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Strength and Durability Analysis of Concrete with Waste-Based Cement Alternatives

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Abstract

Cement production is vital for modern infrastructure but contributes significantly to environmental degradation due to its carbon footprint. This research explores the use of Ground Granulated Blast Furnace Slag (GGBS), Ladle Furnace Slag (LFS), and Sugarcane Bagasse Ash (SCBA) as partial replacements for cement. Laboratory analysis on M40 grade concrete evaluated compressive and tensile strength at 7 and 28 days. The results indicate that up to 25% replacement of cement with these materials can maintain or improve performance, offering a sustainable and cost-effective solution for eco-friendly construction.

Keywords: Sustainable construction, cement alternatives, GGBS, LFS, bagasse ash, concrete performance, eco-friendly materials

1. Introduction

The global cement industry produces over four billion tonnes annually, accounting for nearly 8% of global CO_2 emissions. Given the environmental and health impacts of cement production, sustainable alternatives have become a research priority. India, one of the world's largest cement producers, faces significant challenges in waste management from industries generating by-products like steel slag, bagasse ash, and blast furnace slag. This study investigates the potential of these waste materials to partially replace cement in concrete without compromising strength or durability.

2. Literature Review

Previous studies have demonstrated the feasibility of industrial by-products as supplementary cementitious materials. Manjunatha et al. (2014) found that GGBS can replace up to 50% of cement in M20 grade concrete without strength loss. Marinho et al.

(2017) reported LFS as a suitable binder due to its high CaO content (~88%), while Amin (2011) and Bahurudeen et al. (2015) identified 20–25% SCBA replacement as optimal for maintaining compressive strength. These findings support the incorporation of industrial and agricultural waste into construction materials for sustainability.

3. Methodology

The experimental program involved replacing cement in M40 grade concrete with GGBS, LFS, and SCBA at varying proportions (5%, 10%, 15%, 20%, 25%, and 30%). Compressive and split tensile strength tests were conducted on cube and cylinder specimens after 7 and 28 days of curing. The materials used were characterized for chemical composition, specific gravity, and fineness, following IS 456:2000 and IS 10262:2009 guidelines.

Replacement (%)	GGBS (MPa)	LFS (MPa)	SCBA (MPa)
0.0	38.5	38.5	38.5
5.0	39.8	39.1	39.0
10.0	41.2	40.0	40.5
15.0	42.1	41.5	41.0
20.0	43.0	42.3	42.0
25.0	43.5	43.0	42.5
30.0	41.7	41.2	41.0

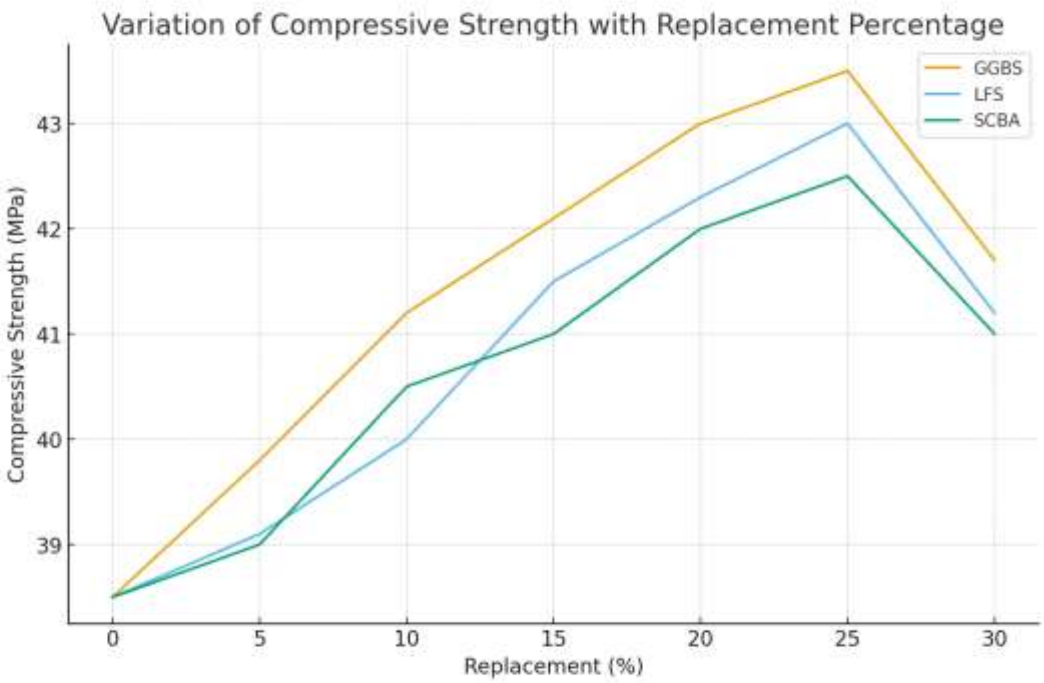

Figure 1: Variation of Compressive Strength with Replacement Percentage

4. Results and Discussion

The results show that GGBS and LFS significantly enhance compressive strength up to 25% replacement. SCBA also improves strength moderately due to its pozzolanic activity and high silica content. Beyond 30% replacement, strength declines, likely due to reduced cementitious content. The cost analysis revealed a 12–18% reduction in overall material cost compared to conventional concrete.

5. Conclusion

This study demonstrates that using industrial and agricultural waste materials like GGBS, LFS, and SCBA can effectively replace up to 25% of cement in concrete. Such substitution not only maintains mechanical performance but also reduces environmental impact and project costs. Future work should focus on the long-term durability, carbonation resistance, and microstructural analysis of such eco-friendly concretes.

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