Exploring Bamboo Leaf Ash as Supplementary Cementitious Material for Enhanced Performance in Compressive and Tension in Mortar Strength as Construction Materials

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ABSTRACT

A recent study explored the use of bamboo leaf ash (BLA) as a partial replacement for cement in mortar, aiming to enhance its strength while promoting environmental sustainability. BLA was added in varying proportions (0%, 5%, 10%, and 15%) to a mortar mix with a 1:2.75 sand-to-cement ratio and a water-to-binder ratio of 0.5. The research focused on evaluating the setting times, consistency, and strength properties, with forty-eight samples cast for compressive and tensile strength tests. These samples were cured for 7, 14, and 28 days, and tested using 50 mm cubes for compressive strength and briquette molds for tensile strength.

The study found that as the BLA content increased, both consistency and setting times of the mortar also increased. Notably, a 10% replacement of BLA resulted in the highest improvement in compressive strength at 28 days compared to the control group, and similar enhancements were observed in tensile strength at both 7 and 28 days. The tensile strength values were 1.734 MPa, 2.588 MPa, and 3.018 MPa at 7, 14, and 21 days, respectively.

This experiment demonstrated that a 10% substitution of bamboo leaf ash significantly enhanced both the compressive and tensile strengths of mortar. Additionally, the innovative mixture showed potential for crack mitigation, a rare benefit in typical cement mortars. This highlights the potential of bamboo leaf ash as an environmentally friendly alternative, reducing the environmental impact of cement production while improving the durability of the mortar.

Keywords: Bamboo leaf ash, mortar, Cementitious material, Block.

INTRODUCTION

Mortar, a crucial material in construction, uses cement as the binder for various ingredients [1]. Cement production not only requires significant energy at high temperatures (around 1500 °C) but also contributes substantially to greenhouse gas emissions [2]. Efforts are being made to reduce manufacturing costs to improve profitability [3], ensure affordability [4], and increase accessibility [5]. Additionally, efforts to reduce raw material consumption and mitigate environmental impacts have gained momentum.

In this context, there is growing interest in using waste materials such as bamboo stem [6], ground glasses, and coal bottom ash [7], along with bamboo leaf ash (BLA) ([8], as partial replacements for cement. These by-products, whether agricultural or industrial, are environmentally friendly and, when mixed with Portland cement, form "blended" or "composite" cements [9] [10]. These materials behave similarly to Portland cement by reacting with water and calcium hydroxide to form cementitious compounds.

Agricultural wastes like oyster shell [11], coconut husk [12], and bamboo leaf ash [13] are being evaluated as cement substitutes in mortar production [14]. BLA, in particular, has been shown to have pozzolanic properties [15], making it an effective cement replacement for mortar [16]. Bamboo's fast growth and abundance, especially in Bangladesh, make it a sustainable source [17].

High-performance mortar (HPM), produced by blending Portland cement with waste by-products, offers superior mechanical properties [18]. While studies have shown the benefits of using BLA in mortar [19], optimal inclusion rates remain under investigation. Future research could explore BLA as a viable sustainable material for mortar production.

MATERIALS AND METHODOLOGY

This study goal is to assess the viability of using BLA in mortar in place of cementitious material. A few steps are taken in order to ascertain the anticipated outcomes. Sincere efforts were made to prepare the materials and conduct laboratory tests in order to assess the anticipated outcome. When making mortar, the right kind of BLA was utilized as cement. This is the thesis work's methodological framework [20] as Figure 2.1.

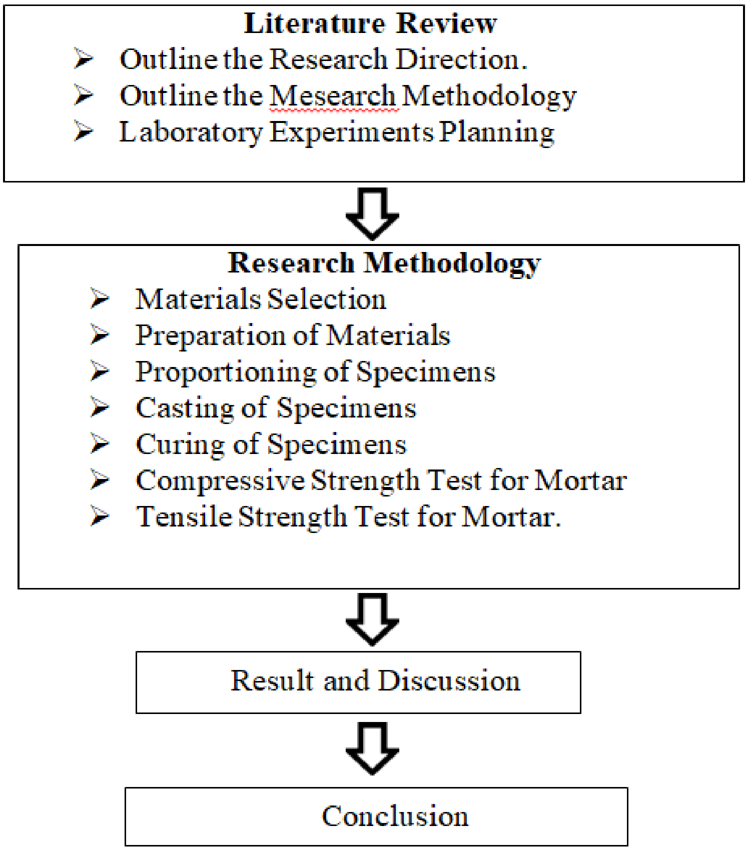

Figure 2.1: Methodological Structure of this Study

Materials

The materials used in this study include Bamboo Leaf Ash (BLA), Ordinary Portland Cement (OPC), sand in Figure 2.2, and water. BLA in Figure 2.3 was obtained by drying bamboo leaves and then incinerating them in a sealed drum in Figure 2.4. After cooling, the resulting ash was sieved through a 0.1 mm mesh to produce fine gray ash, which was tested for its granular composition[21]. Ordinary Portland Cement (OPC) in Figure 2.5, conforming to BS EN 197-1 standards, was used as the binder material for the mortar. Fine sand was sourced locally, dried for 24 hours, and sieved to remove impurities, with a sieve size of 1.8 mm. Water was used both for mixing the dry materials and for curing the mortar samples, as water plays a crucial role in the hydration process of cement-based materials[22].

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Figure 2.2: Sand

Figure 2.3: Drying Process of Bamboo Leaf

Figure 2.4: Burning of Bamboo Leaf

Figure 2.5: Ordinary Portland Cement with water

Methods

In this study, mortar mixes were prepared with varying percentages of BLA (0%, 5%, 10%, and 15%) as a partial replacement for cement as Table 2.1, maintaining a water-to-cement ratio of 0.5[23]. The mortar was mixed with the appropriate amounts of cement, sand, and BLA, and then poured into briquette molds for tensile testing and 50 mm cube molds for compressive strength testing. The samples were cured under controlled environmental conditions and tested at 7, 14, and 28 days to determine their compressive in Figure 2.6 and tensile strengths in Figure 2.7. The compressive strength was measured using ASTM C109 standards, and tensile strength was evaluated using a Cement Mortar Tensile Strength Testing Machine following ASTM C309 guidelines[24][25]. Results were analyzed to compare the effectiveness of BLA in enhancing the mechanical properties of mortar.

Table 2.1 Mix Design for Compressive Test and Tensile Strength Testing

Day	BLA (gm)	Cement (gm)	BLA + Cement (gm)	w/c	Water (gm)	Sand (gm)	Cement +Sand (gm)
7	0	100	100	0.5	50	275	375
	5	95	100	0.5	50	275	370
	10	90	100	0.5	50	275	365
	15	85	100	0.5	50	275	360
14	0	100	100	0.5	50	275	375
	5	95	100	0.5	50	275	370
	10	90	100	0.5	50	275	365
	15	85	100	0.5	50	275	360
28	0	100	100	0.5	50	275	375
	5	95	100	0.5	50	275	370
	10	90	100	0.5	50	275	365
	15	85	100	0.5	50	275	360
Total		1110	1200	0.5	600	3300	4410

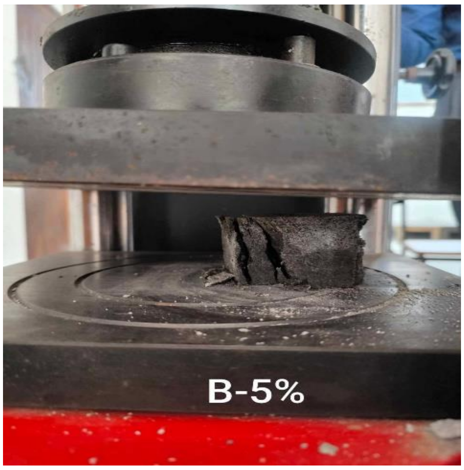

Figure 2.6: 14-Day Compressive Strength Test for 5% BLA Used

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Figure 2.7: Tensile Testing Machine Used in Order to Test the Tensile Strength of the Block

RESULT AND DISCUSSION

The study investigates the mechanical properties of cement mortar incorporating Bamboo Leaf Ash (BLA) as a supplementary cementitious material. The results focus on the tensile strength and compressive strength of the mortar, analysed across various curing periods of 7, 14, and 28 days. The findings highlight the influence of BLA on the material's strength, and the implications of these results are thoroughly discussed, including potential applications for BLA-enhanced cement mortar in construction.

Tensile Strength

The Table 3.1 presented the tensile strength of cement mortar incorporating varying percentages of an additive (likely Bamboo Leaf Ash or another supplementary material) measured over 7, 14, and 28 days. As is typical with cement-based materials, the tensile strength generally increases over time as the mortar cures.

For the 0% additive (no added material), the tensile strength increased from 1.367 MPa at 7 days to 2.266 MPa at 28 days, but these values remained consistently below the standard values, which were set at 1.500 MPa for 7 days, 2.000 MPa for 14 days, and 3.00 MPa for 28 days. This indicated that the base material without any additives does not fully meet the expected strength standards, though it improves over time.

For the 5% additive, the tensile strength values at 7 days (1.239 MPa) and 14 days (1.849 MPa) were close to the standard values, and the value at 28 days (2.876 MPa) exceeded the standard of 3.000 MPa, suggesting that the addition of 5% of the additive might significantly improve the long-term strength of the mortar.

The 10% additive showed even better performance, with the tensile strength at 7 days (1.734 MPa), 14 days (2.588 MPa), and 28 days (3.018 MPa) all surpassing the standard values. This indicateed that the 10% addition may notably enhanced the material’s strength, especially over longer curing periods, compared to the 0% and 5% compositions.

However, the 15% additive yields less favorable results. The tensile strength values were lower than the standard values at all time intervals. For example, at 7 days (1.168 MPa), 14 days (1.638 MPa), and 28 days (1.937 MPa), they fall short of the standard values of 1.500 MPa, 2.000 MPa, and 3.000 MPa, respectively. This suggests that higher percentages of the additive may negatively affect the tensile strength of the mortar, likely due to changes in the material's chemical reactions or curing properties.

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Table 3.1 Tensile Strength of Cement Mortar for 7 Days, 14 Days and 28 Days

Description	7 Days (MPa)	14Days (MPa)	28 Days (MPa)	7 Days (MPa)	Standard Values for 7 days (MPa)	14 Days (MPa)	Standard Values for 14 days (MPa)	28Days (MPa)	Standard Values for 28 days (MPa)
0%	1.415	2.112	2.346	1.367	1.500	2.040	2.000	2.266	3.000
	1.371	2.046	2.273						
	1.314	1.961	2.178						
5%	1.176	1.756	3.018	1.239	1.500	1.849	2.000	2.876	3.000
	1.335	1.993	2.954						
	1.205	1.799	2.656						
10%	1.820	2.715	3.018	1.734	1.500	2.588	2.000	3.018	3.000
	1.781	2.658	2.954						
	1.602	2.391	2.656						
15%	1.168	1.743	1.937	1.168	1.500	1.638	2.000	1.937	3.000
	1.138	1.700	1.888						
	0.986	1.471	1.635						

Compressive Strength

The table presented the compressive strength of cement mortar incorporating different percentages of an additive (likely Bamboo Leaf Ash or another supplementary material), measured at 7, 14, and 28 days. The results showed the material's behavior over time and are compared with standard values for each time interval.

For 0% additive (no additive), the compressive strength increased from 9.850 MPa at 7 days to 17.096 MPa at 28 days, but the values at 7 days and 14 days were lower than the standard values of 12 MPa for 7 days, 20 MPa for 14 days, and 33 MPa for 28 days. This indicated that while the material's strength improved with time, it did not fully meet the expect standard strength, particularly in the early curing stages.

For the 5% additive, the compressive strength at 7 days (13.953 MPa), 14 days (20.825 MPa), and 28 days (24.214 MPa) surpassed the standard values for all time intervals. This suggested that the addition of 5% of the additive improved the mortar's strength and helped it exceed the expected performance over time.

The 10% additive demonstrates excellent resulted, with the compressive strength at 7 days (16.844 MPa), 14 days (25.140 MPa), and 28 days (29.233 MPa) all significantly exceeding the standard values for each time interval. This indicated that the 10% addition of the material enhances the mortar's strength at all curing stages, particularly after 14 days and 28 days.

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For the 15% additive, the results showed less favorable performance. The strength values at 7 days (9.413 MPa), 14 days (12.671 MPa), and 28 days (16.338 MPa) were lower than the standard values of 12 MPa for 7 days, 20 MPa for 14 days, and 33 MPa for 28 days, indicating that higher percentages of the additive may reduce the material's compressive strength, especially during the initial curing phases.

Table 3.2 Compressive Strength of Blocks for 7 Days, 14 Days and 28 Days

Description	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)	7 Days (MPa)	Standard Values for 7 days (MPa)	14 Days (MPa)	Standard Values for 14 days (MPa)	28 Days (MPa)	Standard Values for 28 days (MPa)
0%	9.257	13.817	16.066	9.850	12	14.703	20	17.096	33
	10.842	16.182	18.816						
	9.453	14.109	16.406						
5%	13.953	20.825	24.214	13.953	12	20.825	20	24.215	33
	14.383	21.467	24.962						
	13.056	19.487	22.660						
10%	16.844	25.140	29.233	16.844	12	25.140	20	29.233	33
	17.622	26.302	30.584						
	19.148	28.580	33.232						
15%	9.413	14.051	16.338	9.413	12	14.051	20	16.338	33
	7.301	10.897	12.671						
	7.954	11.872	13.805						

Discussion

At the conclusion of the results explanation, the following inferences were made during the discussion:

1. In discussion, the results suggest that the inclusion of 5% and 10% additives enhances the tensile strength of cement mortar, particularly over longer curing periods. The 5% additive showed a strength of 2.876 MPa at 28 days, not exceeding the standard of 3.000 MPa, while the 10% additive achieves 3.018 MPa at 28 days, surpassing the standard values. However, the 15% additive resulted in lower tensile strength, with values of 1.168 MPa at 7 days, 1.638 MPa at 14 days, and 1.937 MPa at 28 days, indicating a negative effect on the material's strength as the finding of Ikumapayi C and Akingbonmire S (2017) [26].

2. In discussion, the addition of 5% and 10% additive significantly enhanced the compressive strength of cement mortar. The 5% additive achieved strengths of 13.953 MPa at 7 days, 20.825 MPa at 14 days, and 24.214 MPa at 28 days, exceeding standard values. The 10% additive performed even better, with 16.844 MPa at 7 days, 25.140 MPa at 14 days, and 29.233 MPa at 28 days, all surpassing the standard values. However, the 15% additive resulted in lower strengths, with 9.413 MPa at 7 days, 12.671 MPa at 14 days, and 16.338 MPa at 28 days, falling short of the standard values as the finding of Martin J. et al. (2015) [27].

CONCLUSION

The study leads to the following conclusions:

1. The 5% and 10% additives enhanced tensile strength (2.876 MPa and 3.018 MPa), while 15% reduces it (1.168 MPa, 1.638 MPa, 1.937 MPa).

2. The 5% and 10% additives enhanced compressive strength (24.214 MPa and 29.233 MPa), while 15% reduces it (9.413 MPa, 12.671 MPa, 16.338 MPa).

RECOMMENDATION FOR FURTHER CONTRIBUTION

1. Future studies should aim to find solutions that minimize the decrease in pulling strength caused by BLA, while maintaining its improvement of crushing strength.

2. Studies on how BLA-enhanced materials hold up over time are necessary to determine their long-term usefulness in construction.

3. It's essential to thoroughly analyze the environmental consequences of using BLA in building projects.

4. Analysing the cost-effectiveness of BLA as a building material is crucial for its practical application.

Declaration of Competing Interests: The authors declare that they have no financial or personal conflicts of interest that could have influenced the work reported in this paper.

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