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COMPRESSIVE STRENGTH OF CONCRETE MADE WITH BAMBOO STALK AS COARSE AGGREGATE

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ABSTRACT*: This study explores the feasibility of using bamboo stalks as a partial replacement for coarse aggregate in concrete. Bamboo stalks with lengths ranging from 20 to 40 mm, widths from 10 to 20 mm, and a thickness of 10 mm were incorporated at replacement levels of 0%, 5%, 10%, 15%, 20%, and 25%. Standard laboratory methods were used to characterize the properties of the fine and coarse aggregates, as well as the bamboo stalks. Concrete was produced using a mix ratio of* $1:1\frac{1}{2}:3$ *and a constant water-cement ratio of 0.55, cast into 150 × 150 × 150 mm lubricated molds. Density and compressive strength were measured at 7, 14, 21, and 28 days of curing. Sieve analysis confirmed that the fine aggregates met standard specifications. The specific gravity of the fine aggregates, coarse aggregates, and bamboo stalks were 2.52, 2.74, and 0.80, respectively, indicating dense fine aggregates, heavyweight coarse aggregates, and lightweight bamboo material. Results showed that incorporating bamboo stalks improved the workability of the concrete. However, both density and compressive strength decreased as the bamboo content increased. The study concludes that replacing up to 5% of granite with bamboo stalks is optimal for maintaining acceptable concrete strength while promoting sustainability in construction*

Keywords*: Bamboo stalk, Coarse Aggregate, Density, Compressive Strength, Lightweight Concrete*

INTRODUCTION

Concrete is a composite construction material comprising coarse and fine aggregates embedded within a hardened cementitious matrix that binds the components into a unified solid mass. Globally, its consumption surpasses that of steel, wood, plastic, and aluminum combined, making it the most extensively used man-made material after water. The material's cost-effectiveness, durability, structural integrity, and form stability contribute to its widespread application in modern construction, particularly in reinforced concrete systems (Chanadan, 2019)

Concrete is the second most consumed material globally, following only water (Halm, 2021). Approximately ten billion tons of concrete are produced annually, equating to about one ton per person worldwide. However, the large-scale production of concrete poses significant environmental concerns, particularly due to the continuous extraction of natural aggregates, which leads to resource depletion and ecological degradation (Auwale & Dickson, 2019). In response to these challenges, ongoing research is focused on identifying alternative materials—particularly those derived from agricultural sources—that can partially or fully replace conventional aggregates in concrete production. Among these, natural fibers have attracted increasing attention in structural applications due to their low cost, lightweight nature, and environmental sustainability. Bamboo, in particular, is a promising material, offering a favorable stiffness-to-weight ratio that enables the production of lighter structural components (Manlapas *et al*., 2018).

Bamboo is a fast-growing, woody grass characterized by its complex vegetative structure, comprising two similarly organized systems: an above-ground shoot system and a below-ground rhizome system. The stem of the bamboo, known as the culm, is segmented by nodes, with the regions between successive nodes referred to as internodes. These internodes are typically, though not always, hollow. During early growth, they are enclosed by protective sheaths, which naturally detach as the plant matures (Abebaw *et al*., 2021).

Bamboo is a naturally occurring composite material that grows abundantly in tropical and subtropical regions. It is classified as a composite due to its structure, consisting of cellulose fibers embedded within a lignin matrix. The longitudinal alignment of cellulose fibers imparts significant tensile and flexural strength, particularly along the length of the culm (Lakkad & Patel, 2020). Globally, over 1,200 species of bamboo have been identified. Historically, bamboo has played a vital role in human civilization—used for writing materials in ancient China and as one of the earliest known construction materials (Li *et al*., 2018). Its high tensile strength, fast growth rate, and renewability make it an appealing alternative to conventional building materials, especially in regions of Asia and South America (Falayi & Soyoye, 2018). Bamboo is not only abundant and cost-effective but also exhibits strength in both tension and compression. Its culm has been utilized in a wide range of applications, from domestic tools to industrial and structural products (Abebaw *et al*., 2021).

In recent years, the potential of bamboo has garnered increasing attention due to its sustainability, rapid renewability, and mechanical resilience, prompting a growing body of research focused on its application in construction. The use of bamboo as a partial replacement for coarse aggregate in concrete represents an innovative strategy that aligns with sustainable construction practices.

Sajjala (2017) investigated the effectiveness of bamboo fibers as a strength-enhancing additive in concrete, using fiber contents of 0%, 0.5%, 0.75%, 1%, and 1.25%. The results indicated that 1% fiber content yielded the optimum performance, with maximum improvements in 28-day compressive strength and split tensile strength reaching 41 N/mm² and 4.8 N/mm², respectively. The inclusion of bamboo fibers significantly enhanced the concrete's resistance to flexural loading, with a peak 28-day flexural strength of 7.5 N/mm². Similarly, Bhautik *et al*. (2017) examined self-compacting concrete incorporating bamboo as a partial replacement for coarse aggregate at levels of 0%, 2%, 4%, and 5%. The findings revealed that a 2% replacement level resulted in the highest compressive strengths at 7, 28, and 56 days—14.9 N/mm², 28.88 N/mm², and 33.41 N/mm², respectively—as well as the highest flexural strengths at 28 and 56 days, recorded at 4.18 MPa and 5.17 MPa. However, increasing the bamboo content beyond 2% negatively affected both the workability and mechanical properties of the concrete, with noticeable reductions in compressive and flexural strengths at 5% replacement.

Sung-Sik *et al*. (2017) examined the mechanical properties of concrete incorporating bamboo chips as a partial replacement for coarse aggregate. Bamboo chips, 0.5 cm thick and cut into 1 cm × 1 cm pieces, were subjected to drying, wetting, and coating treatments to reduce their water absorption capacity. The concrete specimens were prepared by replacing coarse aggregates with bamboo chips at volume replacement levels of 10%, 20%, and 30%. The results indicated a progressive decrease in both compressive strength and splitting tensile strength with increasing bamboo chip content. This reduction in strength was attributed to the weak interfacial bond between the bamboo chips and the surrounding mortar matrix.

Hamidun *et al*. (2021) aimed to determine the optimal percentage of bamboo fiber as a partial aggregate replacement in concrete and to compare its compressive strength with that of conventional concrete. Four cube specimens were cast for each replacement level of 0%, 5%, 10%, 12.5%, 15%, and 17.5% bamboo fiber. The results demonstrated that a 5% replacement yielded the highest compressive strength of 27.77 N/mm², with only a 2.38% reduction compared to standard concrete. Similarly, Manimaran *et al.* (2017) conducted a laboratory investigation on M40 concrete by replacing coarse aggregate with bamboo at volume percentages of 0%, 5%, 10%, 15%, 20%, and 25%, alongside quarry dust as fine aggregate replacement. Their findings indicated that a 15% bamboo replacement achieved the most favorable improvements in compressive strength, flexural strength, split tensile strength, and durability compared to the control mix. The study further highlighted that substituting bamboo and quarry dust for conventional aggregates contributes to reducing environmental waste and mitigating disposal challenges.

The study investigates the compressive strength of concrete produced with bamboo stalk as a partial replacement for granite. The workability of the fresh concrete and the density of the concrete produced will be examined

MATERIALS AND METHODS

Materials

Dangote Ordinary Portland Cement (OPC) 42.5 grade was used, complying with BS EN 197-1:2011 and ASTM C150/C150M-20 standards. The fine aggregate consisted of river sand with a specific gravity of 2.52, bulk density of 1620 kg/m³, and water absorption of 3.47%. Coarse aggregates had a nominal size of 20 mm, with a specific gravity of 2.74, bulk density of 2444 kg/m³, and water absorption of 0.15%. Both fine and coarse aggregates conformed to ASTM C29 (AASHTO T19) specifications. Bamboo stalks used as partial replacements for coarse aggregates were sourced from Ede, Osun State, Nigeria. The stalks were cut into smaller pieces and sun-dried for six weeks, then soaked in water for 48 hours to remove dirt and impurities. After soaking, the bamboo pieces were air-dried and further cut to aggregate sizes ranging from 20–40 mm in length, 10–20 mm in breadth, and approximately 10 mm in thickness. The bamboo stalks exhibited a specific gravity of 0.8, bulk density of 631 kg/m³, and water absorption of 2.15%

Methods

Basic properties of the aggregates—including sieve analysis, moisture content, specific gravity, bulk density, and water absorption—were determined prior to mixing. Concrete was prepared using a mix ratio of $1:1\frac{1}{2}:3$ with a constant water-cement ratio of 0.55, cast into lubricated molds measuring 150 × 150 × 150 mm. Bamboo stalks were incorporated as partial replacements for coarse aggregate at levels of 0%, 5%, 10%, 15%, 20%, and 25%. The bamboo aggregates are illustrated in Figure 1, and the concrete mix proportions are detailed in Table 1. Mixing was performed manually. Workability was assessed using the slump test on fresh concrete, following the procedures specified in BS 1881: Part 102:1983. A total of 48 concrete

cubes were cast and cured for 24 hours before being submerged, in accordance with ASTM C192 (2014), as shown in Figures 2 and 3.
Compressive strength tests were conducted at curing ages of 7, 14, 21, and 28 days using a compression testing machine. The maximum load at failure was recorded, and the compressive strength, denoted as f_c in N/mm², was calculated using the following:

$$f_c = \frac{P}{A_c}$$

Where: P = the maximum load (in Newton), A_c = The cross-sectional area of concrete specimen in mm^2.

Figure 1 Bamboo Stalk Aggregates

Table 1: Mix Proportions for Mix Ratio 1:1$\frac{1}{2}$:3

Percentage replacement	Cement (kg)	Fine aggregates (kg)	Coarse aggregates (kg)		Water (kg)
			Granite	Bamboo	
0	11.78	17.67	35.34	-	6.50
5	11.78	17.67	33.57	1.77	6.50
10	11.78	17.67	31.81	3.53	6.50
15	11.78	17.67	30.04	5.30	6.50
20	11.78	17.67	28.27	7.07	6.50
25	11.78	17.67	26.50	8.84	6.50

Figure 2 Concrete Cubes

Figure 3 **Curing of Concrete**

RESULTS AND DISCUSSION

Sieve Analysis Test

The results of the sieve analysis for the fine aggregates used in this study is presented in Figure 4. The result shows that the fine aggregate used has large proportion coarse sand with low proportion of medium sand and a very scanty fine sand. The fine aggregate used were found to be within the standard specification range as stipulated by BS EN 12620:2002 and BS 882 (1992) and therefore, make it suitable for concrete production.

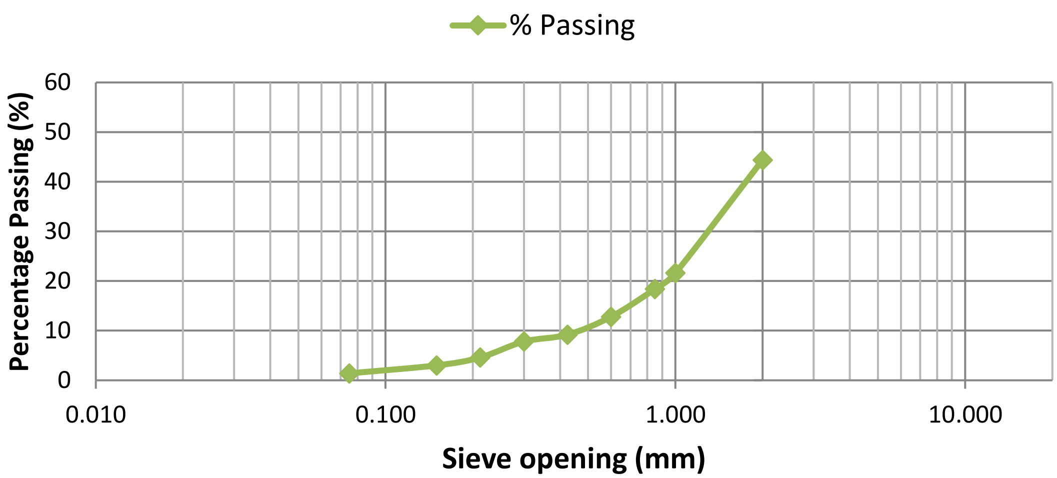

Figure 4 Sieve Analysis Graph for Fine Aggregate

Moisture Content

The moisture content of the bamboo and that of fine aggregates was 4.61% and 2.44% respectively. The values fall within standard range according to BS EN 12620:2002 and BS 882 (1992) which states 3% - 7% moisture content for fine aggregates and 1% - 4% for coarse.

Specific Gravity

The specific gravity of the fine aggregates was 2.52. The value is between the ranges of specification for specific gravity according to BS EN 12620:2002 and BS 882 (1992) whereas the specific gravity bamboo stalk was 0.8. the value falls below specific gravity for coarse aggregate. The result may affect the density and the strength of the concrete produced.

Bulk Density

The compacted bulk density for the fine aggregate, coarse aggregate and bamboo was 1620 kg/m^3, 2444 kg/m^3 and 631 kg/m^3 respectively. The value for fine aggregate falls with stipulated range for sand (1600-2160) kg/m^3, while the granite is heavy aggregate and the bamboo stalk is categorized as lightweight aggregates according to BS EN 1097-3, ASTM C29/C29M-20 and AASHTO T 19-20.

Water Absorption

The result for the water absorption test for the coarse aggregate, fine aggregate and bamboo are 0.15%, 3.47% and 2.15% respectively. According to BS EN 12620:2002 +A1:2008, BS 882 (1992), ASTM C127-15, ASTM C128-15, the coarse aggregate has low absorption whereas fine aggregate has high absorption and bamboo has medium absorption. **Workability**

The results of the slump tests for the percentage replacement of granite with bamboo stalks are given in Table 2. 0%, 5% and 10% fall within low slump, the concrete was stiffed. This concrete is suitable for foundations and columns. Also, 15%, 20% and 20% fall within medium slump, the concrete gives optimal workability, easy placement and good compaction. This is contrary to Bhautik *et al.*, (2017). This concrete is suitable for slabs, beams and walls according to ASTM C143/C143M-20, BS EN 12350-2:2019 and ACI 211.1-91.

Density of Concrete

The results of the concrete cube densities are presented in Table 3. At 28 days, the density of the control mix (0% bamboo replacement) was 2814 kg/m^3, classifying it as high-density concrete according to the range of 2600–3200 kg/m^3 specified by ACI 211.1-19, BS 8500-1:2015, and ASTM C138/C138M-20. However, with the inclusion of bamboo as a partial replacement for coarse aggregate starting at 5%, the density of the concrete progressively decreased as the replacement level increased. At higher replacement levels, the density values fell within the range of lightweight concrete, defined as 400–1600 kg/m^3 by the same.

Table 2 Slump Test Result on Concrete

Bamboo (%)	Height of cone (mm)	Slump measured (mm)	Type of slump
0	300	25	Low
5	300	27	Low
10	300	31	Low
15	300	55	Medium
20	300	58	Medium
25	300	62	Medium

Table 3: Density Test Results of the Concrete

Percentage replacement (%)	Density(kg/m^3)			
	7 Days	14 Days	21 Days	28 Days
0	2666.67	2755.56	2785.19	2814.81
5	2518.52	2459.26	2407.41	2370.37
10	2488.89	2414.81	2340.74	2321.48
15	2414.81	2362.96	2318.53	2259.26
20	2385.19	2340.74	2259.26	2200.00
25	2088.89	2281.48	2200.00	2118.52

Compressive Strength

The compressive strength results of the concrete cubes are presented in Table 4. As expected, the strength of the concrete increased with curing age. However, replacing granite with bamboo stalks led to a noticeable reduction in compressive strength. At 28 days, a 5% bamboo replacement resulted in an 8.4% decrease in strength compared to the control. Increasing the replacement level to 10% led to a 17.3% reduction, while 15% replacement caused a 24% decrease. Further increases to 20% and 25% resulted in strength reductions of 37.4% and 45.7%, respectively. These findings are consistent with the results reported by Manimaran et al. (2017) and Idris et al. (2021). According to BS EN 206 (2013), the minimum required compressive strength for lightweight concrete is 15 N/mm^2. Based on this criterion, up to 15% of granite can be replaced with bamboo stalks when using a 1:1.5:3 mix ratio for lightweight concrete applications. For normal concrete, a 5% bamboo replacement is recommended to maintain acceptable strength performance.

Table 4: Compressive Strength Test Result

Percentage replacement (%)	Compressive strength (N/mm^2)			
	7 Days	14 Days	21 Days	28 Days
0	14.16	17.07	19.60	21.56
5	12.93	15.22	17.59	19.75
10	10.11	13.55	15.62	17.83
15	9.34	12.33	13.97	16.38
20	7.98	11.22	12.62	13.49
25	7.92	9.22	9.92	11.71

CONCLUSION

The lower specific gravity and bulk density of bamboo stalks contribute to the reduction in both the density and compressive strength of concrete. However, the inclusion of bamboo stalks enhances the workability of the concrete. The resulting concrete, when bamboo is used as a partial coarse aggregate, falls within the classification of lightweight concrete. Based on the findings, up to 15% of granite can be replaced with bamboo stalks using a 1:1.5:3 mix ratio for lightweight concrete applications, while a 5% replacement is suitable for producing normal concrete. Future research should explore the treatment of bamboo with water-repellent or sealing agents to mitigate moisture absorption prior to its use as coarse aggregate. Additionally, the use of quarry dust as fine aggregate, in combination with bamboo stalk replacements at varying mix ratios, should be investigated to further enhance concrete performance.

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