KWARA STATE POLYTECHNIC, ILORIN.

INSTITUTE OF TECHNOLOGY

FLEXTURAL STRENGTH OF BAMBOO REINFORCED CONCREATE SLAB

BY

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SUBMITTED TO

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CERTIFICATION

This is to certify that this research study was conducted by OGUNLEYE MATHEW GBENGA (ND/23/CEC/PT/0119) and had been read and approved as meeting the requirement for the award of National Diploma (ND) in Civil Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin.

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DEDICATION

I dedicate this project to my parents Mr & Mrs Azeez and my gaurdiance, Mr Azeez Abiodun and to everyone who has supported and inspired me throughout this journey. To my family and friends, thank you for your unwavering encouragement and belief in me. To my mentors and teachers, your guidance has been invaluable. This work is a reflection of the collective effort and support of all those who have walked alongside me.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to Almighty God & my beloved parents (Mr & Mrs Azeez) and to everyone who supported me throughout the completion of this project.

First and foremost, I thank my project supervisor, [Engr, Saheed Abdulhameed], for his valuable guidance, encouragement, and insightful feedback. His expertise and support were instrumental in shaping this work.

I also appreciate the assistance and cooperation of my team members and colleagues, who contributed their time and ideas, making this project a collaborative success.

Finally, I am grateful to my family and friends for their continuous motivation and understanding during this endeavor.

ABSTRACT

This project investigates the flexural strength of concrete slabs reinforced with bamboo as an alternative to conventional steel reinforcement. Bamboo, being a sustainable and eco-friendly material, offers potential benefits in reducing construction costs and environmental impact. The study involves designing and casting concrete slabs with varying bamboo reinforcement configurations, followed by systematic flexural testing to evaluate their load-bearing capacity and failure modes. Results indicate that bamboo-reinforced concrete slabs exhibit promising flexural strength characteristics, suggesting their viability for low-cost and sustainable construction applications. This research contributes to expanding the use of renewable materials in structural engineering while promoting green building practices.

CHAPTER ONE

1.0 Introduction

1.1 Background

Concrete slabs are fundamental components in modern construction, primarily reinforced with steel to handle tensile stresses. However, due to rising costs and environmental concerns associated with steel production, alternative reinforcement materials are gaining attention. Timber, a renewable and lightweight material, presents a potential reinforcement alternative, especially when sustainably sourced and treated for structural applications.Composite structural systems combine two or more materials with different mechanical properties to achieve performance benefits that exceed those of individual components. In structural engineering, the most common composite systems include steel-reinforced concrete and timber-concrete composites (TCC). These systems are designed to exploit the compressive strength of concrete and the tensile strength of another material — typically steel. However, with rising awareness of environmental sustainability and circular economy principles, alternative composite systems involving timber as a reinforcing or load-sharing component are gaining interest.

Timber has been used as a building material for thousands of years due to its natural abundance, workability, and renewable nature. It possesses a high strength-to-weight ratio and is readily available in many regions of the world. In modern engineering, timber is increasingly used in the form of engineered wood products such Glued Laminated Timber (Glulam), Laminated Veneer Lumber (LVL) and Cross-Laminated Timber (CLT). These engineered products overcome the limitations of natural wood—such as anisotropy, dimensional instability, and strength variability—by providing consistent performance and improved mechanical properties. Reinforced concrete is one of the most widely used construction materials worldwide due to its versatility, strength, and relative economy. Traditionally, reinforcement is achieved with steel bars (rebar), which provide the necessary tensile resistance that concrete lacks. However, steel has several drawbacks such as high carbon footprint due to energy-intensive manufacturing, susceptibility to corrosion in aggressive environments, heavy weight, increasing transportation and structural loads and rising costs of raw materials. These challenges have led researchers and engineers to explore alternative reinforcement materials, including fiber-reinforced polymers (FRPs), bamboo, and timber.

In consequence of the consumers choosing industrialized products, among other effects, activities are suppressed in rural areas or even in small towns, and renewable materials are wasted and causing permanent pollution. In this sense, it becomes obvious that ecological materials satisfy such fundamental requirements, making use of agricultural by-products such as rice husk, coconut fibres, sisal and bamboo and therefore minimizing energy consumption, conserving non-renewable natural resources, reducing pollution and maintaining a healthy environment. Bamboo is one material, which will have a tremendous economical advantage, as it reaches its full growth in just a few months and reaches its maximum mechanical resistance in just few years. Moreover, it exists in abundance in tropical and subtropical regions of the globe. The energy necessary to produce 1m3 per unit stress projected in practice for materials commonly used in civil construction, such as steel or concrete, has been compared with that of bamboo. It was found that for steel it is necessary to spend 50 times more energy than for bamboo . The tensile strength of bamboo is relatively high and can reach 370MPa. This makes bamboo an attractive alternative to steel in tensile loading applications. This is due to the fact that the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel.

The development of timber-reinforced concrete slabs is rooted in the pursuit of sustainable, efficient, and locally adaptable structural systems. By combining concrete's compressive strength with timber's renewable tensile performance, TRC slabs offer a compelling alternative for modern construction. However, successful implementation depends on addressing technical challenges related to bond behavior, durability, moisture effects, and standardization. This background establishes the foundation for further investigation into the performance, feasibility, and application of timber-reinforced concrete slab system.

1.2 Objectives

1. To evaluate the physical and mechanical properties of the bamboo material through review.
2. To evaluate the structural performance of timber-reinforced concrete slabs.
3. To compare mechanical performance against steel-reinforced slabs.

1.3 Scope

The study focuses on slabs using timber as primary reinforcement.Hardwood such as Teak timber is considered as reinforcement in concrete. The specimen preparation were done in accordance with BS 8110 for reinforcement preparation.

CHAPTER TWO

2.0 Literature Review

2.1 Natureanddescriptionofwood's structure

Wood is generallycomposed of cells parallel to each other along the trunk of a tree which is of primary interest to engineers as it is from the trunk that structural timber is manufactured. Wood cells possess cavities inside and are elongated and spindle-shaped. Figure 2.1 shows a cross-section of a trunk pointing out its main features in growing trees. Some basic information and perceptions of wood are prerequisites to understanding the behavior and the limitations of timber.

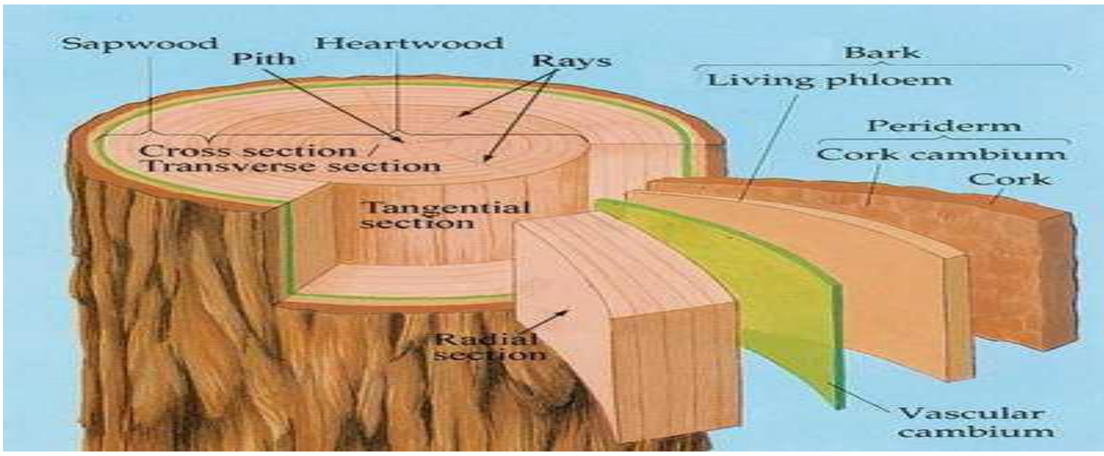


Figure2.1:Cross-sectionofatrunk (Brostowetal.,2010)

In most trunks of trees, the first principal part to notice is the sapwood which is the outer, pale-coloured wood, lighter region close to the cambium that has three main functions in a tree:from the support to the conduction and the storage function. Furthermore, when the cells are dead, they convey water and minerals from the soil. Followed by the heartwood in the second instance which is the inner part of the wood that is mostly darker because of the resins and gums contained inside the cells but in contrast with the sapwood, the heartwood provides the main structural support for the trees. Meanwhile, it does not possess any living cells, water conductsorstores andis notessentialinthegrowingprocess andthesurvivalofthetrees (Forest Products Laboratory, 1966). Another important part is the bark which shelters the interior of the trunk of the tree. The wood cells are produced by a layer of cells called the cambium that can onlybe seen using the microscope and inside all the tissues present at the center of the tree are referred to as xylem while those outside are the bark including the phloem that transport energy sources made by the plant and the cork layers. The ray and axial parenchyma cells, when initially produced by the cambium, are alive but they lose their cell contents and become hollow, microscopic tubes with lignified walls at the moment they become functioning, water-conducting cells, referred to as tracheids and vessels (Bamber, 1964).

2.1.1 Differenttypesofwood

In a living tree from which h timber comes, the two main types of tree are softwood and hardwood which should not be mixed up with the hardness or softness of the wood itself but frequently, hardwood trees are denser than softwood ones though (Ragland, 2010).

Softwoods are woods from gymnosperm coniferous trees, evergreen with vertical cells called tracheid of about 3 mm long and roughly 30 μm wide sometimes referred to as non-pored wood such as Scots Pine which is the most world widely used softwood. Generally, softwoods provide longer trunks and grow faster in line with Ragland, (2010). These cells have an open channel and thin cell walls and are used for support and conduction while the storage cells are found in the radial direction. The water-conducting cells known as tracheid in softwood are taper in shape.

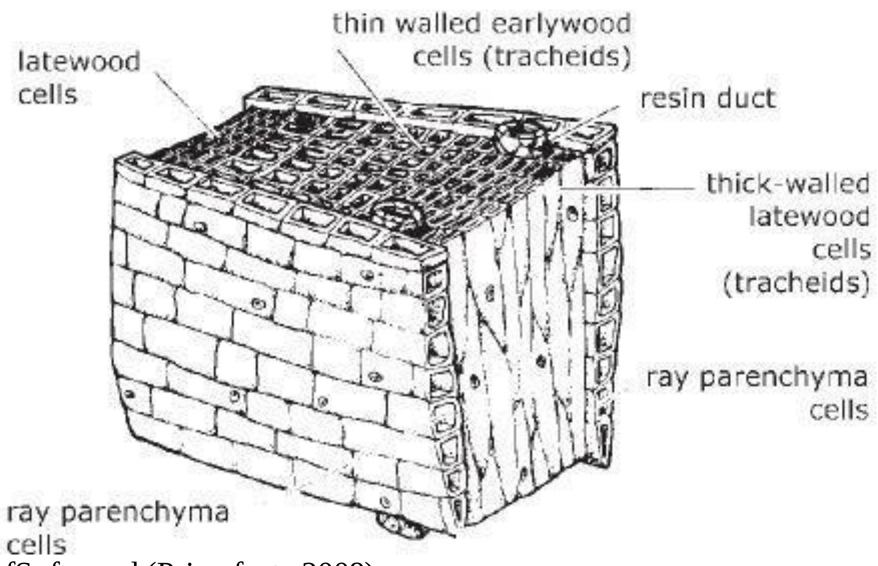


Figure2.2:AsectionofSoftwood (Primefacts,2008)

Hardwoods are broad-leaved trees from dicot angiosperm or trees with enclosed seeds containing pores ranging in size and shape allowing water to travel from the roots to nourish the wood (Armstrong, 2017). They are made up of two distinct types of cells: the vessels that can usually be seen with the naked eye and the fiber cells that impart strength in the broad-leaved trees. They are reproduced by flowers with vertical cells of 1 to 2 mm long and 15 µm wide. Thesecells arethick-walledwith a confiningcentral channel, inappropriate for conduction, used only to support and so, the tree needs vessels for this purpose. Vessels are either open-ended xylem or phloem of 0.2 to 1.2 mm long, stacked verticallyto form tubes of less than 0.5 mm in diameter (Primefacts, 2008). It is all produced bya fluid movement inside the capillary, reaching the tops of even very tall trees related to the surface tension. The vessels and the fibers in hardwood are tubular.

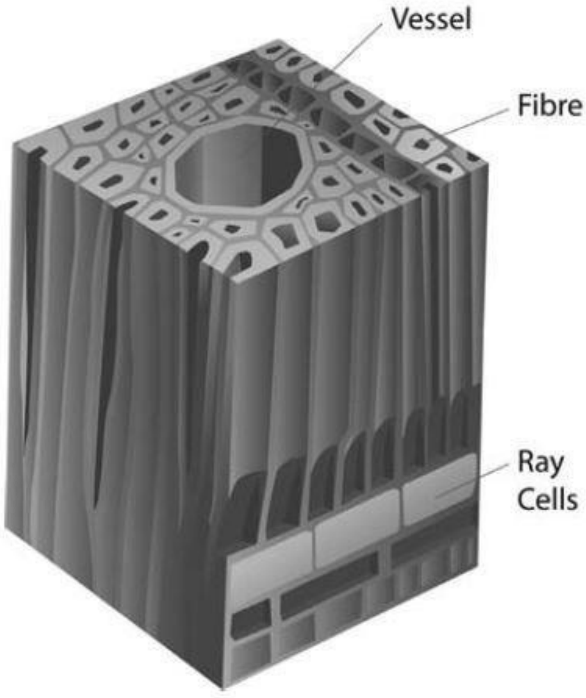


Figure2.3:Aclose-upsectionofhardwood(Primefacts, 2008)

The strength property, shrinkage, and grain pattern properties of timber and other products are affected by the characteristics of the stalky cells and their arrangement. The microscopic cellular structure of wood including the ring in the cross-section of the stem or root of a temperate woody plant, produced by one year's growth and the ray that stores food in the stem, produces the characteristic grain patterns in different species of the trees. This grain pattern is also determined by the plane in which logs are cut at the sawmill. The ray cells unlike other cells are arranged horizontally, extending radially outwards and towards the bark. The annual rings appear like concentric bands with rays extending outward like each of the bars or wire rods connecting the center of a wheel to its outer edge (spokes) in transverse or cross-sections and can be counted to age-date the tree as shown in Figure 2.4 (Brostow et al., 2010).

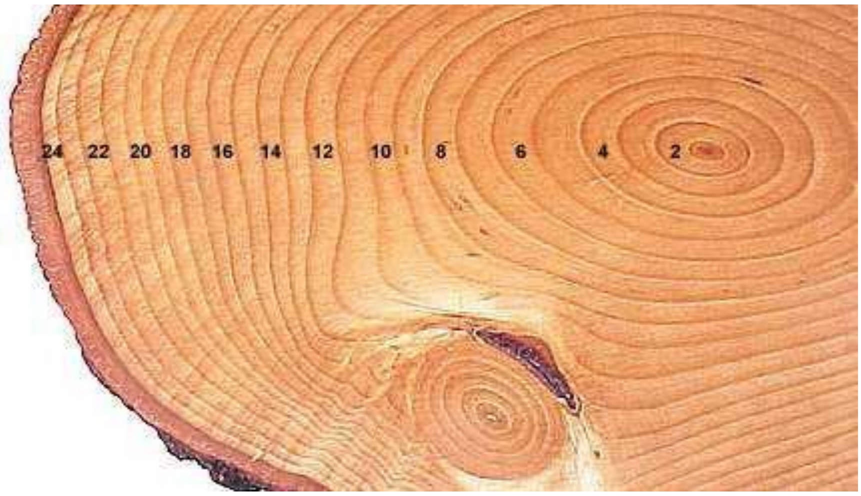


Figure2.4:Atreecross-sectionwith24distinctannual rings (Brostowetal.,2010)

2.1.2 TimberanditsAppearance

Brostow et al. (2010), reported that timber is an organic construction material for most societiesanddescribessawnwoodwithawide rangeofphysical andmechanical properties for which it is important for the ones selected to have properties suitable for aspired use. The strength, appearance, durability, the moisture content (shrinkage rates) are the main properties affecting the choice of timber. But for certain applications, other properties such as density, hardness, fire performance, etc. are also important.

(Trada, 1999) affirmed that most timbers come in a variety of colors between and within species; timbers exposed to light and those that remain unprotected and exposed to weatherwill change color, especially for the latter once mold growth is developed. To broadly describe timber's appearance and some specific characteristics, the term grain may be used; it refers to the direction, size, and arrangement of the woodcells and should not be used alone instead for instance sloppy grain, wavy grain, spiral grain etc. (Forest and Wood Products Research and Development Corporation, 2004). Timbers also come in varieties of textures which can be coarse, fine, even, or uneven, etc., and based on the size and arrangement of wood cells, difference is made between the different types of texture. (National Association of Forest Industries, 2004). It can also divulge some other naturalcharacteristicsthatcanaffectthestrengthpropertiesandaestheticslikestains,splits gum veins, and knots which are the part of the branches embedded in the main stem of the tree and sloping grain.

2.1.3 Structuraltimber

Structural timber or timber machined for structural use has its constituents sawn from the tree trunkinaprismaticshapewitharectangularcross-sectionexcept for someexceptionsintheshape. The size of the trees in the forest is the main factor that determines the maximum possible dimension of those constituents that are applied for load-carrying functions in structures. Many provisions in the production line to obtain the appropriate structural elements therefore exist; for instance, the longitudinal axis of a structural timber component should synchronize with the wood cells grain direction, (Kohler, 2007). As the outcome of the basic processing steps such as debarking, sawing, planning if necessary, finger-jointing only for some products, and gluing on the broader side, during the production of structural timber, its main characteristic is the anisotropic nature it has where the natural wood structure will be retained to a high degree (Angst et al., 2008).

2.2 BriefdescriptionsofNigeriangrowntimbers

2.2.1. Basic characteristics of bamboo

Bamboos are giant grasses and not trees as commonly believed. They belong to the family of the Bambusoideae. The bamboo culm, in general, is a cylindrical shell, which is divided by transversal diaphragms at the nodes. Bamboo shells are orthotropic materials with high strength in the direction parallel to the fibres and low strength perpendicular to the fibres respectively.Bamboo is a composite material, consisting of long and parallel cellulose fibres embedded in a ligneous matrix. The density of the fibres in the cross-section of a bamboo shell varies along its thickness. This presents a functionally gradient material, evolved according to the state of stress distribution in its natural environment. the fibres are concentrated in regions closer to the outer skin. This is consistent with the state of stress distribution when the culm is subjected to wind forces. In establishing the mechanical properties of bamboo, in the elastic range, the rule of mix for the composite materials is used. The properties of the fibres and matrix with their volumetric fractions are taken into account. Eq. (1) presents the calculation of the elasticity modulus, Ec, of the bamboo as a composite. In this equation Ef and Em are elasticity moduli and Vf and Vm = (1-Vf) are the volumetric fractions of the fibres and matrix respectively. In the development of Eq. (1), long, uniformly spaced and aligned fibres are assumed in addition to a perfect bonding between fibres and matrix.

$$E_c = E_f V_f + E_m (1 - V_f) \quad 1$$

In the application of Eq. (1) to the analysis of bamboo, the variation of the volumetric fraction of fibres, $V_f(x)$, with thickness should be taken into account.

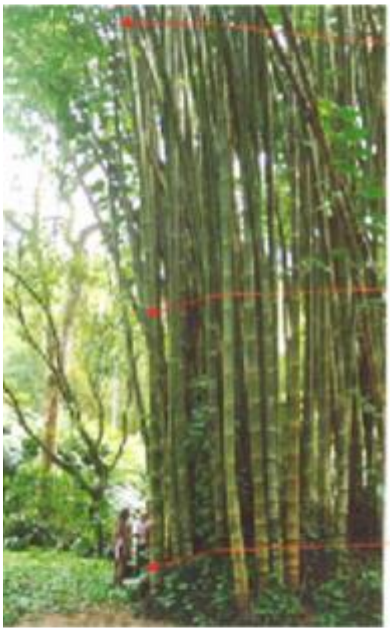


Figure 2.5: Bamboo

2.2.2 Durability Of Bamboo As An Engineering Material

Just like timber, bamboo is vulnerable to environmental degradation and attacks by insects and moulds. Its durability varies with the type of species, age, conservation condition, treatment and curing. Curing should be initiated when bamboo is being cut in the bamboo grove. There is a strong relation between insect attacks and the levels of starch plus humidity content of bamboo culm. In order to reduce the starch content, bamboo receives a variety of treatments including curing on the spot, immersion, heating or smoke. Drying bamboo is fundamental to its conservation for various reasons. Bamboo with low humidity is less prone to mould attacks especially when humidity content is less than 15%. Physical and mechanical properties of bamboo increase with a decrease in its humidity content. Bamboo to be treated with a preservative needs to be dry to facilitate penetration and obtain a better result and reducing transport costs. Bamboo can be dried in air, green house, and oven or by fire. The durability of bamboo depends strongly on the preservative treatment methods in accordance with basic requirements: its chemical composition should not have any effect on the bamboo fibre and once injected it must not be washed out by rain or humidity. The preservative can be applied using simple systems such as leave transpiration, immersion, impregnation, Modified Boucherie Method, Boucherie Method to sophisticated modern equipment of cauldrons and special chambers working with vacuum or pressure. Many steel and concrete structures built in the past 30 years reveal serious deterioration caused mainly by the corrosion of the steel reinforcement. In Fig. 5 a steel reinforced concrete column after 10 service years and the first bamboo reinforced concrete beam tested at PUCRio in 1979 are presented and compared. The steel reinforced column is part of the tunnel structure of Rios Metro. The bamboo reinforced beam after testing has been exposed to open air in the university campus. It can be observed that the bamboo segment of the beam reinforcement, treated against insects as well as for bonding with concrete, is still in satisfactory condition after 15 years. However, the steel reinforcing bars of the column are severely corroded and need to be replaced. The bamboo segments of the beam were taken out of the tested concrete beam to establish its mechanical strength. Compared to the original untreated bamboo a slight deterioration of tensile strength was observed in the weathered samples of bamboo reinforcement.

Figure 2.6: Durability of bamboo and steel reinforcement in concrete elements. (a) Bamboo reinforcement of a tested beam exposed in open air after 15 years. (b) Steel reinforcement of a column in the tunnel of metro after 10 years in closed area.

2.3. Effect Of Water Absorption of Bamboo

One of the main shortcomings of bamboo is water absorption when it is used as a reinforcement and/or permanent shutter form with concrete. The capacity of bamboo to absorb water was studied on several species. DG, and Bambusa vulgaris schard, VS, absorbed the least amount of water among all compared species. The dimensional variations of the transversal section of bamboos DG and VS reached up to 6% after 7 days immersion in water. The dimensional variation of untreated bamboo due to water absorption can cause micro or even macro cracks in cured concrete.

2.4. Bonding Strength of Bamboo

A reinforcing bar in concrete is prevented from slipping by adhesion or bond between them. The main factors which affect the bond between the reinforcing bar and concrete are: adhesive properties of the cement matrix, the compression friction forces appearing on the surface of the reinforcing bar due to shrinkage of the concrete and the shear resistance of concrete due to surface form and roughness of the reinforcing bar. The dimensional changes of bamboo due to moisture and temperature variations influence all the three bond characteristics severely. During the casting and curing of concrete, reinforcing bamboo absorbs water and expands as shown in Fig. 7(a). The swelling of bamboo pushes the concrete away, shown in Fig. 7(b). Then at the end of the curing period, the bamboo loses the moisture and shrinks back almost to its original dimensions leaving voids around itself, shown in Fig. 7(c). The differential thermal expansion of bamboo with respect to concrete may also lead to cracking of the concrete during service life. The swelling and shrinkage of bamboo in concrete create a serious limitation in the use of bamboo as a substitute for steel in concrete. To improve the bond between bamboo segments and concrete, an effective water-repellent treatment is necessary. Various types of treatment have been studied with different degrees of success.

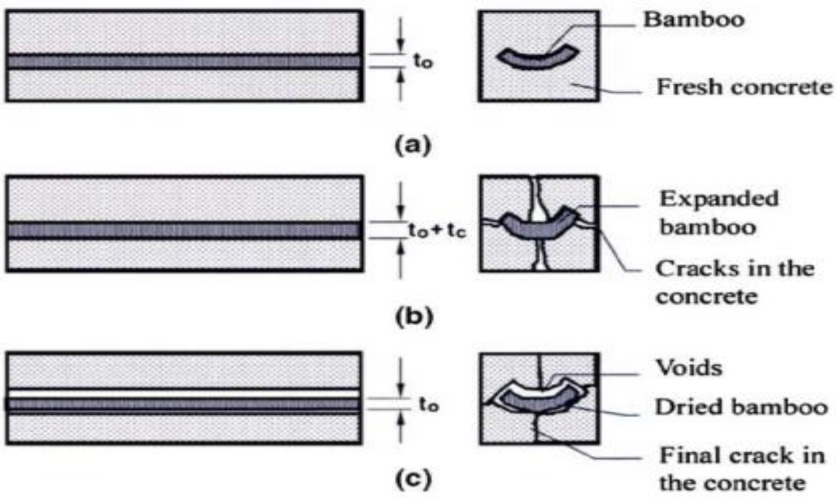


Figure 2.6: Behaviour of untreated segment bamboo as reinforcement in concrete: (a) bamboo in fresh concrete, (b) bamboo during curing of concrete and (c) bamboo after cured concrete.

2.3 Timber as a Structural Material

Timber is characterized by anisotropic behavior, high strength-to-weight ratio, and excellent workability. Engineered wood products like LVL and glulam offer consistent mechanical properties and dimensional stability. Timber has been used as a structural material for thousands of years due to its natural abundance, ease of processing, and favorable mechanical properties. In modern structural engineering, timber has evolved from a traditional building material to an engineered product with consistent and predictable performance characteristics. With the growing emphasis on sustainability and carbon reduction in the built environment, timber is experiencing renewed interest as a primary or hybrid structural material. Timber is an orthotropic material, meaning it exhibits different mechanical properties along its three principal axes—longitudinal, radial, and tangential. Its longitudinal direction, which aligns with the grain, is the strongest and stiffest, making it particularly effective in resisting tensile and compressive forces along the grain.However, timber is relatively weak in tension and compression perpendicular to the grain and in shear, requiring careful detailing to avoid splitting and failure (Green & Evans, 2008). To overcome natural limitations of solid timber—such as knots, grain variability, and dimensional instability—engineered wood products (EWPs) have been developed. These are manufactured by bonding wood strands, veneers, or laminations under controlled conditions. Common EWPs include:

- Glued Laminated Timber (Glulam): Made from layers of dimensional lumber bonded with durable adhesives. Offers high strength and can be curved into custom shapes.
- Laminated Veneer Lumber (LVL): Thin wood veneers glued in the same grain direction, resulting in high strength and stiffness.
- Cross-Laminated Timber (CLT): Layers of timber oriented perpendicularly and bonded together, providing dimensional stability and strength in multiple directions.
- Oriented Strand Board (OSB): Used primarily in sheathing, it consists of wood strands bonded in specific orientations.

These products allow timber to compete with steel and concrete in terms of structural performance, especially in mid- and high-rise construction (Mohammad et al., 2012).

2.6 Composite Action in Timber-Concrete Systems

Timber-concrete composites (TCCs) have been studied primarily in floor systems where concrete bears compression and timber resists tension. The composite action is often achieved using mechanical fasteners, notches, or adhesive bonding. Composite construction integrates two or more distinct materials to act together structurally, achieving enhanced performance by utilizing the strengths of each. In timber-concrete systems, the goal is to combine timber's tensile strength and lightweight characteristics with concrete's compressive strength, rigidity, and mass. These systems are primarily used in floor construction, where timber beams or slabs are topped with a layer of reinforced concrete. Timber-concrete composites (TCC) are a response to the growing demand for sustainable, efficient, and low-carbon construction systems. By leveraging the complementary behavior of wood and concrete, TCC systems offer improved strength, stiffness, and serviceability compared to traditional timber floors, while being lighter and more sustainable than conventional reinforced concrete slabs (Dias et al., 2007). Composite action refers to the degree of cooperation between two bonded materials to resist loads. In a TCC system, full composite action implies that no slip occurs at the interface between timber and concrete, resulting in maximum structural efficiency. However, due to material differences and practical constraints, partial composite action is usually achieved. The effectiveness of composite action depends on interface connection system, material compatibility, stiffness of connectors, shear transfer capability. According to Lukaszewska (2009), partial interaction affects both flexural stiffness (EI) and load distribution, making accurate modeling and testing essential for design.

2.6.1 Structural Behavior of Timber-Concrete Composites

In bending, concrete (in compression) and timber (in tension) share the load based on their stiffness and the level of interaction at the interface. The effective bending stiffness of a TCC system lies between that of a non-composite (no-slip) and a fully composite (perfect bond) section. The γ-method, as introduced in Eurocode 5 (EN 1995-1-1), is a widely used design approach to quantify the degree of composite action by using a gamma factor (γ) to modify the stiffness of the system (Lukaszewska, 2009). Key structural benefits includes increased load-bearing capacity, reduced mid-span deflection, improved vibration performance, better sound insulation and fire resistance due to the mass of the concrete. Timber-concrete composite floors are increasingly used in residential and commercial buildings, retrofits of old timber structures (to increase capacity without full demolition), sustainable mid-rise and low-rise buildings and modular and prefabricated systems.

Composite action in timber-concrete systems allows for the efficient use of both materials by combining their strengths. While full composite action is rarely achieved due to interface slip, partial interaction—properly designed—can result in structurally sound, cost-effective, and sustainable systems. These hybrid structures hold great promise for both new construction and renovation, particularly in low- to mid-rise applications where lightweight construction and environmental performance are priorities.

2.7 Flexural Strength

In the flexural test, the theoretical maximum tensile stress reached in the bottom fiber of atest beam orslab is known as the modulus of rupture, which is also flexural strength, bending strength, or fracture strength. When concrete is subjected to bending, the transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until it fractures or yields. The value of flexural strength would be the same as tensile strength if the materials are homogenous. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured interms of stress represented with the symbol sigma. For determining the flexural strength or modulus of rupture, the following two systems of loading of the specimen maybe adopted (Gupta & Gupta, 2004):

Central Point Loading

In this system of loading, the load is applied at the mid or central point of the test specimen which gives a triangular bending moment distribution. The maximum stress fiber stress will be below the point of loading wherethe bendingmoment is maximum.Thus, the maximum stress occurs at one section of the specimen, not necessarily the weakest section of the specimen. Figure 2.19 shows the arrangement of the apparatus in a one-point test to determine the flexural strength of a rectangular beam.

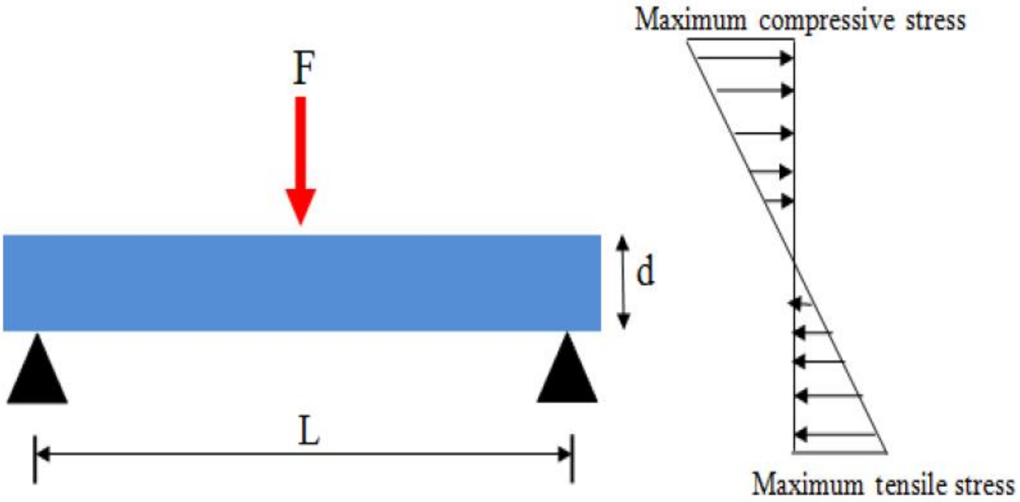


Figure2.1: Flexuraltest(Centralloading). Source:(Gupta andGupta, 2004)

For a rectangular sample under a load in a two-point bending setup (Figure 2.1), the flexural strength is calculated with equation (2.1)

$$\sigma = \frac{3FL}{2bd^2} \qquad (2.1)$$

Where

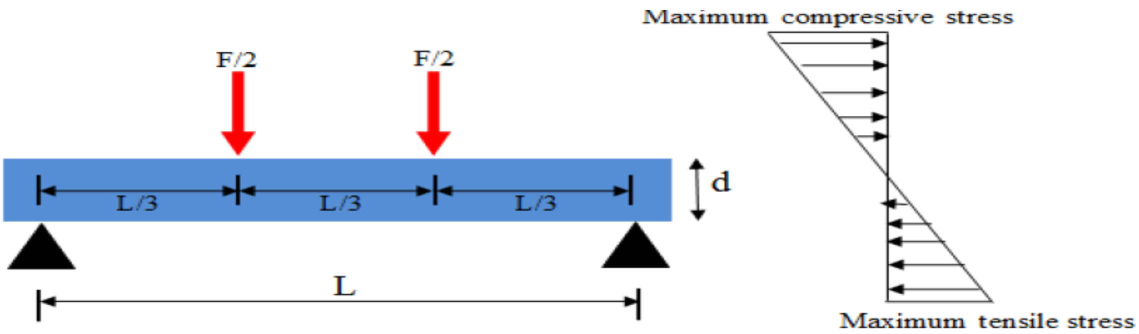
Fistheload(force)atthefracturepoint(N) L is the length of the support span (mm) biswidth(mm)

disthickness(mm)

Two Points Loading

This system of loading produces a constant bending moment between the load points so that one-third of the span is subjected to the maximum stress and thus in this region cracking is likely to take place. Nowadays, this system of loading is taken as the standard method of

loading. The system of two points loading is shown in Figure 2.2For a rectangular sample under a



load in a four-point bending setup (Figure 2.20) where the loading span is one-third of the support span, the flexural strength is calculated with equation (2.2)

Figure2.2:Flexuraltest(Twopointsloading). Source:(Gupta andGupta, 2004)

$$\sigma = \frac{FL}{bd^2} \qquad (2.2)$$

Where:

Fistheload(force)atthefracturepoint(N) L is the length of the support span (mm)
biswidth(mm), disthickness(m)

CHAPTER THREE

3.0 Methodology

3.1 Material Sourcing

3.1.1 Samplingofsawntimberlengths

3.0 Methodology

3.1 Material Sourcing

3.1.1 Samplingofsawntimberlengths

Bamboospecie were sourced from the forest and processed to sample specimen.

3.1.2 Preparationoftestspecimens

After conditioning, the solid-sawn woods were cut by the required specimen dimensions given by the Code of Practice BS EN 373:1957. The preparation of test specimens took place in the wood workshop of the Faculty of Engineering, University of Ilorin.The split bamboo culms were of 30mm wide rectangular sections. The smooth surface of the bamboo splints was cleaned and slightly roughened before being coated with a thin layer of the impermeable product together with sand. The pieces were then wrapped with 1.5mm wire at 10mm distance and once more coated with the same product. Immediately after that, fine sand was manually pressed into the surface and the splints were allowed to dry for 24 h before being fixed inside the formwork. The bamboo reinforcing ratio, q, varied between 1% to 3%

3.1.3 Coarse Aggregate

The coarse aggregate used for this experiment is granite. Granite size ranging from 5mm to 10mm from quarry along roval valley road Gariki, Ilorin, Kwara State. The coarse aggregate use conformed to the requirement of BS EN 12620:2013

3.1.4 Fine Aggregate

The fine aggregate used for this experiment is sand. Sand was gotten from a river along oko-olowo area, Ilorin, Kwara State. The fine aggregate use conformed to the requirement of BS EN 12620:2013

3.1.6 Portland Cement

Dangote (3X) cement with strength of 42.5R is obtained from a local seller along old Kwara polytechnic campus, Ilorin, Kwara State. The cement is used as a binder and conformed to requirement of BS EN 197-1-2000.

3.1.7 Water

The water use for this study conforms to the requirement of BS EN 1008:2002 (Mixing water for concrete).

3.2 FlexuralStrengthTestofTimberReinforcedConcreteSlab

This section covers the flexural test on the bamboo reinforced concrete slab to determine the variation of the slab's flexural strength with an increase in the percentage of longitudinal timber reinforcement. The flexural test was carried out by BS EN 12390-5:2009 (Testing hardened concrete: Flexural strength of test specimens) using a universal testometric machine (UTM) at Material Science, Mechanical Department, University of Ilorin, Ilorin, Kwara State.

3.2.1 Reinforcement Preparation

Design parameters were formulated based on BS 8110-1:1997 to give average initial values for laboratory tests. Longitudinal reinforcements were varied by section of the slab (area) in 1%and 3% concrete slab samples. In this case, the longitudinal squares of two different local timber each 360 mm long, and square transverse timber each 160 mm long were nailed together at a right angle. The longitudinal timber bars were placed below while the transverse bars were placed above. Also, Steelreinforcementforcontrolslabs was preparedsimilarly. Information on reinforcement sizes and arrangement using timber are shown in Table 3 below. Table 4 also shows the arrangement of steel reinforcement for slab test as control.

Table 1: Description of Timber Rebar Arrangement for Slab Test.

Label	h mm	d mm	Longitudinal Bar					Transverse Bar				
			As mm^2	100As /bh (%)	ϕ mm	No	S mm	As mm^2	100As /Lh (%)	ϕ mm	No	S mm
1CT	75	54	150	1	12	2	160	900	3	16	5	72
2CT	75	53	300	2	12	3	80	900	3	16	5	72

h denotes the thickness of the slab (mm)

TT denotes treated top

d denotes the effective depth (mm)

TB denotes the treated bottom

As denoted the area of reinforcement (mm^2)

■ denotes the bar size in square (mm).

S denotes the spacing (mm).

Table 2: Description of Steel Reinforcement Arrangement for Slab Test.

Label	h mm	d mm	LongitudinalSteel bar					Transverse Steel Bar				
			As mm^2	100As/bh (%)	ϕ mm	No	S mm	As mm^2	100As/ Lh (%)	ϕ mm	No	S mm
SS1	75	54	120	0.8	10	2	160	360	1.2	10	5	72

Note:

The minimum reinforcement for high-yield steel in Slab is 0.12% bh while the maximum range is from 1 to 2% bh (BS 8110:Part1:1997). The percentage to be used for this research is chosen as 0.80% for the longitudinal bar and 1.2% for the transverse bar.

Concrete Slab Preparation

The preparation of concrete samples was carried out after the arrangement of timber reinforcement. The concrete samples used were cement, fine aggregate (sand), and coarse aggregate (granite). Hand mixing techniques were employed to mix the ingredients of the concrete with a designed trial mix ratio of **1**:2:4 with a water/cement ratio of **0.50** on a clean concrete slab. Sample slabs of 75 mm deep by 200 mm wide by 400 mm long (Figure 3.1) were cased inside a prepared wooden formwork. Casting started by first placing the wooden formwork on the floor. The internal surface of the formwork was oiled to prevent the adhesion of concrete onto the surface of the formwork. A concrete layer of 20 mm was initially poured into the formwork which served as a cover for the reinforcement. The slab reinforcement was then placed in the formwork on the concrete cover and more concrete was poured until the formwork was filled up. The wet concrete in the formwork was then tamped round with a 25 mm square steel tamping rod. After 60 minutes of setting the concrete, identification inscriptions were made on the slabs for easy identification. The wooden formwork was then taken off after 24 hours of casting and the concrete slabs were cured for 7,14, and 28 days by wetting the slabs daily and covering the slabs with polythene sheeting to prevent loss of moisture. A total of eighteen (18) slabs consisting of 12 No. of timber reinforced slabs and 6 No. of steel-reinforced slabs were cast on different days.

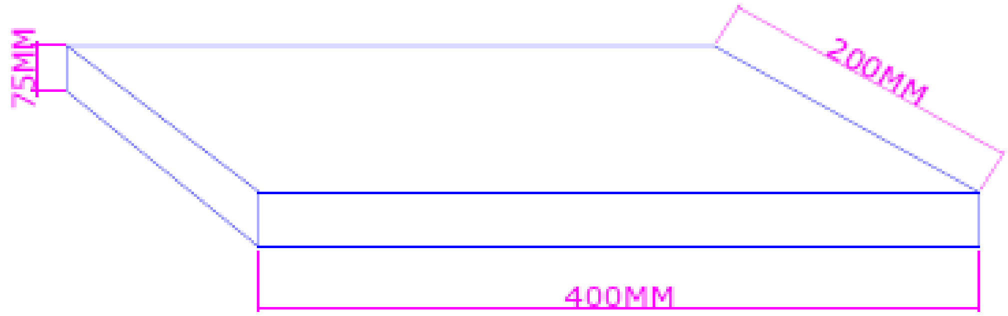


Figure 3.1: Concrete Slab Section.

Plate V: Arrangement and Failure Mode of Timber Reinforced Slab

CHAPTER FOUR

4.0 Result and Discussions

4.1 Flexural Test Strength

4.1.1 Flexural Strength Test on Teak Timber Reinforced Concrete Slab

Table 4.1 shows experimental load results of the central point flexural test on the teak reinforced concrete slabs. The flexural strength of the teak reinforced slabs (CRS) at 28 days strength was from 2.20 N/mm^2 to 2.43 N/mm^2 with increase in the percentage of teak rebar from 1% and3%.

Table 4.1 Flexural Strength (Experimental Load) Result of Teak Rebar Slab

Label		1st crack load P_{cr} (N)	Failure load P_{ult} (N)	Deflection at peak (mm)	Flexural Strength (N/mm^2)	Mode of failure
1BRS	Minimum	3051	5502	3.13	2.74	Two number of cracks and failure is in Tension
	Maximum	4300	7530	5.02	2.90	
	Mean	**3676**	**6516**	**4.08**	**2.82**	
3BRS	Minimum	3642	5514	2.40	2.86	Two number of cracks and failure is in Tension
	Maximum	5200	8540	3.63	3.10	
	Mean	**3859**	**5954**	**3.38**	**2.98**	

4.2 Flexural Strength on Steel Reinforced Concrete Slab

Table 4.2 shows experimental load results of the central point flexural test on the steel reinforced concrete slabs. The failure stress of the steel reinforce slabs at 28 days strength is 5.28 N/mm^2

Table 4.2: ***Flexural Strength Test (Experimental Load) Result of Steel Reinf. Slab***

Label	1st Crack Load	Failure Load (N/mm^2)	Deflection at Peak (mm)	Flexural Strength (N/mm^2)	Mode of Failure
SRS	9647	12863	4.12	5.28	visible cracks and failure is in tension

CHAPTER FIVE

5.0 Conclusion

The study concluded that a slab reinforced with bambooat 3% cross-sectional slab area can achieve up to 56% in terms of flexural strength compared with a steel rebar of 10mm diameter. Teak wood can effectively be used as reinforcement in concrete if a sufficient percentage is used as reinforcement in concrete.

5.1 Reccommendation

1. More comprehensive research is essential to explore the potential of locally available Nigeria timbers in various types of concrete under different loading conditions and environments.
2. More research work should be embarked upon to cover for higher reinforcement percentage (4% and 5% respectively).

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