

Experimental Project on Partial Replacement of Cement By Bamboo Stem Ash Powder

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Abstract: This project investigates the partial replacement of cement with bamboo stem ash (BSA) in M20 grade concrete. Bamboo stem ash is obtained by burning dry bamboo stems at controlled temperatures. It contains silica and alumina, which provide pozzolanic properties similar to cement. Concrete mixes were prepared with 0%, 5%, and 10% replacement levels of BSA. Tests were conducted to determine workability and compressive strength. The slump cone test showed a slight reduction in workability with increased ash content. Compressive strength tests indicated that 5% replacement performs close to normal concrete. Beyond 10%, a noticeable reduction in strength was observed. The study concludes that up to 5% replacement is suitable for structural use. Using bamboo stem ash helps reduce cement usage and supports sustainable construction.

Keywords: Bamboo Stem Ash (BSA), Cement Replacement, Sustainable Concrete, M20 Grade Concrete, Pozzolanic Material, Compressive Strength, Workability, Eco-friendly Construction Waste Utilization, Green Building Materials

I. INTRODUCTION

Concrete is one of the most widely used materials in the construction industry because of its strength, durability, and versatility. However, the production of cement, which is the main binding material in concrete, contributes significantly to environmental pollution due to the release of a large amount of carbon dioxide during manufacturing. To promote sustainable construction and reduce the dependency on cement, researchers are exploring the use of alternative and eco-friendly materials that can partially replace cement without compromising the quality of concrete. One such promising material is bamboo stem ash, which is obtained by burning dry bamboo stems. Bamboo stem ash is rich in silica and alumina, which exhibit pozzolanic properties. These compounds react with calcium hydroxide released during the hydration of cement to form calcium silicate hydrate (C-S-H) gel, improving the strength and durability of concrete. In this project, cement is partially replaced with bamboo stem ash at 5% and 10% levels to evaluate its effect on the workability and compressive strength of concrete, and to determine its potential as an eco-friendly and sustainable construction material.

1.1 OBJECTIVE

The main objective of this project is to study the partial replacement of cement with bamboo stem ash (BSA) in M20 grade concrete.

It aims to evaluate the mechanical and physical properties of concrete containing BSA.

The project seeks to promote sustainable and eco-friendly construction materials.

It focuses on reducing cement consumption to minimize carbon emissions.

Another objective is to utilize bamboo waste effectively instead of discarding it.

The study investigates the effect of BSA on the workability of fresh concrete.

It analyzes the compressive strength of concrete at 7, 14, and 28 days.

The experiment aims to determine the optimal percentage of BSA replacement.

It compares the performance of normal concrete with BSA-blended concrete.



The project identifies how BSA affects durability and strength development.
It explores the pozzolanic behavior of bamboo ash in cementitious systems.
Another goal is to assess cost reduction in concrete production using waste materials.
The study helps understand how particle fineness influences mix properties.
It evaluates the consistency and water demand of BSA concrete mixes.
The project demonstrates the feasibility of using bamboo ash in structural concrete.
It aims to support sustainable waste management in the construction sector.
The findings can guide future research on agricultural waste utilization.
It encourages green technology adoption in civil engineering practices.
Overall, the project aims to balance strength, economy, and environmental protection.
The final goal is to develop a sustainable, efficient, and eco-friendly concrete mix design.

II. LITERATURE REVIEW

Several studies have explored the use of agricultural and industrial waste as cement replacements. Researchers have found that bamboo ash possesses good pozzolanic properties due to its silica and alumina content. Mao Mydin et al. (2025) reported that bamboo stem ash enhances microstructural and thermal properties of concrete. FKS Junior et al. (2024) observed that bamboo leaf ash improves concrete strength and durability when used in small proportions. Mendonça et al. (2023) confirmed that partial replacement of cement with bamboo ash reduces environmental impact. Adnan et al. (2023) showed that bamboo ash can be effectively used in cement sand bricks with satisfactory strength. Barman et al. (2025) studied the use of bamboo biochar and rice husk ash and found improved strength characteristics. Nduka et al. (2022) highlighted that bamboo leaf ash reduces cement demand and promotes green construction. Rahim et al. (2020) demonstrated the potential of bamboo in construction for low-cost housing applications. Previous studies indicate that 5–10% replacement with bamboo ash gives optimal results. Most researchers agree that beyond 10%, concrete strength begins to decline. Bamboo ash contributes to better long-term performance due to pozzolanic reactions. It improves durability and reduces permeability when properly processed. The fineness of bamboo ash enhances binding with cement particles. However, excessive ash content can increase water demand and reduce workability. The chemical similarity between bamboo ash and cement enables partial substitution. Studies emphasize the importance of controlled burning and proper sieving of bamboo ash. Literature supports bamboo ash as a sustainable supplementary cementitious material. The collective findings provide a strong foundation for further experimental validation. Hence, this study builds upon past research to evaluate bamboo stem ash in M20 concrete mixes.

III. METHODOLOGY

The experimental study was conducted to evaluate bamboo stem ash (BSA) as a partial cement replacement. Dry bamboo stems were collected, cleaned, and burned at 600–700°C to produce ash. The obtained ash was cooled, ground, and sieved through a 75-micron sieve. Concrete mixes of M20 grade were prepared with 0%, 5%, and 10% BSA replacement. All mixes were proportioned using standard mix design procedures. Cement, fine aggregate, coarse aggregate, and water were kept constant for comparison. Workability of fresh concrete was tested using the slump cone method. Compressive strength tests were performed on cubes after 7, 14, and 28 days of curing. Test results were compared to determine the optimal percentage of replacement. The entire process aimed to assess both performance and sustainability of BSA concrete.



Material Selection:

The quality and properties of materials directly affect concrete performance. Materials used in this study include cement, bamboo stem ash, fine aggregate, coarse aggregate, and water. Ordinary Portland Cement (OPC) was used as the main binding material. It provides strength and durability through hydration reactions. Bamboo stem ash was used as a partial replacement for cement at 5% and 10%. It was prepared by burning, grinding, and sieving dry bamboo stems. Fine aggregate (manufactured sand) was used to fill voids between coarse aggregates. It improved the workability and finish of the concrete mix. The sand used was clean, well-graded, and passed through a 4.75 mm sieve. Coarse aggregates of size 10–20 mm were selected for strength and stability. They were angular, hard, and free from dust or organic impurities. The specific gravity of coarse aggregates was around 2.8, indicating good quality. Water used in the mix was clean, potable, and free from harmful salts. It played a vital role in the hydration and workability of the mix. All materials were tested for physical properties before use. Sieve analysis and density tests were done for aggregates. Specific gravity tests were conducted for cement and aggregates. Mixing proportions were designed based on M20 grade concrete standards. Uniform mixing and proper curing ensured reliable test results. The selected materials together ensured strength, economy, and sustainability in the final mix.

REASON FOR USING BAMBOO STEM ASH:

Bamboo stem ash is used in this project as a **partial replacement for cement** because it offers both environmental and performance benefits. The main reasons for using bamboo stem ash are:

- **Eco-friendly material:** It utilizes agricultural waste (bamboo) that would otherwise be discarded, helping to reduce pollution and promote sustainable construction.
- **Reduction in cement usage:** Cement production releases a large amount of carbon dioxide (CO₂); using bamboo stem ash helps reduce the overall cement content and associated emissions.
- **Pozzolanic property:** Bamboo stem ash contains silica and alumina, which react with calcium hydroxide in cement to form additional binding compounds (C–S–H gel), improving strength and durability.
- **Cost-effective:** Bamboo ash is easily available and inexpensive compared to cement, reducing the overall cost of concrete production.
- **Improved performance:** When used in limited proportions (5–10%), it can enhance the strength, resistance to cracking, and long-term durability of concrete.

MAIN SIMILARITIES BETWEEN CEMENT AND BAMBOO STEM ASH:

Both contain **silica (SiO₂)**, **alumina (Al₂O₃)**, and **ferric oxide (Fe₂O₃)** — the key oxides responsible for cementitious and pozzolanic activity.

Both materials contribute to the formation of **calcium silicate hydrate (C–S–H) gel**, which provides strength in concrete.

Both are **fine powders** with similar texture and color, allowing easy blending in the mix.

Both show **binding properties**, improving the cohesion of concrete ingredients.

Both play a role in **strength and durability** development when used in proper proportions



MATERIALS USED:

The quality and properties of materials play a vital role in determining the strength, durability, and performance of concrete. In this experimental study, various materials such as cement, fine aggregate, coarse aggregate, bamboo stem ash, and water were used to prepare M20 grade concrete. Each material was carefully selected and tested to ensure it met the required specifications. The bamboo stem ash used as a partial replacement for cement serves as the main variable in this experiment, while other materials were kept constant to maintain uniformity in the mix design.

2.1.1. BAMBOO STEM ASH:

Bamboo stem ash is obtained by burning dry bamboo stems and processing the residue into a fine powder. It contains silica and alumina, which give it pozzolanic properties similar to cement. When used as a partial replacement for cement, bamboo stem ash can enhance strength and reduce the environmental impact of concrete production.



Fig 2.1

2.1.2. CEMENT:

Cement is one of the main binding material in concrete. It reacts with water and forms a paste that hold the aggregates together. The most common type is OPC (Ordinary Portland Cement), which got good compressive strength and set fast. It also got good durability and makes the concrete strong. But it produce a lot of carbon emission during it's production.



Fig 2.2

2.1.3.Fine Aggregates (Sand):

Sand is used as fine aggregate in the mix. It fills the gaps between coarse aggregates and cement paste. Natural river sand is mostly used because it is clean and strong. The particle size usually below 4.75 mm. It also helps in finishing and workability of concrete. But the quality of sand should be proper, otherwise it affect the strength.



Fig 2.3



2.1.4. Coarse Aggregates:

Coarse aggregate are the bigger stones that give volume and strength to concrete. They are usually size from 10 mm to 20 mm depending on the mix. Crushed stones are commonly used. It should be hard, clean and free from dust or organic material. The shape and size also affect the strength and workability.



Fig 2.4

2.1.5. Water:

Water is needed for hydration of cement. It should be clean and free from any harmful substances. If water is not clean, it can reduce the strength of concrete. The amount of water also important, too much water make concrete weak, while too less water make it hard to mix and place.



Fig 2.5

2.2. PREPARATION OF BAMBOO STEM ASH:

Collection of Bamboo Stems:

Dry bamboo stems are collected from construction or agricultural waste. The stems should be free from mud, leaves, and other impurities.



Cutting and Drying:

The collected bamboo stems are cut into small pieces and sun-dried for several days to remove moisture.

Burning Process:

The dried bamboo pieces are then burned in an open area or furnace at a controlled temperature of about 600–700°C until complete combustion occurs.

Cooling of Ash:

After burning, the ash is allowed to cool naturally at room temperature to avoid moisture absorption.

Grinding:

The cooled ash is ground into a fine powder using a grinder or mortar to improve its fineness and reactivity.

Sieving: The ground ash is sieved through a **75-micron sieve** to obtain a uniform and smooth powder suitable for mixing with cement.



2.3 MIX DESIGN:

The mix design for this experimental project was developed to produce M20 grade concrete, following the standard proportioning guidelines. The objective was to study the effect of partial replacement of cement with bamboo stem ash at 5% and 10% levels. The mix design ensures that the concrete attains the desired strength, workability, and durability while optimizing material use. The calculated quantities were proportionally scaled down for casting 120 mm cubes for testing purposes.

Quantities for M20 Concrete (0% Cement Replacement):

For M20 concrete (without any bamboo stem ash replacement), the mix typically requires the following quantities for 1 cubic meter:

Cement = 320 kg

Fine Aggregate = 480 kg

Coarse Aggregate = 960 kg

Water = 160L

Now, for one 120 mm cube (which is 0.001728 m^3), the quantities are scaled down as follows:

Cement = $320 \text{ kg} \times 0.001728 = 0.553 \text{ kg} = 553 \text{ g}$

Fine Aggregate = $480 \text{ kg} \times 0.001728 = 0.829 \text{ kg} = 829 \text{ g}$

Coarse Aggregate = $960 \text{ kg} \times 0.001728 = 1.658 \text{ kg} = 1658 \text{ g}$

Water = $160 \text{ L} \times 0.001728 = 0.276 \text{ L} = 276 \text{ ml}$

Quantities for 5% and 10% Cement Replacement by Bamboo Stem Ash:

For 5% Cement Replacement:

Cement = $553 \text{ g} - (5\% \text{ of } 553 \text{ g}) = 525 \text{ g}$

Bamboo Stem Ash = $5\% \text{ of } 553 \text{ g} = 28 \text{ g}$

Fine Aggregate = 829 g

Coarse Aggregate = 1658 g

Water = 276ml

For 10% Cement Replacement:

Cement = $553 \text{ g} - (10\% \text{ of } 553 \text{ g}) = 498 \text{ g}$

Bamboo Stem Ash = $10\% \text{ of } 553 \text{ g} = 55 \text{ g}$

Fine Aggregate = 829 g

Coarse Aggregate = 1658 g

Water = 276ml

Arrived Quantities:

Material	0% Replacement	5% BSA	10%BSA
Cement(g)	553	525	498
Bamboo Stem Ash(g)	0	28	55
Fine Aggregate(g)	829	829	829
Coarse Aggregate(g)	1658	1658	1658
Water(ml)	276	276	276

Table 3.1



III. TESTS DONE TO CONFIRM THE QUALITY OF MATERIALS:

3.1. Tests on fine aggregates:

In this project, manufactured sand (M-sand) was used as the fine aggregate, and it was in a saturated surface dry (SSD) condition during use. The following tests were conducted on the M-sand in accordance with IS: 2386 – 1968:

Sieve analysis

Density

Specific gravity

3.1.1.Sieve analysis on fine aggregate:

The experiment is conducted to determine and verify the gradation of fine aggregate, specifically manufactured sand (M-sand). M-sand is classified based on its gradation, and well-graded M-sand has the ability to form a dense, compact structure, leading to greater strength

IS sieve size(mm)	Weight retained(g)	% of weight retained	Cumulative % retained	% pass
4.75	94	4.75	4.7	95.3
2.36	158	7.6	12.6	87.4
1.18	708	35.4	48	52
0.6	812	40.6	88	11.4
0.3	180	9	97.6	2.4
0.15	4	0.2	99.6	0.4
0.075	2	0.1	99.7	0.3
pan	6	0.3	100	0

Table3.2

Density Test on Fine Aggregate (M-Sand):

This test is conducted to determine the bulk density of fine aggregate. Knowing the bulk density allows us to calculate the mass of aggregate needed to fill a unit volume container. Bulk density also gives an indication of the amount of voids present within the aggregate. The percentage of voids has a direct impact on the grading of the aggregate, which plays a crucial role in producing high-strength concrete. The percentage of voids is determined by comparing the bulk density in the loose and compacted states.

Volume of the cylinder used = $9.81 \times 10^{-3} \text{ m}^3$

Trial	Weight of compacted aggregate (kg)	Weight of loose aggregate (kg)
Trial I	17.36	16.12
Trial II	17.46	16.6
Average	17.41	16.36

Table 3.3

Tests on coarse aggregates

In this project, coarse aggregate was used in a saturated surface dry (SSD) condition. The properties of the coarse aggregate were evaluated to ensure its suitability for use in concrete. The following tests were conducted on the coarse aggregate in accordance with IS: 2386 – 1963:

Sieve analysis

Density (Bulk density in loose and compacted states)

Specific gravity



3.2.1.Sieve Analysis Test on Coarse Aggregate:

The sieve analysis of coarse aggregate is conducted to determine the average particle size, represented by an index number. This is done by measuring the cumulative percentage of material retained on each sieve. The cumulative retained values are summed, and subtracting this sum from 100 provides an indication of the fineness or grading of the coarse aggregate.

Is sieve size (mm)	Weight retained(g)	% of weight retained	Cumulative % retained	% pass
20	290	5.8	5.08	94.2
16	2768	55.36	61.16	38.84
12.5	1454	29.08	90.24	9.76
10	430	8.06	98.84	1.16
6.3	58	1.16	100	0
4.75	0	0	100	0
pan	0	0	100	0

Table 3.4

3.2.2.Density Test on Coarse Aggregate:

This test is conducted to determine the bulk density of coarse aggregate. Knowing the bulk density helps in calculating the mass of aggregate needed to fill a unit volume container. Bulk density also reflects the percentage of voids within the aggregate, which directly affects the overall grading and is crucial for producing high-strength concrete. The percentage of voids is determined by comparing the aggregate in its loose and compacted states. For coarse aggregate, a higher bulk density indicates fewer voids, meaning less space needs to be filled by cement paste. Therefore, bulk density is also influenced by the degree of packing of the particles

Trial	Weight of compacted aggregate (kg)	Weight of loose aggregate (kg)
Trial I	16.64	15.78
Trial II	16.45	15.67
Average	16.55	15.73

Table 3.5

S.No	Material	Specific Gravity
1	Fine Aggregate	2.65
2	Coarse Aggregate	2.8
3	Cement	3.14

Table 3.6

3.3.Specific Gravity Test on Materials:

Following were the test results of specific gravity of materials,

IV. TESTS ON CONCRETE

To evaluate the performance of concrete when cement is partially replaced with bamboo stem ash, two major tests were conducted: one on fresh concrete and another on hardened concrete.

The Slump Cone Test was performed to assess workability, while the Compressive Strength Test was carried out on concrete cubes at 7, 14, and 28 days to study the strength development. These tests were conducted for 0%, 5%, and 10% replacement levels of cement by bamboo stem ash.

% of Bamboo Ash Replacement	Observation	Slump Value (mm)	Workability
0% (Normal concrete)	High flow	80	Good
5%	Medium flow	70	Medium
10%	Low flow	60	Low

4.1. Test on Fresh Concrete:

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4.1.1. Slump Cone Test:

The Slump Cone Test measures the consistency and workability of fresh concrete. A standard cone (300 mm height, 200 mm bottom diameter, 100 mm top diameter) was used. The concrete was filled in three equal layers, each tamped 25 times. The slump value was measured as the vertical difference between the top of the cone and the top of the subsided concrete.



Fig 4.1

4.2. Test on Hardened Concrete:

4.2.1. Compressive Strength Test:

The Compressive Strength Test was carried out using a Compression Testing Machine (CTM) on 120 mm × 120 mm × 120 mm cubes after curing for 7, 14, and 28 days. The load at failure was recorded for each mix.

% of Bamboo Ash Replacement	7 Days Load (N/mm)	14 Days Load (N/mm)	28 Days Load (N/mm)
0% (Normal concrete)	23.5	29.4	33.6
5%	22.7	28.6	32.8
10%	21.5	27.2	31.3

Table 4.1

The below graph shows the variation in compressive strength of concrete at different curing ages (7, 14, and 28 days) for various percentages of bamboo ash replacement.

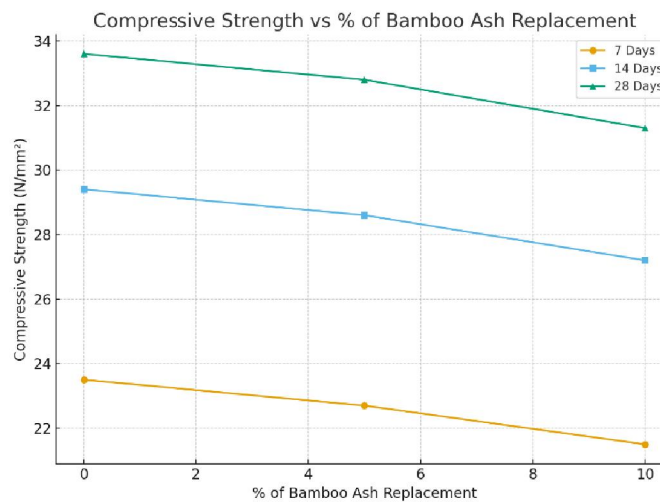


Fig 4.2

V. DISCUSSION AND LEARNINGS



The experimental study on partial replacement of cement with bamboo stem ash provided valuable insights into the behavior of both fresh and hardened concrete. From the slump cone test, it was observed that workability slightly decreased with an increase in bamboo ash content due to its finer particle size and higher water absorption capacity. This indicates that proper water adjustment may be necessary when using higher percentages of bamboo ash. The compressive strength test showed that the load-bearing capacity of concrete gradually decreased as the percentage of bamboo ash increased. The 5% replacement mix exhibited only a minor reduction in strength and still met the requirements for M20 grade concrete, while the 10% replacement mix showed a moderate decline. These results demonstrate that bamboo stem ash can be effectively used as a supplementary cementitious material up to 5% without compromising structural performance. Overall, the project highlighted the potential of bamboo ash as an eco-friendly, sustainable alternative to cement, reducing environmental impact and promoting the utilization of agricultural waste in construction.

VI. CONCLUSION

The experimental investigation on partial replacement of cement with bamboo stem ash in M20 grade concrete leads to the following conclusions:

1. **Workability:** The slump cone test showed that workability decreases slightly with increasing bamboo ash content due to its fine particle size and water absorption characteristics.
2. **Compressive Strength:** Concrete with 5% bamboo ash replacement exhibited only a minor reduction in compressive strength and still meets the requirements for M20 grade concrete. At 10% replacement, the strength decreased moderately.
3. **Optimal Replacement:** The study indicates that up to 5% replacement of cement with bamboo stem ash is suitable for maintaining structural performance while promoting sustainability.
4. **Sustainability:** Using bamboo stem ash as a partial cement replacement reduces cement consumption and helps utilize agricultural waste, contributing to environmentally friendly construction practices.

Overall Conclusion: Bamboo stem ash can be effectively used as a supplementary cementitious material in concrete up to 5%, providing a sustainable and eco-friendly alternative without significantly compromising strength and durability.

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