

Performance Evaluation of Modified Concrete Incorporating Fly Ash, Silica Fume, Rice Husk Ash, and Calcium Nitrate

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Abstract

The growing demand for sustainable and high-performance concrete has led to the incorporation of supplementary cementitious materials (SCMs) and chemical admixtures to enhance mechanical and durability properties. This study investigates the effect of 15% fly ash, 10% silica fume, 10% rice husk ash, and 3% calcium nitrate as a partial replacement for cement in M25 and M30 grade concrete. Experimental results demonstrate that the modified concrete exhibited an increase in compressive strength compared to conventional concrete, with improvements of 7.03% (M25) and 2.60% (M30) at 28 days, progressively increasing at later ages. Similarly, split tensile strength also showed a marginal improvement, with M25 gaining up to 6.68% and M30 up to 1.98% at 120 days. The enhancement in strength characteristics is attributed to the pozzolanic reaction, refined microstructure, and improved interfacial bonding of the cementitious matrix. Additionally, reduced water absorption indicates improved durability, making the modified mix a viable alternative for sustainable construction. However, the increase in tensile strength was relatively modest, suggesting the need for further optimization. The study highlights the potential of industrial byproducts and chemical admixtures in improving concrete performance while promoting eco-friendly construction practices. Further research is recommended on durability aspects, large-scale field applications, and cost-effectiveness to validate the findings and establish practical guidelines for implementation.

Keywords: Fly ash, silica fume, rice husk ash, calcium nitrate, supplementary cementitious materials, pozzolanic reaction, compressive strength, tensile strength, durability, sustainable concrete

INTRODUCTION

Multi-component blended concrete incorporates multiple supplementary cementitious materials

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(SCMs) and admixtures to enhance its mechanical strength and durability. This type of concrete is developed to optimize performance by utilizing industrial byproducts such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, and metakaolin. These materials improve workability, reduce permeability, and enhance long-term strength, making the concrete more sustainable and durable. Additionally, multi-component blended concrete helps in reducing the carbon footprint of traditional Portland cement by partially replacing it with alternative materials. The synergy of these components results in improved resistance to chemical attacks, reduced heat of hydration, and better performance under aggressive environmental conditions [1–3].

The increasing demand for durable and high-performance concrete has led to the development of multi-component blended concrete, which incorporates multiple supplementary cementitious materials (SCMs) and chemical admixtures. This approach enhances both the mechanical and durability properties of concrete, making it suitable for modern infrastructure requirements. Multi-component blended concrete typically includes materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, and other industrial byproducts, which act as partial replacements for ordinary Portland cement (OPC). These materials contribute to improved strength gain, reduced permeability, enhanced workability, and increased resistance to environmental degradation [4–6].

OBJECTIVES

The primary objective of this research is to evaluate the mechanical properties and durability characteristics of M25 and M30 grade concrete modified with 15% fly ash, 10% silica fume, 10% rice husk ash, and 3% calcium nitrate as a partial replacement for cement. The specific objectives are:

- To assess the compressive strength development over different curing ages (28, 56, 90, 120, and 180 days) and compare it with conventional concrete [7–9].

MATERIAL

Fine Aggregate

The fine aggregate utilized in this research consists of well-graded, sharp, and angular grains of natural river sand. It was tested and found to conform to the standards outlined in IS 2386 (Part II)-1963 (1996), IS 2386 (Part III)-1963 (1997), IS 2386 (Part IV)-1963 (1996), and IS 2386 (Part VI)-1963 (1997).

Coarse Aggregate

Coarse aggregates constitute 50 to 60% of the total volume of concrete, significantly influencing its mechanical and durability properties. In this study, high-quality crushed granite stones were used as coarse aggregates. These aggregates were tested and confirmed to meet the requirements of IS 2386 (Part III)-1963 (1997), IS 2386 (Part IV)-1963 (1996), IS 2386 (Part V)-1963 (1996), IS 2386 (Part VII)-1963 (1996), and IS 2386 (Part VIII)-1963 (1991). Additionally, the crushing strength of the coarse aggregate was assessed following IS 9376-1979 (1997), while the impact value was determined in accordance with IS 9377-1979 (1990), were consulted for guidelines on coarse aggregate testing [10–13].

Cement

Cement acts as a binding agent that holds together fine and coarse aggregates in the presence of water. The cement used in this study was 53 Grade Ordinary Portland Cement (OPC), known for its fine grinding, ease of workability, and high resistance to moisture. The cement adhered to IS 12269-1987 (1997) specifications and was tested in accordance with IS 4031-1988 (1988).

Water

Water plays a vital role in concrete production, as it actively participates in the hydration process, leading to the hardening of the mixture. The water used in this study was potable water, which met the requirements outlined in IS 456-2000 (2000) [14–17].

Fly Ash

Fly ash is a fine, solid byproduct generated from the combustion of pulverized coal in thermal power plants. The chemical and mineral composition of fly ash varies based on the type and characteristics of coal used in power generation.

Silica Fume

Silica fume, also known as micro silica, is a byproduct generated during the production of silicon and ferrosilicon alloys in an electric arc furnace. It exhibits exceptionally high pozzolanic activity, significantly enhancing concrete performance. The addition of silica fume in concrete improves both early-age and long-term strength compared to other pozzolanic materials.

Rice Husk Ash (RHA)

Rice Husk Ash (RHA) is obtained from the controlled combustion of rice husks and exhibits pozzolanic properties. Due to its high reactivity, RHA is utilized in high-performance concrete to enhance its overall properties.

Calcium Nitrate

Calcium nitrate is a soluble chemical admixture that interacts with the hydration process of cementitious materials through physical, chemical, or physicochemical mechanisms, altering the properties of concrete in both fresh and hardened states.

RESULTS

Compressive Strength of Concrete

The compressive strength test is the most commonly performed evaluation on hardened concrete due to its simplicity and the direct correlation of compressive strength with other key properties of concrete. Since concrete is primarily designed to withstand compressive forces, assessing its compressive strength provides valuable insights into its overall performance. This test serves as a qualitative indicator of other hardened concrete characteristics and is crucial in structural applications where concrete is subjected to compressive loads [18–19].

The specimens are cast, cured, and tested following standard procedures, and since individual test results may vary, the average value from three specimens is recorded for consistency. In the following graphs, “CON” denotes conventional concrete, while “ADM” represents concrete containing admixtures. For M25 grade conventional concrete, the compressive strength measured was 29.96 MPa at 28 days, 30.85 MPa at 56 days, 32.61 MPa at 90 days, 33.22 MPa at 120 days, and 33.35 MPa at 180 days. In contrast, the concrete mix incorporating 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash, and 3.0% calcium nitrate exhibited compressive strengths of 32.06, 32.81, 33.21, 33.90, and 34.01 MPa at the corresponding ages.

The results indicate that the admixture-modified concrete achieved 7.03, 6.34, 1.83, 2.01, and 1.97% higher compressive strength than conventional concrete at 28, 56, 90, 120, and 180 days, respectively. Furthermore, Figure 1 clearly demonstrates a gradual increase in compressive strength over time. This improvement can be attributed to the enhanced hydration process facilitated by the presence of admixtures. 5–7% increase in compressive strength was observed with the partial replacement of cement using these admixtures. For M30 grade conventional concrete, the measured compressive strength was 35.72 MPa at 28 days, 36.43 MPa at 56 days, 36.78 MPa at 90 days, 36.92 MPa at 120 days, and 37.13 MPa at 180 days. In contrast, concrete incorporating 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash, and 3.0% calcium nitrate exhibited 36.63, 36.96, 37.53, 37.94, and 38.13 MPa at the respective testing intervals.

The results indicate that the modified concrete exhibited 2.60, 1.52, 1.97, 2.77, and 2.71% higher compressive strength than conventional concrete at 28, 56, 90, 120, and 180 days, respectively, as depicted in Figure 2. The trend in the graph clearly shows an increase in compressive strength as the concrete ages. The presence of fly ash contributed to strength enhancement due to its pozzolanic reactivity. While the initial strength gain was relatively moderate, a more pronounced increase was observed over time due to the prolonged pozzolanic activity of fly ash. Additionally, silica fume significantly improved the compressive strength due to its ultra-fine particle size and high pozzolanic activity. An increase in compressive strength ranging between 3.0 and 7.5% with silica fume incorporation was observed. Figure 3 illustrates the compressive strength test in progress, confirming the positive impact of admixtures on concrete performance.

It was concluded from the results that the compressive strength of M25 and M30 grade concrete showed a significant increase when 15.0% fly ash, 10.0% silica fume, 10.0% rice husk ash, and 3.0% calcium nitrate were used as partial replacements for cement.

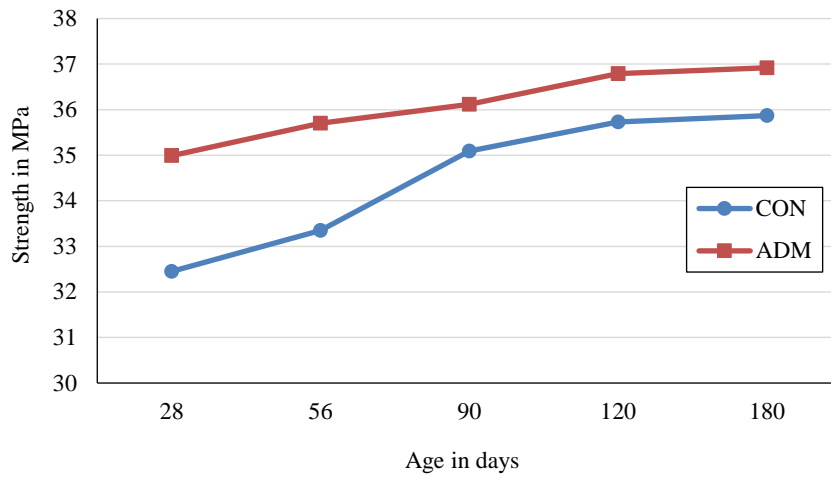


Figure 1. Variation of compressive strength with age of M25 grade concrete.

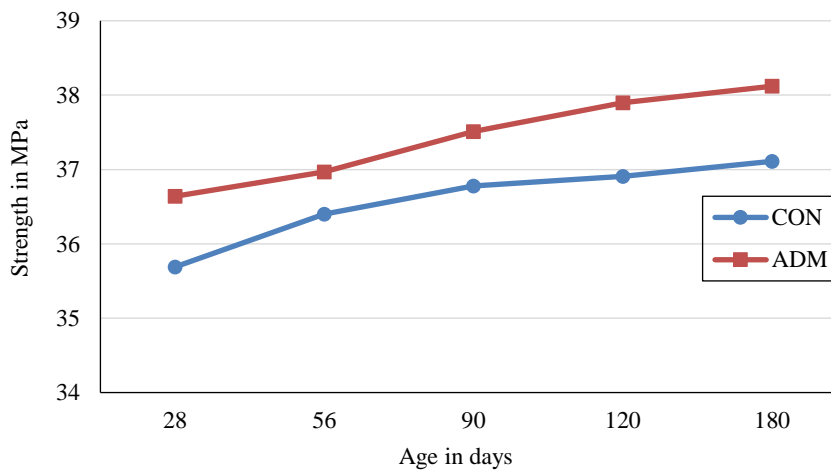


Figure 2. Variation of compressive strength with age of M30 grade concrete.



Figure 3. Failure pattern of cube under compression.

CONCLUSION

The partial replacement of cement with 15% fly ash, 10% silica fume, 10% rice husk ash, and 3% calcium nitrate led to a notable improvement in the mechanical properties of M25 and M30 grade concrete.

Compressive Strength

- For M25 grade concrete, the replacement mix showed an increase of 7.03% at 28 days, 6.34% at 56 days, 1.83% at 90 days, 2.01% at 120 days, and 1.97% at 180 days compared to conventional concrete.
- For M30 grade concrete, the replacement mix exhibited 2.60% higher strength at 28 days, 1.52% at 56 days, 1.97% at 90 days, 2.77% at 120 days, and 2.71% at 180 days than the conventional mix.
- The increase in strength was primarily due to pozzolanic activity and improved particle packing, leading to enhanced matrix densification.

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