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Partial Replacement of Cement by Flyash and Silica Fume along with the Steel Fibres in Fibre Reinforced Concrete

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Abstract: *The project focuses on enhancing the performance of Fibre Reinforced Concrete (FRC) through the partial replacement of cement with industrial by-products and the inclusion of steel fibres. Cement production is a major source of CO_2 emissions, necessitating the exploration of sustainable alternatives. This study utilizes Fly Ash and Silica Fume as partial cement replacements to improve the long-term strength and durability of concrete, while incorporating steel fibres to enhance it tensile strength, ductility, and crack resistance. The concrete mixes will be tested for compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days. A comparison of strength gain over these periods will be made to determine the optimum mix proportion that balances sustainability and mechanical performance. The scope includes testing various percentages of cement replacement and steel fibre volumes to formulate a high-performance, eco-friendly concrete mix.*

Keywords: Fibre Reinforced Concrete, Fly Ash, Silica Fume Eco-friendly

I. INTRODUCTION

Concrete is one of the most widely used construction materials because of its high compressive strength, durability, and versatility. However, it has some limitations such as low tensile strength and brittle behavior, which can lead to cracks and sudden failure. In addition, the production of Ordinary Portland Cement (OPC) releases a large amount of CO_2, which creates environmental concerns. To overcome these issues, there is a need for more sustainable and improved concrete materials.

One effective method is to use fibre reinforced concrete (FRC) by adding steel fibres, which improve tensile strength, ductility, and crack resistance. At the same time, replacing a part of cement with materials like fly ash and silica fume helps reduce environmental impact and improves long-term strength and durability. This project focuses on combining these methods to produce a stronger, more durable, and eco-friendly concrete.

II.OBJECTIVES

- To design concrete mixes with partial replacement of cement by Fly Ash and Silica Fume at varying percentages (e.g., 20% Fly Ash, 10% Silica Fume).
- To incorporate hooked-end steel fibres at different volume fractions (e.g., 0.5%, 1.0%) into the optimized SCM-based mix to produce FRC.
- To evaluate and compare the mechanical properties of the proposed mixes, including compressive strength, split tensile strength, and flexural strength, with those of a conventional concrete mix at 7, 14, and 28 days.
- To determine the optimum combination of Fly Ash, Silica Fume, and steel fibre content that delivers the best balance of sustainability, workability, and mechanical performance.

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III. METHODOLOGY

Understanding the Problem & Research Void
Literature Review & Determination of Research Approach
Procurement of Materials & Preliminary Material Testing
Design of Trial Mix Proportions
Casting of Specimens
Curing of Specimens
Testing of Hardeded Concrete
Analysis of Results & Determination of Optimum Mix
Interpretation & Conclusion

IV. MATERIALS

Cement

Cement is the primary binding material used in concrete, commonly in the form of Ordinary Portland Cement (OPC). It reacts with water to form a hard matrix that binds aggregates together and provides strength.

Fly ash

Fly ash is a fine powder obtained from thermal power plants. It improves workability, reduces heat of hydration, and enhances long-term strength and durability.

Silica fume

Silica fume is an ultrafine material rich in silica. It fills micro voids and improves strength, durability, and resistance to chemical attack.

Steel fibre

Steel fibres are short pieces of steel added to concrete to improve tensile strength, ductility, and crack resistance.
Fine aggregate consists of sand passing 4.75 mm sieve. It improves workability and fills voids between coarse aggregates.

Coarse aggregate

Coarse aggregate consists of crushed stones retained on 4.75 mm sieve. It provides strength and bulk to concrete.

Supperplasticizer

Superplasticizers are chemical admixtures that improve workability without increasing water content, enabling high-performance concrete.

V.MIX DESIGN

At present, there are several scientific methods available for proportioning the materials to achieve the desired strength of concrete. However, it is difficult to select a single best method, as most methods require trial adjustments at the final stage. The main objective of mix design is to achieve the required strength and durability while minimizing the cement content as much as possible without compromising performance.
The grade of concrete adopted for this project is M30, and all comparisons are made with the conventional M30 mix. The mix design calculations were carried out as per IS 10262:2019. In this study, cement is partially replaced with fly ash and silica fume, and steel fibres are added to improve the mechanical properties of concrete.
Tests are conducted by maintaining a constant target strength of 30 MPa (N/mm^2) for all mixes. The properties of concrete vary based on the percentage of fly ash, silica fume, and steel fibres added.

Control Mix
M1: 0% replacement.
M2: 15% Fly Ash + 5% Silica Fume + 0.5% Steel Fibre.
M3: 20% Fly Ash + 5% Silica Fume + 1% Steel Fibre.
M4: 20% Fly Ash + 10% Silica Fume + 1.5% Steel Fibre.
The performance of concrete is evaluated based on compressive strength, tensile strength, flexural strength, workability, and durability. The study helps in identifying the optimum mix for better strength and sustainability.

VI. FRESH CONCRETE PROPERTIES

SLUMP CONE TEST

Fresh concrete properties were evaluated using the slump cone test and compaction factor test to determine the workability of fibre reinforced concrete containing fly ash, silica fume, and steel fibres. The slump test was conducted to measure the consistency of fresh concrete. Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished without segregation or bleeding. In this study, the addition of steel fibres reduced the slump value due to increased internal resistance, while fly ash improved workability because of its spherical particle shape. The slump value obtained indicates the suitability of the mix for different construction applications.

COMPACTION FACTOR TEST

The compaction factor test was performed to assess the workability of concrete mixes with low consistency. This test is more precise and sensitive compared to the slump test, especially for fibre reinforced concrete. The compaction factor is defined as the ratio of the weight of partially compacted concrete to that of fully compacted concrete. The presence of steel fibres reduces workability, making compaction more difficult, which is effectively captured in this test. The results help in identifying variations in workability among different mixes and in selecting the optimum mix for better performance and durability.

VII. HARDENED CONCRETE PROPERTIES

COMPRESSIVE STRENGTH TEST

The compressive strength test was conducted to evaluate the strength characteristics of concrete containing fly ash, silica fume, and steel fibres. Concrete was mixed in required proportions, placed into cube moulds, and compacted properly to eliminate voids. After 24 hours, the specimens were demoulded and cured in water for 7 and 28 days. The specimens were then tested using a compression testing machine (CTM), where load was applied gradually until failure occurred. The compressive strength was calculated by dividing the ultimate load by the cross-sectional area of the specimen. The failure pattern observed was typically of hourglass type due to lateral restraint provided by the testing machine, and the results indicate the improvement in strength due to the presence of mineral admixtures and steel fibres.

SPLIT TENSILE STRENGTH TEST

The split tensile strength test was performed to determine the tensile behaviour of concrete, which is generally weak in tension. Cylindrical specimens were cast, cured, and tested after 28 days by applying a diametrical compressive load along the length of the specimen. This induces tensile stresses perpendicular to the applied load, causing the specimen to fail in tension. The splitting tensile strength was calculated using the standard formula based on maximum load and specimen dimensions. The inclusion of steel fibres enhances the tensile strength by bridging cracks and delaying failure, while fly ash and silica fume contribute to improved bonding and microstructure. The test results help in understanding the ductility and crack resistance of fibre reinforced concrete.

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VIII. RESULT

SLUMP CONE TEST

Table 1. Test result of Slump Cone

Mix	Slump Value (mm)	Workability
M1 (Control)	85	Medium
M2	95	Medium-High
M3	80	Medium
M4	70	Low

COMPACTION FACTOR TEST

Table 2. Test result of Compaction Factor Test

Mix	Compaction Factor	Workability
M1 (Control)	0.90	Medium
M2	0.92	Medium-High
M3	0.88	Medium
M4	0.85	Low

HARDENED CONCRETE PROPERTIES

The hardened concrete properties of fibre reinforced concrete containing fly ash, silica fume, and steel fibres were evaluated through compressive strength and split tensile strength tests. These tests were carried out to determine the mechanical performance and strength characteristics of the developed concrete mixes. The results were compared with the conventional M30 grade concrete to assess the improvement in properties due to the addition of mineral admixtures and steel fibres.

COMPRESSIVE STRENGTH TEST

The compressive strength test was conducted on cube specimens after 7 and 28 days of curing using a Compression Testing Machine (CTM). As per Bureau of Indian Standards guidelines (IS 456:2000 and IS 516:1959), the compressive strength of M30 grade concrete should not be less than 30 N/mm².

SPLIT TENSILE STRENGTH TEST

The split tensile strength test was carried out on cylindrical specimens after 28 days of curing. According to IS 456:2000 and IS 5816:1999, the split tensile strength of concrete should be approximately 1/10 of the characteristic compressive strength (fck). The inclusion of steel fibres enhances tensile strength and crack resistance, while fly ash and silica fume improve the overall strength and durability of concrete.

IX. CONCLUSION

The use of fly ash and silica fume as partial replacement of cement, along with the inclusion of steel fibres, contributes to the development of sustainable and high-performance concrete. This approach helps in reducing cement consumption, thereby lowering environmental impact and promoting greener construction practices. Based on the experimental investigation carried out in this study, the following conclusions are drawn:

The properties of all materials used, including cement, fly ash, silica fume, aggregates, and steel fibres, were found to be satisfactory as per relevant standards.

The partial replacement of cement with fly ash and silica fume, along with the addition of steel fibres, resulted in an improvement in compressive strength and split tensile strength compared to conventional concrete.

The optimum mix proportion was observed at 20% Fly Ash + 10% Silica Fume + 1.5% Steel Fibres, which showed better overall performance.

The maximum compressive strength and split tensile strength were achieved at 28 days for the optimum mix, indicating enhanced mechanical properties due to the combined effect of pozzolanic materials and fibre reinforcement.
The addition of steel fibres significantly improved crack resistance, ductility, and tensile behaviour of concrete.
Based on the results, it is concluded that the developed fibre reinforced concrete with mineral admixtures can be effectively used in structural applications, providing improved strength, durability, and sustainability compared to conventional concrete.

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