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INVESTIGATING THE IMPACT OF PARTIAL CEMENT REPLACEMENT WITH SILICA FUME IN STEEL FIBRE REINFORCED CONCRETE

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ABSTRACT
We use supplementary cementitious materials (SCMs) to improve the performance and environmental impact of concrete. We demonstrate this in a sustainable manner. This study investigates the effects of substituting silica fume (SF) for some cement in steel fibre-reinforced concrete (SFRC). Silica fume is a by-product of the production of silicon and ferrosilicon alloys. Silica fume, with its small particles and high pozzolanic activity, enhances the performance of concrete. This study examines the effects of adding silica fume at 5%, 10%, and 15% by weight of cement on the tensile strength, compressive strength, and bending properties of silica fume-reinforced concrete (SFRC). We examine the synergistic effects of silica dust and steel fibres in enhancing the flexibility, breaking resistance, and post-crack performance of SFRC. We make and examine samples of SFRC in an experimental study. We then compare the results to a control mix that contains no silica fume. According to early results, using silica fume as a partial replacement for cement makes SFRC much stronger, both in the short term and over a long period of time. The smaller particle size and pozzolanic activity of silica fume make it easier for the steel fibres to stick to the cementitious matrix, which is a big part of these improvements. This research demonstrates that the combination of silica fume and steel fibres can produce high-performance concrete, ideal for construction applications demanding strength, durability, and environmental friendliness. The results are very helpful for making high-strength concrete mixes that are long-lasting and suitable for current building needs. This study focussed on the effect of partial replacement of cement with silica fume in steel fibre reinforced concrete for M40 grade of concrete having mix proportions 1:1.38:1.81 with water cement ratio 0.35 of steel fibre reinforced concrete by partial replacing of cement with silica fume of various percentage and containing steel fibres of 2% and 2.5% volume fraction, steel fibres of 50 aspect ratio used and the investigation of compressive strength, flexural strength and split tensile strength.

1.0 Introduction

Concrete, being the most commonly used building material worldwide, plays a crucial role in the construction of various structures. But it uses a lot of Portland cement, which is an important filler in concrete. The environmental impact is significant due to the high energy consumption and carbon dioxide emissions during the manufacturing process [1]. The use of extra cementitious materials (SCMs), such as silica fume, has garnered significant attention to mitigate these effects. Silicon and ferrosilicon alloys create silica fume. It has tiny particles and a lot of pozzolanic action. It combines with calcium hydroxide to make more calcium silicate hydrate (C-S-H), which makes the concrete stronger, lasts longer, and is less likely to be damaged by chemicals [2]. Also, silica fume is a beneficial SCM for high-performance concrete uses because it can improve the texture of the cementitious matrix. Concrete often incorporates steel strands to enhance its strength, reduce cracking risk, and enhance energy absorption, particularly during load movement or bending [3]. Putting silica dust and steel threads together might make concrete stronger and last longer. This study investigates the effects of substituting silica fume for some cement in steel fibre-reinforced concrete (SFRC). The study looks at the mechanical properties and longevity of SFRC with different amounts of silica fume. The goal is to learn how to make high-performance, long-lasting concrete that can handle the difficulties of modern building.

2.0 Literature Review

Silica fume improves the mechanical characteristics and durability of concrete owing to its significant pozzolanic activity and ultrafine particle size, which facilitate the densification of the cementitious matrix [1]. Silica fume undergoes pozzolanic reactions with calcium hydroxide, resulting in the formation of supplementary C-S-H gel, which enhances compressive strength and reduces permeability [4]. The substitution of cement with silica fume up to 15% enhances compressive strength, particularly at early stages [2]. Durability Enhancements: Silica fume improves resistance to sulfate assault, chloride ingress, and alkali-silica interactions, hence augmenting the durability of concrete [5]. Steel fibres enhance tensile strength, ductility, and energy absorption capacity in concrete, rendering it appropriate for dynamic and high-impact loads [3]. The amalgamation of silica fume and steel fibre markedly improves fracture resistance and post-crack performance. Optimization of Fibre Content: The ideal steel fibre content (0.5–2%) achieves a balance between mechanical enhancements and workability [6]. Microstructural Alterations: Silica fume enhances the interfacial transition zone (ITZ) between cement paste and steel fibre, hence improving bond strength [7]. Silica fume mitigates drying shrinkage and creep by matrix densification. The addition of steel fibres with silica fume enhances flexural toughness and energy dissipation [8]. Workability Issues: Elevated silica fume concentration diminishes workability, requiring the use of superplasticizers [9].

Effect on Setting Time: Silica fume hastens setting time owing to its small particles and elevated reactivity. Eco-efficiency: Silica fume and steel fibres enhance sustainable building by diminishing cement consumption and augmenting concrete durability [10]. Thermal Performance: Silica fumes improve fire resistance by enhancing microstructural stability [11]. Crack Control: Steel fibres reduce shrinkage and thermal cracking, hence improving structural integrity [12].

Fatigue Resistance: SFRC demonstrates enhanced fatigue resistance under cyclic stress, due to the reinforcement provided by steel fibres [13]. The amalgamation of silica fume and steel fibres markedly enhances energy absorption and impact resistance [14]. Chloride Resistance: Silica fume enhances resistance to chloride-ion penetration, hence diminishing corrosion hazards in steel fibres. Freeze-Thaw Resistance: The augmented matrix density from silica fume improves freeze-thaw resistance. Cost-Benefit Analysis: Although initial expenses are elevated, the long-term advantages of SFRC including silica fume surpass the expenditures due to enhanced durability and diminished maintenance [15].

3.0 Experimental Investigation

This study examines the integration of glass fibres and fly ash in high-performance concrete to assess their joint impacts on mechanical properties, including compressive, tensile, and flexural strength. Glass fibres reinforce the concrete matrix, increasing toughness and crack resistance, whereas fly ash partially replaces cement, thereby improving sustainability and reducing the carbon footprint of the concrete mix. This study seeks to identify optimal ratios of glass fibre and fly ash to enhance the mechanical performance of concrete, thereby ensuring its suitability for high-strength, durable applications. To find out the pros and cons of using these materials in high-performance concrete (HPC), this study uses controlled laboratory tests to measure their compressive, tensile, and flexural strengths. This will help come up with possible solutions for using sustainable and high-performing concrete in a variety of situations.

3.1 Material Properties

The material properties plays a vital role in the performance of concrete since the mechanical properties of concrete. The material properties such as specific gravity, fineness modulus of materials are determined by conducting specific gravity and sieve analysis test in the laboratory. The test results are shown in Table 1 and Table 2. The materials used in this research are shown in Figure 1 and 2. Figure 3 shows the curing of concrete and hardened concrete.

Fig. 1 Cement, River sand and Crushed Stone Aggregate

Fig. 2 Silica fume and Steel Fibres

Fig. 3 Curing of Concrete Specimens and Hardened Concrete

Table 1 Properties of Materials

Sl. No.	Type of Test	Type of Material	Findings	Value
1	Specific Gravity	Cement	Specific Gravity	3.13
2		Fly Ash		1.96
3		Sand		2.65
4		Crushed Stone		2.70
5	Water absorption	Sand	% of water absorption	0.86
6		Crushed Stone		0.30
7	Sieve Analysis	Sand	Fineness Modulus	2.83
8		Crushed Stone		7.35
9	Slump Test	Conventional Concrete (M1)	Workability in mm	75
10		M2 (8% Silica fume & 2% Steel Fibre)		78
11		M3 (10% Silica fume & 2% Steel Fibre)		82
12		M4 (8% Silica fume & 2.5% Steel Fibre)		85
13		M5 (10% Silica fume & 2.5% Steel Fibre)		88

3.2 Mechanical Properties

Construction commonly uses concrete, a composite material known for its versatility, strength, and durability. Cement, water, aggregates (fine and coarse), admixtures, mix design, curing process, and ambient conditions influence its properties. We can divide the properties of concrete material into three categories: mechanical, physical, and durability.

Compressive Strength: Concrete has a high compressive strength, which means it can hold up against axial loads. This property is mostly affected by the amount of water to cement and the quality of the aggregates.

Tensile Strength: The tensile strength of concrete is very low, only about a tenth of its compressive strength. Adding fibres or reinforcements is often a good way to make this better.

Flexural Strength: This shows how well concrete can handle bending stresses and is very important for building parts like slabs and beams. The modulus of elasticity shows how stiff concrete is and how much it can stretch when it's loaded. The test results are shown Table 2.

Table 2 Mechanical Properties of Concrete Specimens

Sl.No.	Percentage of Steel Fibre	Percentage of Silica Fume	Compressive Strength	Flexural Strength	Split Tensile Strength
1	0	0	48.38	2.80	3.02
2	2	8	48.60	4.10	4.74
3	2	10	49.20	4.40	4.80
4	2.5	8	52.10	4.60	4.82
5	2.5	10	51.70	4.80	4.91

4.0 Result and Discussions

Prior to the discourse on this study, the authors believe it is essential to revisit the background of Silica fume concrete and Fibre reinforced concrete as previously established. These two concretes pertain to high-strength concrete, which possesses a compressive strength above 40 MPa (5800 psi). High-strength concrete is produced by reducing the water-cement (W/C) ratio to 0.35 or below. Silica fume is frequently used to inhibit the development of free calcium hydroxide crystals in the cement matrix, which might compromise the strength of the cement-aggregate link. Low water-to-cement ratios and the use of silica fume substantially reduce the workability of concrete mixes, posing a particular challenge in high-strength concrete applications that often utilize thick rebar cages. The optimal amount of silica substitution for cement is around 4% to 6%, which results in a strength increase of 20% to 25% compared to traditional concrete. The optimal proportion for the insertion of fibres in fibre-reinforced concrete is between 2% and 2.5% by weight fraction. This study used M40 grade concrete, with cement partially substituted by 0%, 4%, 6%, 8%, and 10% silica fume, and fibre included at 0%, 2%, and 2.5% of the concrete's weight. The findings obtained in this investigation were commendable, with the optimal combined percentages being around 10% silica fume replacement and 2.5% fibre addition. These percentages yield more significant outcomes as compared to other percentages and traditional concrete. The optimal percentages yield results that are 28%, 70%, and over 75% superior in the compression test, split tensile test, and flexure test, respectively, as compared to standard concrete.

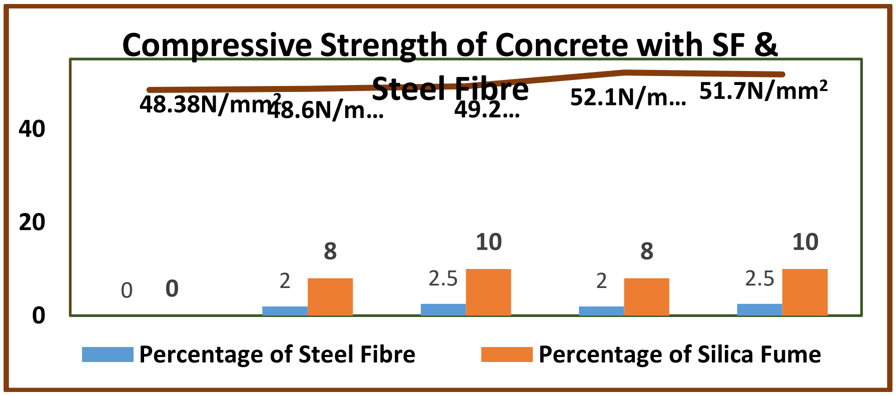

Fig. 1. Compressive Strength of Concrete with SF & Silica Fume

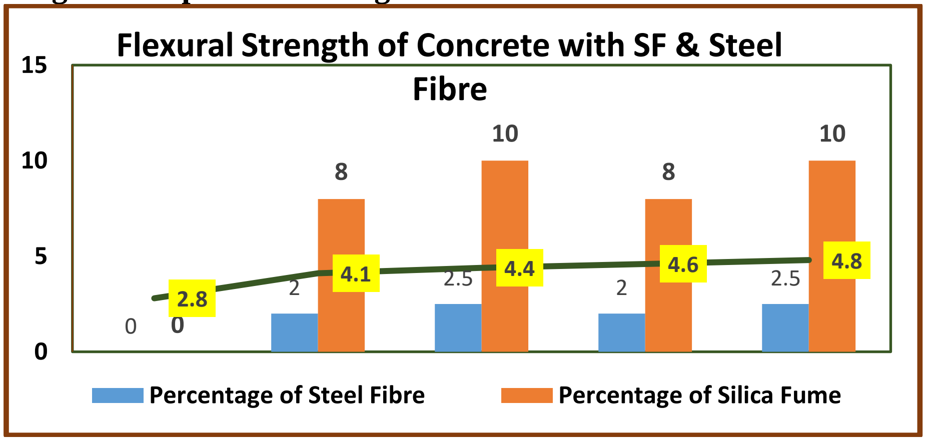

Fig. 2. Flexural Strength of Concrete with SF & Silica Fume

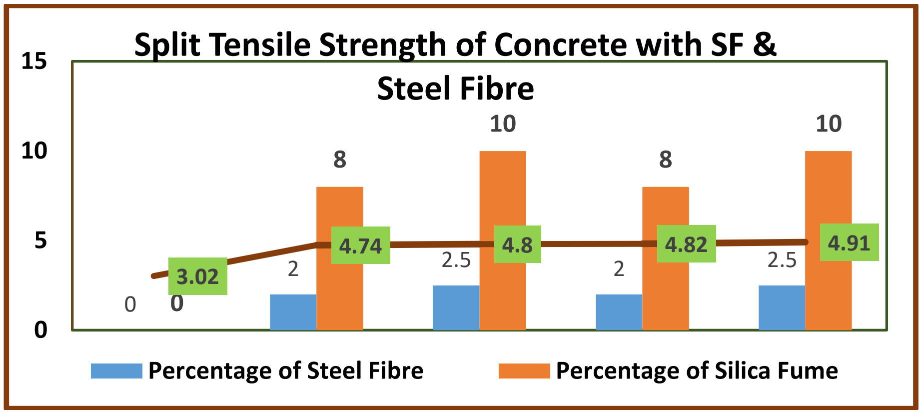

Fig. 3. Split Tensile Strength of Concrete with SF & Silica Fume

5.0 Conclusions

1. The specific gravity of cement, fly ash, river sand and crushed stones are found as 3.13, 1.96, 2.65, and 2.70 respectively.
2. The water absorption of river sand and crushed stone aggregate are found as 0.86% and 0.30 respectively.
3. The fineness of modulus of river sand and crushed stone aggregate are found as 2.83 and 7.35 respectively.
4. The workability of conventional concrete is found as 75 mm.
5. The workability of concrete with silica fume (8% , 10%) and steel fibre (2%, 2.5%) with 1.2 % of super plasticizer are found as 78 mm, 82 mm, 85 mm and 88 mm respectively.
6. The compressive strength, flexural strength and split tensile strength of conventional concrete are found as 48.38 N/mm^2, 2.80 N/mm^2 and 3.02 N/mm^2 respectively.
7. The compressive strength of concrete with silica fume (8% , 10%) and steel fibre (2%, 2.5%) with 1.2 % of super plasticizer found as 48.60 N/mm^2, 49.20 N/mm^2, 52.10 N/mm^2 and 51.70 N/mm^2 respectively.
8. The flexural strength of concrete with silica fume (8% , 10%) and steel fibre (2%, 2.5%) with 1.2 % of super plasticizer found as 4.10 N/mm^2, 4.40 N/mm^2, 4.60 N/mm^2 and 4.80 N/mm^2 respectively.
9. The split strength of concrete with silica fume (8% , 10%) and steel fibre (2%, 2.5%) with 1.2 % of super plasticizer 4.74 N/mm^2, 4.80 N/mm^2, 4.82 N/mm^2 and 4.91 N/mm^2 respectively.
10. The 10% silica fume and 2.5 steel fibre is found to be optimum percentage for improvement of the concrete.

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