Sustainable Blended Concrete Using Bamboo and Fly Ash

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Abstract

The urgent need to reduce the environmental footprint of the construction industry, where cement production contributes significantly to global co_2 emissions motivates the search for sustainable alternatives. This study evaluates the potential of bamboo fibers and fly ash as eco-friendly substitutes in concrete production. Bamboo fibers were incorporated as a fine aggregate replacement, while fly ash partially substituted cement to mitigate environmental impacts. A series of 45 cylindrical specimens were cast with varying proportions of bamboo (2%, 4%, 6% and 8%) and fly ash (5%, 10%, 15% and 20%), and compressive strength tests were conducted at 7, 14 and 28 days of curing. The results indicate that an optimal mix, containing 4% bamboo fibers and 15% fly ash, balances mechanical performance with sustainability objectives. Although increased bamboo content slightly reduced workability, fly ash contributed to long-term strength gain through its pozzolanic activity. This research provides valuable insights into the design of sustainable concrete mixes that reduce cement consumption and lower carbon emissions. Future investigations should address durability aspects and large-scale application feasibility to further advance eco-friendly construction practices.

Keywords: Bamboo fiber, fly ash, sustainable construction, compressive strength, concrete mix design.

1. Introduction

The construction industry is one of the major contributors to global CO2 emissions, with cement production alone accounting for approximately 7% of worldwide emissions [1, 2]. Efforts to mitigate this impact have led to the exploration of alternative materials that are both sustainable and environmentally friendly [3-5]. Fly ash, a by-product of coal combustion, and bamboo, a renewable natural resource, have shown promise in this regard. Fly ash serves as a supplementary cementitious material, while bamboo fibers have been studied as a potential fine aggregate replacement [3].

Concrete, as the backbone of modern infrastructure, consumes vast amounts of natural resources. Exploring sustainable alternatives like bamboo and fly ash not only reduces environmental degradation but also promotes the efficient use of industrial by-products. This study delves into the feasibility of these materials in construction applications and their contribution to achieving global sustainability goals.

The primary objectives of this research are: 1)To evaluate the mechanical properties of concrete incorporating bamboo and fly ash. 2)To determine the optimal replacement levels for achieving maximum strength and sustainability. 3)To analyze the environmental benefits of substituting traditional materials with sustainable alternatives.

The study contributes to the growing field of sustainable construction by providing empirical data on the use of bamboo and fly ash in concrete. It aims to inform industry practices and encourage the adoption of eco-friendly materials.

Researches are going on to utilize bamboo fiber as a reinforcement in concrete and as a structural material because of its positive physical features [6]. Ultrafine fly ash, acquired through a dry and closed separation process, improves the strength and workability properties of concrete [7]. Fly ash, with its pozzolanic properties, chemically reacts with calcium hydroxide in the presence of moisture to form additional cementitious compounds, enhancing the durability and strength of concrete over time [8].

2. Overview of Sustainable Materials

The use of fly ash in concrete increases the workability of plastic concrete and increases the strength and durability of hardened concrete [3]. The use of fly ash is also cost-effective. When fly ash is added to concrete, the amount of silicate cement used can be reduced.

The use of FA is important in civil engineering due to its economic and environmental benefits. The amount of cement that can be replaced with FA is limited by the amount of free lime in the ash. In addition to its chemical composition, the reactivity of FA depends on the phase structure, the amount of glassy phase, the thermal conductivity of the coal or lignite, the specific surface area (SSA), etc. FA is a pozzolanic material [9]. The term "pozzolan" refers to materials that form cementitious compounds that do not dissolve when exposed to lime and water, although such materials have little or no effect when used alone [9].

Class F fly ash is typically used as a replacement for Portland cement in amounts ranging from 20% to 30% of the total cementitious material. Factors Affecting the Suitable. Percentage: Desired Concrete Properties: If higher strength or durability is required, a lower percentage of fly ash might be used. Conversely, if improved workability or reduced heat of hydration is the primary goal, a higher percentage might be suitable. Fly Ash Characteristics: The specific properties of the fly ash, such as fineness, chemical composition, and reactivity, can influence the optimum replacement level [10]. Mechanical and electrical dust collectors or baghouses collect solid particles in the exhaust gases. FA refers to ash particles that “fly” away from the furnace and flue gases [11].

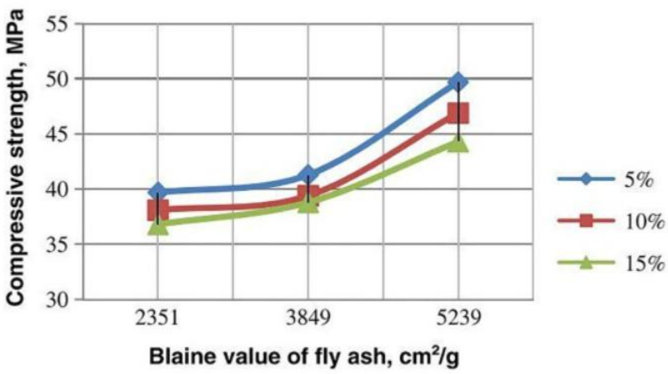

Figure 1. 28-days CS of concrete vs the fineness of FA concrete [12]

Sajjala, 2017 [13] carried out research on the Use of Bamboo within Reinforced Concrete approached the problem of using bamboo as a fiber reinforcing concrete composite. The bamboo ratio substituted was 0%, 0.5%, 0.75%, 1% and 1.25%. The result shows that, 1% is the optimum fiber content. The maximum values of 28 days compressive strength and split tensile strength were 41 N/mm2 and 4.8 N/mm2 respectively. The addition of bamboo fibbers significantly increases the flexural resistance of concrete with the maximum increase in flexural strength reaching 7.5 N/mm2 after 28 days. In this study, it showed that the workability of fresh concrete was found to be good lacking with an increase in the fiber content of up to 1.25 percent.

Dudhatra, Parmar, & Patel, 2017 [14] focused on the design of self-compacting concrete by using bamboo as a substitute for aggregates. The proportions of bamboo used were 0%, 2%, 4% and 5%. It was discovered that 2% is the optimum percentage for the concrete since it has the highest compressive strength of 14.9 N/mm2, 28.88 N/mm2 and 33.41 N/mm2 at days 7, 28, and 56 respectively. Furthermore, it registered the highest flexural for 28 days at 4.18 MPa and 56days at 5.17 MPa. From this study, it was observed that as the content of bamboo pieces increased, the workability of the concrete did not improve. The compressive strength and flexural strength of the concrete also reduced when the bamboo pieces content went beyond 5%.

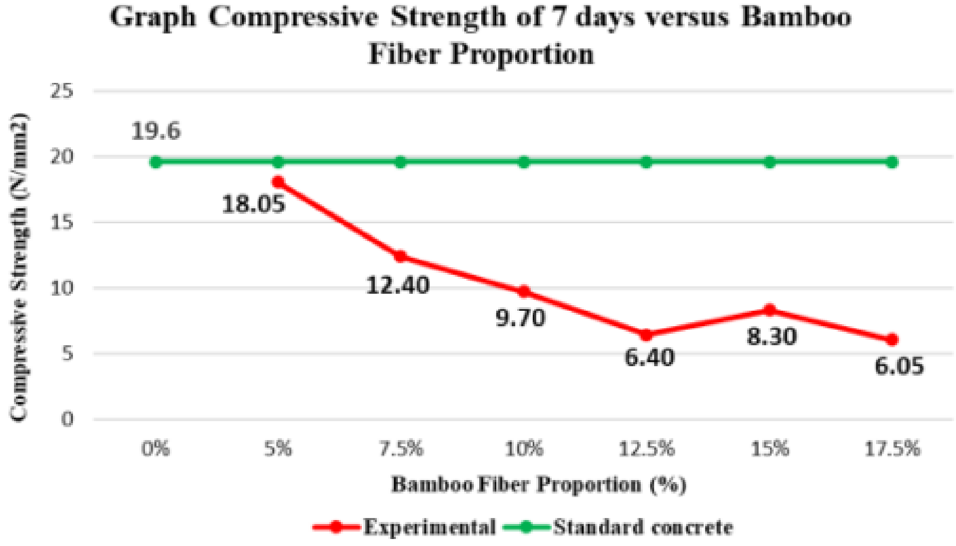

Figure 2. Graph compressive strength of 7 days vs bamboo fiber proportion [3]

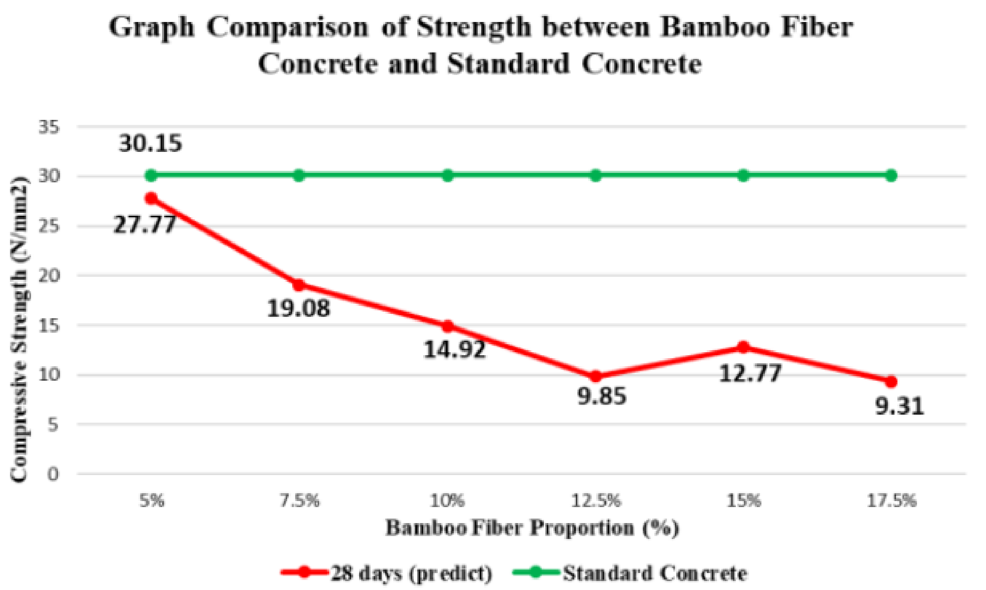

Figure 3. Graph Prediction of Compressive Strength for 28 days vs Bamboo Fiber Proportion [3]

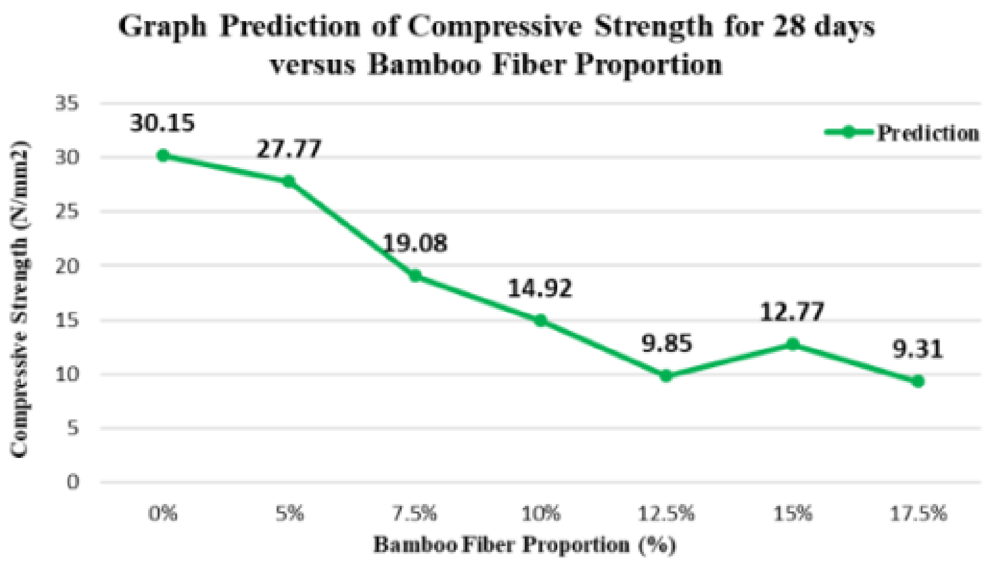

Figure 4. Graph comparison strength of bamboo fiber concrete between 7 days and 28 days (Prediction) [3]

Sustainability in construction has gained momentum as industries worldwide aim to reduce carbon footprints. Cement, as a key component of concrete, is one of the largest contributors to CO2 emissions [9]. Fly ash, a pozzolanic material, and bamboo, a renewable resource, provide viable pathways for reducing the environmental impact of concrete production [9].

Bamboo has been utilized in construction for centuries, especially in Asia and Africa [3]. Its high tensile strength, lightweight nature, and rapid growth make it an ideal candidate for sustainable construction. Studies show that bamboo fibers enhance the ductility and toughness of concrete, though workability may be adversely affected at higher concentrations [3].

Fly ash, a by-product of thermal power plants, has pozzolanic properties that enhance the long-term strength and durability of concrete. Replacing cement with fly ash reduces greenhouse gas emissions and the heat of hydration, making it ideal for large-scale construction projects [10].

Limited studies have explored the combined use of bamboo and fly ash in concrete. This research addresses this gap by investigating their collective impact on the mechanical properties and sustainability of concrete.

3. Methodology

All the information regarding concrete mix design and the planned testing schedule for a blended concrete sample and the information presented is used to assess the properties of the concrete and evaluate the effectiveness of using fly ash and bamboo as blended materials. The Percentage of Fly ash, Percentage of Bamboo fibers, Testing Schedule, Quantity of Cement and Quantity of Fine Aggregates are as Follow:

3.1 Materials

Materials used in the in this Study is Given below:

Table 1. Materials Used and their Specifications

Sr No.	***Materials***	***Properties/ Specifications***
1	Cement	Ordinary Portland Cement (OPC) conforming to ASTM standards.
2	Fine Aggregate	Locally available manufactured sand

3	Coarse Aggregate	Crushed stone with a maximum size of 20 mm
4	Bamboo Fiber	Treated and processed bamboo fibers, sieved to fine aggregate size.
5	Fly Ash	Class F fly ash.
6	Water	Clean potable water for mixing and curing.

3.2 Mix Design

A standard mix design of 1:2:4 (cement: fine aggregate: coarse aggregate) M15 grade by weight was adopted. Figure 5 Shows fly ash in powder form ready to be used in mix design. Five concrete compositions were prepared as follows:

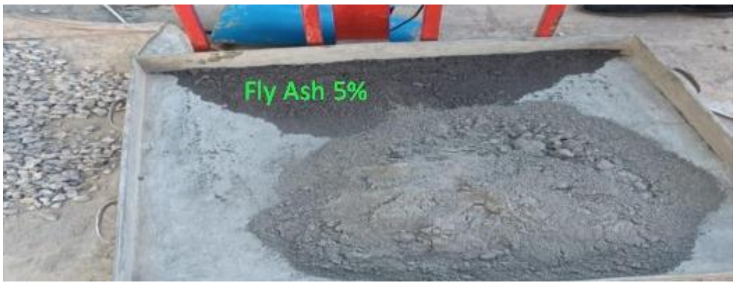

Figure 5. Fly ash in Powder Form

Table 2 and 3. Mix Design

Sample Model of Blended Concrete			**Testing Schedule**				**Quantity of Cement/ Sample**		**Quantity of Fine / Sample**	
% Age of Fly Ash	**% Age of Bamboo Fiber**		**7 days Testing**	**14 Days Testing**	**28 Days Testing**	**Total Samples**	**Fly Ash (g)**	**Cement (g)**	**Bamboo (g)**	**Fine (g)**
0	0	**Conventional Concrete 9 Samples**	3	3	3	9	0	1774	0	3696
5	2	**Blended Concrete Samples**	3	3	3	9	88.7	1685.8	73.92	3622.1
10	4		3	3	3	9	177.4	1596.6	147.84	3548.2
15	6		3	3	3	9	266.1	1507.9	221.8	3474.2
20	8		3	3	3	9	354.8	1419	295.7	3400.3
			12	12	12	45				

Concrete Grade	M15
Volume of Cylinder	
Wet (m^3)	0.00556
Dry (kg)	0.008624
Quantity of Cement Without Blend/ Sample (kg)	1.774
Quantity of Fine Without Blend/ Sample (kg)	3.696
Quantity of Coarse/ Sample (kg)	7.885
W/C Ratio	0.55
Water Content in Each Sample (g)	975.7
Total Cement Required (kg)	71.85
No. of Bags Approx.	1.5

3.3 Preparation of Bamboo Fibers

The bamboo fibers were processed to ensure uniformity. Raw bamboo was cleaned, dried, and treated with a borax solution to enhance its durability and resistance to biological degradation. The treated bamboo was then ground and sieved to achieve the desired particle size. Figure 6 Shows Bamboo Fibers which are used in mix design.

Figure 6. Bamboo Fibers

3.4 Casting and Curing

A total of 45 cylindrical specimens (150 mm diameter × 300 mm height) were cast. Each composition had 9 specimens, tested at curing ages of 7, 14, and 28 days. Specimens were demolded after 24 hours and cured in a water tank at room temperature. Figure 7 shows cylinders of blended concrete casted for testing.

Figure 7. Cylinders Casting for Testing

3.5 Testing Procedure

Compressive strength tests were conducted using a Compression Testing Machine in accordance with ASTM C39 standards as shown in Figure 8. Figure 10 and 11 shows different type of failure in compression testing machine. Results were recorded and analyzed to compare performance across compositions. Additionally, Figure 9 shows slump tests were performed during casting of cylinders to assess workability, and density measurements were taken to evaluate the impact of material replacements on concrete properties.

Figure 8. Compression Testing Machine Sample Result

Figure 9. Slump Test

Figure 10 and 11. Sample in Compression Testing Machine

4. Results and Discussion

Strength Increase: In general, the strength of the material increases with curing time. For each row, the value in the 14-day column is higher than the 7-day column, and the 28-day value is the highest. Rate of Increase: The rate of strength increase seems to slow down over time. The difference between 7-day and 14-day values is typically larger than the difference between 14-day and 28-day values.

4.1 Compressive Strength Analysis

The compressive strength results (assumed data) are summarized in Table 1. The control mix (M1) achieved strengths of 25 MPa, 30 MPa, and 35 MPa at 7, 14, and 28 days, respectively. Mix M2 showed a marginal decrease, achieving 24 MPa, 29 MPa, and 34 MPa at corresponding ages. Mixes M3 and M4 demonstrated moderate decreases, while M5 exhibited the lowest strengths due to higher replacement levels.

Table 4. Compressive Strength of Various Mix Design

Mix ID	*7 Days (MPA)*	*14 Days (MPA)*	*28 Days (MPA)*
M1	25	28	33.5
M2	23	27	32
M3	21.5	26	32
M4	20	25	30
M5	15.16	22	28

4.2 Workability and Density

The slump test results indicated an increase in workability with increasing bamboo content and Fly ash. M1 exhibited a slump of 75 mm, while M5 showed a slump of only 40 mm. The density measurements revealed a reduction in weight as the percentage of bamboo and fly ash increased, contributing to the potential use of this blend in lightweight concrete applications.

4.3 Discussion

Table 5. Key Findings of the Study

Parameter	*Observations*

Optimal Performance	M2 demonstrated the closest performance to M1, suggesting that 4% bamboo fibers and 15% fly ash replacements are optimal for maintaining strength while promoting sustainability
Effect of Bamboo	Increasing bamboo content reduced workability and compressive strength due to its fibrous nature
Effect of Fly Ash	Moderate fly ash replacement improved long-term strength gain due to its pozzolanic activity

5. Conclusion

This study highlights the potential of bamboo and fly ash as sustainable materials for concrete production. 4% bamboo fibers and up to 15% fly ash will be the optimal percentages for fine aggregates and cement replacement respectively Higher replacement levels led to significant strength decreases, underscoring the need for careful proportioning. Future work should explore durability properties, long-term performance, and large-scale applications to validate these findings.

The integration of bamboo and fly ash into concrete production aligns with global efforts to reduce CO2 emissions and promote resource efficiency. This research contributes to the development of eco-friendly construction materials and offers a viable solution for addressing environmental challenges in the construction industry.

Further studies should investigate the impact of bamboo and fly ash on other properties, such as tensile strength, durability under aggressive environmental conditions, and thermal insulation. Life-cycle assessments can also provide a comprehensive evaluation of the environmental benefits of these materials.

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Disclosure of Interests. The authors declare no competing interests

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