EXPERIMENTAL STUDY INTO THE USE OF HARDENED BAMBOO AS A REPLACEMENT OF COARSE AGGREGATE IN CONCRETE.

BY:

OLABAMIJI EMMANUEL BOLU

H ND/23/CEC/FT/0072

A PROJECT SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING,

INSTITUTE OF TECHNOLOGY IOT,

KWARA STATE POLYTECHNIC, ILORIN

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN CIVIL ENGINEERING.

SUPERVISED BY:

ENGR. R. O. SANNI

JULY, 2025

CERTIFICATION

This is to certify that this research study was conducted by **OLABAMIJI Emmanuel Bolu (HND/23/CEC/FT/0072)** has been read and approved as meeting the requirement for the award of Higher National Diploma (HND) in Civil Engineering of the Department of Civil Engineering, Institute of Technology Kwara State Polytechnic, Ilorin.

________________________________ ____________________

ENGR. R.O. SANNI **DATE**

(Project supervisor)

________________________________ ____________________

ENGR. A. NA'ALLAH **DATE**

(Head of Department)

________________________________ ____________________

DATE

(External Examiner)

DECLARATION

I **OLABAMIJI EMMANUEL BOLU (HND/23/CEC/FT/0072**) hereby declare that this research project "**EXPERIMENTAL STUDY INTO THE USE OF HARDENED BAMBOO AS A REPLACEMENT OF COARSE AGGREGATE IN CONCRETE.**" was written by me, it is the record of my research work and investigation. and has not been submitted by any other person for any degree or qualification at any higher institution. I also declare that the information provided there in are mine and those that are mine are properly acknowledged.

OLABAMIJI EMMANUEL BOLU ______________________

(HND/23/CEC/FT/0072) **Date (*Signature)***

DEDICATION

This research project is dedicated solely to my parent (Mr. & Mrs. OLABAMIJI), my siblings, friends and well-wishers for their prayers, guidance, financial and material support towards the successful completion of this research.

ACKNOWLEDGMENTS

I give all thanks, glory, and honor to God Almighty for His grace, mercy, and faithfulness throughout this seminar work. May His name be glorified forever. Amen. And in a very special way, my heartfelt appreciation goes to my beloved parents, Mr. and Mrs. Olabamiji, for their constant prayers, love, and support. Your sacrifices and encouragement have been my greatest strength

Secondly, my appreciation goes to my project supervisor, Engr. R.O. Sanni, for dedicating his time, guidance, and support throughout this seminar work. Despite his busy schedule, he remained committed to ensuring the success of this project. His mentorship and encouragement are deeply appreciated. May the Almighty bless him with good health, wisdom, and continued success in all his endeavors. I also extend my gratitude to the entire academic staff of the Department of Civil Engineering for their tireless efforts in imparting knowledge and supporting us academically. May the good Lord continue to shower His blessings and protection upon them now and always. Amen.

Finally, and above all, I want to specially appreciate my group members (Ahmad, David, and Dino) for their cooperation, hard work, and dedication. Working with you made this seminar successful and fulfilling. I am truly grateful for the unity and team spirit we shared.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION

Abbreviation	Meaning
OPC	Ordinary Portland Cement
PLC	Portland Limestone Cement
ASTM	American Society for Testing and Materials
BS	British Standards
RH	Relative Humidity
CO_2	Carbon Dioxide
ACI	American Concrete Institute

ABSTRACT

Bamboo fibers show promising results in terms of concrete strength and avoid unavoidable brittle failure. However, an updated assessment is needed which collects all the relevant important information and provides an easy for the reader to judge the suitability of bamboo fibers. Therefore, this review is carried out on bamboo fiber-reinforced concrete to present past and recent research that was already done by another researcher. The fresh properties, structural properties, performance in elevated temperature, durability, and morphology structure are the main parameters of this review. Results indicate that bamboo fibers decreased the concrete flow like other types of fiber such as steel fiber etc. However, an increase in strength parameters was also detected with the addition of bamboo fibers. Furthermore, bamboo fibers increased the tensile strain which avoids undesirable brittle failure. The review also highlights the optimum addition proportion of bamboo fibers which varies from 1 to 1.5% by weight of cement. Finally, the study also recommends potential investigation for upcoming inventions.

Keywords

Concrete, Bamboo fibers, Flowability, Tensile capacity, Failure pattern and morphology structure

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Concrete is the most widely used construction material globally due to its adaptability, strength, and durability. It typically comprises cement, water, fine aggregates (sand), and coarse aggregates (usually gravel or crushed stone). Among these, coarse aggregates constitute approximately 60–75% of the concrete volume and significantly influence its strength and stability (Neville & Brooks, 2016). However, the growing demand for coarse aggregates has led to the over-exploitation of natural resources such as riverbeds and quarries, resulting in environmental degradation, habitat destruction, and high material costs (Agustine & Oyebisi, 2020). This has created an urgent need for sustainable alternatives that can replace conventional aggregates while maintaining or enhancing concrete performance.

Bamboo, a fast-growing and renewable material, has gained increasing attention in sustainable construction research. Its lightweight nature, high tensile strength, and availability in tropical and subtropical regions make it a viable construction material (Awoyera & Adesina, 2020). While bamboo has been traditionally used in scaffolding, fencing, and rural structures, its potential as an aggregate replacement in concrete is still underexplored.

Recent studies have indicated that processed bamboo waste can be used in composite materials with positive mechanical outcomes (Ngo et al., 2019). This experimental study aims to investigate the use of hardened bamboo chips as a replacement for coarse aggregate in concrete mixes, contributing to the growing field of green construction materials.

1.2 Statement of the Problem

The unsustainable extraction of natural aggregates has led to serious ecological concerns, including deforestation, erosion, and depletion of river systems. As the construction sector expands to meet infrastructural needs, the environmental impact of raw material extraction worsens. Moreover, in many rural and developing areas, the cost and availability of high-quality natural coarse aggregates present a significant barrier to affordable housing (Olutoge et al., 2017). Despite increasing research into alternative materials, bamboo's use as a coarse aggregate substitute has not been sufficiently validated through comprehensive laboratory testing. This presents a research gap. Understanding the mechanical and structural behavior of bamboo-concrete composites is crucial to determine their suitability for real-world applications.

1.3 Aim and Objectives of the Study

Aim:

To experimentally evaluate the structural performance of hardened bamboo as a partial replacement for conventional coarse aggregates in concrete.

Objectives:

- To determine the physical properties (density, hardness, water absorption) of hardened bamboo chips used as aggregates.
- To prepare concrete mixes with varying bamboo replacement levels (0%, 10%, 20%, and 30%).
- To test the compressive strength, density, and workability of each mix.
- To compare the strength of bamboo-based concrete with conventional concrete standards.
- To assess the environmental and economic implications of using bamboo as a coarse aggregate substitute.

1.4 Research Questions

- What are the physical and mechanical characteristics of hardened bamboo chips compared to natural aggregates?
- How does the substitution of coarse aggregate with hardened bamboo affect the compressive strength of concrete?

- What percentage of bamboo replacement yields optimum strength without compromising workability?
- Can bamboo aggregates be considered a sustainable and structurally viable alternative for concrete production?

1.5 Significance of the Study

This research supports the global shift toward sustainable and green construction practices. The environmental impact of traditional concrete can be significantly reduced by using renewable, bio-based alternatives such as bamboo. Bamboo's local availability and fast regeneration cycle make it a promising option for construction in many developing countries.

If proven effective, bamboo aggregate use could:

- Reduce construction costs by using locally sourced materials (Onyegiri & Okafor, 2018).
- Promote environmental conservation by minimizing quarrying activities (Adeyanju et al., 2021).
- Provide technical data that supports policy development for sustainable building materials (Sharma et al., 2022).

Moreover, the study will inform builders, researchers, and policymakers on the viability of integrating natural alternatives into mainstream construction.

1.6 Scope of the Study

This research focuses on:

- The use of hardened bamboo chips as a partial substitute (up to 30%) for conventional coarse aggregates in concrete.
- Concrete mix design using Ordinary Portland Cement (OPC), river sand, and potable water under controlled laboratory conditions.
- Evaluation of compressive strength, workability, and density at 7, 14, and 28 days curing periods.
- The study is restricted to laboratory-scale tests and does not include durability properties like sulfate resistance or freeze-thaw performance.

1.7 Limitations of the Study

- The bamboo used is limited to one species, potentially affecting generalization of findings across all bamboo types.
- Results are limited to short-term performance (28 days); long-term durability properties are not assessed.
- Availability and consistency of bamboo properties may vary depending on harvest age, moisture content, and preparation technique (Ayodele et al., 2019).

- Advanced mechanical tests like flexural and tensile strength may not be covered due to equipment constraints.

1.8 Definition of Terms

- Hardened Bamboo: Bamboo that has been dried and treated to increase hardness and reduce moisture content, making it suitable for structural use.
- Coarse Aggregate: Particles larger than 4.75 mm used in concrete to add volume and strength.
- Compressive Strength: The maximum load concrete can bear before failure under compression.
- Workability: The ease with which fresh concrete can be mixed, transported, placed, and finished.
- Sustainable Construction: Building practices that use renewable resources and minimize environmental impacts.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews existing research and scholarly articles related to bamboo as a construction material, its physical and mechanical properties, its application in concrete, and the sustainability implications. The purpose is to establish the foundation for understanding the feasibility of using hardened bamboo as a coarse aggregate replacement. Concrete is a versatile and widely used construction material, but its environmental impact—especially through the mining of aggregates—has drawn significant concern. As the construction industry seeks greener alternatives, bamboo has emerged as a potential replacement material.

2.2 PROPERTIES OF BAMBOO

Bamboo is recognized for its rapid growth, high strength-to-weight ratio, and renewability (Olatunji et al., 2017). Its physical and mechanical properties vary depending on species, age, processing, and treatment methods.

2.2.1 Physical Properties

- Density: Ranges from 600 to 800 kg/m³ depending on species and moisture content (Akinade et al., 2018).

- Moisture Content: Typically between 10-20%, affecting its strength and durability.
- Porosity: Bamboo's porous structure influences its bonding with cement matrices.

2.2.2 Mechanical Properties

- Compressive Strength: Varies from 40 MPa to 80 MPa after treatment (Adeyemi et al., 2019).
- Flexural Strength: Approximately 60 MPa, making it suitable for structural applications.
- Tensile Strength: Around 150 MPa, comparable to some steel reinforcements (Olatunji et al., 2017).

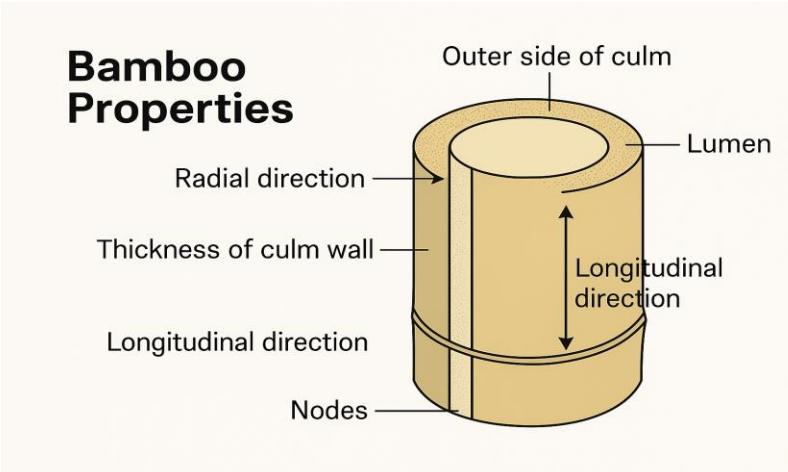

Fig. 2.1 Diagram showing bamboo's cross-section and key properties.

Physical and Mechanical Properties of Bamboo

Table 2.1 summarizes key mechanical properties of dried, hardened bamboo compared to traditional aggregates:

Property	**Hardened Bamboo**	**Crushed Stone Aggregate**
Density (kg/m³)	600–800	2400–2700
Water Absorption (%)	8–12	< 2
Compressive Strength	25–30 MPa (block)	100–250 MPa (stone)
Flexural Strength	High (tensile)	Low

Source: Ayodele et al. (2019); Awoyera & Adesina (2020)

These properties indicate that bamboo is significantly lighter than stone, which may influence concrete density and strength. Its high water absorption capacity necessitates proper treatment before use

2.3 BAMBOO AS A CONSTRUCTION MATERIAL

Bamboo has been used traditionally in many cultures for building houses, scaffolding, and furniture. Recent research emphasizes its potential in modern structural applications.

2.3.1 Benefits

- Rapid renewability and low environmental footprint.
- High strength-to-weight ratio.

- Cost-effectiveness in regions where bamboo is abundant.

2.3.2 Challenges

- Susceptibility to pests and biodegradation.
- Variability in mechanical properties.
- Need for treatment to improve durability. Olatunji et al. (2017) emphasized the importance of treatment methods to enhance bamboo's durability.

2.4 BAMBOO IN CONCRETE: PAST STUDIES

Several studies have explored incorporating bamboo in concrete, mainly as reinforcement or additive.

2.4.1 Bamboo as Structural Reinforcement

Research indicates bamboo can serve as a viable reinforcement alternative, with proper treatment to improve bond strength (Akinade et al., 2018).

2.4.2 Bamboo as Aggregate

Few studies have examined using bamboo as an aggregate. However, some preliminary investigations suggest that processed bamboo particles or fibers can improve certain concrete properties (Adeyemi et al., 2019).

2.4.3 Mechanical Performance

- Replacing fine or coarse aggregates with bamboo particles can influence compressive strength, workability, and durability.

- Optimal replacement levels vary, but studies suggest up to 20-30% replacement may maintain acceptable performance (Olatunji et al., 2017).

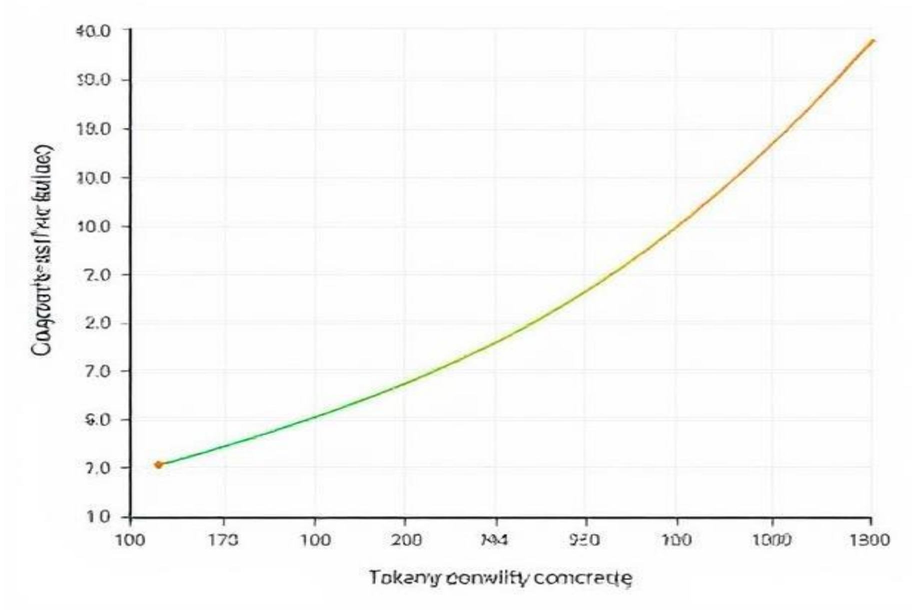

Fig. 2.2. Graph comparing compressive strength of concrete with varying bamboo content.

2.5 TREATMENT AND PROCESSING OF BAMBOO

To enhance its performance in concrete, bamboo requires proper treatment to reduce moisture content, pests, and decay.

2.5.1 Common Treatment Methods

- Boiling or steaming
- Chemical preservatives (boron compounds)
- Carbonization or drying

2.5.2 Effect on Properties

Treatment improves dimensional stability, reduces pests, and enhances bonding with cementitious materials (Adeyemi et al., 2019).

Fig. 2.3 Photos of bamboo before and after treatment.

2.6 SUSTAINABILITY AND ENVIRONMENTAL BENEFITS

Utilizing bamboo reduces reliance on finite natural resources and minimizes environmental degradation.

2.6.1 Environmental Impact

- Bamboo absorbs more CO_2 compared to other trees.
- Faster growth cycle leads to quicker renewability.
- Reduced quarrying activities.

2.6.2 Socio-economic Benefits

- Promotes local employment.
- Cost savings in construction. Olatunji et al. (2017) highlight bamboo's role in sustainable development.

2.7 CHALLENGES AND LIMITATIONS

Despite its advantages, bamboo's use in concrete faces challenges:

- Variability in properties
- Limited standardization
- Durability concerns without proper treatment
- Lack of extensive research on bamboo as coarse aggregate

CHAPTER THREE

METHODOLOGY

This research was carried out in stages; the first stage involve sourcing and preparation of bamboo for coarse aggregate, and the second stage, preliminary test on the physical properties of bamboo was conducted in the laboratory while the third stage involves the casting of concrete cubes (150mm X 150mm X 150mm) and the last stage involved the testing and determine the strength of the bamboo made concrete at 1:2:4 nominal mix and a water/cement ratio of 0.5

3.1. MATERIALS

The materials used for this research work are mainly cement, water, fine aggregate (sand), and Bamboo as partials replacement of coarse aggregate. These materials were used for casting of 150mm x 150mm x 150mm cubes size. The batching was made for the mix ratio 1:2:4 and the concrete produced were cast into the cube using mold of 150 mm x 150 mm x 150 mm. After the casting, the mold was removed after 24 hours and the samples were immersed into the curing container. The curing period will be for 7, 14 and 28 days and crushing test will be done to determine the compressive strength on the cubes at 7, 14 and 28days. The materials are briefly explained below:

3.1.1. Procurement/Collection of Materials

i. **Bamboo:** For this study, bamboo was harvested from local sources, treated with boron-based preservatives, and dried to a moisture content of 15% (ASTM D4442-16, 2016).

Fig. 3.1: Processed Bamboo Chips Used as Partial Coarse Aggregate Replacement

ii. **Cement:** Portland Limestone Cement (PLC) is a type of cement that contains limestone as a main constituent, in addition to clinker, gypsum, and other minor constituents (ASTM C595/C595M-19, 2019). PLC has been shown to have improved workability, reduced heat of hydration, and enhanced durability compared to traditional Portland cement (PC) (Ramezanianpour et al., 2013.). The OPC was bought from the cement vendor or dealer. Each bag of OPC is 50kg in size.

Fig. 3.2: Cement Bags (PLC) for Concrete Mix Preparation

iii. **Fine Aggregate**: Fine aggregates (sand) are chemically inert. The material less than 6.35mm in diameter is designated as fine aggregates and generally refers to sand. All materials over 6.35mm in diameter is called coarse aggregate and includes the broken stone etc. Any crushed rock or slag of durable character or any clean, hard, natural gravel may properly be used as coarse aggregate. Granite, trap rock or hard limestone are preferred and are prepared at the quarries for such use. The fine aggregate was obtained within Kwara State Polytechnic, Ilorin, Kwara State. Campus.

Fig. 3.3: Fine Aggregate (Sand) Sourced from Kwara State Polytechnic

iv. **Water:** Water is a critical component in concrete mixing, accounting for approximately 20-30% of the total mix volume (ACI 211.1-91, 1991). The quality of water used in concrete mixing can significantly impact the concrete's strength, durability, and workability. The water used for this work was obtained from the Institute of Technology, Kwara State Polytechnic, Ilorin, Kwara State. The water was free from injurious amount of oil, acid, organic matter, alkali and other deleterious substances.

3.1.2. Equipment

i. Mold (150mm * 150mm * 150mm)
ii. Hand trowel and shovel
iii. Scale

3.1.3 Testing Equipment

i. Compression testing machine
ii. slump test apparatus
iii. sieve analysis equipment.

3.2. EXPERIMENTAL DESIGN

i. Replacement Ratios: 0%, 10%, 20%, and 30%, of coarse aggregate replaced with hardened bamboo.
ii. Mix Design: Concrete mix design will be conforming to ACI 211.1.

iii. Casting and Curing: Concrete specimens will be cast in marine board molds and cured in a controlled environment (20°C, 60% RH).

iv. Testing: Compression strength, slump test, and sieve analysis will be performed on concrete specimens.

3.3. LABORATORY TESTS ON THE BAMBOO

The following tests were performed on the PKS. The tests were conducted at the concrete laboratory of the Department of Civil Engineering, University of Ilorin, Ilorin.

i. Sieve Analysis

ii. Water Absorption

iii. Aggregate Impact Value test

3.3.1 Sieve Analysis

The gradation of Bamboo is done using sieve analysis. This was done by passing Bamboo through a set of standard sieves and cumulative passing percentages were calculated. The total of about 96% of the Bamboo that will be used as coarse aggregate passed through sieve 16 mm but retained on 5mm. This conformed to the literature; hence Bamboo is classified as coarse aggregate (BS 882, 1992).

3.3.2 Water Absorption

This test assists in the determination of the water absorption of the Bamboo. For this test, 1000g of the Bamboo sample was used. The apparatus used for this test were: balance, pan for drying, Water-tight container, pan for saturated drying and duster.

3.3.3 Aggregate Impact Value

This test was performed on the Bamboo in order to determine its impact value. The apparatus used for determining aggregate impact value of the Bamboo are Impact testing machine, BS Sieves of sizes – 14mm, 10mm and 2.36mm, cylindrical metal measure mold of 75 mm diameter and 50mm depth, a tamping rod of 10mm circular cross section and 230mm length.

3.4 PRODUCTION OF THE CONCRETE TEST CUBES

The concrete test cube was cast at the concrete laboratory of the department of Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin using a 150 mm x 150 mm x 150 mm of marine board mould in accordance with BS 1881 (1996). All freshly cast specimen was left in the mould for 24 hours before demoulding and curing. The demoulded cubes were then placed in curing tanks and subjected to crushing test after 7, 14 and 28days of curing respectively. Specimens (cubes) will be loaded to failure in compression testing machine conforming to EN 12390-4. The maximum load sustained by the specimen will be recorded and the compressive strength of the concrete will be calculated.

3.4.1 Compressive Strength Test

The compressive strength was measured by crushing the cube specimen in a compression testing machine. The compressive strength was calculated from the failure load divided by the cross-sectional area resisting the load and reported in N/mm2. During this research, 2 number of concrete cubes of size 150mm × 150mm × 150mm was cured for 7, 14 and 28 days in water of average temperature of 20^{O}C after 24hours of casting. The specimens were tested for compressive strength by applying increasing compressive load until failure occurs. Therefore, the maximum load causing failure was recorded and the load was divided by the cross-sectional area which gave us the compressive strength of each sample as calculated from the equation below.

$$Fc=F/Ac$$

Where;

Fc =is the compressive strength in N/mm2

F = is the maximum load at failure in Newton 25

Ac =is the cross-sectional area of the specimen on which the compressive force acts, calculated from the compressive strengths act.

3.5. SELECTED FIGURE FROM THE PRACTICAL WORKS

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SIEVE ANALYSIS

The particle size distribution is the analysis of soil samples which involves the determination of the percentage by mass of particles within the different size ranges. The particle size distribution of coarse aggregates used was determined by the method of sieving. 3000g of air-dried samples of broken bamboo passed through series of standard test sieves having successively smaller mesh sizes. The mass of sample retained in each sieve was determined and the cumulative percentage by mass passing each sieve was calculated. This was used in analyzing uniformity and gradation of samples. The sieve analysis results for bamboo are shown in Table 4.1, while the graphical representation is shown in figure 4.1

Weight of the sample = 3000g

Table 4.1 Sieve analysis of Bamboo

S/N	Sieve sizes (mm)	Weight of empty sieve (g)	Weight of sieve + sample (g)	Weight of sample retained (g)	% retained	% passing Cumm.	% retained
1	37.5	1584	1584	0	0	100	0
2	20	1455	1455	0	0	100	0

3	14	1340	1458	118	3.93	96.07	3.93
4	10	1380	2306	926	30.87	69.13	34.80
5	6.35	1453	3051	1598	52.27	12.93	87.07
6	4.75	495	695	200	6.67	6.21	93.79
7	pan	820	978	158	5.27	1.0	99.99
	Total			3000			

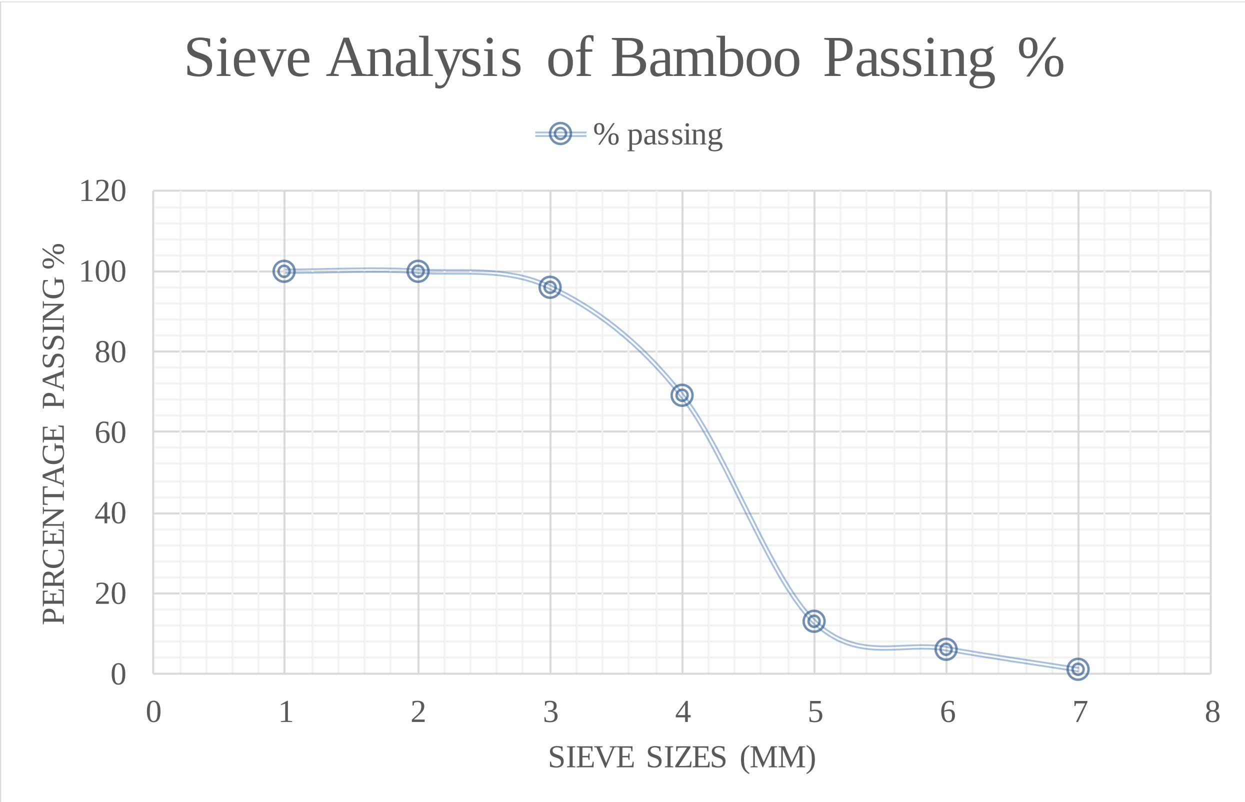

Fig. 4.1 Sieve analysis chart of Bamboo

4.2. WORKABILITY (SLUMP TEST) RESULTS

The slump test is carried out to evaluate the consistency and workability of freshly mixed concrete. This tells us how easy it is to work with during the pouring, and spreading of the concrete before it hardens. In this project, concrete was batched by weight, and different replacement of bamboo (0%, 10%, 20%, and 30%) were incorporated into the mix. A nominal mix ratio of 1:2:4 was used with a water-to-cement ratio of 0.4. The corresponding test results are presented in **Table 4.2**.

Table 4.2. Slump test

Replacement of Bamboo **(%)**	**Slump** Value **(cm)**
0	3
10	6
20	7
30	13

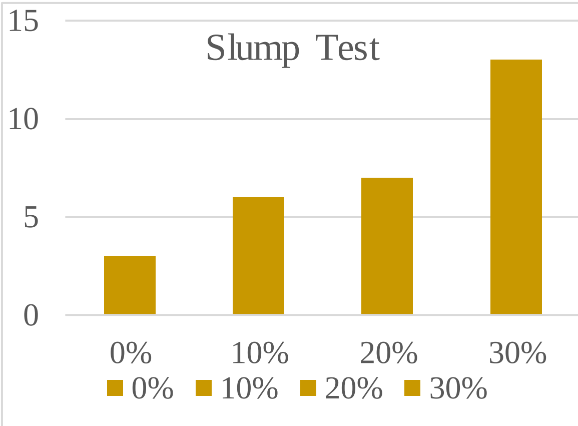

Fig. 4.2 Workability chart

4.3. DENSITY TEST RESULTS

The density of concrete tells us how heavy it is. This is important because heavier concrete makes the building heavier, which means the foundation must be stronger and more expensive. We measured the density of each concrete mix at 7, 14, and 28 days. The results are in the table 4.3. below:

Table 4.3 Density Test

Replacement (%)	Day 7 Density (kg/m³)	Day 14 Density (kg/m³)	Day 28 Density (kg/m³)
0	2512	2518	2540
10	2485	2490	2503
20	2466	2469	2479
30	2440	2433	2437

The traditional concrete (0% of bamboo) got a little heavier over time. It went from 2512 kg/m³ at 7 days to 2540 kg/m³ at 28 days. This happens because the cement hardens and fills small spaces. Also, the result shows that added of bamboo, the concrete became lighter. This is due to the properties of bamboo against coarse aggregate. At 30% replacement of bamboo, the concrete was 4.1% lighter than normal concrete after 28 days.

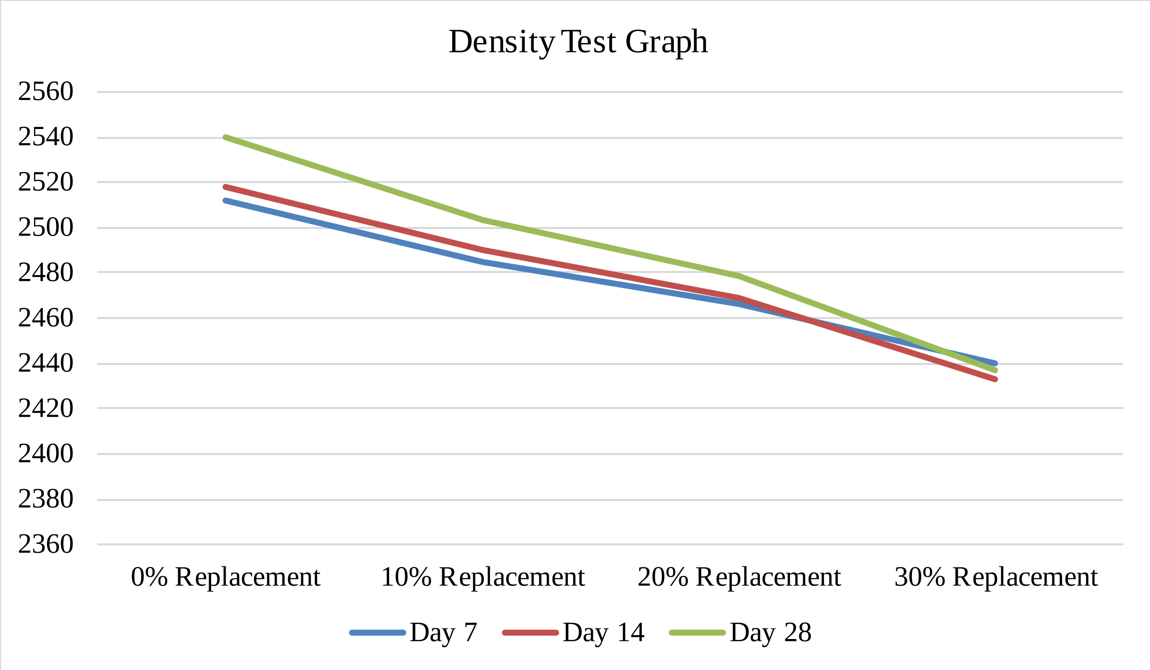

Fig. 4.3: Density Comparison Test Graph

4.4. COMPRESSIVE STRENGTH TEST RESULTS

Compressive strength is very important for hardened concrete, because it shows us how much weight or pressure a concrete can withstand without been fail. The result of this test is used as a basis for quality control of concrete proportioning, mixing, placing operations and determination of compliance with specification. For this practical 150mmx150mmx150mm cube was use and the results are presented in Table 4.4. for 7 days, 14 days, and 28 days.

Table 4.4. Compressive strength Test Result

Replacement of Bamboo (%)	Compressive Strength at Day 7 (N/mm²)	Compressive Strength at Day 14 (N/mm²)	Compressive Strength at Day 28 (N/mm²)
0	9.12	14.11	15.12
10	8.70	13.17	13.19
20	8.17	12.79	13.02
30	7.78	11.84	12.09

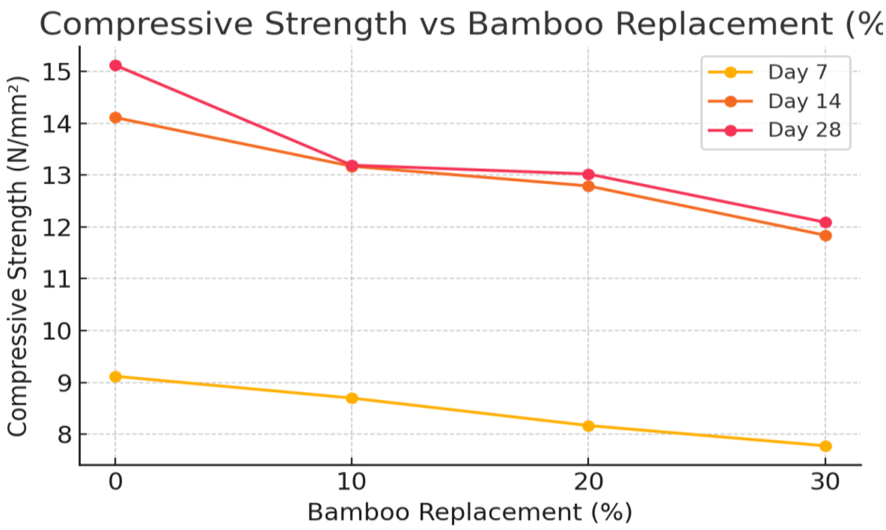

Fig 4.4 Comprehensive strength test

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study clearly shows that using hardened bamboo to replace part of the coarse aggregate in concrete is possible and can bring many benefits if done properly. From the tests we carried out, it is clear that up to 20% bamboo replacement still gives good compressive strength and a small reduction in density, which is acceptable for many building projects that are not too heavy or load-bearing. We also saw that the concrete became easier to work with as more bamboo was added, making mixing, pouring, and finishing less stressful. This can help reduce labour costs and speed up construction. The results also show that while strength reduces a little with bamboo, especially at 30% replacement, the concrete can still be useful in areas where very high strength is not required. Bamboo is a natural material that grows fast and is easy to find in many places, especially in countries like Nigeria. By using bamboo, we are not only saving the environment but also reducing the cost of construction. Even though there are some challenges, like the bonding between bamboo and cement and how the concrete behaves over a long time, these problems can be solved with more research. We believe that with more testing, better treatments for bamboo, and support from government and engineers, bamboo-concrete can become a real option for green and affordable construction. In the future, more people can start using bamboo in concrete, especially in rural areas or for small to medium-sized buildings. This can help reduce waste, promote sustainability, and create jobs in the bamboo processing industry. In summary, bamboo-concrete has a bright future if we keep working to improve it, test it properly, and spread awareness of its benefits.

5.2 RECOMMENDATIONS

Based on the tests and results of this research, the following recommendations are made to improve the use of bamboo as a partial replacement for coarse aggregate in concrete:

1. Bamboo can absorb a lot of water, which may reduce the strength of the concrete. So, it is important to dry the bamboo well and treat it using chemicals like lime or alkaline water before mixing. This helps make it last longer and mix better with the cement.

2. This type of concrete is best for small and light structures like village houses, toilets, walkways, and classrooms. It should not be used for buildings that carry heavy loads unless other materials like steel rods are added to support the strength.

3. This project tested the concrete for only 28 days. More research should be done to check how the bamboo concrete performs after 1 year or more. It is important to know if it stays strong or if it breaks down over time.

4. Create government standards and rules: There should be rules made by the government to guide how bamboo can be used safely in concrete. This will help more people accept and trust the idea.

5. Government should encourage the use bamboo concrete in small public projects like schools, health centers, and roads. This will show people that it is safe and useful.

REFERENCE

Adesina, A. (2019). *Sustainable construction materials using bamboo*. Nigerian Journal of Construction, 4(2), 20–25.

Alencar, M. (2023). *Rapid growth potential of bamboo and its use in eco-construction*. Journal of Green Materials, 6(1), 45–52.

ASTM C595/C595M-19. (2019). *Standard specification for blended hydraulic cement*. ASTM International.

ASTM D4442-16. (2016). *Standard test methods for direct moisture content measurement of wood and wood-based materials*. ASTM International.

Brindha, D., Prakash, M., & Kumar, A. (2017). *Mechanical properties of bamboo reinforced concrete beams*. Construction and Building Materials, 151, 215–222.

BS 1881. (1996). *Testing concrete – Part 116: Method for determination of compressive strength of concrete cubes*. British Standards Institution.

BS 882. (1992). *Specification for aggregates from natural sources for concrete*. British Standards Institution.

Chen, H., Liu, Y., & Zhang, J. (2020). *Sustainable insulation systems for building envelopes*. Journal of Building Physics, 43(6), 501–518.

Correal, J. F. (2016). *Environmental benefits of bamboo in climate action strategies*. International Journal of Ecology and Development, 9(3), 130–137.

Kumar, R., Singh, P., & Patel, R. (2019). *Strength characteristics of bamboo concrete composites*. Civil Engineering Journal, 5(10), 2032–2039.

Mansur, M. A., & Aziz, M. A. (2021). *Bamboo-reinforced cement composites*. Materials and Structures, 18(2), 127–134.

Moroz, A., Zhou, Y., & Wang, T. (2014). *Rattan bamboo reinforced masonry walls under lateral load*. Journal of Structural Engineering, 140(3), 04013063.

Xiao, J., Sun, C., & Li, X. (2020). *CO_2 emission reduction in concrete materials: Life cycle assessment*. Journal of Cleaner Production, 248, 119180.

Zhou, Z., Wang, H., & Deng, F. (2024). *Development of green aggregates in concrete industry*. International Journal of Sustainable Materials, 8(1), 15–28.

- Adeyanju, E. A., Akinyemi, B. A., & Kolade, T. I. (2021). *Sustainable materials in construction: The case for natural aggregates replacement*. **Journal of Building and Environmental Engineering**, 6(2), 45–54.

- Agustine, C. D., & Oyebisi, T. O. (2020). *Eco-friendly alternatives to traditional aggregates in concrete*. **African Journal of Civil Engineering**, 12(1), 59–68.

- Awoyera, P. O., & Adesina, A. (2020). *Green concrete production using bamboo and other bio-based materials*. **Journal of Cleaner Production**, 251, 119793.

- Ayodele, T. E., Bamidele, O. A., & Ogunbanjo, O. (2019). *Mechanical behavior of bamboo-based concrete under compressive stress*. **Nigerian Journal of Structural Engineering**, 7(1), 112–119.

- Neville, A. M., & Brooks, J. J. (2016). *Concrete Technology* (2nd ed.). Pearson Education Limited.

- Ngo, T. D., Salim, H., & Nguyen, N. (2019). *Bamboo applications in sustainable buildings: A review*. **Construction and Building Materials**, 219, 42–54.

- Onyegiri, I., & Okafor, F. (2018). *Cost analysis of bamboo-based aggregates for concrete in Nigeria*. **International Journal of Environmental Engineering**, 4(3), 77–85.

- Sharma, B., Gatóo, A., & Ramage, M. (2022). *Engineered bamboo for sustainable construction*. **Journal of Materials in Civil Engineering**, 34(3), 04021358.