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EXPERIMENTAL INVESTIGATION OF MICRO SILICA FUME AND RECYCLED STEEL FIBER ON CONCRETE BY PARTIAL SUBSTITUTE OF CEMENT

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ABSTRACT

Concrete is one of the most widely used materials in building construction due to its workability and ability to be molded into various shapes. However, ordinary concrete has low tensile strength, limited ductility, and weak resistance to cracking. It exhibits fragile behavior and fails to handle tensile loads, leading to internal cracks, which are primarily responsible for its structural failure. Over the years, significant efforts have been made to enhance the strength and toughness of concrete, especially in aggressive environments. High-performance concrete emerges as a superior choice for durable and robust construction. The extensive generation of byproducts or industrial wastes such as fly ash, silica fume, and slags poses environmental and health challenges due to improper disposal. Incorporating silica fume into concrete significantly enhances its mechanical and durability properties. Silica fume, a byproduct from the production of ferro-silicon and silicon metal, is an efficient pozzolanic material. In this research, 90 samples were cast, including 30 cubes (150 mm x 150 mm x 150 mm), 30 beams (500 mm x 100 mm x 100 mm), and 30 cylinders (150 mm diameter and 300 mm height), to analyze the impact of silica fume and steel fiber on concrete's properties.

Keywords: Silica Fume, Steel Fiber, Compressive Strength, Flexural Strength, Durability.

1. INTRODUCTION

1.1 General

In recent years, extensive research has focused on energy conservation in the cement and concrete industry. This has encouraged the use of materials such as fly ash, slags, and pozzolans, which demand less energy for production. More recently, attention has shifted to utilizing compressed silica fume as a potential partial replacement for cement. Also known as microsilica or condensed silica fume, it is a synthetic pozzolanic admixture produced by reducing quartz with coal in an electric arc kiln. The chemical composition of silica fume consists of over 90% silicon dioxide, along with trace elements like carbon, sulfur, aluminum oxides, iron, calcium, magnesium, sodium, and potassium. Its physical characteristics include particle diameters of 0.1 to 0.2 microns, a surface area of approximately 30,000 m^2/kg, and a density ranging from 150 to 700 kg/m^3.

Fiber-reinforced concrete (FRC) is a cement-based composite that has gained attention in recent years for its excellent flexural-tensile strength, resistance to cracking, impact resistance, and

remarkable durability under frost conditions. FRC also enhances toughness and reduces plastic shrinkage cracking. Fibers, which serve as reinforcing materials, can have various cross-sections, including spherical, trilateral, or planar. The aspect ratio of a fiber, defined as the ratio of its length to its diameter, is a critical parameter.
While precise data on the annual production of silica fume in Canada and the United States is limited, estimates from 1981 suggest a production of about 15,000 tons in Canada and 300,000 tons in the U.S. Norway, a leading producer of silica fume, recorded an estimated production of 120,000 tons in 1981, which was expected to double in the following years.
The use of steel fibers and silica fume offers significant benefits in concrete construction, improving strength and durability while addressing challenges such as surface resistance and tensile failure.

2. REVIEW OF LITERATURE
2.1 GENERAL
Mohd Anas Siddiqi, M. Umer Rizvi, Junaid Ahmed, Md. Kashif Khan, and Dr. Tasleem
This study investigates the impact of silica fume as a mineral admixture on the durability and mechanical properties of concrete. Beyond measuring workability, cubic compressive strength, and splitting tensile strength, the research examines durability parameters, including water absorption, permeability, sulfate attack, and chloride attack. The findings highlight significant improvements in both fresh and hardened concrete properties with silica fume inclusion.
Key observations include the reduction in workability, as indicated by a decrease in slump value, with increasing silica fume replacement. This suggests that higher silica fume percentages enhance flexural strength more effectively than compressive strength. The study also provides guidance on optimal replacement levels for silica fume in both normal-strength and high-strength concrete. Overall, it emphasizes the benefits of incorporating silica fume, including improved mechanical performance and durability.

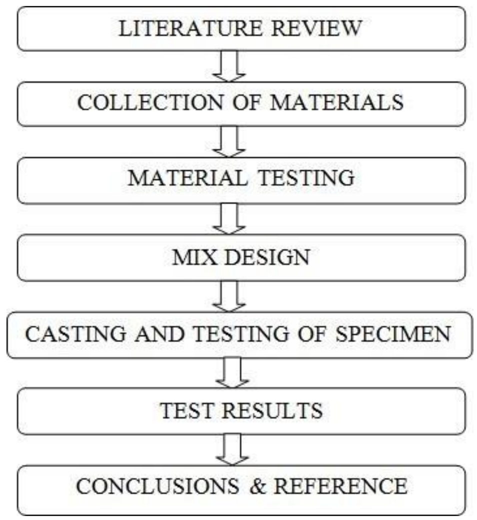
Muhammad N. S. Hadi
Steel reinforcement in concrete construction is highly effective due to its excellent properties, such as increased tensile strength and ductility. However, in high-humidity areas, steel reinforcement faces challenges like rust and oxidation, leading to deterioration of concrete structures. Protective measures such as wrapping with Fiber Reinforced Polymer (FRP) or using cathodic protection can mitigate these effects.
This research investigates the behavior of concrete columns reinforced with vertical and horizontal FRP under eccentric axial loads. Twelve specimens were cast and tested to understand the behavior of FRP-wrapped reinforced concrete columns. The findings reveal that columns wrapped with FRP exhibit improved performance, with increased ductility observed in configurations with continuous or overlapping FRP wrapping.
Studies by Mirmiran et al. validated the benefits of external confinement using FRP tubes, which enhanced the strength and ductility of reinforced columns. Saadatmanesh et al. demonstrated that ductility increases linearly with strap thickness but decreases with increased strap spacing. Chaalla! et al. tested cylindrical specimens and concluded that reinforced concrete columns with carbon FRP wrapping showed significant improvements in structural behavior under concentric and eccentric loading conditions.

METHODOLOGY

4. MATERIAL SELECTION

4.1 Cement

Cement is a fundamental material in the infrastructure industry and is utilized for various purposes. It is manufactured in multiple compositions to suit a wide range of applications. Cements are often named based on their principal constituents, intended use, the objects to which they are applied, or their characteristic properties.



For instance, some cements are named after their place of origin, such as Roman cement, while others are named for their resemblance to specific materials, like Portland cement, which produces a concrete resembling the Portland stone used in British construction. The term "cement" is derived from the Latin word *Cacmentum*, referring to stone chippings used in Roman mortar, rather than the binding material itself.

In general, cement is described as a material with adhesive and cohesive properties, enabling it to bond mineral fragments into a compact and solid whole. This makes it an indispensable component in construction, providing the essential binding properties needed for the structural integrity of buildings and infrastructure.

Fig 4.1 Cement

WATER

Water is a key ingredient in the manufacture of concrete and serves two primary functions. First, it reacts chemically with cement to initiate the setting and hardening process. Second, it lubricates the other materials in the mix, ensuring workability and ease of handling. While water is an essential component of concrete, its quality and quantity significantly impact the final product.

One of the most common causes of poor-quality concrete is the use of excessive mixing water. The strength of concrete is fundamentally governed by the ratio of the weight of water to the weight of cement in the mix. This is true provided the mix is plastic, workable, fully compacted, and adequately cured. Thus, maintaining the proper water-to-cement ratio is crucial for achieving the desired concrete strength and durability.

AGGREGATE

Aggregates were initially thought to simply reduce the amount of cement required in concrete. However, they are now recognized as crucial components influencing both the plastic and hardened properties of concrete. Aggregates can constitute up to 80% of the concrete mix, making their quality and properties vital to the overall performance of the concrete.

Aggregates are broadly classified into four categories: heavyweight, normal weight, lightweight, and ultra-lightweight aggregates. Among these, normal weight and lightweight aggregates are most commonly used in conventional concrete practices, while the other types are reserved for specialized applications such as nuclear radiation shielding in concrete.

Classification of Aggregates

Aggregates are generally classified into two size groups for use in concrete:

- **Fine Aggregate:** Materials smaller than 4.75 mm in size, often referred to as sand. Locally available natural sand is typically used as fine aggregate. In areas where natural sand is unavailable, crushed stone can serve as an alternative. For this study, **river sand Zone II** was used, classified according to IS 383: 1970. The classification system divides fine aggregates into four zones: Zone I, Zone II, Zone III, and Zone IV.
- **Coarse Aggregate:** Materials larger than 5 mm in size. Coarse aggregates contribute to the strength and durability of concrete and include properties like particle shape, surface texture, and absorption, which influence the fresh and hardened states of concrete.

Fine Aggregate Properties

Fine aggregate used in this study conforms to IS 383: 1970 standards. River sand classified under Zone II was selected based on its quality and availability. In places where natural sand is scarce, crushed stone is used as a substitute. The testing results for fine aggregates are provided in a table (reference to be included as per study).

Fig 4.2 Fine Aggregate

Coarse Aggregate

The shape and particle size distribution of coarse aggregate play a crucial role in concrete production as they significantly influence packing density, void content, water absorption, and grading. Variations in the fines content of aggregates should be closely and continuously monitored to ensure consistent quality in concrete.

In this experimental study, coarse aggregate with a maximum size of **20 mm** was used. This size was chosen to provide an optimal balance between strength, durability, and workability in the concrete mix.

Fig 4.3 Coarse Aggregate

Micro Silica Fume

Silica fume, also referred to as **micro silica**, is an ultrafine powder obtained as a byproduct of silicon and ferrosilicon alloy production. It consists of spherical particles with an average diameter of approximately **150 nm**.

The primary application of silica fume is as a **pozzolanic material** in the production of high-performance concrete. Its use enhances the mechanical properties, durability, and overall performance of concrete, making it a valuable addition to modern construction practices.

Fig 4.4 Micro Silica Fume

CONCLUSION

Steel Fibre Reinforced Concrete (SFRC), a relatively new construction material, is regarded as a specialized type of fibre-reinforced concrete. It demonstrates excellent results when silica fume is added to the mix. Laboratory and field experiments have revealed that SFRC is a unique construction material with high compressive and flexural strength. Due to its superior strength and ductility, SFRC has significant potential for structural applications in demanding service conditions where conventional concrete may not perform satisfactorily.

Based on the findings of this investigation, the following conclusions can be drawn:

1. **Improved Properties:** The experimental results indicate that the properties of M40-grade concrete are significantly enhanced with the incorporation of steel fibres and silica fume.
2. **Reduced Workability:** Workability of SFRC decreases as the percentage of steel fibres and silica content increases.
3. **Consistency of Cement Paste:** The consistency of the cement paste improves with increasing silica fume content, reaching a maximum value at 10% silica fume addition.
4. **Soundness:** The soundness of the cement paste decreases with an increase in the percentage of silica fume.
5. **Compressive Strength:** After 7 days, the compressive strength of SFRC increases to 31.41 MPa with the addition of 1.4% steel fibres and 10% silica fume, compared to plain concrete.
6. **Flexural Strength:** The flexural strength of SFRC after 7 days increases to 3.07 MPa with the addition of 1.4% steel fibres and 10% silica fume, compared to plain concrete.

These results demonstrate that SFRC, with silica fume and steel fibre enhancements, provides superior performance for structural applications requiring higher strength, durability, and resistance to demanding conditions.

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