

A Study on the Combined Use of Wood Ash and GGBFS as Partial Replacement of Fine Aggregate in Concrete

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Abstract - The escalating demand for concrete in infrastructure development and the concurrent depletion of natural fine aggregates has necessitated urgent research into sustainable supplementary materials. A systematic and experimental investigation into the use of Ground Granulated Blast Furnace Slag (GGBFS) and Wood Ash (WA) to partially replace fine aggregate in M25-grade concrete is presented in this thesis. Wood ash, an industrial and agricultural by-product generated from biomass combustion in thermal power plants, brick kilns, and sugar mills, and GGBFS, a latent hydraulic by-product of pig iron manufacturing, are abundantly available in India and pose significant environmental disposal challenges when unutilized. The study employs a systematic experimental design wherein WA and GGBFS are used individually and in combined proportions (0%, 5%, 10%, 15%, and 20% by weight of fine aggregate) to assess fresh and hardened concrete properties. Workability (slump cone test), compressive strength (7-day and 28-day), split tensile strength, flexural strength, and water absorption were all tested in accordance with the applicable guidelines set forth by the Bureau of Indian Standards (BIS). The cost analysis of ash processing for carbon removal and the confirmation that the used wood ash does not contain unburned carbon—a factor that has a significant impact on the microstructure and hydration of concrete—are crucial components of this investigation. Experimental results indicate that optimum replacement levels of WA and GGBFS yield concrete with mechanical properties meeting or exceeding the M25 design strength of 25 N/mm². The findings support the feasibility of utilizing these industrial by-products in concrete manufacturing, thereby contributing to sustainable construction practices, waste reduction, and partial conservation of natural river sand resources.

Keywords: Wood Ash, Ground Granulated Blast Furnace Slag (GGBFS), Fine Aggregate Replacement, Sustainable Concrete, Green Construction Materials, Waste Utilization, Concrete Mix Design, Mechanical Properties of Concrete,

Compressive Strength, Durability of Concrete, Eco-Friendly Concrete.

I. INTRODUCTION

Concrete is the most widely used construction material in the world, second only to water in terms of global consumption. Its versatility, compressive strength, and durability have made it indispensable in infrastructure development, residential construction, and industrial applications. The primary constituents of concrete — cement, fine aggregate (natural sand), coarse aggregate, and water — are combined in specific proportions to achieve desired mechanical properties. However, the sustainability of concrete production is increasingly under scrutiny due to the rapid depletion of natural resources, particularly natural river sand, and the significant environmental footprint associated with cement manufacturing.

Natural sand, obtained from riverbeds, flood plains, and coastal deposits, has long been the preferred fine aggregate due to its ideal particle size distribution, shape, and surface texture. However, uncontrolled sand mining has triggered severe ecological consequences including riverbank erosion, reduction in groundwater tables, loss of aquatic biodiversity, and disruption of fluvial ecosystems. The Government of India, through various regulatory frameworks and the Ministry of Environment, Forests and Climate Change (MoEFCC), has imposed stringent restrictions on river sand extraction, thereby creating an acute shortage and escalating its market price. This has intensified the search for viable, cost-effective, and environmentally benign alternatives to natural sand. Wood ash contains significant proportions of silica (SiO₂), calcium oxide (CaO), potassium oxide (K₂O), and aluminum oxide (Al₂O₃), which impart latent pozzolanic and cementitious properties. When used as a fine aggregate replacement, wood ash can modify the particle packing density, interfacial transition zone (ITZ) characteristics, and overall microstructural properties of the concrete matrix. Several studies have reported improvements in workability and compressive strength at optimal replacement levels, though excessive substitution can

lead to deterioration in performance due to increased void ratio and disruption of the aggregate gradation curve. Because of its affordability, adaptability, and durability, concrete is the most popular building material worldwide. Cement, fine aggregate (sand), coarse aggregate, and water make up its main constituents. Natural sand is one of these components that is widely utilized as fine aggregate. However, excessive natural sand extraction brought on by the growing demand for construction projects has resulted in resource depletion, riverbed erosion, and environmental deterioration.

II. MATERIALS & EXPERIMENTAL

OPC 53 Grade cement conforming to IS 12269:2013 was used throughout the study. The cement was procured from a single batch to eliminate inter-batch variability. Physical properties were determined as per IS 4031 (various parts), and chemical properties were obtained from the manufacturer's test certificate and corroborated by laboratory analysis.

Natural River Sand (Fine Aggregate)

Natural river sand conforming to Zone II grading as per IS 383:2016 was used as the standard fine aggregate in the control mix. The sand was clean, free from organic impurities, silt, and clay. Sieve analysis was performed as per IS 2386 (Part I):1963.

Wood Ash (Pre-Treated) — Physical Properties

Wood ash was collected from a biomass-fired brick kiln located in the study region. Prior to use, the ash was subjected to a pre-treatment process (detailed in Chapter 6) to eliminate unburnt carbon.

Wood Ash (Pre-Treated) — Chemical Properties

XRF (X-ray Fluorescence) analysis was performed on the pre-treated wood ash sample at an accredited material testing laboratory. The oxide composition is tabulated below. The sum of $SiO_2 + Al_2O_3 + Fe_2O_3 = 53.7\%$, which indicates Class

C pozzolanic classification per ASTM C618 (referenced for comparative evaluation alongside IS 3812:2003).

Coarse Aggregate & Water

Coarse Aggregate

Crushed granite coarse aggregate of 20 mm nominal maximum size, conforming to IS 383:2016, was used. The aggregate was clean, hard, strong, and durable, free from soft, friable, or flaky particles. Properties were determined as per IS 2386 (various parts).

Mix Design (IS 10262:2019)

Concrete mix design for M25 grade (target mean compressive strength = 31.6 MPa, assuming standard deviation of 4 MPa per IS 10262:2019, for good degree of control) was carried out as per IS 10262:2019. A water-cement ratio of 0.45 was adopted. Seven concrete mix proportions were prepared corresponding to 0%, 5%, 10%, 15%, 20%, 25%, and 30% replacement of natural sand by weight with pre-treated wood ash. All other mix variables — cement content, coarse aggregate content, water content, and water-cement ratio — were held constant.

Compressive Strength

150 mm × 150 mm × 150 mm cubes

Split Tensile Strength

150 mm dia. × 300 mm cylinders

III. RESULTS AND DISCUSSION

Compressive Strength Results

Compressive strength tests were conducted on 150 mm cube specimens at 7 and 28 days of water curing. Each reported value is the average of three specimens. Results are presented below.

Mix ID	WA + GGBFS (%)	7d Strength (N/mm ²)	28d Strength (N/mm ²)	% Change vs. M0
M0	0 + 0	20.8	28.4	— (Control)
M1	5 + 5	21.4	29.6	+4.2%
M2	5 + 10	22.1	30.8	+8.5%
M3	10 + 5	21.8	30.2	+6.3%
M4	10 + 10	22.6	30.7	+8.1%
M5	15 + 5	19.4	26.8	-5.6%

Presents the compressive strength at 7 and 28 days when Waste Ash (WA) and Ground Granulated Blast Furnace Slag (GGBFS) are combined. Baseline strengths of 20.8 N/mm² (7 days) and 28.4 N/mm² (28 days) are observed in the control mix (M0). When WA and GGBFS are combined, strength generally rises to an optimal level. M2 (5 percent WA + 10 percent GGBFS) achieves the highest 28-day strength of 30.8 N/mm², an increase of 8.5 percent over M0. Cementitious reactions and long-term strength gain are both enhanced by balanced proportions, as evidenced by the significant improvements in M3 and M4. However, M5 (15% WA + 5% GGBFS) shows reduced strength compared to the control, with a 5.6% decrease. This suggests that excessive WA negatively affects strength. Overall, moderate replacement

levels improve performance, while higher WA content can be detrimental.

Split Tensile Strength Results

IS 5816:1999

Split tensile strength was measured on 150 mm diameter × 300 mm long cylindrical specimens at 28 days of curing. This test indirectly measures the tensile strength of concrete, which is typically 8–12% of compressive strength for normal-weight concrete. The split tensile strength is critical for structural members subjected to bending, torsion, and shear — elements common in reinforced concrete construction.

Mix ID	Replacement (%)	Split Tensile Strength (N/mm ²)	% Change vs. M0
M0	0 + 0	2.64	— (Control)
M1	5 + 5	2.78	+5.3%
M2	5 + 10	2.94	+11.4%
M3	10 + 5	2.88	+9.1%
M4	10 + 10	2.92	+10.6%
M5	15 + 5	2.46	-6.8%

The impact that various replacement levels of Ground Granulated Blast Furnace Slag (GGBFS) and Waste Ash (WA) have on the split tensile strength of concrete. The control mix (M0) has a tensile strength of 2.64 N/mm². The tensile strength noticeably improves when WA and GGBFS are added in moderate amounts. Mix M1 (5% WA + 5% GGBFS) increases strength by 5.3%, while Mix M2 (5% WA + 10% GGBFS) increases strength by 11.4% to 2.94 N/mm². Similarly, M3 and M4 also demonstrate significant gains, indicating that balanced combinations enhance bonding and resistance to cracking. However, mix M5 (15% WA + 5% GGBFS) shows a reduction in tensile strength by 6.8% compared to the control. This decline suggests that excessive replacement, particularly higher WA content, weakens the internal structure. Overall, the findings show that while higher replacement levels have a negative impact on the concrete's resistance to tension, partial replacement at optimal levels improves tensile performance.

IV. CONCLUSIONS

The combined results of compressive strength and split tensile strength tests show a clear trend regarding the influence of Waste Ash (WA) and Ground Granulated Blast Furnace Slag (GGBFS) on concrete performance. For both tests, the control mix (M0) provides the baseline values. With partial replacement, mixes M1 to M4 exhibit improved performance

in both compressive and tensile strength. The best mix is M2, which has the highest split tensile strength (2.94 N/mm², +11.4%) and highest 28-day compressive strength (30.8 N/mm², +8.5%). Mixes M3 and M4 also show significant improvements, indicating that balanced proportions of WA and GGBFS enhance both strength and bonding characteristics of concrete. However, mix M5 (15% WA + 5% GGBFS) shows a reduction in both compressive strength (-5.6%) and tensile strength (-6.8%), highlighting that excessive WA content negatively affects the concrete matrix.

Overall, the results conclude that moderate replacement levels improve strength properties, while higher replacement—especially with increased WA—leads to reduced performance. Thus, an optimal combination of WA and GGBFS is essential for achieving better mechanical properties.

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