

Evaluating the Performance of Ternary Concrete Composites Incorporating Fly Ash and Ground Granulated Blast Furnace Slag as Supplementary Cementitious Materials

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Abstract

Supplementary Cementitious Materials (SCMs) play a vital role in enhancing the properties of concrete through their hydraulic and pozzolanic activities. Among these materials, Ground Granulated Blast Furnace Slag (GGBFS) stands out due to its economic and performance benefits when used as a partial replacement for cement. This study investigates the effects of varying proportions of GGBFS and fly ash on the mechanical properties of concrete. A total of eight different mix designs were prepared, incorporating different ratios of fly ash and GGBFS, while maintaining a constant weight of water throughout. The GGBFS was progressively added, while the proportion of fly ash was reduced correspondingly, ensuring a combined SCM replacement of cement. Mechanical properties, specifically compressive strength and final setting time, were evaluated across the different mix proportions. Compressive strength tests were conducted at 3, 7, and 28 days to assess the development of strength over time. The results indicate that GGBFS can effectively replace up to 20% of cement when combined with 30% fly ash without compromising compressive strength compared to conventional concrete. However, it is important to note that early-age strength development was slower in mixtures containing GGBFS. These findings suggest that while GGBFS contributes to long-term durability and sustainability in concrete applications, its slower early-age strength gain may necessitate careful consideration in projects where rapid strength development is critical. Overall, the study highlights the potential of using GGBFS in combination with fly ash as a viable approach to enhance the performance of concrete, paving the way for more sustainable construction practices. Future research should focus on the long-term durability of these mixtures and explore their performance under various environmental conditions to further validate the benefits of incorporating GGBFS and fly ash in concrete formulations.

Keywords: SCMs, GGBFS, Compressive strength, fly ash, final setting time, sustainable construction practices

1. Introduction

The construction industry is facing significant challenges related to sustainability, the disposal of industrial waste, the reduction of raw material usage, and the energy demands of cement production. One of the most pressing concerns is the substantial carbon emissions generated during Ordinary Portland Cement (OPC) manufacturing, which contributes heavily to global CO₂ levels. As a result, there is a growing need to find more sustainable solutions that not only reduce cement consumption but also improve the durability and service life of construction materials.

In response to these challenges, extensive research in concrete technology has focused on

discovering alternative materials that can partially or fully replace OPC while maintaining, or even enhancing, the strength and durability of concrete. Among the most promising solutions are Supplementary Cementitious Materials (SCMs), which include industrial by-products such as Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), silica fume, metakaolin, and rice husk ash. These materials exhibit cementitious properties, making them suitable substitutes for a portion of the cement in concrete mixtures.

The use of SCMs has led to the development of binary, ternary, and even quaternary blended concretes, depending on the number and combination of materials used. These blended concrete mixes have shown promising results in

terms of strength, workability, and durability, thus contributing to more sustainable and long-lasting construction practices. Among these innovations, **ternary concrete**, which incorporates three distinct cementitious components, has demonstrated particular success. By blending SCMs such as Fly Ash and GGBS, engineers can balance the strengths of one material against the shortcomings of another, resulting in a concrete that offers excellent fresh and hardened properties.

This paper investigates the performance of ternary concrete mixtures incorporating Fly Ash and GGBS as SCMs. The aim of this study is to evaluate the fresh and hardened properties of these mixes, focusing on key performance indicators such as workability, compressive strength, and durability. By exploring the potential of ternary blends, this research seeks to contribute to the production of sustainable and durable concrete composites, addressing both environmental and structural concerns in modern construction.

2. Literature Review

Aliakbar Golampur (2017) investigated the performance of concrete made with high-volume ternary binders containing F-grade Fly Ash (FA) and **GGBS**, which replaced a significant portion of the cement. The results indicated a dramatic reduction in compressive strength as the replacement level of cement increased from 50% to 90%. However, after 28 days, the compressive strength of concrete containing GGBS was comparable to that of conventional concrete, particularly when the mixture was altered at an angle up to 90 degrees.

P. Ganesh et al. (2019) investigated the use of Ground Granulated Blast Furnace Slag (GGBS) to replace up to 80% of cement in Ultra High-Performance Concrete (UHPC). The study evaluated key properties such as flow ability, mechanical strength, fracture resistance, and endurance of UHPC containing a large volume of GGBS under two curing conditions: standard water curing and elevated temperature curing. The Uniaxial Tensile (UAT) strength test was used to assess the tensile strength of UHPC. Results showed that under standard water curing, GGBS-

based UHPC exhibited improved properties up to 40% cement replacement & Under elevated temperature curing, the performance increased, supporting a cement replacement level of up to 60%.

Prasath Kumar et al. (2019) explored the complete replacement of coarse aggregates with coconut shell (CS) in concrete and the use of GGBS to improve its mechanical properties. Cement was replaced with GGBS at various levels—0%, 5%, 10%, 15%, and 20%. The study found that the optimum substitution level for cement with GGBS was 10%, which yielded the best compressive strength. With GGBS, the concrete's strength improved by around 15%, and microstructural analysis revealed an enhancement in the hydration process, leading to increased formation of Calcium Aluminum Silicate Hydrate (C-A-S-H) and Calcium Silicate Hydrate (C-S-H).

Soundarya (2021) explored the impact of Fly Ash and GGBS on the properties of lime-stabilized mud blocks. The study employed 5% lime as a stabilizer, with varying proportions of Fly Ash and GGBS, starting at 0% and increasing to 10% in increments of 2%. The results showed that the mechanical properties of the mud blocks improved as the percentages of both Fly Ash and GGBS increased. GGBS had a more significant positive effect on the moist mechanical properties compared to Fly Ash. In addition to mechanical testing, a moisture absorption test was conducted. It was found that Fly Ash had a more substantial influence on increasing moisture absorption levels compared to GGBS in the lime-stabilized blocks.

S. Elavarasan et al. (2021) investigated the use of GGBS and metakaolin as individual cement replacements in M25 grade concrete with a water-cement ratio of 0.45. Cement content was replaced at levels of 20%, 30%, 40%, and 50% by weight of cement. The study involved casting 36 concrete samples and conducting strength tests according to IS 516 (1964) for compressive strength and ASTM C78 for bending strength. These tests were performed at 7, 14, and 28 days. The mechanical strength of concrete increased with GGBS replacement up to 10%,

after which it began to decrease compared to conventional concrete. For metakaolin, replacement up to 20% led to an increase in tensile strength, outperforming conventional concrete.

3. Experimental Studies

3.1 Materials

The materials used in this study were carefully selected to ensure compliance with relevant standards for achieving the desired performance in ternary concrete mixtures. The following materials were used:

- **Cement:** Ordinary Portland Cement (OPC) of 53 grade was used, conforming to the requirements outlined in **IS 269:2015**.
- **Fly Ash:** Class F Fly Ash was incorporated as a Supplementary Cementitious Material (SCM). The Fly Ash used met the specifications of **IS 3812 (Part 1):2013**.
- **Ground Granulated Blast Furnace Slag (GGBS):** GGBS was utilized as another SCM in this study, conforming to the standards prescribed in **IS 12089:1987**.
- **Coarse and Fine Aggregates:** Both the

Table 1 Detail of Various Mix Proportions

- coarse aggregates and fine aggregates used in the concrete mixes adhered to the guidelines specified in **IS 383:2016**.

3.2 Methodology

The experimental investigation focused on the preparation and testing of concrete mixes with varying combinations of OPC, Fly Ash, and GGBS. The following outlines the key steps and parameters involved in the study:

- **Concrete Mixes:** M25 grade concrete was prepared with different proportions of Ordinary Portland Cement (OPC), Fly Ash, and Ground Granulated Blast Furnace Slag (GGBS) to create various mixes, including ternary blended concrete (TBC).
- **Testing Parameters:** Several performance metrics were evaluated to assess the quality and behavior of the concrete mixes:

- **Final Setting Time:** The time taken for the concrete to set fully was recorded.

Mix	Cement	Flyash	Slag	Final Setting Time (Hrs)
M1	175	175	0	15
M2	175	150	25	14
M3	175	125	50	14.5
M4	175	100	75	14.8
M5	175	75	100	12
M6	175	50	125	14
M7	175	0	175	14
M8	350	0	0	10

➤ **Compressive Strength:**

Compressive strength was measured at 3, 7 & 28 days. The growth rate of compressive strength over time was also analyzed.

Mix	Grade	Cement (kg)	Fly ash (kg)	Slag (kg)	Sand (kg)	20mm (kg)	10mm (kg)	Water (kg)
M1	M25	175	175	0	75	66	44	16
M2	M25	350	0	0	80	67	45	16
M3	M25	175	150	25	76	66	44	16
M4	M25	175	125	50	76	67	44	16
M5	M25	175	100	75	77	66	44	16
M6	M25	175	75	100	78	66	44	16
M7	M25	175	0	175	79	67	44	16
M8	M25	175	50	125	78	66	44	16

4 Results and Discussions

Table 2 Value of Compressive Strength of Different Design Mix

Mix	Cement	Fly ash	Slag	Compressive Strength-3Days	Compressive Strength-7Days	Compressive Strength-28Days
M1	175	175	0	11.44	17.75	33.16
M2	175	150	25	15.02	21.78	37.13
M3	175	125	50	16.29	25.49	41.63
M4	175	100	75	17.8	29.5	46.87
M5	175	75	100	17.2	25.75	41.79

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M6	175	50	125	19.2	26.93	41.39
M7	175	0	175	22.6	32.2	44.24
M8	350	0	0	30.98	43.02	52.5

Table 3 Value of Final Setting of Different Design Mix

Portland Cement Concrete (PCC) consistently exhibits higher compressive strength compared to Ternary Blended Concrete (TBC) at early stages—specifically at 3 days, 7 days, and 28 days. In Ternary Blended Concrete, as the Fly Ash (FA) content decreases and the Ground Granulated Blast Furnace Slag (GGBS) content increases, the compressive strength improves at all the given time intervals (3, 7, and 28 days).

5. Conclusions

1) The experimental investigation revealed that Ternary Blended Concrete (TBC) mixes exhibited several advantages, particularly in terms of final setting time. However, the compressive strength of TBC was generally lower than that of conventional Portland Cement Concrete (PCC) at early stages of testing, specifically at 3, 7, and 28 days.

2) Despite this, the rate of strength development in TBC was higher than that of PCC, indicating that TBC continues to gain strength at a faster rate over time, particularly beyond 28 days.

3) The production of ternary concrete not only supports greater utilization of industrial waste materials but also allows for a reduction in the cement content in concrete mixes. This leads to resource conservation, enhanced waste utilization, and improved sustainability in construction practices.

4) As the construction industry continues to seek greener and more durable materials, ternary concrete emerges as a viable solution to address both environmental and performance concerns.

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