KWARA STATE POLYTECHNIC, ILORIN

FLEXURAL STRENGTH OF COPALWOOD REINFORCED CONCRETE SLAB

BY

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CERTIFICATION

This is to certify that this project was carried out by **ALIU HAMAD ADISA** of matriculation number **ND/23/CEC/PT/0073** in the Department of Civil Engineering, Kwara State Polytechnic in partial fulfillment of the requirements for the award of National Diploma (ND) certificate in Civil Engineering.

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DEDICATION

This project is dedicated to Almighty Allah for sparing my life and giving me the opportunity to accomplish this project.

Also to my beloved parents who have made the journey so easy and successful one, who continually provide their moral, spiritual, emotional, and financial support.

ACKNOWLEDGEMENT

I give thanks to Almighty Allah that makes it possible for me to go through safety and for counting me worthy to be among the living. I also acknowledge my parent for their prayer, support and love towards me.

Foremost, I give all praises, honour, glory with thank to the God Almighty who made the writing of this project possible with His total mercy on me from the beginning till the end.

My appreciation goes to my project supervisor **ENGR. ABDULRAHEEM K.K** for his exceptional mentorship and technical expertise. His guidance and insightful suggestions have been instrumental in shaping the direction of this project.

I also express my gratitude to the Head of Department **ENGR. NAALAH ABDULMUMEEN** project coordinator **ENGR. SAANI A.** and other amiable lecturers for their expertise and assistance in various aspects of the project.

ABSTRACT

This research explores the flexural strength characteristics of concrete slabs reinforced with African Copalwood as a sustainable alternative to conventional steel reinforcement. Copalwood logs were processed into sawn timber at a sawmill in Igbaja, Kwara State, and sample specimens were selected from near the bark of the logs. The timber was conditioned under controlled laboratory conditions in accordance with BS EN 373:1957 and cut into standard test sizes. Other concrete materials—including granite (5–10 mm), river sand, Dangote 42.5R cement, and potable water—were sourced locally and met the requirements of BS EN standards. Flexural strength testing was conducted using a Universal Testing Machine in line with BS EN 12390-5:2009. Slab specimens were reinforced with longitudinal Copalwood bars at 1% and 2% reinforcement ratios, complemented with transverse members, and compared against slabs with conventional steel reinforcement. The methodology enabled an assessment of how variations in Copalwood reinforcement influence the flexural behavior of concrete slabs, contributing to the growing field of alternative, eco-friendly structural materials.

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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.

Lastly, 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 selected timber 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

CHAPTER TWO

2.0 Literature Review

2.1 Nature and description of wood's structure

Wood is generally composed 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.

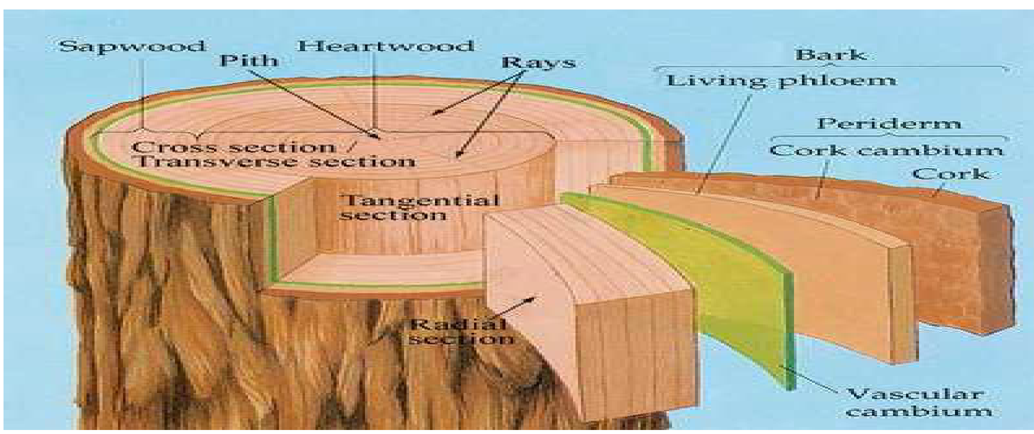


Figure 2.1: Cross-section of a trunk (Brostow et al., 2010)

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 conducts or stores and is not essential in the growing process and the survival of the trees (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 only be 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 Different types of wood

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.

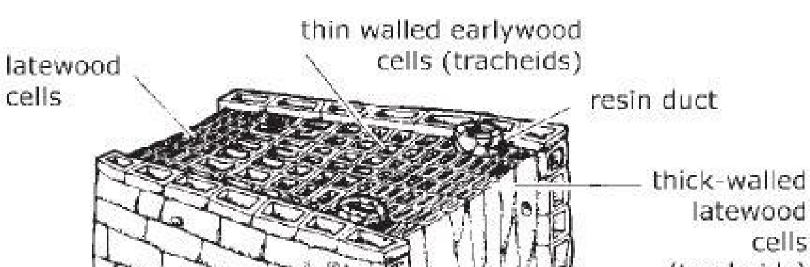


Figure 2.2: A section of Softwood (Primefacts, 2008)

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. These cells are thick-walled with a confining central 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 vertically to form tubes of less than 0.5 mm in diameter (Primefacts, 2008). It is all produced by a 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.

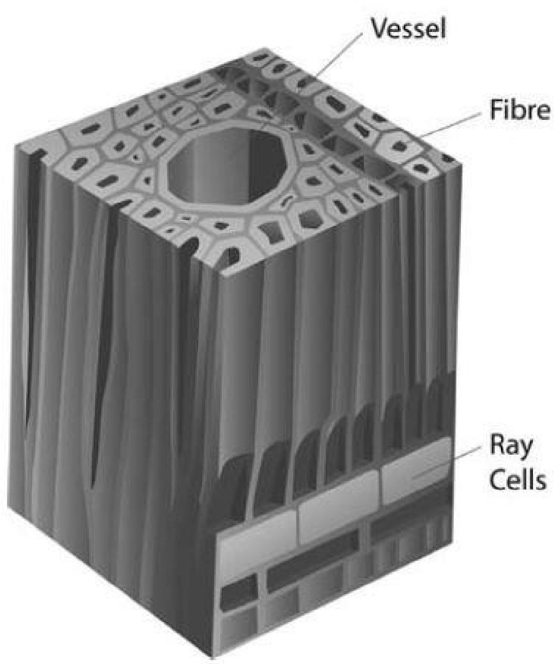


Figure 2.3: A close-up section of hardwood (Primefacts, 2008)

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).

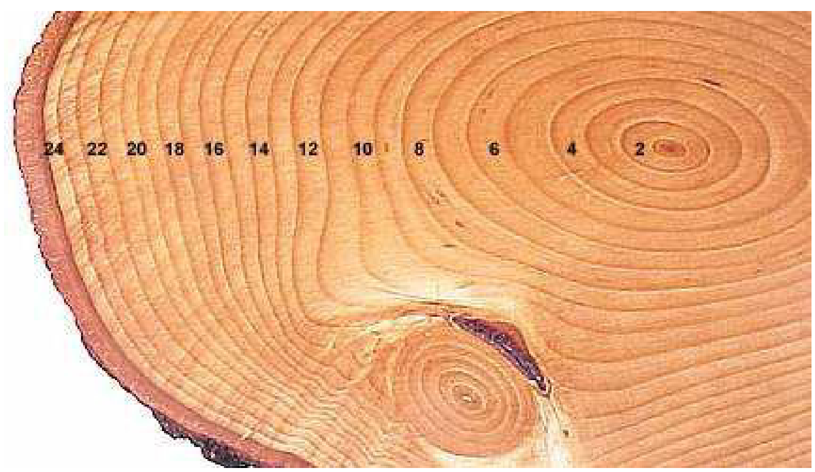


Figure 2.4: A tree cross-section with 24 distinct annual rings (Brostow et al., 2010)

2.1.2 Timber and its Appearance

Brostow et al. (2010), reported that timber is an organic construction material for most societies and describes sawn wood with a wide range of physical and mechanical 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 weather will 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 wood cells 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 natural characteristics that can affect the strength properties and aesthetics like stains, 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 Structural timber

Structural timber or timber machined for structural use has its constituents sawn from the tree trunk in a prismatic shape with a rectangular cross-section except for some exceptions in the shape. 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 Brief descriptions of Nigerian grown timbers

2.2.1 African Sandal Wood (*Daniellia Olivera*)

African Copalwood *or Daniellia olivera or Iya* is a large tree, a genus in the subfamily of *Caesalpinioideae* of the family *Fabaceae* (angiosperm) that can grow up to 45 m in height with a trunk of approximately 20 – 30 m occurring in Nigeria in old tree plantations. Its heartwood is pale pinkish to reddish brown with some darker rings occurring periodically. The wood is soft, light in weight with a possible presence of brittle heart and coarse texture, and works easily with hand and machine tools; with a very slight risk of distortion, it seasons quickly. It is used for furniture components, plywood, joinery, etc. (Fern A., 2014).

Figure 2.5: Africa Copalwood Timber

2.3 Physical properties of timber

2.3.1 Moisture content

Green timber which refers to timber that has a moisture content greater than % and resists splitting and cracking easily, has a very high moisture content. Furthermore, the timber, until it reaches the equilibrium moisture content of the surrounding environment, will dry out. During the year 1932, Wilson proclaimed that with the current temperature and humidity, the moisture content at the surface of a piece of green wood reaches equilibrium and from that way forward, varies irregularly with changes in these factors after being subjected for some time to natural atmospheric conditions. The size of the piece in addition to the climatic conditions are the main factors to focus on to know how soon such a condition is attained.

The Nigeria Standard Code of Practice (NCP2, 1973), stipulates that wood with moisture content above 18 % be considered green, but in dry condition if below. The fiber saturation point is the moisture content (MC) at which the cell walls are fully saturated with bound water but no free water occurs in the timber, and this strongly influences the mechanical properties. The Moisture Content of wood below the FSP is a function of the temperature and relative humidity (RH) of the surrounding environment (Adeyemi, 2016).

In the case of structural timber, a large variation in terms of shrinkage and swelling as a result of changes in moisture content is noted therefore, a 1% change in moisture content leads to a 0.01% change in the longitudinal direction, 0.1% change in the radial direction and 0.2% change in the tangential direction. Furthermore, a change in the moisture content is likely to cause distortion which can either be a twist, a spring, or a bow. When the moisture content is too high (>20%), it could lead to mold or rot and when it is too low (<10%), it could be responsible for the timber to be more difficult to nail (Kliger, 2006).

The increase in strength in moisture reduction can be explained by the fact that cellulose, which is a major structural component of timber always exhibits greater strength when it is dry than when it is wet as reported by Taragon, (2000). The three main factors that cause the greater strength when the timber is dry are as follows: first is the microfibrils that become compact and thus increase in attractive forces; then the frictional resistance among the cellulose which is being reduced by the moisture acting as a lubricant and finally the reduction in the moisture content leads to shrinkage.

2.3.2 Durability

For a required period, the ability of the timber to achieve its task is referred to as durability which signifies the performance of the timber when it is exposed to jeopardies such as decay like fungi and insects like for instance, termites and borers attack. Timber species have distinct natural durability characteristics which have been classified based on their expected service life either in the ground or above and exposed to hazards as shown in Table 2.1.

Table 2.1: Classification of durability by different classes.

Durability Class	**Durability Rating**	**Expected Service Life (Yrs)**	
		In ground	**Outside / above ground**
1	High	25	**>40**
2	Reasonably High	15 – 25	**15 – 40**
3	Moderate	5 – 15	**7 – 15**
4	**Low**	**<5**	**<7**

Source: (Timber Queensland, 2014)

Regardless of the species, the sapwood of all timbers is not durable and can be ranked as Class 4 durability.

Note: There is no direct relationship between the stress grade and the durability for instance certain low-durability hardwoods such as *Tasmanian oak* can have a high stress grade (Timber Queensland, 2014).

2.3.3 Density

Wood density is a highly important property defined as an expression of the weight per unit volume (kg/m^3) or specific gravity owing to its aid to some parameters such as stiffness and strength (Kennedy, 1995; Vikram, et al., 2011); also, it is not commonly satisfactory to associate the density of green wood due to the reason that, ultimately, the amount of water in wood is variable. The compressive and shear strength parallel to grain and the fiber stress in bending strength at the elastic limit of wood, change in direct proportion to the weight of dry wood per unit of volume when green according to data obtained from a bunch of tests on the strength of different woods. (Record, 1914). The density of the lignin, cellulose, and hemicellulose at approximately $1500kg/m^3$ is substantially constant, and the presence of extractives that can vary within a proportion of 1 to 20% conditional to the age of the tree species and their position in the stem, overwhelm greatly the wood density.

2.4 Reinforced Concrete: Traditional Approaches

Traditionally, steel reinforcement in concrete provides high tensile strength and ductility. Steel-concrete bond strength and corrosion resistance are critical factors affecting long-term durability. Reinforced concrete (RC) is a composite material wherein concrete, strong in compression but weak in tension, is combined with reinforcement, typically steel, which is strong in tension. This synergy allows reinforced concrete to perform effectively under various loading conditions. Since its introduction in the 19th century, reinforced concrete has become the backbone of modern infrastructure, from buildings and bridges to tunnels and retaining walls. Concrete's compressive strength, durability, and formability, when paired with steel's tensile strength and ductility, make the RC system highly adaptable and cost-effective. The steel is strategically placed in regions of the concrete cross-section expected to experience tension under loading. This configuration is governed by principles of equilibrium and compatibility under structural mechanics (Nilson, Darwin, & Dolan, 2010). The use of reinforced concrete dates back to the mid-1800s, pioneered by innovators such as Joseph Monier, who patented a reinforced concrete flowerpot in 1867, and François Hennebique, who developed a systematic construction method in the late 19th century (Collins & Mitchell, 1991). The development of standardized design practices and construction codes through the 20th century allowed RC to dominate global construction practices.

RC slabs are designed based on limit state design principles defined in structural codes such as Eurocode 2 (EN 1992-1-1) and ACI 318. These consider Ultimate Limit States (ULS) and Serviceability Limit States (SLS). The most common types of RC slabs include:

- One-way slabs: Reinforced in one direction, typically used in beam-supported spans.
- Two-way slabs: Reinforced in two directions, used in flat plates or flat slabs with column supports.

Key structural behaviors considered in slab design include bending, shear, deflection, punching shear, and crack control. To address the limitations of reinforced concrete, research over the past few decades has explored the use of:

- Fiber-Reinforced Polymers (FRP): Non-corrosive and lightweight, but cost and long-term performance are concerns.
- Stainless Steel or Galvanized Rebar: Offers better corrosion resistance at higher cost.
- Natural Fibers and Alternative Materials: Such as bamboo or timber for specific applications, especially in low-cost or sustainable construction contexts (Ashour, 2000).

This shift toward alternative reinforcement materials forms the foundational motivation behind the current study into timber-reinforced concrete slabs as a sustainable, lightweight, and regionally adaptable solution

2.5 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 a test beam or slab 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 in terms 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 may be 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 where the bending moment 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.

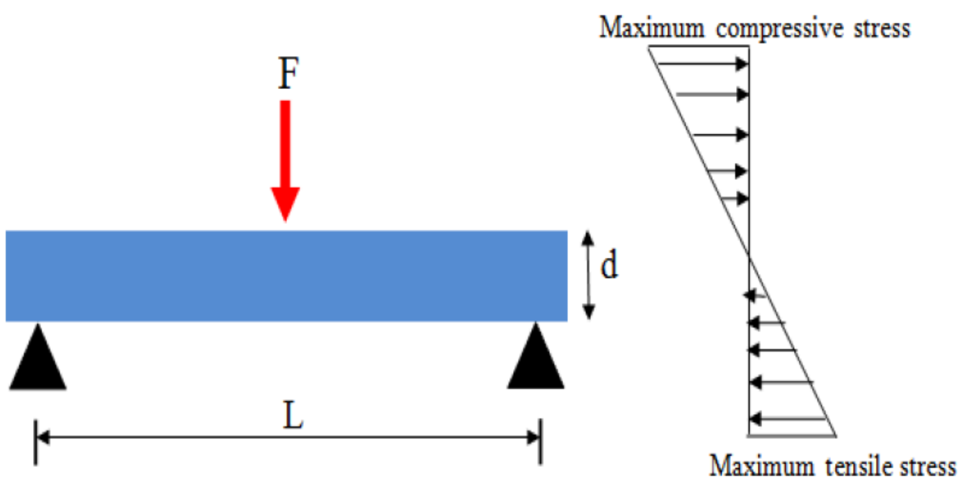


Figure 2.1: Flexural test (Central loading). Source: (Gupta and Gupta, 2004)

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

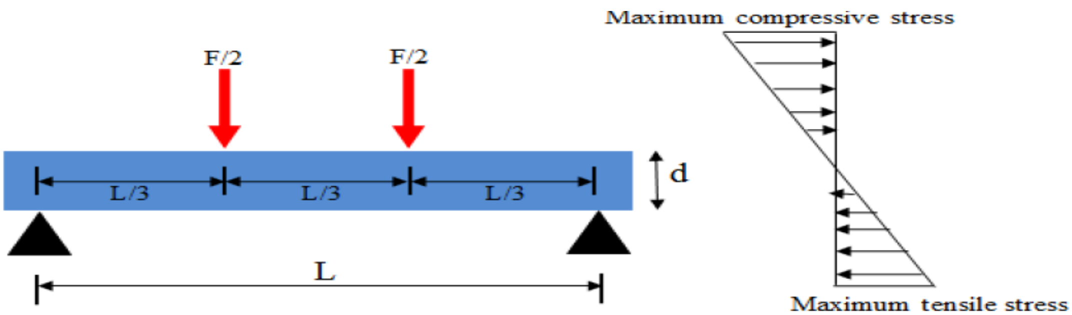
F is the load (force) at the fracture point (N) L is the length of the support span (mm) b is width (mm)

d is thickness (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 2.2 For 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)

Figure 2.2: Flexural test (Two points loading). Source: (Gupta and Gupta, 2004)



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

Where:

F is the load (force) at the fracture point (N) L is the length of the support span (mm)

b is width (mm), d is thickness (m)

CHAPTER THREE

3.0 Methodology

3.1 Material Sourcing

3.1.1 Sampling of sawn timber lengths

The African Copal wood logs from the forests were processed to solid sawn wood boards of 100 mm x 150 mm x 1200 mm (4” x 6” x 4ft) in a sawmill at Igbaja Area of Kwara State. The sample specimens were taken from the top position close to the bark of a tree.

Plate I: Sawing of timber from the log at the sawmill

3.1.2 Conditioning of sawn timber lengths

The sawn timber prepared was therefore transported to the Civil Engineering Department of the University of Ilorin where they were conditioned at a standard environment temperature of (20 ± 2) °C and (65 ± 5) °C relative humidity according to the code of practice BS EN 373:1957.

3.1.3 Preparation of test specimens

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.

3.1.4 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

3.1.5 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 Flexural Strength Test of Timber Reinforced Concrete Slab

This section covers the flexural test on the teak 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 2% 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, Steel reinforcement for control slabs was prepared similarly. 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 3: 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 4: Description of Steel Reinforcement Arrangement for Slab Test.

Label	h mm	d mm	Longitudinal Steel 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.

Plate II: 1% Timber Rebar Plate III: 2% Timber Rebar

Plate IV: Steel Rebar

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.

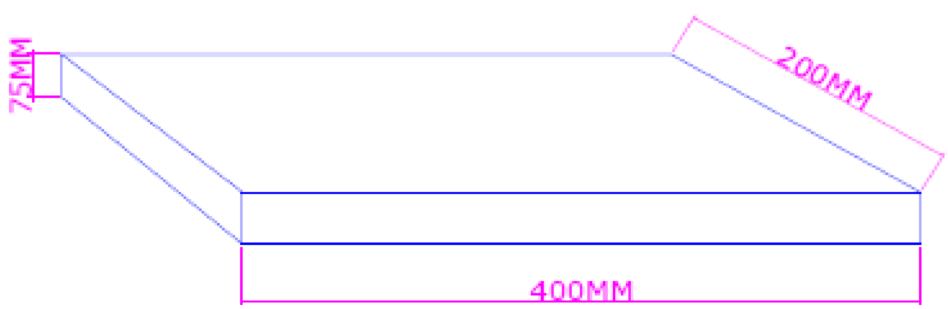


Figure 3.1: Concrete Slab Section.

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 Copal wood Reinforced Concrete Slab

Table 4.1 shows experimental load results of the central point flexural test on the copal wood reinforced concrete slabs. The flexural strength of the teak reinforced slabs (CRS) at 28 days strength was from 2.39 N/mm^2 to 2.46 N/mm^2 with increase in the percentage of teak rebar from 1% to 2%.

Table 4.1 Flexural Strength (Experimental Load) Result of Copal Wood 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
1TTTS	Minimum	3250	5804	5.64	2.35	Two number of cracks and failure is in Tension
	Maximum	4675	5993	5.62	2.43	
	Mean	**3963**	**5899**	**5.63**	**2.39**	
2TTTS	Minimum	3851	5663	6.76	2.62	Two number of cracks and failure is in Tension
	Maximum	5551	6455	7.92	2.3	
	Mean	**4701**	**6059**	**7.34**	**2.46**	

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

4.3 Mechanical Properties Test Results

4.3.1 Tensile Parallel to Grain

Tensile strength parallel to grain results of copal wood are presented in Table 4.3. The studies shows that the average tensile strength of the copal wood timber parallel to the grain at the top parts of stem heartwood is 15.79 N/mm^2 with a coefficient of variation of 22.35%. The average tensile strain is 1.08% and the youngs modulus (modulus of elasticity) is 2276.17 N/mm^2.

Table 4.3: Tensile Strength Test Results of Copal wood

	Stress (σ) at Yield (N/mm^2)	Strain (ε) at Yield (%)	Youngs Modulus (N/mm^2)	Energy to Yield (N.m)
Minimum	13.29	0.99	1925.78	4.66
Maximum	18.28	1.16	2626.56	7.31
Mean	15.79	1.08	2276.17	5.99
S.D	3.53	0.12	495.52	1.87
C. of V.	22.35%	11.11	21.77	31.22
L.C.L	± 30.98%	±15.50%	± 30.17%	± 43,39%
U.C.L	± 40.72%	± 20.37%	± 39.65%	± 57.03%

Source (Abdulraheem, etal., 2024)

4.3.2 Bending Strength Parallel to Grain

Bending strength parallel to grain results of copal wood are presented in Table 4.4. The studies shows that the average bending strength of the copal wood timber parallel to the grain at the top parts of stem heartwood is 63.36 N/mm^2 with a coefficient of variation of 25.66%. The average strain is 2.24% and the bending modulus (modulus of elasticity) is 6423.71 N/mm^2.

Table 4.4: Bending Strength Test Results of Copal Wood

	Stress (σ) at Yield (N/mm^2)	Strain (ε) at Yield (%)	Deflection at yield (mm)	Youngs Modulus (N/mm^2)	Energy to Yield (N.m)
Minimum	60.16	1.48	7.77	5460.85	8.25
Maximum	74.86	3.00	17.86	7386.57	23.55
Mean	63.36	2.24	12.82	6423.71	15.9
S.D	16.26	1.07	7.13	1361.69	10.82
C. of V.	25.66	47.76	55.61	21.19	68.05
L.C.L	± 35.57%	± 66.50%	± 77.16%	± 29.38%	± 94.30%
U.C.L	± 46.76%	± 87.40%	± 101.41%	± 38.61%	± 123.94%

Source (Abdulraheem, etal., 2024)

4.3.3 Local Modulus of Elasticity

Local MOE results of copal wood are presented in Table 4.5. The studies shows that the average local MOE in bending of the copal wood at the top parts of stem heartwood is 60.55 N/mm^2 with a coefficient of variation of 19.42%. The average strain is 2.45% and the bending modulus (modulus of elasticity) is 5965.71 N/mm^2.

Table 4.5: Local MOE Test Results of Copal Wood

Local MOE						
Parts		Stress (σ) at Yield (N/mm^2)	Strain (ε) at Yield (%)	Deflection at yield (mm)	Youngs Modulus (N/mm^2)	Energy to Yield (N.m)
Top	Minimum	52.23	2.23	12.48	5060.34	15.71
	Maximum	68.86	6.26	31.04	6871.08	75.20
	Mean	60.55	4.25	21.76	5965.71	45.46
	S.D	11.76	2.85	13.12	1280.39	42.07
	C. of V.	19.42	67.05	60.29	21.46	92.54

	L.C.L	± 26.92%	± 93.04%	± 83.59%	± 29.75%	± 128.26%

Source (Abdulraheem, etal., 2024)

CHAPTER FIVE

5.0 Conclusion

The study concluded that a slab reinforced with copal wood at 2% cross-sectional slab area can achieve up to 47% 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 (3% 4% and 5% respectively).

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