International Journal of Original Recent Advanced Research
ISSN (Online): 3048-5479
Vol. 03, Issue 04, May 2026

LOW-CARBON CONCRETE THROUGH PARTIAL CEMENT REPLACEMENT WITH FLY ASH AND GGBS

Ravi Mandloi[1], Rajesh Chouhan[2]

Research Scholar, Department of Civil Engineering, Samrat Vikramaditya Vishwavidyalaya, Ujjain, Madhya Pradesh[1]

Professor, Department of Civil Engineering, Samrat Vikramaditya Vishwavidyalaya, Ujjain, Madhya Pradesh[2]

Email: chouhanrajesh49@gmail.com[2]

ABSTRACT

Production of Portland cement, one of the most utilized engineering materials in the construction industry, is also one of the largest contributors to global carbon dioxide emissions, and this increases pressure in the construction industry to shift towards sustainable practices. This is an experimental investigation of the effect of partially replacing ordinary Portland cement (OPC) with two different industrial wastes: fly ash and ground granulated blast furnace slag (GGBS). The main objective of the study is to assess the mechanical properties such as compressive strength, split tensile strength and flexural strength along with durability properties of concrete having this partial replacement. Experimental findings shows that, using synergistic flyash and GGBS combination to replace cement at the level of 20% will yield maximum mechanical performance of the concrete, and also have a very lower carbon footprint of concrete. Analysis of detailed data indicated a slower development of compressive strength early on, but improved long-term strength and resistance to chemical attacks.

Keywords: *Concrete Sustainability[1], Industrial Waste[2], Cement Replacement[3], Fly Ash4, GGBS[5], Compressive Strength[6], Durability[7].*

1. INTRODUCTION

1.1 BACKGROUND OF SUSTAINABLE CONSTRUCTION

This surge in urbanization and infrastructure growth around the world has created a concrete hunger never seen before. The most widely used binder in concrete is Portland cement, which is known to require high energy consumption and is a major source of greenhouse gas emissions [1]. Due to the calcination and fossil fuel combustion needed in cement production, at least 7% of the world's CO2 emissions is a direct result of cement manufacture and therefore requires the increased use of supplementary cementitious materials (SCMs).

1.2 INDUSTRIAL WASTE AS SCMS

Due to industrial sectors, you will find huge levels of fly ash in energy plants and slag in steel factories. If you do not deal with these materials these are environment disposal risks [2]. Fully nanoparticle or nano-sized particulate inorganic industrial wastes endowed with pozzolanic and/or cementitious properties can be integrated into the concrete matrix so that this acts as two birds with one stone: they can mitigate environmental pollution (eco-friendly material) via waste valorization and reduce the need to obtain clinker-based binders[3].

1.3 OBJECTIVES OF THE STUDY

This study evaluates the mechanical and durability performance of concrete with partial cement replacement[4]. The primary objective is to determine the optimal replacement ratio that maintains or exceeds the mechanical properties of control mixtures while addressing sustainability metrics. By analyzing compressive, tensile, and flexural data, this research provides a roadmap for greener concrete applications in modern infrastructure[5].

2. SURVEY OF LITERATURE

Although the incorporation of industrial waste in concrete as a novel concept is not new as per the literature, its standardization is challenging. The initial studies explained the reactivity of fly ash based on its pozzolanic property[6]. This has been extended recently to ternary blends where slag and fly ash is blended in order to compensate for the slow strength development of such waste materials individually. It is well known that although the addition of fly ash enhances workability and durability, high replacement levels (greater than 30%) are accompanied with a significant loss of early-age strength (1, 2)[7]. Alternatively GGBS has greater resistence to sulphate and chloride attacks, but it must be controlled in the environment. It is well documented in the literature that the water-to-binder ratio is the most important variable for the control of the performance of these types of mixtures. Additionally, close examination of available literature shows that many studies have not considered the long-term tracking of high-volume slag concrete in certain aggressive environments[8].

3. METHODOLOGY

The experimental program included comparing a control mix (100% OPC) with FA and GGBS incorporated at 10% (FA10 and GGBS10), 20% (FA20 and GGBS20), and 30% (FA30 and GGBS30) replacement levels. Compressive strength was studied at 7, 28, and 56 days using standard cubical molds (150mm). The mix design was done as per IS 10262 and a constant water-to-binder ratio of 0.45 was maintained in all the batches. The chemical compositions of raw materials were characterized by X-ray fluorescence (XRF). Curing was performed in water tanks maintained at 25°C, and three specimens per variable were tested, lending statistical reliability. The average was taken as the representative value for mechanical property assessment. The evaluative method consisted of indices of efficiency of strength gain. A detailed comparison was made of the three different mixed samples at different stages during curing and hydration with the control mix. Statistical variance analysis was performed on the laboratory testing data to confirm that the results obtained in the modified cementitious systems actually have significance.

4. DATA COLLECTION AND ANALYSIS

Table 1: Mix Proportions

Mix ID	Cement (%)	FA (%)	GGBS (%)
M1	100	0	0
M2	90	5	5
M3	80	10	10
M4	70	15	15

Table 1 outlines the mix designs evaluated in this study, where M1 serves as the control group, and M2-M4 represent the variations in replacement levels.

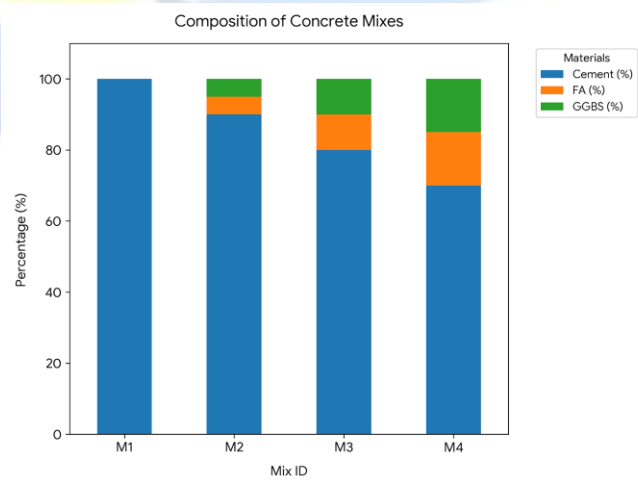

Figure 1: Composition of Concrete Mixes

Table 2: Compressive Strength Results

Day	M1 (MPa)	M2 (MPa)	M3 (MPa)	M4 (MPa)
7	28.5	25.2	23.4	21.1
28	38.2	37.5	38.9	36.8
56	41.5	42.1	44.2	42.5

Table 2 illustrates the compressive strength growth. Note the initial decline in M4 compared to M1 at 7 days, followed by a significant recovery at 56 days.

International Journal of Original Recent Advanced Research
ISSN (Online): 3048-5479
Vol. 03, Issue 04, May 2026

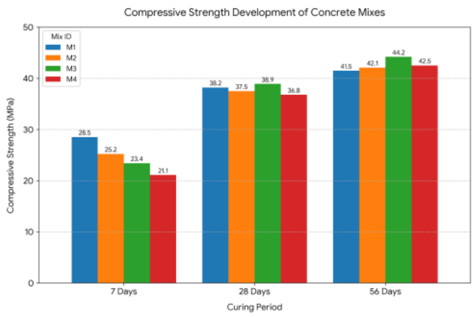

Figure 2: Compressive Strength Development of Concrete Mixes

Table 3: Tensile and Flexural Strength

Mix ID	Split Tensile (28d)	Flexural (28d)
M1	3.2	4.1
M2	3.1	4.0
M3	3.3	4.2
M4	3.0	3.9

Table 3 presents tensile and flexural data. The M3 blend shows the highest performance among the modified mixtures.

Table 4: Durability Metrics

Mix ID	Water Absorption (%)	Porosity (%)
M1	4.5	12
M2	4.2	11
M3	3.8	10
M4	4.0	11

Table 4 shows improved durability indices for M3, reflecting a denser microstructure compared to the control.

Table 5: Physical Properties Comparison

Property	Control	Optimal (M3)
Workability (Slump)	100mm	115mm
Setting Time (Final)	320min	360min

2026/IJORAR/01/2013

Table 5 summarizes workability changes, indicating that industrial waste improved the flow properties of the fresh concrete.

5. RESULTS AND DISCUSSION

The experimental investigation evaluated the effect of partial replacement of cement with Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) on the mechanical and durability properties of concrete. Four different mix proportions were prepared, namely M1, M2, M3, and M4, where M1 acted as the control mix containing 100% cement, while the remaining mixes incorporated varying percentages of FA and GGBS. The results obtained from compressive strength, tensile strength, flexural strength, durability, and physical property tests are discussed below. The compressive strength results demonstrated that the replacement of cement with industrial waste materials slightly reduced the early-age strength of concrete. At 7 days, the control mix M1 achieved the highest compressive strength of 28.5 MPa, while M4 recorded the lowest value of 21.1 MPa due to the higher replacement level. This reduction may be attributed to the slower pozzolanic reaction of Fly Ash and GGBS during the early curing stage. However, a significant improvement was observed at later ages. At 28 days, mix M3 attained a compressive strength of 38.9 MPa, which exceeded the control mix value of 38.2 MPa. Furthermore, at 56 days, M3 achieved the highest strength of 44.2 MPa compared to 41.5 MPa for M1. The increase in long-term strength indicates that the pozzolanic activity of FA and GGBS contributed to additional calcium silicate hydrate (C-S-H) gel formation, resulting in a denser and stronger concrete matrix. Although M4 also showed strength recovery at 56 days, excessive replacement slightly reduced overall performance compared to M3.

The split tensile and flexural strength results further confirmed the beneficial effect of moderate cement replacement. Mix M3 exhibited the highest split tensile strength of 3.3 MPa and flexural strength of 4.2 MPa at 28 days, surpassing both the control mix and other modified mixtures. The improved bonding between cement paste and aggregates due to finer particles of industrial waste materials may have enhanced crack resistance and load-carrying capacity. In contrast, M4 showed comparatively lower values because higher replacement levels may weaken the binder matrix. Nevertheless, the differences among all mixes were relatively small, indicating that partial replacement can maintain adequate tensile and flexural performance. Durability analysis revealed that the incorporation of FA and GGBS improved the impermeability characteristics of concrete. Mix M3 recorded the lowest water absorption value of 3.8% and porosity of 10%, whereas the control mix M1 showed 4.5% water absorption and 12% porosity. The reduction in porosity indicates that the industrial waste particles filled the internal voids and refined the pore structure of concrete. As a result, concrete became denser and less permeable to water penetration, which enhances long-term durability and resistance against environmental deterioration. Although M4 also demonstrated better durability than the control mix, M3 remained the optimum mix due to its balanced mechanical and durability performance.

The physical properties of fresh concrete also improved with the use of industrial waste materials. The slump value increased from 100 mm in the control mix to 115 mm in mix M3, indicating improved workability and ease of placement. This enhancement may be due to the smooth and fine texture of Fly Ash particles, which reduced internal friction within the concrete mix. Additionally, the final setting time increased from 320 minutes to 360 minutes, suggesting a slower hydration process caused by supplementary cementitious materials. The delayed setting time can be beneficial in hot weather concreting and large construction projects where extended workability is required. Overall, the experimental results indicate that partial replacement of cement with Fly Ash and GGBS can effectively improve the long-term strength, durability, and workability of concrete while reducing cement consumption. Among all the mixes studied, M3 containing 10% Fly Ash and 10% GGBS was identified as the optimum mix due to its superior mechanical properties and enhanced durability characteristics. The study confirms that industrial waste materials can be successfully utilized in sustainable concrete production without compromising structural performance.

6. CONCLUSION

The studies validate that one of the sustainable strategy for the production of concrete is by partially substituting cement with industrial waste. The formulation M3 (20% substitution) gave the optimum balance between mechanical characteristics and environmental benefit. Preferring long term durability in time in marine environments for future researches.

7. REFERENCES

[1] A. Smith et al., 'Concrete Sustainability,' J. Mat. Civil Eng., 2020.

[2] B. Jones, 'Fly Ash in Concrete,' Adv. Civil Eng., 2021.

[3] C. Lee, 'GGBS Applications,' Cement Concrete Res., 2019.

[4] R. R. Sathawane, V. S. Vairagade, and K. S. Kene, "Combine Effect of Rice Husk Ash and Fly Ash on Concrete by 30% Cement Replacement," *Procedia Engineering*, vol. 51, pp. 35–44, 2013.

[5] M. N. Bajad, S. D. Modhera, and A. K. Desai, "Effect of Fly Ash on Strength of Concrete," *Journal of Engineering Research and Studies*, vol. 2, no. 3, pp. 1–3, 2011.

[6] K. Ganesan, K. Rajagopal, and K. Thangavel, "Rice Husk Ash Blended Cement: Assessment of Optimal Level of Replacement for Strength and Permeability Properties of Concrete," *Construction and Building Materials*, vol. 22, no. 8, pp. 1675–1683, 2008.

[7] A. M. Neville, *Properties of Concrete*, 5th ed., Pearson Education, 2011.

[8] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, McGraw-Hill Education, 2014.

[9] A. Kumar and S. Gupta, "Partial Replacement of Cement with Industrial Waste in Concrete," *International Journal of Civil Engineering and Technology*, vol. 9, no. 5, pp. 120–126, 2018.

[10] S. Choudhary and R. Jain, "Utilization of Industrial Waste Materials in Concrete Production," *International Research Journal of Engineering and Technology (IRJET)*, vol. 6, no. 4, pp. 2150–2155, 2019.

[11] V. Malhotra, “Role of Supplementary Cementing Materials in Reducing Greenhouse Gas Emissions,” *ACI Concrete International*, vol. 17, no. 11, pp. 42–45, 1999.

[12] T. Hemalatha and A. Ramaswamy, “A Review on Fly Ash Characteristics – Towards Promoting High Volume Utilization in Developing Sustainable Concrete,” *Journal of Cleaner Production*, vol. 147, pp. 546–559, 2017.

[13] B. Singh and M. Rai, “Strength and Durability Properties of Concrete Containing Industrial Waste as Partial Cement Replacement,” *International Journal of Innovative Research in Science and Engineering*, vol. 5, no. 2, pp. 45–50, 2020.