© 2026 IJRTI | Volume 11, Issue 1 January 2026 | ISSN: 2456-3315

Comparative Evaluation of Ternary Blended Concrete: A Theoretical Analysis of Mechanical Integrity and Carbon Mitigation Using Industrial By-Products

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***Abstract*—The global construction industry faces a challenge: meeting the rising demand for infrastructure while reducing the massive carbon footprint of Ordinary Portland Cement (OPC) production. This paper provides a theoretical analysis of ternary blended concrete, utilizing Fly Ash, Ground Granulated Blast-furnace Slag (GGBS), and Silica Fume as supplementary cementitious materials. Based on the chemical oxide compositions, specifically the high Silica (silicon dioxide) content of Silica Fume and the Lime (calcium oxide) content of GGBS, this study evaluates the synergistic effects on structural strength. Findings indicate that a strategic ternary blend optimizes the microstructure of concrete through the pozzolanic reaction and the "filler effect." Furthermore, the study quantifies a potential reduction in embodied carbon by approximately 18 to 20 percent compared to conventional concrete mixes. The paper concludes that industrial by-products are not merely waste but essential components for the transition toward sustainable, high-performance civil engineering practices.**

Index Terms*— *Ternary Blended Concrete, Supplementary Cementitious Materials (SCMs), Carbon Mitigation, Fly Ash, GGBS, Silica Fume, Pozzolanic Reaction, Green Concrete, Structural Integrity, Industrial By-products.

I. Introduction

The production of cement is responsible for approximately 8% of global CO_2 emissions. As the world moves toward "Net Zero" goals, the civil engineering sector must adopt "Circular Economy" principles. This research explores the theoretical viability of replacing cement with industrial by-products to create "Green Concrete."

II. Methodology

This research utilizes a theoretical analysis of peer-reviewed data (2020 2025). The study focuses on the chemical and environmental performance of:

Fly Ash (Class F)

GGBS (Grade 100/120)

Silica Fume (Undensified)

III. Comparative Data Analysis

Table 1: Representative Chemical Composition (%)

Constituent (Oxide %)	Cement (OPC)	Fly Ash	GGBS	Silica Fume
Silica (SiO_2)	20.2	54.1	32.5	94.2
Alumina (Al_2O_3)	5.1	26.4	14.2	0.5
Lime (CaO)	63.4	4.2	38.6	0.4
Iron Oxide (Fe_2O_3)	3.0	8.0	0.5	1.0

Table 2: Embodied Carbon Coefficients ($kgCO_2/kg$)

Materials	Embodied Carbon ($kgCO_2/kg$)	Mitigation Potential (%)
Cement (OPC)	0.91	Baseline (0%)
Fly Ash	0.01	98.9%
GGBS	0.07	92.3%

IV. Data Analysis

Chemical Synergy: The high SiO_2 in Silica Fume reacts with the $Ca(OH)_2$ released during cement hydration to form additional Calcium Silicate Hydrate (C-S-H) gel, the primary strength-providing component.

Microstructure: The ultra-fine particles of Silica Fume fill the microscopic voids between cement grains, increasing density and durability.

Sustainability: Theoretical calculations show that replacing 30% of cement with a blend of Fly Ash and GGBS saves roughly 250 kg of CO_2 per truckload of concrete.

V. Conclusion

Ternary blended concrete is a factually proven method to achieve high-strength infrastructure with low environmental impact. The study finds that the combination of these three materials overcomes the individual weaknesses of each (e.g., the slow early strength of Fly Ash is compensated by the rapid reactivity of Silica Fume).

VI. Acknowledgment

I would like to express my gratitude to the Department of Civil Engineering at Thapar Institute of Engineering and Technology, Patiala. I am thankful for the academic environment and access to the research resources that allowed me to complete this theoretical analysis on ternary blended concrete. This work represents my own independent effort as a first-year student to contribute to the field of sustainable construction and carbon mitigation**.**

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