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An Effect on Steel Fiber-Reinforced Concrete (SFRC) with Silica Fume and Metakaolin as Partial Replacements for OPC Cement

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ABSTRACT: The goal of this study is to look at what happens to M25 grade concrete when silica fume and steel fiber are used to replace some of the cement. This will help find out how strong the concrete is when it is compressed and when it is bent. Prepare concrete mixes with varying proportions of silica fume e.g., 5%, 10%, 15% & 20% and metakaolin e.g. ,5%, 10%, 15% & 20% as partial replacements for OPC. Incorporate steel fibers at different volume fractions e.g., 0.5%, 1%, 1.5% & 2.0%. Conduct tests for compressive strength, flexural strength, toughness, workability (slump test), setting time, and durability assessments (e.g., permeability tests).This study investigated how silica fume and metakaolin could be utilized as partial cement replacements to improve the mechanical characteristics and durability of Steel fiber-reinforced concrete. The results of the Compressive Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 22.89 N/mm2 - 26.31 N/mm2 in 14.95 % , 22.89 N/mm2-26.44 N/mm2 in 15.53 %, 22.89 N/mm2-26.49 N/mm2 in 15.72 % at 7 days. The results of the Compressive Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 31.82 N/mm2- 35.47 N/mm2 in 11.46 %, 31.82 N/mm2- 35.42 N/mm2 in 11.32 %, 31.82 N/mm2- 35.42 N/mm2 in 8.15 % at 28 days. The results of the Flexural Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 3.73 N/mm2 – 4.07 N/mm2 in 9.27 % , 3.73 N/mm2 -3.98 N/mm2 in 6.76 % ,3.73 N/mm2-4.07 N/mm2 in 9.15 % at 28 days.

KEYWORDS: Conventional Concrete, Steel Fiber-Reinforced Concrete, Silica Fume , Metakaolin Compressive Strength, Tensile Strength & Flexural Strength.

I. INTRODUCTION

Steel fiber-reinforced concrete (SFRC) is a composite material that incorporates steel fibers into the concrete mix to enhance its mechanical properties. The addition of steel fibers improves the tensile strength, ductility, and toughness of the concrete, making it more resistant to cracking and deformation under load.

Silica Fume

Silica fume, also known as micro silica, is an ultrafine powder that consists primarily of amorphous silicon dioxide (SiO2). It is produced as a by-product during the manufacturing of silicon metal or ferrosilicon alloys in electric arc furnaces. The particles of silica fume are extremely small, with an average diameter of about 150 nanometres (0.15 micrometres), making them approximately 100 times smaller than typical cement particles. This fine particle size contributes to its high surface area, which ranges from 15,000 to 30,000 m²/kg.

Properties

Silica fume has several notable properties that make it valuable in construction applications:Particle Size and Surface Area: The ultrafine nature of silica fume provides a large surface area that enhances its reactivity.

Specific Gravity: Typically ranges from 2.2 to 2.3.

Bulk Density: Varies between 130 kg/m³ (unidentified) to 600 kg/m³ depending on how it is stored.

These properties contribute to its effectiveness as a pozzolanic material when added to concrete mixtures.

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Metakaolin
Metakaolin is the anhydrous calcined form of the clay mineral kaolinite. It is produced by heating kaolinite, which is also known as China clay or kaolin, to high temperatures that lead to the removal of chemically bonded water. The resulting material has a complex amorphous structure that retains some long-range order due to layer stacking. Metakaolin particles are smaller than cement particles but larger than silica fume particles.

Ordinary Portland Cement (OPC)
Ordinary Portland Cement (OPC) is a widely used type of cement that serves as a fundamental ingredient in various construction applications, including concrete, mortar, and plaster. It is characterized by its hydraulic properties, meaning it can set and harden when mixed with water. The production of OPC involves several key steps and considerations:

River Sand as Fine Aggregate
River sand has traditionally been used as a fine aggregate in concrete production due to its availability, workability, and performance characteristics. It is composed of naturally occurring granular material that is primarily made up of silica (SiO_2) and is extracted from riverbeds. The use of river sand in concrete contributes to the overall strength and durability of the final product.

Crushed Stone as Coarse Aggregate
Coarse aggregate, which includes crushed stone, plays a crucial role in construction and civil engineering projects. Crushed stone is defined as rock that has been mechanically broken down into smaller pieces and is typically used in various applications due to its strength, durability, and versatility.

Production Process of Crushed Stone
The production of crushed stone involves several stages:
1. Extraction: The process begins with the extraction of larger boulders from quarries. These boulders are then transported to a crushing facility.
2. Primary Crushing: In this stage, large rocks are broken down into manageable sizes using primary crushers. This initial step reduces the size of the stones significantly.
3. Secondary and Tertiary Crushing: After primary crushing, the material undergoes secondary and tertiary crushing processes where it is further reduced to specific sizes suitable for various applications.
4. Screening: Once crushed, the material is screened to separate it into different size categories. This ensures that the final product meets specific standards required for construction use.

Size Specifications
Coarse aggregates consist of particles ranging from 3/8 inch (9 mm) to 1.5 inches (37.5 mm). They are categorized based on their size and application:
- Common designations include #4, #467, #5, #56, #57, #6, #67, #7, #8, #89, and #9.
- Each designation corresponds to a specific particle size range and is used for different construction purposes.

II. PROBLEM STATEMENT

1. The use of Steel Fiber-Reinforced Concrete (SFRC) has gained significant attention in the construction industry due to its enhanced mechanical properties and durability compared to conventional concrete.
2. The incorporation of steel fibers into the concrete matrix improves tensile strength, ductility, and resistance to cracking, making it suitable for various structural applications. However, the environmental impact of Ordinary Portland Cement (OPC) production is a growing concern, prompting researchers to explore sustainable alternatives.
3. In this context, the partial replacement of OPC with supplementary cementitious materials (SCMs) such as silica fume and metakaolin presents an opportunity to enhance the performance characteristics of SFRC while reducing its carbon footprint. Silica fume is a byproduct from silicon metal or ferrosilicon alloy production and is known for its pozzolanic properties, which contribute to improved strength and durability when used in concrete. Metakaolin, derived from the calcination of kaolinite clay, also exhibits pozzolanic behavior and enhances the microstructure of concrete.
4. Prepare concrete mixes with varying proportions of silica fume e.g., 5%, 10%, 15% & 20% and metakaolin e.g. ,5%, 10%, 15% & 20% as partial replacements for OPC.

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5. Incorporate steel fibers at different volume fractions e.g., 0.5%, 1%, 1.5% & 20%.
6. Conduct tests for compressive strength, flexural strength, toughness, workability (slump test), setting time, and durability assessments (e.g., permeability tests).

III. METHODOLOGY

Methodology of Steel Fiber-Reinforced Concrete Using Silica Fume & Metakaolin as Partial Replacements for OPC Cement.The methodology for creating steel fiber-reinforced concrete (SFRC) using silica fume and metakaolin as partial replacements for ordinary Portland cement (OPC) involves several systematic steps. This approach aims to enhance the mechanical properties and durability of concrete while addressing environmental concerns associated with cement production.

Materials Selection

The first step in the methodology is selecting appropriate materials:

- Ordinary Portland Cement (OPC): The primary binder in the concrete mix.
- Silica Fume: A byproduct from silicon metal or ferrosilicon alloy production, silica fume is known for its pozzolanic properties, which can enhance strength and durability when used as a partial replacement for OPC.
- Metakaolin: A calcined clay material that also exhibits pozzolanic behavior, metakaolin improves workability and strength characteristics of concrete.
- Steel Fibers: Short lengths of steel fibers are added to improve tensile strength, ductility, and impact resistance of the concrete mix.
- Aggregates: Coarse and fine aggregates are selected based on grading requirements to ensure proper workability and strength.

Mix Design

The next step involves designing the concrete mix. This includes determining the proportions of each component:

- Replacement Ratios: Typically, silica fume can replace 5% to 20% of OPC by weight, while metakaolin may replace 5% to 20%. The specific ratios depend on desired performance characteristics.
- Water-Cement Ratio: A lower water-cement ratio is often used to achieve higher strength; however, this must be balanced with workability needs.
- Fiber Content: Steel fibers are usually added at volumes ranging from 0.5% to 2% by volume of concrete.
- A typical mix design might look like this:
- OPC: kg/m³
- Silica Fume: kg/m³ (5%,10%,15% & 20% replacement)
- Metakaolin: kg/m³ (5%,10%,15% & 20% replacement)
- Water: Adjusted based on workability requirements
- Aggregates: As per standard specifications
- Steel Fibers: % by volume

Mixing Process

Once the materials are selected and proportions determined, the mixing process begins:

1. Dry Mixing: First, dry ingredients (OPC, silica fume, metakaolin, and aggregates) are mixed thoroughly in a concrete mixer to ensure uniform distribution.
2. Adding Water: Gradually add water while mixing until achieving the desired consistency.
3. Incorporating Steel Fibers: After achieving a homogenous mixture without fibers, steel fibers should be added gradually while continuing to mix to prevent clumping.

Casting After mixing:

1. Prepare molds according to relevant standards (e.g., ASTM C31).
2. Pour the mixed concrete into molds using appropriate techniques to avoid segregation.
3. Use vibration or compaction methods to eliminate air voids and ensure dense packing.

Curing

Proper curing is crucial for developing strength:

1. Cover the cast specimens with wet burlap or plastic sheets immediately after casting.
2. Maintain moisture for at least 7 days at ambient temperature or longer if possible.

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Regularly monitor moisture levels during curing.

Testing

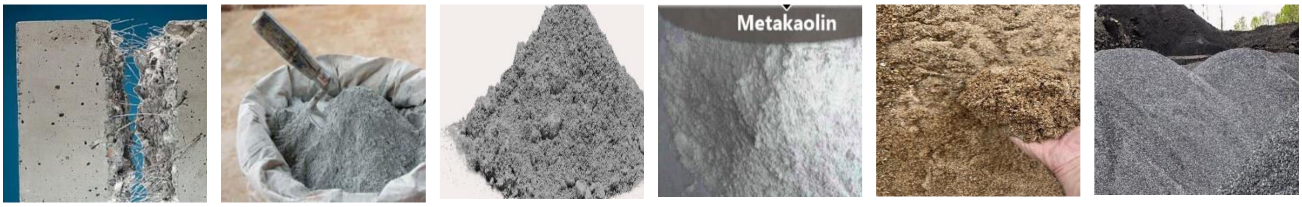
Finally, testing is essential to evaluate performance:

1. Conduct compressive strength tests at various intervals (e.g., 7 days, 28 days).
2. Perform flexural strength tests and toughness assessments using standardized methods such as ASTM C1609 for SFRC.
3. Evaluate durability through tests like permeability or freeze-thaw resistance.

Material Used

The materials used in this investigation are…

1. OPC Cement
2. Fine aggregate
3. Coarse aggregate
4. Water
5. Steel fibers
6. Silica fume
7. Chemical Admixture
8. Metakaolin.



Steel fiber reinforced concrete | **Ordinary Portland Cement (OPC** | **Silica fume** | **Metakaolin** | **River Sand as Fine Aggregate** | **Crushed Stone as Coarse Aggregate**

Figure no. 1; Ingredients of Steel fiber reinforced concrete

IV. RESULT DISCUSSION

Mix design of M25 Steel Fiber-Reinforced Concrete Using Silica Fume & Metakaolin as Partial Replacements for OPC Cement

Table no. 1 ; The Final Batches with Silica Fume and Metakaolin of M25 Steel Fiber-Reinforced Concrete in kg/m3

Mix Designation	Quantity (Kg/m^3)							
	Cement	Silica Fume	Metakaolin	Steel Fiber	Fine aggregates	Coarse aggregates	Super Plasticizer	Water
M1	362.00	0.00	0.00	0.00	679.00	1207.00	3.45	155.50
M34	271.50	18.10	72.40	30.00	679.00	1207.00	3.45	155.50
M35	271.50	36.20	54.30	30.00	679.00	1207.00	3.45	155.50
M36	271.50	54.30	36.20	30.00	679.00	1207.00	3.45	155.50
M37	271.50	72.40	18.10	30.00	679.00	1207.00	3.45	155.50
M38	271.50	18.10	72.40	60.00	679.00	1207.00	3.45	155.50
M39	271.50	36.20	54.30	60.00	679.00	1207.00	3.45	155.50

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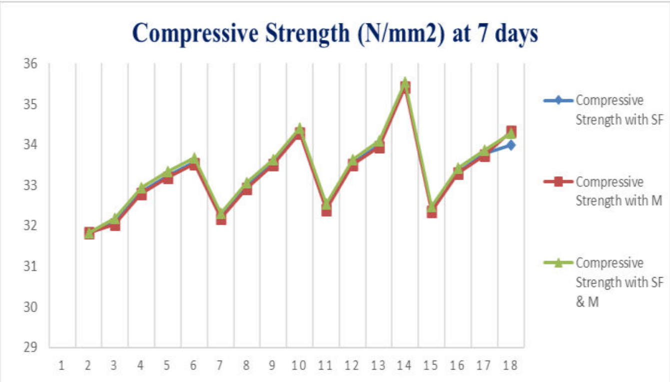
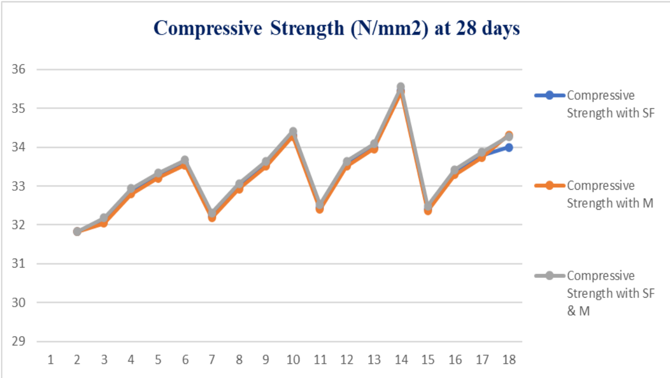
M40	271.50	54.30	36.20	60.00	679.00	1207.00	3.45	155.50
M41	271.50	72.40	18.10	60.00	679.00	1207.00	3.45	155.50
M42	271.50	18.10	72.40	90.00	679.00	1207.00	3.45	155.50
M43	271.50	36.20	54.30	90.00	679.00	1207.00	3.45	155.50
M44	271.50	54.30	36.20	90.00	679.00	1207.00	3.45	155.50
M45	271.50	72.40	18.10	90.00	679.00	1207.00	3.45	155.50
M46	271.50	18.10	72.40	120.00	679.00	1207.00	3.45	155.50
M47	271.50	36.20	54.30	120.00	679.00	1207.00	3.45	155.50
M48	271.50	54.30	36.20	120.00	679.00	1207.00	3.45	155.50
M49	271.50	72.40	18.10	120.00	679.00	1207.00	3.45	155.50

Compressive Strength

The results of the Compressive Strength (N/mm2) show the replacement of silica fume and Metakaolin separately and the mixing of both for cement in the M25 Steel Fiber-Reinforced Concrete.



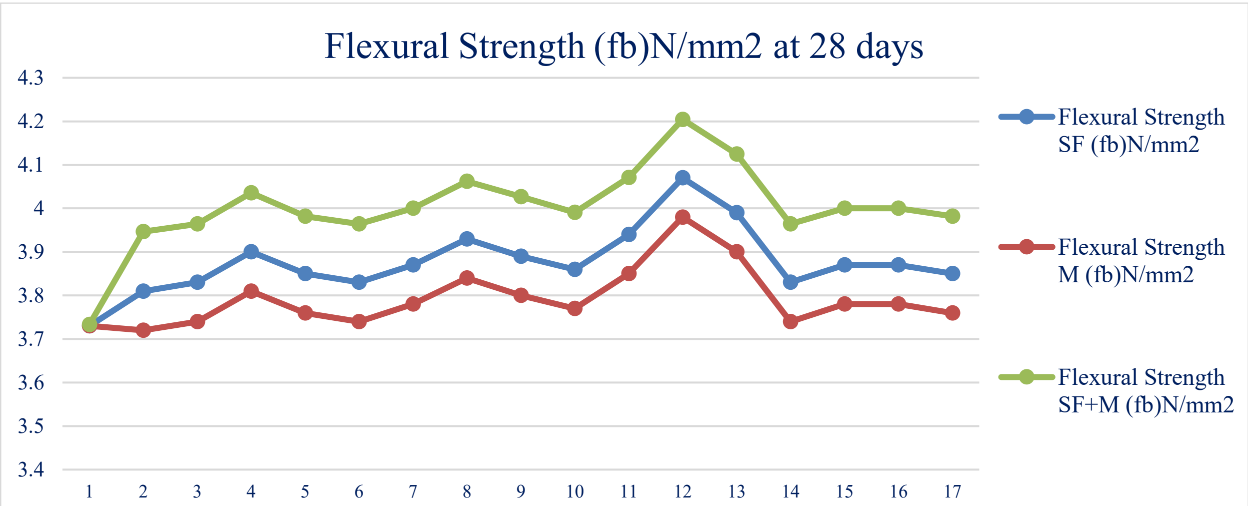
Graph no. 1; The results of the Compressive Strength (N/mm2) at 7 days



Graph no. 2; The results of the Compressive Strength (N/mm2) at 28 days

Flexural strength

The results of Flexural strength for Beams (N/mm2) show the partial replacement of silica fume for cement in the M25 Steel Fiber-Reinforced Concrete at 28 Days



Graph no. 3; The results of the Flexural Strength (N/mm2) show the replacement of silica fume and Metakaolin separately and the mixing of both for cement in the M25 Steel Fiber-Reinforced Concrete.

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V. CONCLUSION

1. The flexural & compressive strength of Metakaolin and silica fume based multi blended concrete were improved when compared with conventional concrete and Steel Fiber-Reinforced Concrete on mix design M25.
2. Super plasticizer agent is required to produce workable mix.
3. Slump Cone test results workability of
4. when compared with conventional concrete and Steel Fiber-Reinforced Concrete on mix design M25 with Silica Fume M-17 Slump value 80 mm.
5. when compared with conventional concrete and Steel Fiber-Reinforced Concrete on mix design M25 with Metakaolin M-33 Slump value 79 mm.
6. when compared with conventional concrete and Steel Fiber-Reinforced Concrete on mix design M25 with Silica Fume and Metakaolin M-49 Slump value 81mm.
7. The results of the Compressive Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 22.89 N/mm2 -26.31 N/mm2 in 14.95 % , 22.89 N/mm2-26.44 N/mm2 in 15.53 %, 22.89 N/mm2-26.49 N/mm2 in 15.72 % at 7 days.
8. The results of the Compressive Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 31.82 N/mm2- 35.47 N/mm2 in 11.46 %, 31.82 N/mm2- 35.42 N/mm2 in 11.32 %, 31.82 N/mm2- 35.42 N/mm2 in 8.15 % at 28 days.
9. The results of the Flexural Strength (N/mm2) show the replacement of silica fume and metakaolin separately and the mixing of both for cement in the concrete 3.73 N/mm2 – 4.07 N/mm2 in 9.27 % , 3.73 N/mm2 -3.98 N/mm2 in 6.76 % ,3.73 N/mm2-4.07 N/mm2 in 9.15 % at 28 days.

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