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Partial Replacement of Cement with Bamboo Leaf Ash as a Sustainable Approach in Concrete Production

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ABSTRACT

This study showcases the binding ability of bamboo leaf ash as a partial substitute for ordinary Portland cement in concrete production. This is to improve the sustainability approach to the impact of the construction industry on global warming. Bamboo leaf ash was used because of the presence of pozzolanic properties and it possesses a very eco-friendly and can be used as an alternative to conventional cement. Conventional cement has been discovered to possess significant amounts of carbon emissions. The partial replacement of Bamboo leaf ash used in the concrete production for this study was within the content of 0%, 2.5%, and 5%. The workability, compressive strength, and durability of the concrete were determined over a standard curing period of 7, 14, 21, and 28 days. The result shows that as the content of bamboo leaf ash increases in concrete production, the compressive strength decreases. The study supports bamboo leaf ash as a partial substitute which is sustainable in the construction industry minimizing environmental impact and reducing carbon emissions. This study highlights the binding potential of bamboo leaf ash as a partial substitute for ordinary Portland cement in concrete production, aiming to enhance the sustainability of the construction industry's impact on global warming.

Keywords: Concrete, bamboo leaf, bamboo leaf ash, concrete production, partial replacement of cement

I. INTRODUCTION

The production process of conventional ordinary Portland cement (OPC) has been identified as a significant source of carbon dioxide emissions, adversely impacting the environment. Bamboo leaf ash (BLA) has gained attention as a promising alternative to traditional cement due to its pozzolanic properties, which enhance sustainability and durability in concrete production. Extensive research has explored the use of BLA in replacing cement in concrete mixtures, particularly its effect on workability, strength, and long-term durability

Nduka et al. (2022) conducted a study in which BLA was heated in a muffle furnace at approximately 600°C for two hours to assess its pozzolanic properties. The study found that after 28 days of curing, the compressive strength reached an average of 33.5 MPa with 10% BLA substitution, although the density decreased as the amount of BLA increased. Odeyemi et al. (2022) researched the use of BLA in high-performance concrete. In their experiments, BLA was subjected to high temperatures in an electric furnace at 700°C, and varying percentages of BLA (5%, 10%, 15%, and 20%) were tested. The study revealed that the highest strength was achieved with a 5% replacement of cement by BLA after 56 days of curing.

Lee and Wang (2006) discovered that bamboo leaf ash contains significant pozzolanic properties, including silica, potassium, calcium, and other minerals. They also observed that the percentage of BLA substitution affects concrete workability, setting time, and shrinkage. Kumar et al. (2019) examined the properties of BLA as a partial substitute for cement and found it positively impacted concrete durability, sustainability, and strength.

Research by Liu et al. (2020) focused on the durability of concrete containing bamboo leaf ash when exposed to sulfate attacks. Their findings indicated that incorporating BLA could mitigate sulfate damage and enhance the long-term durability of concrete structures. Wu et al. (2019)

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assessed the efficiency of BLA in concrete for pavement construction, evaluating its mechanical properties, durability, and resistance to rutting and cracking. The research highlighted that bamboo leaf ash concrete could be advantageous for thinner pavements while improving performance under heavy traffic loads.

Gupta et al. (2020) and Das et al. (2021) investigated various curing methods, including the use of admixtures to enhance the durability and strength of BLA concrete. Their findings underscored the importance of proper curing practices in optimizing the performance of concrete mixtures. Additional research by Li et al. (2022) explored the effects of combining bamboo leaf ash with fly ash and silica fume to further develop mechanical properties and reduce environmental impact. Similarly, Li et al. (2017) found that substituting bamboo leaf ash in precast concrete for beams and lintels resulted in mechanical properties and durability comparable to those of conventional Portland cement (OPC).

In earlier studies, BLA's efficacy in concrete production has been demonstrated. For instance, Charles et al. (2018) evaluated the influence of corrosion inhibitors on bond behavior in reinforced concrete exposed to corrosive environments, showcasing alternative approaches to improving concrete's structural integrity under challenging conditions. Similarly, Charles et al. (2018) investigated the chloride-induced bond strength degradation in reinforced concrete, providing insights into durability improvements when utilizing innovative materials. These findings underline the importance of enhancing the mechanical and durability properties of concrete with additives.

Further studies by Ogunjiofor et al. (2023) on the compressive strength development of concrete partially replacing fine aggregate with crushed glass demonstrated the potential for incorporating waste materials into construction. Additionally, Ogunjiofor et al. (2023) assessed the mechanical properties of concrete reinforced with palm kernel shell as a partial coarse aggregate substitute, highlighting sustainability improvements and the practical application of eco-friendly alternatives. The use of pozzolanic materials, including BLA, has also been shown to mitigate thermal cracking in concrete. Ogunjiofor et al. (2023) reported that replacing OPC with coal ash reduced thermal cracking, enhancing concrete's performance in high-temperature environments. The inclusion of coal ash and other agricultural waste fibers, such as banana and plantain fibers, has demonstrated a significant improvement in concrete's strength and durability (Ogunjiofor et al., 2023).

The integration of BLA aligns with findings by Ogunjiofor (2020), who explored the potential of using seawater for mixing and curing concrete in saline environments. This research underscores the adaptability of alternative materials in diverse construction scenarios. Moreover, geopolymer concrete, produced using bamboo fibers and coal ash (Ogunjiofor et al., 2023), further illustrates the viability of incorporating alternative binders into sustainable concrete production practices. The promising results from studies on alternative materials such as BLA, coal ash, and agricultural waste not only reduce the carbon footprint of construction activities but also support the circular economy by repurposing waste materials into high-value construction applications. These advancements pave the way for sustainable and durable construction practices in alignment with global environmental goals.

II. MATERIALS

The materials utilized in this research were carefully selected to ensure quality and compliance with relevant standards.

The materials used during this research include:

Bamboo leaf

Portable water

Ordinary Portland Cement (Elephant Superset)

Coarse aggregate

Fine aggregate

2.1. Bamboo leaf ash:

The fresh bamboo leaves as seen in figure 1 were sourced at Uli surrounding precisely Umuoma village behind Chukwuemeka Odumegu Ojukwu University in Uli town of Ihiala local government of Anambra state. The dried bamboo leaves were shown in figure 2.

Plate 1: Fresh bamboo leaves sourced

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Plate 2: Dried bamboo leaves sourced

2.2. Portable water:

The portable water in figure 3 used was sourced from a borehole within the university premises in Uli, Anambra State. This water was verified to be free from impurities, making it suitable for concrete production. The significance of using clean water in concrete production aligns with the practices recommended by Ogunjiofor et al. (2023a), who emphasized the role of material purity in achieving optimal mechanical properties in concrete.

Plate 3: Portable water

2.3. Ordinary Portland cement (Elephant Supaset):

Ordinary Portland cement (Elephant Supaset) shown in Figure 4 was chosen as the primary binder for this study. The cement was sourced from an authorized vendor at Egbu Timber Market, Uli, and met the Nigerian Industrial Standard (NIS 444-1:2003). The quality of cement is critical for ensuring adequate hydration and strength development in concrete, as highlighted in studies on steel fiber-reinforced concrete for low-cost construction (Ogunjiofor et al., 2023b).

Plate 4: Ordinary Portland cement (Elephant Supaset)

2.4. Coarse aggregate:

The coarse aggregate shown in figure 5 was sourced from Egbu timber market Uli, Anambra state.

Plate 5: Coarse aggregate

2.5. Fine aggregate:

The fine aggregate used was white river sand, figure 6, also sourced from Egbu Timber Market in Uli. This sand was free from clay impurities, ensuring good binding properties and workability in the concrete mix. Ogunjiofor et al. (2023c) demonstrated the importance of aggregate quality in enhancing the compressive strength of concrete, particularly in studies involving alternative fine aggregates such as crushed glass.

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Plate 6: Batching of fine aggregate

III. METHODOLOGY

The fresh bamboo leaves were dried and burnt in a furnace for 2 hours at 700°c in the school's chemistry laboratory to obtain the ashes required for the experiment. The concrete was batched with a mix ratio of 1:3:6 with a water/cement ratio of 0.65 in the mixture of the concrete which comprised cement, bamboo leaf ash, portable water, fine aggregate, and coarse aggregate. In this experiment, various proportions of bamboo leaf ash were partially replaced. The proportions were 0%, 2.5, and 5.0. The cube used was a 150mm × 150mm square mould and number produced were shown in Table 1. The concrete was cured within a period of 7, 14, 21, and 28 days respectively. Various test was conducted on the cube to determine the workability of the cube and its compressive strength.

Table 1: Shows the total number of cubes required.

Percentage of bamboo leaf ash	Number of cubes required in various curing days				Total number of cubes
Duration	7days	14days	21days	28days	
0%	2	2	2	2	8
2.0%	2	2	2	2	8
5.0%	2	2	2	2	8
Total number of cubes required					24

IV. TEST AND RESULT

4.1 Fineness Test (sieve analysis):

The fineness test was conducted on the fine aggregate using sieve analysis to determine the particle size distribution. Sieves of various sizes were used to measure the retained and passing material, with a total sample weight of 1600g. The importance of aggregate fineness in concrete production is corroborated by Ogunjiofor and Ayodele (2023), who utilized response surface methodology to optimize aggregate gradation and improve concrete performance. Additionally, Charles et al. (2018) demonstrated that well-graded aggregates contribute to enhanced bond strength and durability, even in aggressive environments as in Table 2.

Table 2: Shows the table of values obtained from the sieve analysis test.

New sieve number	Sieve size (mm)	Weight retained (g)	Percentage retained	Cumulative % retained	Cumulative % passing
8	2.86	50	3.13	3.13	96.87
10	2.00	50	3.13	6.26	93.74
12	1.70	300	18.75	25.01	74.99
20	0.80	800	50	75.01	24.99
30	0.60	250	15.63	90.64	9.36
40	0.425	100	6.25	96.89	3.11
80	0.180	50	3.13	100.02	-0.2
Pan	Pan	0	0	100.02	-0.2

The material distribution shows significant retention in certain sieve sizes, with the highest retention of 800 g (50%) on the 20 sieves (0.80 mm opening). Smaller amounts are retained on finer sieves (e.g., 100 g on the 40 sieve and 50 g on the 80 sieve). Other notable retentions include 18.75%

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on the 12 sieve and 15.63% on the 30 sieve. The cumulative retained values increase steadily, reaching 100.02% at the 80 sieve and the pan. This small excess is likely due to rounding errors in calculations.

The cumulative percent passing starts at 96.87% for the 8 sieves and reduces progressively, ending with a negative value (-0.2%) at the pan. This inconsistency at the end is also likely a calculation error. These discrepancies suggest rounding or computational errors that need correction. Most of the particles in the sample are medium-sized, concentrated around the 0.80 mm sieve size. A smaller proportion of particles passed through the 40 sieves (0.425 mm) and finer, indicating limited fine particles. The results highlight a well-graded material with significant retention at mid-range sieve sizes and tapering amounts toward finer sieves as indicated in Figure 1 and Figure 2.

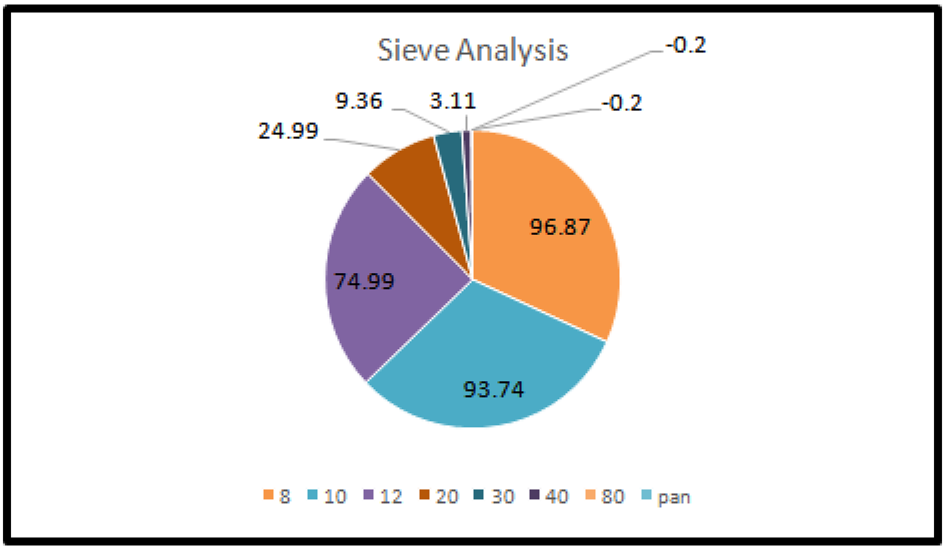

Figure 1: Pie chart representing sieve analysis

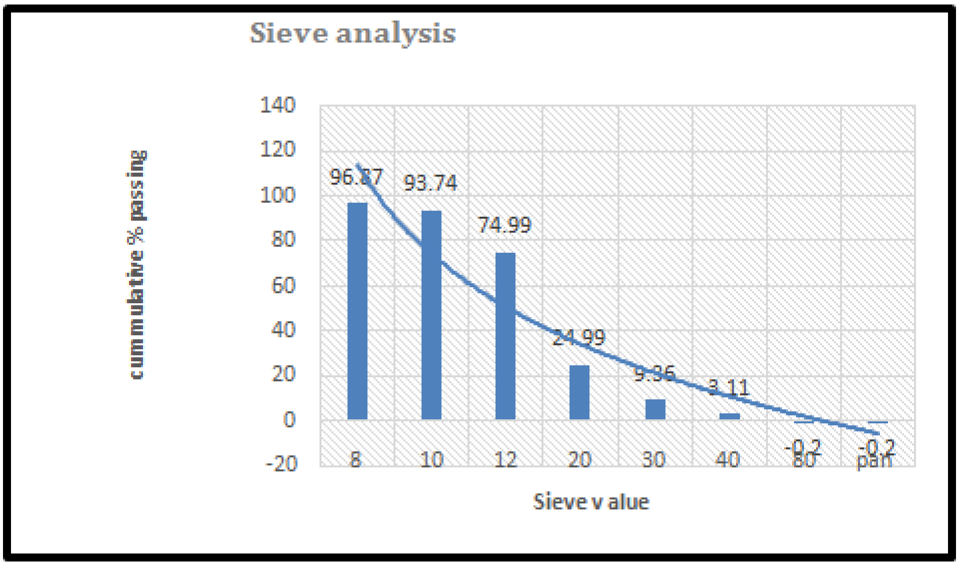

Figure 2: Bar chart representing sieve analysis

This sieve analysis reveals that the material is predominantly composed of medium-sized particles, making it suitable for applications requiring intermediate grain sizes. However, the presence of calculation errors (cumulative values exceeding 100% and negative values) necessitates revisiting the computations to ensure accuracy. This material is likely well-suited for uses such as

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construction aggregates, where a mix of sizes is required for compaction and stability.

4.2 Slump Test:

The slump test was performed on fresh concrete to assess its workability. This involved pouring the fresh concrete into a slump cone and compacting it by giving 25 blows per layer. The height difference between the original cone height and the slumped concrete was measured to determine workability as presented in Table 3. Studies such as those by Charles et al. (2018) and Ogunjiofor et al. (2020) have underscored the relationship between concrete workability and the use of alternative materials like resins and seawater for mixing and curing. Workability influences the ease of handling, placing, and compacting the concrete, which is critical in construction processes.

Table 3: Shows the slump difference from the slump test carried out on the fresh concrete

Specimen sample	Bamboo leaf ash	Trial	Water cement ratio	Height of cone	Height of the slumped concrete	Slump value	Type of slump
Sample 1	0%	1	0.7	300 mm	250 mm	51mm	True slump
Sample 2	2.0%	1	0.7	300 mm	255 mm	43mm	True slump
Sample 3	5.0%	1	0.7	300 mm	280 mm	32mm	True slump

The 0% Bamboo Leaf Ash (BLA) which is the control mix without any BLA recorded a slump value of 51 mm. This indicates a high level of workability, allowing for easy handling, placement, and finishing. The 2% BLA resulted in a decrease in slump to 43 mm. This reduction signifies a noticeable decline in fluidity, suggesting that while some BLA can be incorporated without severely compromising workability, it begins to affect the mix's manageability as seen in figure 3. The 5.0% Bamboo Leaf Ash, higher replacement level, the slump value further decreased to 36 mm. This significant reduction indicates a marked decline in workability, making the concrete mix stiffer and more challenging to manipulate during construction processes. The data reveals a consistent trend, as the percentage of bamboo leaf ash increases, the slump value decreases. This trend highlights an inverse relationship between BLA content and workability. In practical terms, this means that higher concentrations of BLA lead to stiffer mixes that are less amenable to conventional handling techniques.

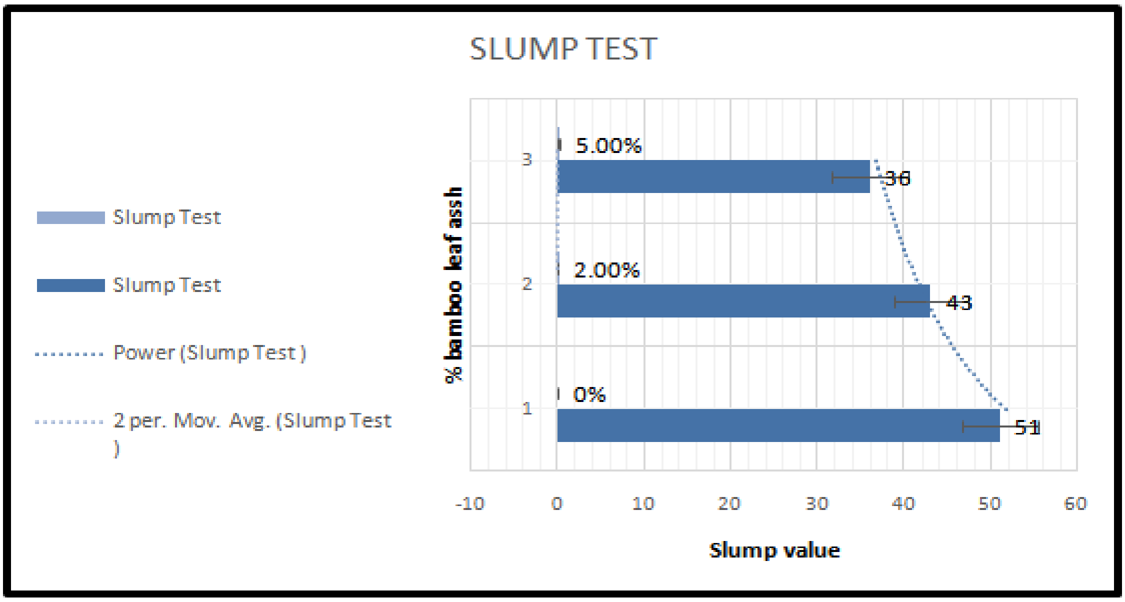

Figure 3: Graphical representation of slump test

This comprehensive analysis underscores that incorporating bamboo leaf ash into concrete mixes adversely affects slump values, indicating a reduction in workability as ash content increases. Although BLA presents opportunities for enhancing sustainability and potentially improving certain mechanical properties, careful adjustments to mix designs are essential to achieve desired workability levels when utilizing higher percentages of this alternative material.

This insight is vital for engineers and construction professionals striving to implement eco-friendly materials without compromising quality or usability. By understanding these dynamics, practitioners can develop optimized formulations that leverage the benefits of bamboo leaf ash while ensuring that performance standards are met throughout construction processes.

4.3 Compressive strength test:

The compressive strength test was conducted to evaluate the durability and load-bearing capacity of the concrete, ensuring its sustainability for structural applications. This test determines the maximum compressive load the concrete can withstand. The importance of compressive strength in structural performance has been highlighted in studies by Ogunjiofor et al. (2023), where the development of concrete with crushed glass as a partial fine aggregate replacement showed improved compressive performance over standard curing periods. Similarly, Ogunjiofor et al. (2023) emphasized the role of innovative materials like palm kernel shell in enhancing concrete's structural behavior when used as a partial substitute for coarse aggregates.

Compressive Strength Results

Control sample (0% BLA replacement):

The control sample, which contained no BLA, exhibited a robust strength development profile. At 28 days, this sample achieved a compressive strength of 28.10 MPa. This consistent strength gain can be attributed to the effective hydration reactions inherent in Portland cement, which facilitates the formation of calcium silicate hydrate (C-S-H)—the primary binding agent that contributes to the overall strength of concrete.

2.5% BLA replacement:

Concrete samples with a 2.5% replacement of BLA demonstrated commendable performance, peaking at a compressive strength of 25.03 MPa at the 28-day mark. This result indicates that incorporating a modest amount of BLA can still yield satisfactory mechanical properties without significantly compromising structural integrity. The presence of BLA appears to enhance workability due to its fine particle size and pozzolanic characteristics, allowing for improved mixing and placement.

5% BLA replacement:

In contrast, the sample with a 5% BLA replacement exhibited a marked decline in compressive strength, recording only 20.49 MPa at 28 days. This reduction highlights the diminishing returns associated with higher levels of BLA as a binder. The lower compressive strength can be attributed to the insufficient binding capacity of BLA compared to traditional cement, which limits its effectiveness in contributing to the overall structural performance of concrete as in Figure 4.

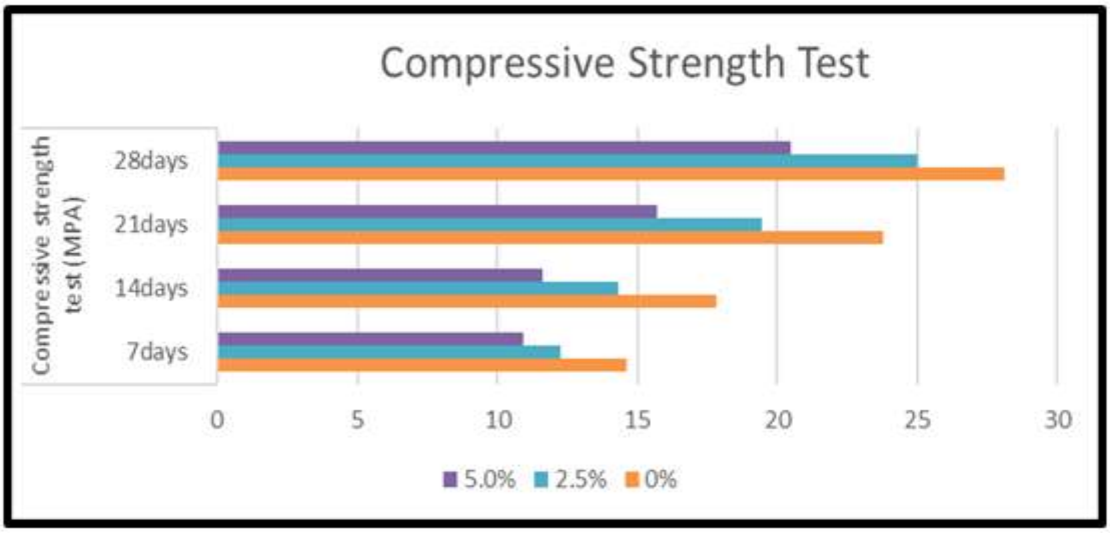

Figure 4: Bar chart representing compressive strength test

4.4. Implications of Bamboo Leaf Ash on Concrete Properties

Strength Development:

The observed decrease in compressive strength with increased BLA content underscores the importance of optimal replacement levels. While BLA contains silica that can participate in pozzolanic reactions—contributing positively to strength through the formation of additional C-S-H—the effectiveness of these reactions diminishes as the proportion of BLA increases beyond certain thresholds.

Workability and Sustainability:

Despite the reduction in compressive strength at higher BLA contents, it is essential to consider other benefits associated with its use. Higher percentages of BLA can enhance workability due to its fine texture, making it easier to mix and place concrete. Furthermore, utilizing BLA as a partial cement replacement can significantly reduce the carbon footprint associated with concrete production, aligning with contemporary sustainability goals in construction.

V. CONCLUSION

This study concludes that bamboo leaf ash can serve as an effective partial replacement for cement in concrete applications; however, its incorporation should be limited to approximately 2.5% to ensure adequate compressive strength for structural applications. This balanced approach not only supports sustainability initiatives by reducing reliance on traditional cement but also maintains satisfactory mechanical performance. As such, bamboo leaf ash presents a promising avenue for enhancing eco-friendly practices within the construction industry while ensuring structural integrity and performance standards are met.

5.1 Recommendation

Partial Replacement of Cement with Bamboo Leaf Ash as a Sustainable Approach in Concrete Production" is a valuable contribution to sustainable construction research. It highlights the use of bamboo leaf ash (BLA) as a partial substitute for ordinary Portland cement (OPC), addressing carbon emission concerns in cement production.

The study's results show that a 2.5% BLA replacement achieves an optimal balance between sustainability and structural performance. Using standard tests like compressive strength and slump, the research confirms BLA's potential to reduce the carbon footprint while maintaining acceptable concrete strength.

With its clear methodology, practical findings, and alignment with sustainability goals, this manuscript is highly relevant and suitable for publication, offering significant insights for eco-friendly construction practices.

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