



Comparative Analysis Of Compressive Strength By Partial Replacement Of Fly Ash And GGBS In Concrete

¹ Prashant Kishor Nawale, ² Soham Somnath Borkar, ² Sarthak Subhash Pasalkar ,

² Alok Bhagwan Pawar, ² Anjali Babaso Sutar

¹ Assistant Professor , ² Research Scholar

^{1,2} Department of Civil Engineering,

^{1,2} Zeal College of Engineering & Research, Pune, India

Abstract:

This study investigates the compressive strength and cost-effectiveness of M40 grade concrete when cement is partially replaced with Fly Ash and Ground Granulated Blast Furnace Slag (GGBS). The research aims to determine the optimal replacement proportions for achieving desired strength while reducing material costs. A design mix with a water-cement ratio of 0.4 was used. Concrete specimens were prepared by replacing cement with 20–30% Fly Ash, 40–50% GGBS, and combinations of both. Compressive strength was tested at 7, 14, and 28 days. Results showed that while conventional concrete achieved the highest strength, blended mixes also performed well and offered significant cost benefits. The combined use of 30% GGBS + 15% Fly Ash emerged as a balanced option in terms of strength and economy.

I. INTRODUCTION

Concrete is a fundamental material in the construction industry. However, the production of ordinary Portland cement (OPC), a primary ingredient in concrete, is a major contributor to global CO₂ emissions. As the demand for sustainable construction materials increases, the use of supplementary cementitious materials (SCMs) like fly ash and ground granulated blast furnace slag (GGBS) has gained momentum. Fly ash is a by-product of coal combustion, while GGBS is produced during iron and steel manufacturing. Both materials possess pozzolanic or latent hydraulic properties, which allow them to react with calcium hydroxide in concrete and enhance strength and durability over time. Their use also contributes to waste reduction and energy conservation.

The use of these materials not only reduces the reliance on OPC but also addresses the environmental burden associated with industrial waste disposal. Despite their benefits, the individual and combined effects of fly ash and GGBS on concrete properties—especially compressive strength—vary with replacement levels, curing durations, and mix proportions. Understanding these effects is critical for optimizing concrete mix designs that align with sustainability goals while meeting structural performance requirements.



(Image no :1) - GGBS

Both fly ash and GGBS possess pozzolanic and latent hydraulic properties, contributing to improved durability, reduced permeability, and enhanced long-term strength of concrete. However, their effects on early-age and later-age compressive strength can differ significantly, depending on the replacement ratio, curing conditions, and mix design.

This study aims to compare the compressive strength and cost-effectiveness of concrete mixes partially replaced with fly ash, GGBS, and a combination of both. The focus is on evaluating their performance over time and identifying an optimal mix for sustainable construction applications.



(Image no :2) – Fly ash

1.1 Research objectives

- * To study the effect of partial replacement of cement with Fly Ash and GGBS on compressive strength.
- * To compare the strength development of conventional and blended concretes at 7, 14, and 28 days.
- * To analyze the cost-effectiveness of different replacement ratios.

2 EXPERIMENTAL STUDY

2.1 Material used

The cement used in this study was ordinary Portland cement in M40 Grade of concrete. The specific gravity of cement used was 3.10. Ordinary Portland cement, 53 Grade conforming to IS: 8112-1989 was used. River sand passing through 4.75 mm IS sieve conforming to grading zone II of IS 383:1970 and having a specific gravity of 2.68 was used in this work. Crushed aggregate available from local sources with a maximum size of 20 mm having a specific gravity of 2.78 and conforming to IS 2386:1963 was used as coarse aggregate in this study. The GGBS having a specific gravity of 2.87 was used in this study to determine the optimum replacement level. The replacement level of the GGBS in concrete is 40%, 45%, and 50% of the total weight of cement and replacement of FLY ASH in concrete is 20%, 25%, and 30% and replacement of GGBS and FLY ASH blend in concrete is 30%GGBS+15%F-A, 30%GGBS+20%F-A and 25% GGBS+25%F-A.

2.2 Test on Materials

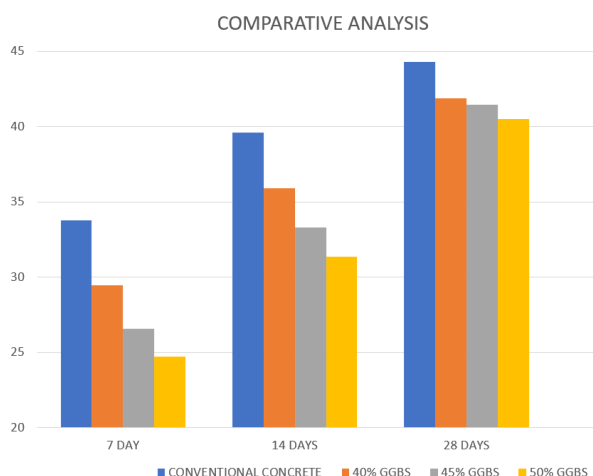
In the field of concrete technology, the quality assessment of materials such as aggregates, cement, fly ash, and Ground Granulated Blast Furnace Slag (GGBS) is critical to ensuring structural performance and durability. Aggregates are tested for particle size distribution through sieve analysis, while other essential tests include specific gravity and water absorption (to determine porosity and density), aggregate crushing value and impact value (to evaluate strength and toughness), Los Angeles abrasion test (to assess hardness), and shape tests such as flakiness and elongation index. Additionally, soundness and organic impurity tests are conducted to confirm durability and cleanliness. Cement is characterized by tests for fineness (Blaine's method or sieve analysis), standard consistency, setting times (initial and final using Vicat apparatus), compressive strength at various curing ages (typically 3, 7, and 28 days), soundness (via Le Chatelier method), and specific gravity. Fly ash, used as a pozzolanic material, is evaluated for fineness, loss on ignition (LOI), specific gravity, pozzolanic activity index, soundness, and chemical composition (typically via X-ray fluorescence). Similarly, GGBS is tested for fineness, specific gravity, chemical composition (including key oxides such as CaO , SiO_2 , and Al_2O_3), glass content, and activity index to determine its effectiveness as a supplementary cementitious material. Tests for setting time and soundness are also conducted to ensure compatibility with other concrete components. These tests are essential for selecting suitable materials, optimizing mix designs, and ensuring the long-term performance of concrete structures.

2.3 Testing of Specimens

The performance evaluation of concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) and fly ash is typically conducted through standard specimen testing to assess mechanical and durability characteristics. Concrete specimens, such as cubes, cylinders, and beams, are prepared and tested at various curing ages—commonly 7, 28, and 56 days—to determine compressive strength, split tensile strength, and flexural strength, in accordance with relevant standards (e.g., ASTM C39, C496, and C78 or equivalent IS codes). While blended concretes often exhibit reduced early-age strength due to the slower pozzolanic reaction of fly ash and GGBS, they generally demonstrate enhanced long-term strength and improved durability. Durability assessments include water absorption, sorptivity, acid resistance, and rapid chloride penetration tests (RCPT), which provide insight into permeability and resistance to chemical ingress. Microstructural analysis using techniques such as Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) further supports understanding of the hydration process and matrix densification. Overall, test results consistently indicate that the incorporation of GGBS and fly ash contributes to improved long-term performance, lower heat of hydration, and greater environmental sustainability by reducing cement content and associated carbon emissions.

3 RESULT AND DISCUSSION

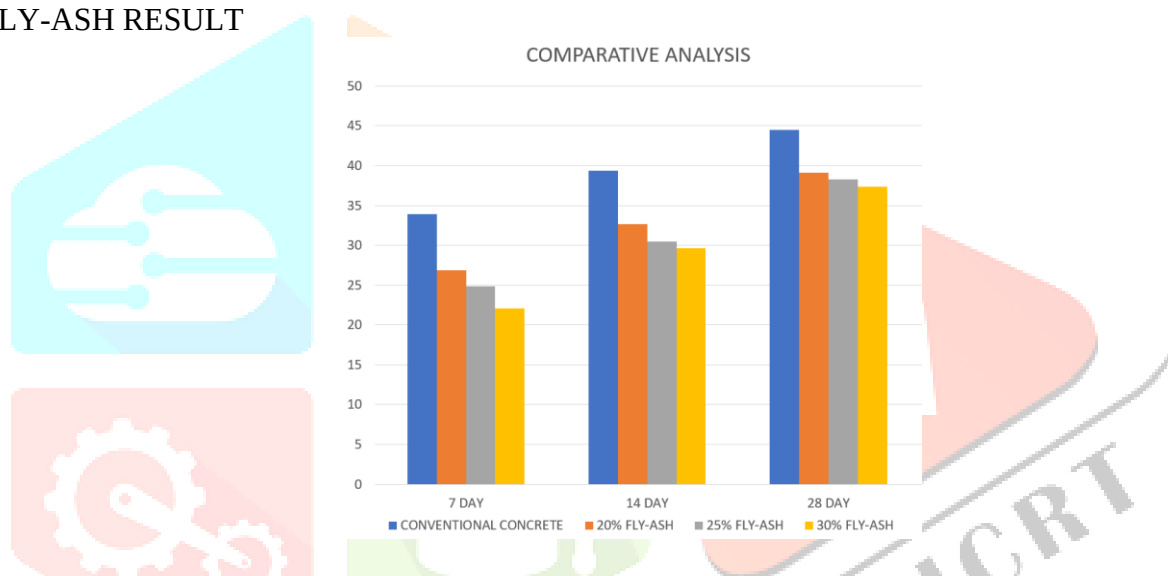
3.1 GGBS RESULT



The analysis of concrete with partial replacement of cement by GGBS (Ground Granulated Blast Furnace Slag) reveals a notable trend in both strength development and cost efficiency. As the replacement levels of GGBS increase from 40% to 50%, there is a slight reduction in early compressive strength at 7 days—from 29.89 MPa to 24.80 MPa—compared to 33.90 MPa for conventional concrete. However, as curing progresses, the strength of GGBS-blended mixes significantly improves. By 28 days, the compressive strength of the 40% GGBS mix reaches 42.60 MPa, closely approaching the 44.50 MPa of conventional concrete, while the 45% and 50% GGBS mixes achieve 41.30 MPa and 40.20 MPa respectively. This indicates that GGBS contributes positively to long-term strength development, despite lower early-age strength.

	CONVENTIONAL CONCRETE	GGBS- 40%	GGBS- 45%	GGBS- 50%
7 DAYS	33.90	29.89	26.79	24.80
14 DAYS	39.40	36.46	33.45	32.70
28 DAYS	44.50	42.60	41.30	40.20

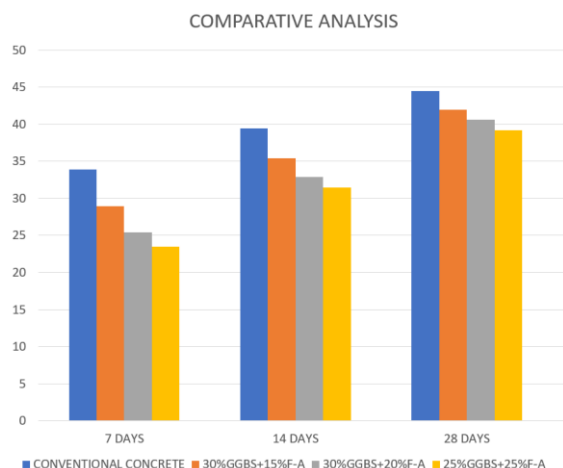
3.2 FLY-ASH RESULT



The use of fly ash as a partial replacement for cement in concrete exhibits a noticeable impact on both compressive strength development and cost reduction. At early curing stages (7 days), the strength of fly ash-modified concrete is significantly lower than that of conventional concrete (33.90 MPa), recording 26.90 MPa for 20% fly ash, 24.86 MPa for 25% fly ash, and 22.10 MPa for 30% fly ash. This reduction is attributed to the slower pozzolanic reaction of fly ash. However, by 28 days, there is a substantial increase in compressive strength, with 20% fly ash achieving 39.08 MPa, 25% fly ash reaching 38.29 MPa, and 30% fly ash yielding 37.32 MPa, indicating effective strength gain over time.

	CONVENTIONAL CONCRETE	FLY-ASH 20%	FLY-ASH 25%	FLY-ASH 30%
7 DAYS	33.90	26.90	24.86	22.1
14 DAYS	39.40	32.66	30.45	29.66
28 DAYS	44.50	39.08	38.29	37.32

3.3 GGBS AND FLY-ASH BLEND RESULT



The combined use of GGBS (Ground Granulated Blast Furnace Slag) and Fly Ash as partial replacements for cement offers a balanced approach in achieving both compressive strength and economic benefits in concrete. Three mix combinations were analyzed: 30% GGBS + 15% Fly Ash, 30% GGBS + 20% Fly Ash, and 25% GGBS + 25% Fly Ash. At 7 days, compressive strength values were 28.91 MPa, 25.41 MPa, and 23.50 MPa respectively, compared to 33.90 MPa for conventional concrete. By 28 days, the strengths improved considerably to 41.96 MPa, 39.64 MPa, and 39.18 MPa, respectively, showing that the blended cement mixes can closely match conventional concrete's long-term performance (44.50 MPa at 28 days). This indicates that while early strength is lower due to the slower pozzolanic activity of both GGBS and fly ash, the overall strength gain at later stages is substantial.

	CONVENTIONAL CONCRETE	GGBS- 30% + FLY ASH- 15%	GGBS- 30% + FLY ASH- 20%	GGBS- 25% + FLY ASH-25%
7 DAYS	33.90	28.91	25.41	23.50
14 DAYS	39.40	35.36	31.89	30.45
28 DAYS	44.50	41.96	39.64	36.18

4 COST ANALYSIS

Mix	Cost (Rs/m ³)
Conventional Concrete	25876
GGBS 40%	25185
GGBS 45%	24987
GGBS 50%	24987
Fly-Ash 20%	25452
Fly-Ash 25%	25307
Fly-Ash 30%	25062
GGBS 30% + fly-ash 15%	25047
GGBS 30% + fly-ash 20%	24910
GGBS 25% + fly-ash 25%	24848

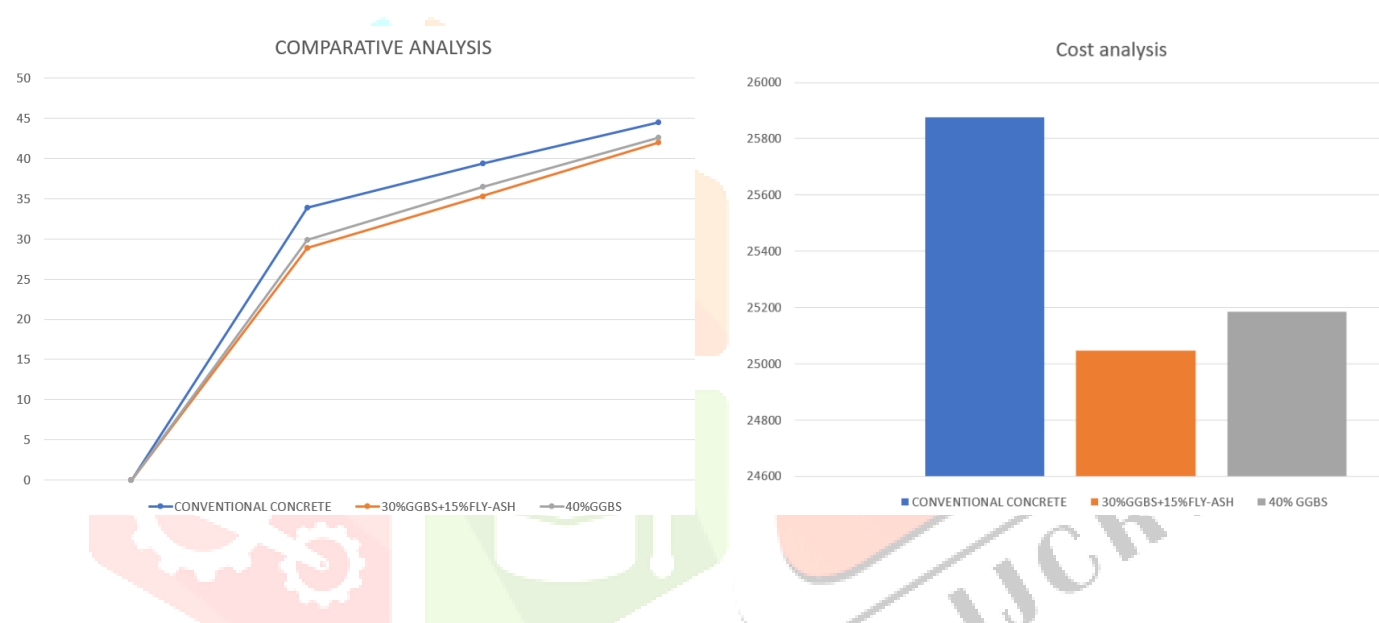
This indicates that GGBS contributes positively to long-term strength development, despite lower early-age strength. In terms of cost, the inclusion of GGBS leads to a reduction in the cost per cubic meter of concrete. While conventional concrete costs ₹25,876/m³, mixes with 45% and 50% GGBS cost only ₹24,987/m³,

representing a cost saving of approximately 3.4%. The 40% GGBS mix, costing ₹25,185/m³, offers a balanced option with both high strength and economic benefits. These results affirm the suitability of GGBS as a sustainable and cost-effective partial replacement for cement in concrete production.

The cost analysis shows a clear economic advantage: while conventional concrete costs ₹25,876 per cubic meter, GGBS-based mixes range from ₹25,185 (40% GGBS) to ₹24,987 (45% and 50% GGBS), resulting in cost savings of up to 3.4%. This dual benefit of sustainable material use and economic viability highlights GGBS as an effective supplementary cementitious material in concrete production.

In terms of cost efficiency, fly ash significantly lowers the production cost of concrete. While conventional concrete costs ₹25,876 per cubic meter, 20%, 25%, and 30% fly ash mixes reduce the cost to ₹25,452, ₹25,307, and ₹25,062 respectively. This demonstrates a clear economic advantage, particularly with higher fly ash content. Thus, fly ash is a viable supplementary material for sustainable and cost-effective concrete, especially in applications where early strength is not a critical factor.

5 OPTIMUM MIX PROPORTION AND COST-EFFECTIVE ANALYSIS



From the analysis, it was observed that while conventional concrete achieved the highest 28-day compressive strength (44.50 MPa), the mixes with 40% GGBS and a blend of 30% GGBS + 15% Fly Ash demonstrated nearly equivalent strength, with values of 42.60 MPa and 41.96 MPa respectively. Notably, these mixes also offered substantial cost benefits. The cost per cubic meter of concrete for 40% GGBS was ₹25,185, and for 30% GGBS + 15% Fly Ash, it was ₹25,047—both significantly lower than the ₹25,876/m³ cost of conventional concrete. This translates to cost savings of ₹691 and ₹829 per cubic meter, respectively.

6 CONCLUSION

The study aimed to compare the compressive strength and cost-effectiveness of concrete with partial replacement of cement by Fly Ash and Ground Granulated Blast Furnace Slag (GGBS), both individually and in combination. Experimental results were evaluated at 7, 14, and 28 days for various mix proportions. The results indicate that 40% GGBS is the most effective single replacement option, providing a strong balance of performance and economy. On the other hand, the combination of 30% GGBS + 15% Fly Ash not only delivers competitive strength but also adds the benefit of greater sustainability by incorporating two industrial by-products. While early-age strength is slightly reduced in all blended mixes due to slower pozzolanic activity, the long-term strength development is satisfactory and meets structural requirements. Therefore, 40% GGBS and 30% GGBS + 15% Fly Ash are identified as the most economical and strength-efficient mix designs, making them ideal alternatives to conventional concrete in terms of both structural performance and cost efficiency. These findings support the broader use of blended cementitious materials in modern construction, promoting sustainable practices without compromising quality.

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