)	50	47.5	45	42.5
Silica fume (kg)	0	2.5	5	7.5
Water (lit)	21	21	21	21
Fine aggregate (kg)	86	86	86	86
Coarse aggregates (kg)	178	178	178	178

5.Test on Fresh Concrete: The slump cone test was performed to evaluate the workability and consistency of fresh concrete. The concrete showed a uniform subsidence without segregation, indicating good cohesiveness. The slump value obtained for the control mix was 70 mm, which represents medium workability suitable for normal RCC construction.

Table: 3-Slump values

Mix %	Height After Subsidence (mm)	Slump (mm)
0	230	70
5	235	65
10	240	60
15	245	55

It was observed that as the percentage of silica fume increased from 0% to 15%, the slump value gradually decreased from 70 mm to 55 mm. This reduction in workability is due to the extremely fine particles and high surface area of silica fume, which increases the water demand of the mix.

4.Batching & Mixing of Concrete: Batching and mixing of concrete were carried out to achieve a uniform and workable mix. The required quantities of cement, silica fume, fine aggregate, and coarse aggregate were measured accurately using the weighing method to maintain proper proportions. All dry materials were mixed thoroughly to ensure uniform distribution of silica fume and artificial sand throughout the mix. Potable clean water was then added gradually while mixing to achieve the desired consistency and workability. A suitable water-cement ratio was maintained throughout the process to ensure proper hydration and uniformity. Proper mixing was continued until a homogeneous and cohesive concrete mix was obtained.

5.Casting and curing Specimens: Fresh concrete was poured into standard cube moulds of size 150 mm × 150 mm × 150 mm to prepare test specimens. Proper compaction was carried out to remove air voids and ensure a dense and uniform structure. The moulds were kept undisturbed at room temperature for 24 hours. After demoulding, the specimens were placed in a water tank for curing to allow proper hydration and strength development. The curing periods were maintained for 7, 14, and 28 days to study the variation in compressive strength with time.

Fig -2: Casting and Curing of cubes

6.Testing of Specimens: After curing for 7, 14, and 28 days, the concrete cube specimens were tested using a Compression Testing Machine (Accro-Tech, Delhi; Ram diameter: 234 mm) to determine their compressive strength. The load was applied gradually at a constant rate of approximately 2–5 kN/sec as per IS: 516-1959 until failure of the specimen. The maximum load indicated on the dial gauge was recorded for each specimen. The compressive strength was calculated and compared for different silica fume replacement mixes with the control concrete. The variation in strength with respect to curing period and percentage replacement was observed and recorded.

Fig -3: Compression Testing Machine

Table: 4-Compressive strength of Samples

Silica fume %	7 days [N/mm^2]	14 days [N/mm^2]	28 days [N/mm^2]
0	17.18	18.52	14.81
5	12	20.88	26.52
10	9.87	15.64	18.22
15	9.33	16	18.67

5. Graph and Observation

The graph shows that compressive strength varies with silica fume percentage. The 28-day strength increases significantly at 5% replacement and then decreases gradually at higher percentages. The 7-day strength shows a decreasing trend, while the 14-day strength initially increases and then reduces. This indicates that optimum strength is achieved around 5% silica fume replacement.

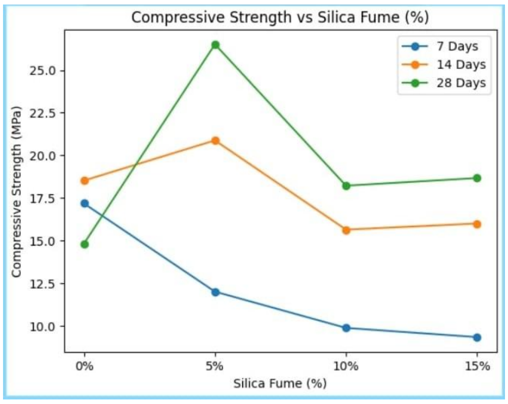

Chart -1: Variation of Compressive Strength with Silica Fume Replacement at Different Curing Ages

6. CONCLUSIONS

This study successfully evaluated the effect of silica fume as a partial replacement of cement and M-Sand as a complete replacement of river sand in M30 grade concrete.
The results show that silica fumes improve compressive strength and durability due to its pozzolanic reaction and micro-filling effect. The optimum replacement level is around 5%, which gives the best balance between strength and workability. M-Sand proved to be an effective alternative to river sand. No chemical admixture was used in this project, yet the slump value of 70 mm confirms that the concrete remains workable and suitable for RCC work. Silica fume concrete can be used in both high-rise structures as well as small residential buildings.

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