

UTILIZATION OF ORGANIC RESIDUES IN SUSTAINABLE CEMENTITIOUS COMPOSITES

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Abstract: The cement industry contributes significantly to global carbon emissions, accounting for nearly 8% of the total carbon dioxide (CO₂) emissions worldwide. The increasing demand for sustainable construction materials has encouraged the exploration of alternative supplementary cementitious materials that can partially replace cement without compromising mechanical performance. This study investigates the feasibility of utilizing agricultural organic wastes, namely Banana Leaf Ash (BLA) and Wheat Straw Ash (WSA), as partial replacements for cement in mortar. Mortar cubes of size 70.6 mm ×

70.6 mm × 70.6 mm were prepared with varying replacement proportions of BLA and WSA. Compressive strength tests were conducted at curing periods of 7, 14, and 28 days to evaluate the mechanical behavior of the modified mortar mixes. The experimental results indicate that the incorporation of BLA and WSA influences the development of mortar. The mix containing 2% BLA and 3% WSA achieved the highest compressive strength of 13.88 MPa at 28 days, representing an increase of approximately 30% compared to the control mix. Moderate replacement levels demonstrated comparable or improved strength due to enhanced particle packing and pozzolanic reactions leading to the formation of additional calcium silicate hydrate (C-S-H) gel. However, higher replacement levels resulted in a gradual reduction in compressive strength due to the dilution of cementitious compounds. The findings demonstrate that agricultural wastes such as BLA and WSA can be effectively utilized as sustainable supplementary cementitious materials. Their utilization not only improves certain mechanical properties but also contributes to waste management and reduction of environmental impacts associated with cement production.

Keywords: Cement, Sand, Banana Leaf ash, Wheat Straw Ash

I. INTRODUCTION

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II. FONTS AND SPACES

Globally, cement is recognized as one of the most important materials in the construction industry, yet primary binding material. The production of cement is a highly energy intensive process. This process is a major contributor to global greenhouse gas emissions accounting for approximately 8% of the world's total carbon dioxide emissions. This significant environmental footprint has encouraged a global effort to find sustainable alternatives that can reduce cement consumption without compromising the properties of concrete. Using organic waste in cement production reduces the environmental impact and also reduces the strain on waste treatment processes. This project addresses the dual challenge by investigating the use of two specific Argon industrial wastes, Banana Leaf Ash (BLA) and Wheat Straw Ash (WSA), to partially replacing cement. This approach transforms a disposal problem into a resource opportunity. Currently, the agricultural sector generates vast amounts of organic waste materials that often pose disposal challenges. Banana cultivation and wheat production result in substantial residues, specifically banana leaves and wheat straw, which are often discarded after harvest. Considering the negative impact on environment, this idea explores the use of organic waste (Banana Leaf Ash and Wheat Straw Ash) as partial replacement for cement.

A. Theory

Although several studies have investigated the use of agricultural wastes such as rice husk ash, wood ash, banana leaf ash (BLA), and wheat straw ash (WSA) as supplementary cementitious materials in concrete, most of the existing research has focused on the individual use of these materials as partial replacements for cement or aggregates. Limited studies have examined the combined effect of BLA and WSA in blended form on the mechanical properties of cement mortar. In addition, previous investigations have mainly concentrated on single replacement levels or conventional concrete mixes, with comparatively less attention given to optimized combinations of multiple organic ashes and their influence on early and later age development. Furthermore, there is a lack of experimental data evaluating the compressive strength performance of mortar mixes containing both BLA and WSA at different curing ages. Therefore, this study aims to address this research gap by investigating the combined partial replacement of cement with Banana Leaf Ash and Wheat Straw Ash and

evaluating the compressive strength of mortar cubes at 7, 14, and 28 days, thereby contributing to the development of sustainable and eco-friendly construction materials

III. MATERIALS AND METHODOLOGY

Portland Pozzolanic Cement

The pozzolanic materials, commonly as fly ash (a by-product of coal-fired power plants), volcanic ash, or calcined clay. PPC is considered a more sustainable choice in construction. By utilizing industrial by-products like fly ash, it reduces the amount of clinker needed in the mix, which directly lowers the consumption of natural resources (limestone) and the carbon dioxide emissions associated with cement manufacturing. Practically, its finer particles also give it better workability and a smoother finish, making it excellent for plastering and masonry work in residential buildings.



Figure 1: PPC Cement

M-Sand

Manufactured Sand (M-Sand) is simply an modern answer to the old construction problem. Instead of being hole up from a river, it's engineered right in a factory. We take hard, quarry rocks like granite and run them through high-tech crushers that natural erosion, grinding them down into fine particles. This controlled process is key it ensures every grain is consistent in size and has a desirable shape, giving builders a reliable material that performs better than inconsistent river sand. M-Sand comes out clean, too, thanks to careful screening and washing that removes the harmful dirt and silt often found in natural sources.



Fig. 2: M-Sand

Banana Leaf Ash (BLA)

The primary reason BLA is effective is its pozzolanic activity. This means it does not act as a binder on its own but reacts chemically with the calcium hydroxide (a byproduct of cement hydration) to form additional Calcium Silicate Hydrate (C-S-H) gel. BLA typically contains a high percentage of Silicon Dioxide. Along with Aluminum Oxide this composition satisfies the chemical requirements.



Fig. 4: Banana Leaf Ash

Wheat Straw Ash (WSA):

WSA as a resourceful support that can give ordinary cement a superpower increase. When wheat straw, a common agricultural waste, is burned, the leftover ash contains a lot of silica in a highly reactive form. It acts as a Supplementary Cementitious Material (SCM), similar to fly ash or slag.

It doesn't just fill space; it actively participates in a slow, secondary chemical reaction, known as the pozzolanic reaction, with the cement's byproducts. This reaction results in the formation of extra binding compounds, which ultimately makes the finished concrete mix stronger, less porous, and more durable against harsh environments, all while making construction more sustainable by using less



conventional cement.

Fig. 3: Wheat Straw Ash

Methodology:



Experimental Work

The experimental investigation was carried out to evaluate the effect of partially replacing cement with Banana Leaf Ash (BLA) and Wheat Straw Ash (WSA) on the compressive strength of mortar. The materials used in this study included Portland Pozzolana Cement (PPC), Manufactured Sand (M-Sand), Banana Leaf Ash, Wheat Straw Ash, and potable water.

Banana leaves and wheat straw were collected from agricultural fields and subjected to controlled burning to obtain ash. The resulting ash was sieved through a 90µ sieve to obtain fine particles suitable for use as a supplementary cementitious material. The mortar mixes were prepared by partially replacing cement with different proportions of BLA and WSA while maintaining the same water–cement ratio for all mixes.

Five different mortar mixes were prepared, including one control mix (M0) without any replacement and four mixes with varying percentages of BLA and WSA. The replacement levels were 2% BLA + 3% WSA (M1), 4% BLA + 6% WSA (M2), 6% BLA + 9% WSA (M3), and 9% BLA + 9%

WSA (M4). Mortar cubes of size 70.6 mm

× 70.6 mm × 70.6 mm were cast using standard moulds. After casting, the specimens were kept for 24 hours at room temperature and then demoulded and cured in water.

Compressive strength tests were conducted on the mortar cubes at 7, 14, and 28 days of curing using a universal testing machine (UTM). For each mix, the average compressive strength was calculated based

Mix ID	Cement Replacement (%)	Age (Days)	Avg. Weight (g)	Avg. Load (kN)	Avg. Compressive Strength (MPa)
M0	0	7	700	53.05	10.64
M1	2 BLA + 3WSA	7	710	42.23	9.2
M2	4 BLA + 6WSA	7	685	41.02	9.1
M3	6 BLA + 9WSA	7	670	39.5	8.5
M4	9 BLA + 9 WSA	7	690	37.22	8.1

on the test results. The experimental results were analysed to determine the influence of BLA and WSA replacement on the strength characteristics of mortar and to identify the optimum replacement level for sustainable concrete production.

Compressive Strength Test

The compressive strength test is one of the most important tests used to evaluate the mechanical performance of mortar or concrete. It determines the ability of a material to withstand compressive loads without failure. In this study, the compressive strength of mortar cubes prepared with partial replacement of cement by Banana Leaf Ash (BLA) and Wheat Straw Ash (WSA) was determined.

Mortar cubes of size 70.6 mm × 70.6 mm × 70.6 mm were cast using standard steel moulds. After casting, the specimens were kept undisturbed for 24 hours at room temperature and then demoulded. The cubes were subsequently cured in clean water for 7, 14, and 28 days to allow proper hydration and strength development.

After the specified curing period, the cubes were removed from the curing tank and their surfaces were cleaned to remove excess moisture. The specimens were then placed in a Universal Testing Machine (CTM) such that the load was applied uniformly on the opposite faces of the cube. The load was applied gradually and continuously until the specimen failed. The maximum load at failure was recorded.



Fig.5: Compression strength

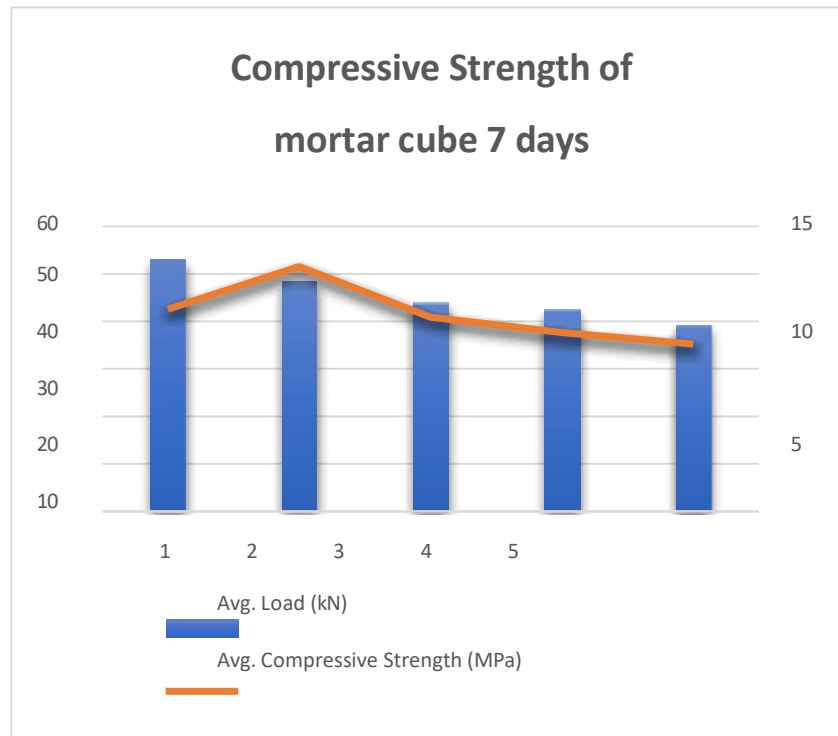


**Table 1.1: Compressive strength of mortar cubes on 7 days
(70.6X70.6X70.6)**

The 7-day compressive strength results of mortar cubes incorporating blended cement replacements of BLA and WSA are presented in Table 4.1 The control mix (M0) achieved an average compressive



Fig.6: Specimen after Testing

strength of 10.64 MPa, serving as the benchmark for performance comparison. Mixes M1 and M2, containing lower combined replacement levels (2% BLA + 3% WSA and 4% BLA + 6% WSA),

exhibited compressive strengths of 9.20 MPa and 9.10 MPa, respectively. These values indicate only a marginal reduction compared to the control mix, suggesting that limited replacement levels do not significantly affect early-age strength.

As the replacement percentage increased, a gradual decrease in compressive strength was observed. Mix M3 (6% BLA + 9% WSA) recorded a strength of 8.50 MPa, while the highest replacement mix, M4 (9% BLA + 9% WSA), showed the lowest strength of 8.10 MPa. This reduction may be attributed to dilution of cementitious compounds and slower pozzolanic reaction at early curing ages. However, the observed strengths remain within an acceptable range for non-structural and masonry applications. Overall, the results indicate that partial replacement of cement with BLA and WSA up to moderate levels is feasible without severe loss of early-age compressive strength, supporting the potential use as sustainable supplementary materials.

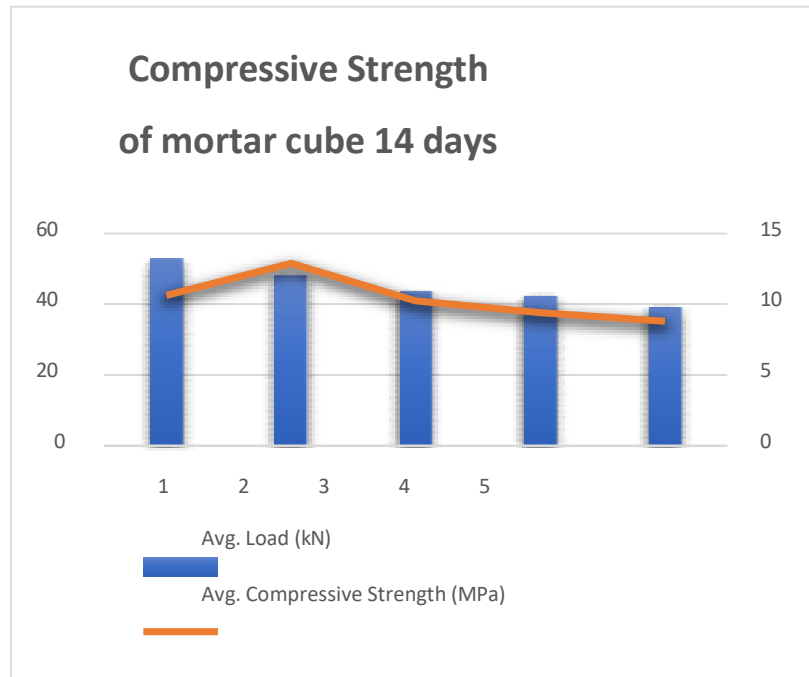


Fig. 1.2: Graph of 7th day Compressive Strength

Table 4.2: Compressive strength of mortar cubes on 14th day

Mix ID	Cement Replacement (%)	Age (Days)	Avg. Weight (g)	Avg. Load (kN)	Avg. Compressive Strength (MPa)
M0	0	14	725	53.02	10.64
M1	2 BLA + 3WSA	14	710	48.33	12.88
M2	4 BLA + 6WSA	14	680	44.02	10.23
M3	6 BLA + 9WSA	14	670	42.50	9.40
M4	9 BLA + 9 WSA	14	690	39.23	8.80

IV. RESULT AND DISCUSSION

The 14-day compressive strength results of mortar cubes incorporating blended cement replacements of BLA and WSA are summarized in Table II. The control mix (M0) achieved an average compressive strength of 10.64 MPa. Mix M1, containing a low replacement level of 2% BLA and 3% WSA, exhibited the highest compressive strength of 12.88 MPa, exceeding the control mix. This improvement can be attributed to enhanced particle packing and the initiation of pozzolanic reactions, which contribute to additional formation of calcium silicate hydrate (C–S–H) gel at intermediate curing ages.

Mix M2 (4% BLA + 6% WSA) recorded a compressive strength of 10.23 MPa, which is comparable to the control mix, indicating that moderate replacement levels do not adversely affect strength development. However, further increase in replacement content resulted in a gradual reduction in compressive strength. Mixes M3 and M4 achieved strengths of 9.40 MPa and 8.80 MPa, respectively. This decline may be due to the reduced availability of cementitious compounds and slower pozzolanic reaction rates at higher replacement levels. Overall, the results demonstrate that limited substitution of cement with BLA and WSA can enhance or maintain compressive strength at 14 days, while excessive replacement leads to strength reduction.

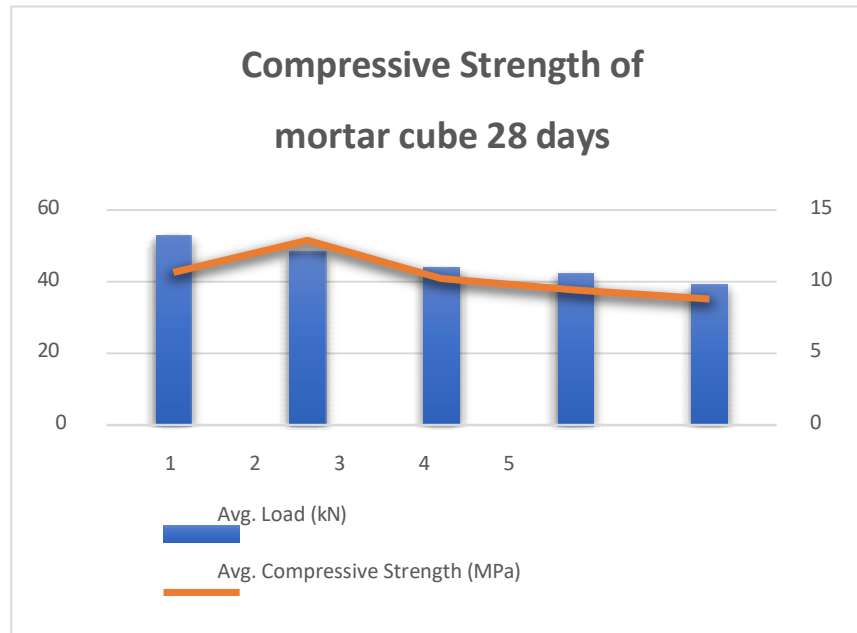


Fig. 1.3: Graph of 14 day Compressive Strength

Table 4.3: Compressive strength of mortar cubes on 28 day

Mix ID	Cement Replacement (%)	Age (Days)	Avg. Weight (g)	Avg. Load (kN)	Avg. Compressive Strength (MPa)
M0	0	28	735	53.05	10.64
M1	2 BLA + 3WSA	28	725	47.23	13.88
M2	4 BLA + 6WSA	28	695	32.02	11.23
M3	6 BLA + 9WSA	28	725	30.5	9.53
M4	9 BLA + 9 WSA	28	710	29.22	9.06

The 28-day compressive strength results of concrete incorporating BLA and WSA as partial cement replacements are presented in Table X. The control mix (M0) achieved a compressive strength of 10.64 MPa, which is taken as the reference value. Mix M1 (2% BLA + 3% WSA) recorded the highest compressive strength of 13.88 MPa, corresponding to an increase of approximately 30% compared to the control mix. The improvement is attributed to the synergistic pozzolanic activity of BLA and WSA, leading to the formation of additional calcium silicate hydrate (C-S-H) gel and refinement of the pore structure. Mix M2 (4% BLA + 6% WSA) achieved a compressive strength of 12.23 MPa, which is still higher than that of the control mix. This indicates that cement replacement up to 10% does not adversely affect strength at later curing ages. For mixes M3 and M4, compressive strength values decreased to 11.53 MPa and 9.82 MPa, respectively. The reduction at higher replacement levels is mainly due to the dilution effect caused by reduced cement content and insufficient calcium hydroxide for sustained pozzolanic reactions.

V. CONCLUSION

This study investigated the effect of partial replacement of cement with BLA and WSA on the compressive strength of concrete. The results indicate that a combined replacement of 2% BLA and 3% WSA yielded the maximum 28-day compressive strength, showing an improvement of approximately 30% over the control mix. Cement replacement up to 10% produced strength values comparable to the control mix, while higher replacement levels resulted in strength reduction due to dilution effects. The findings confirm the beneficial pozzolanic contribution of BLA and WSA and their potential for sustainable concrete production.

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