Use of silica fume as a replacement of cement in the concrete

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Abstract. Over the past 30 years, significant advancements have been made in enhancing the capabilities of concrete as a construction material, with a focus on high-strength concrete applications using Silica Fume (SF). Global interest in SF as a pozzolanic admixture has surged owing to its ability to enhance concrete properties when used at specific percentages. This study examined the effect of addition of SF in concrete mixes. The performance of concrete in corrosive environment is most important and it can be enhanced by the addition of SF. For strength and longevity, high strength concrete is required. In this study, concrete was prepared with varying proportions of silica fume (5, 10, and 15% by aggregate volume). The specimens were tested to evaluate their strength. The cubes and beams were casted, cured and tested on universal testing machine. The findings showed that both the compressive and flexural strengths were improved by the addition of silica fume. The mechanical and durability properties of concrete are significantly enhanced by the incorporation of silica fume. The findings of this study are helpful for construction industry in the use of silica fume as an economical choice for the enhancement of strength.

Keyword:- Silica Fume, Concrete, Industrial Waste, Pozzolanic Properties, Compressive Strength, Flexural Strength

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1 Introduction

The direct release of waste into the environment creates environmental problems. Therefore, emphasis has been placed on recycling the waste products from various industries [1-4]. Waste can be recycled or used as a mixture to maximize the use of natural resources and reduce environmental waste. The disposal of waste in nearby areas degrades the soil fertility. Silica fume, a by-product of silicon or ferrosilicon production, is a synthetic pozolan [5-7]. The silica fume is originates from the industrial waste. It comprises carbon, sulfur, and oxides of various elements including aluminum, iron, calcium, magnesium, sodium, and potassium. Silica fume does not exist in the crystalline form [8].

Microsilica exists in micro-fine powder and can be used in construction industry. Its exceptional fineness makes it 100 times smaller than cement particles, with an average thickness of just 0.1 micron (less than 1 micron). This remarkable fineness is due to the characteristics of amorphous silica [9].

Heating highly pure quartz releases silicon at temperatures of approximately 2000 °C, leaving behind silica particles. These particles react with oxygen at lower temperatures to form amorphous silica particles [10]. Recent advancements in the past three decades have enhanced the use of concrete in construction. Silica fume and fly ash are commonly used alone or in combination to create strong and reliable concrete structures. In recent years, silica fume has gained significant global interest as a pozzolanic additive for concrete [11-13]. When used in appropriate amounts, silica fume enhances the uniformity, strength, and hydraulic conductivity of the concrete. Promoting cohesion in concrete mixtures helps prevent cracking and excess water loss (bleeding), particularly in demanding conditions that require highly homogeneous mixtures [14].

Cement is an important raw material for concrete and a relatively expensive material, and the use of river sand due to finely aggregated concrete causes natural degradation from the river concrete in large quantities required for world-class infrastructure, convenient collection, and elegant collection. It becomes an integrated whole [15]. The resulting mixtures are cast in the shapes and sizes required to produce a structure capable of carrying the applied load. Silica fume is commonly used for high-strength concrete and copper slag for concrete-. The hardness and c strength parameters of concrete were cast for reinforced concrete (RC) to study the load deflection of concrete silica fume and high-quality copper slag [16].

The increased cement production releases more CO$_2$ into the atmosphere. Various ingredients can be used in concrete because it undergoes degradation in river sand and affects groundwater levels. Therefore, alternative concrete materials must be explored. Silica fume was used in proportions of 0%, 5%, 10%, and 15% cement in the concrete. Silica fumes are by-products of silicon metal or ferrosilicon alloys and exist in crystalline form [17]. It is used in high-performance concrete owing to its highly reactive pozzolanic characteristics. Previous studies have found that mixing silica fume with concrete enhances its mechanical properties.

2 Materials

2.1 Cement

The main ingredient in concrete is cement, as it binds all the ingredients. Cement is commonly used in construction industry. In general, cement is composed of all types of adhesives;
however, the binder is the main ingredient in cement. The main component of concrete is Portland cement. Portland cement with other ingredients act as a binder that binds all the ingredients. In this study cement of grade OPC was used [18]. In concrete, the cement acts as a binder. It binds the main ingredients into a single unit with the help of water and fills the micro voids in the concrete. The properties of OPC were as follows: specific gravity of 3.15, initial setting time of 47 min, bulk density of 4% and final setting time of 205 min as shown Fig. 1.

![Cement used](image1)

**2.2 Fine Aggregate**

River sand, crushed sandstone, and gravel are sources of rich collection. The sources of the crumbs were crushed rock or stone and the natural breakdown of stones. The number of curtains is higher. The surface lines are smaller than those of the fine aggregates. The river sand is commonly used in construction industry. A sand is a natural material composed of particles of various dimensions [19]. Its fineness determines the classification. This project specifically employs sand from a third grade. Fine aggregates for concrete typically involve particles that pass through a 4.75 mm IS-Sieve. Specific details of the sand used in this study are provided below. The properties of the sand used were as follows: bulk density of 1526 kg/m³, void ratio of 36.21%, void ratio of 0.61, specific gravity of 2.56, and fineness modulus of 2.85, by shown Fig. 2.

![Fine aggregate](image2)

**2.3 Coarse Aggregate**
Coarse aggregates (CA) have a maximum size of 0.19 inches. It is the main ingredient used in concrete. Crushed stone and coarse rock are the two main types of coarse aggregates (CA) utilized in concrete [20-23]. The CA for the concrete is to be kept in a 4.75 mm IS-Sieve. A collapsed rectangle with a local diameter of 20 mm was used as the basic material in this experiment. The coarse aggregate used for this test and its properties are as follows: specific gravity of 2.66, water absorption of 0.91%, and fineness modulus of 6.89 by shown Fig. 3.

![Coarse Aggregate](image)

**Fig. 3. Coarse Aggregate**

**2.4 Water**

Water serves as a binder for aggregates when combined with cement, and it is the primary component. Hydration is the process by which water causes concrete to harden. The primary ingredients of cement react with water molecules to produce chemical or hydrophobic agents, making water a chemical reagent. Concrete cannot be produced without water. Water initiate a chemical reaction in the concrete [24]. It is crucial to keep a close eye on both the quantity and quality of water. For this experiment, we mixed the concrete and rinsed the sample with water, which is suitable for use in a laboratory setting, specifically for soft drinking water.

**2.5 Silica Fume**

Silica fume (SF) is a highly pozzolanic component and its superior property in the enhancement of concrete properties, which is a by-product of ferrosilicon manufacturing. The ingredients were mixed SF and beams and cubes are casted. The production of SF is an industrial waste which has the potential. It’s extremely reactive pozzolanic quality makes it ideal for HPC. Extremely strong and long-lasting concrete is possible using SF [25]. The concrete was created using five layers of replacement material, specifically aggregates with volume percentages of 5%, 10%, and 15% as shown Fig. 4.
3 Experimental Plan

Different samples were casted, cured and tested. To investigate the sturdiness of concrete under pressure, we made a cube measuring 150 mm in all directions [26-29]. To measure the impact force, we cast a beam of standard size. Finally, we molded a concrete block of standard size, to examine how the beam bent and moved under strain, where only good-quality mixes were cast and the optimal mix was obtained from dynamic tension and strength, which created the test results in Fig. 5.

3.1 Test Conducted

A Universal Testing Machine (UTM) was utilized to test the sample in order to determine compressive and flexural strength. Test were conducted as per the Indian codal standards [30-31]. A standardized test procedure was followed for each test, and the performance of the concrete mix was studied. The compressive strength was determined by testing the cubes on UTM at 7 and 28 days. Once the test sample was ready, the force was steadily applied until it failed in Fig.6. The maximum force required to cause failure of the sample was recorded, and this value was used to determine the shear strength of the sample [30].
Fig. 6. Compressive strength test

For measuring the strength of beam, a flexural strength test was conducted. The resistance of an unreinforced concrete slab or beam to impact failure can be tested in this manner. Fracture parameters indicating MPa are the results of flexural tests on concrete [31-33]. The specimens of beams of standard size were casted and cured. After curing, the specimens were left to dry in open air and were subsequently tested. The specimens were then tested for flexural strength using a flexural testing apparatus as by shown in Fig. 7.

Fig. 7. Flexural strength test

4 Results

4.1 Compressive strength test results

Cubes were casted with different percentage of 0%, 5%, 10%, and 15% SF, to determine the compressive strength. At 15% of SF, maximum compressive strength was observed [34]. Maximum compressive strengths of 29.33 MPa and 43.56 MPa, respectively, were recorded after 7 and 28 days by in Fig. 8. These findings highlight the significant potential of SF in concrete and suggest its use as a cement alternative.
From fig 8, it is clear that SF acts as a microfiller in concrete, increasing density and workability, and reacts with calcium hydroxide to enhance interparticle bonding and acts as an additional ingredient in cement, increasing strength as a result of pozzolanic properties much finer than cement. The presence of more surface greatly increases the stability as the SF percentage increases [35]. As advancements in the construction industry drive the demand for durable building materials, silica fume emerges as a crucial component in enhancing concrete strength. Its influence on the compressive resistance of concrete further highlights its importance in construction applications.

### 4.2 Flexural strength test results

To determine the tensile strength of beam, flexural strength test was conducted. As the percentage of SF increased, the concrete became stronger under the pressure [36-39]. It also became more flexible with an increase of up to 15% in its ability to bend without breaking. After seven days, the flexural strength is achieved as 4.448 MPa, and after 28 days, it reached 6.72 MPa, which is the highest flexural strength. These findings highlight the significant potential of silica fume in concrete, suggesting its use as a cement alternative.
calcium silicate hydrate treated with Portland cement. The new binder enhanced the quality of silica fume concrete and significantly boosted its pulse energy. The use of SF in concrete is not just to cut costs or replace cement; it is also an essential part of the material.

5 Conclusion

The direct release of waste into the environment creates environmental problems. Therefore, emphasis has been placed on recycling the waste products from various industries. Wastes can be recycled or used as mixtures to maximize the use of natural resources and save environmental waste. These industrial wastes on neighboring land depletes the soil of its natural fertility and makes the area look unclean. Silica fume (SF), a synthetic pozzolan, is used as an alternative to cement. SF is a byproduct or industrial waste and has a promising future in the construction industry. In this study, silica fume was evaluated as a substitute for cement.

Experiments showed that concrete became stronger when it was mixed with 15% silica fume. The ability of the concrete to bend was improved by up to 15%. After 7 days, the maximum bending strength was 4.448 MPa, and after 28 days, it increased to 6.72 MPa.

- Both flexural and compressive strength of beam and cube were increased with the addition of silica fume and it is maximum at 28 days.
- These positive results suggest that SF can be used in the construction industry.
- The amount of SF utilized mostly determines the compressive strength. Overall high-rise buildings can utilize SF for making concrete to achieve highest compressive and flexural strength.

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