

**EXPERIMENTAL AND ANALYTICAL ASSESSMENT OF TIMBER PORTAL FRAME  
USING EURO CODE 5**

**BY**

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## **CERTIFICATION**

This is to certify that this project topic titled “Experimental and Analytical Assessment of Timber Portal Frame Using Euro Code 5” was carried out by Ozoani Chibuike Jude with registration number (NAU/2016224031) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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## APPROVAL PAGE

This research work “Experimental and Analytical Assessment of Timber Portal Frame Using Euro Code 5” is an authentic academic work undertaken by Ozoani Chibuiké Jude and is presented to the department of Civil Engineering, Faculty of Engineering, Nnamdi Azikiwe University Awka for approval in partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng).

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## **DEDICATION**

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my beloved family and friends and everyone who served as a real source of inspiration towards my academic pursuit.

## **ACKNOWLEDGEMENTS**

I want to thank GOD Almighty for His mercy and grace, in seeing me through my stay in this institution and completion of my project.

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## ABSTRACT

The study conducted an experimental and analytical assessment of timber portal frame using Euro code 5. Three species of timber namely: Obeche (*Triplochiton Sclereoxylen*), Mahogany (*Swietenia Macrophylla*) and Ekki (*Lophira Alata*) were used for the study. The timber species was subjected to experimental testing. The test conducted on the species are bending strength test, bending stiffness test and charpy impact energy test. The study also assigned strength class to the selected species of timber. Results obtained from bending strength test, bending stiffness test and charpy impact energy. Results obtained from bending strength tests revealed that Ekki yielded the highest the bending stiffness while the lowest bending stiffness was produced by extract from Obeche, the bending strength results showed that Ekki yielded the highest bending strength while the lowest bending strength was recorded for extract from obeche. Assessment of the impact energy of the hardwood timber species revealed that the impact strength of Ekki, Obeche and Mahogany were 2.86joules/cm<sup>2</sup>, 2.72joules/cm<sup>2</sup> and 2.64joules/cm<sup>2</sup>. Allocation of strength class to the selected species of timber revealed that Ekki with a strength class of D60 was allocated the highest strength class; the strength class of obeche and mahogany were the same.

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## **LIST OF SYMBOL & ABBREVIATION**

**CIE** — Charpy Impact Energy

**MOE** – Modulus of Elasticity

**MOE** – Modulus of Rupture

**SW** –Softwood

**HW**- Hardwood

**BM** – Bending Moment

**BS** – Bending Stress

**SF**- Shear force

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of Study

Experimental and analytical assessment of engineering materials has continued to develop a growing importance in modern structural engineering application especially when it comes to natural occurring materials like timber (Aguwa, 2014). However, research on experimental and analytical assessment of timber structures especially when subjected to loading is complex due to the large natural variability of timber as an engineering material (Abubakar, et al., 2020).

Timber portal frame are most commonly used structural forms for single-storey industrial structures (Kumar and Kumar, 2014). They are commonly used to provide large span open spaces for industrial, farming and residential purposes (Blum and Zhanjie, 2019). Timber portal frames are used as shed, garage, shelters and are particularly common in rural areas. Timber portal frame have been in use since 1960s and are typically used in large industrial type construction which spans bigger than 15-20m (Hayder, et al. 2018).

During the last decade, there is growing resurgence in interest in the use of steel over timber for the construction of portal frame in Nigeria. These developments have been attributed to the uncertainty in the service behaviour of locally available timber species used for portal frame construction. Consequently, this has limited the use of timber in the construction of portal frames and other civil engineering structures. Therefore, in other restore interest in the use of timber for civil engineering construction, there is a need to carry out detailed experimental and analytical assessment of timber species used for portal frame construction.

Experimental and analytical assessment of engineering materials is done to ascertain the service behaviour of structures subjected to loading. The structural performance of timber portal frame is determined by loads and resistance which are random variables. Experimental and analytical assessment is the rational assessment of uncertainties that could arise on structures when in use (Aguwa, 2014). The important processes in experimental and analytical assessment of timber structures are the determination of the structural behaviour based on structural types and variables with sufficient examination of the effects on the whole structures (Han, 2015).

The investigation of structural performance of timber structures were done in accordance with the requirements of the British standard code of practice. The former British standard code of practice for experimental and analytical assessment of timber structure BS5628 is based on permissible stress method, the code was withdrawn in April 2020 and replaced with Euro code 5 (Mohammed, 2016). Euro code 5 is based on limit state concept and has been mostly employed for experimental and analytical assessment of timber structures subjected to loading.

## **1.2 Statement of Problem**

The service behaviour of timber portal frame is largely dependent on the grade and structural properties of the timber species used for its construction. Timber portal frames show variable performance during service. The variability in the performance of timber portal frame structures have been largely attributed to the uncertainties in the properties of timber used for its construction. This development has limited the use of the material in the construction of portal frame and other civil engineering structures. Therefore, there is a need to carry out experimental and analytical assessment of selected species of timber commonly utilized in the construction of portal frame as a means of promoting the use of the material which will thereby ensure sustainable development in the area of infrastructures.

## **1.3 Aim and Objectives of Study**

The aim of the study is to carry out experimental and analytical assessment of timber portal frame using Euro code 5 while the objectives are:

1. To determine the structural properties of some selected timber species in accordance with Euro code 5 specifications.
2. To assign strength class to the selected timber species based on EN 338 (2009) specifications.
3. To carry out analytical assessment of some selected timber species so as to analyze their effect on structures subjected to loading.
4. To draw conclusion and make recommendation in the light of findings obtained from the study.

## **1.4 Scope of Study**

The study will carry out experimental and analytical assessment of selected species of timber commonly used in portal frame construction. The experimental and analytical assessment will be done based on Euro code 5. Tree timber species namely Obeche (*Triplochiton scleroxylon*), Mahogany (*Swietenia macrophylla*) and Ekki (*Lophira alata*) will be used for the study. The selected species of timber will be subjected to laboratory testing. The test to be conducted on the timber species are: bending strength test, charpy impact test and stiffness test. Analytical assessment of the selected timber species will be done based on Euro code 5. Strength class of the timber species will also be assigned.

## **1.5 Significance of Study**

Key findings obtained from the study on experimental and analytical assessment of timber portal frame will be significant in the following ways;

1. Promote knowledge on the inherent structural properties of some selected species of timber.
2. Reduce resource depletion in production of construction material through the use of natural and renewable material.
3. Ensure environmental sustainability through the reduction in production of environmental harmful construction material.
4. Promote high level of portal frame construction.

## **1.6 Limitation of Study**

**Inconsistency in Timber Properties:** The inconsistencies in the properties of timber perpendicular and parallel to the grain, makes it impossible for the properties of small piece of timber cut from a large log to be representative of the whole log. This development would probably affect the research findings.

**Inconsistencies in Timber Properties from Different Study Area:** The properties of different softwood and hardwood laminate obtained from different study area are relatively different. This discrepancy could be attributed to the distortion in the grain reorientation in the respective areas.

## **1.7 Justification of Study**

Timber is a natural and renewable material used for building construction. Most of the portal frame structures in Nigeria are constructed using steel. This is due to knowledge gap on the properties of timber to withstand high intensity of loads. Steel which possess high strength properties, is marked by high cost, especially in Nigeria where steel is imported. Wood on the other hand is a renewable raw material that grows back naturally.

There are different Wood species in Nigeria with varying strengths. If properly sawn and treated these timbers species can be used as a more economical alternative to steel and can be used in the construction of portal frame building, bridges and other infrastructures. Procuring the timber with the most desirable strength properties requires that tests be conducted on the timber species. Some of the test used to assess the strength properties of timber includes: flexural strength, bending stiffness and charpy impact test.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Overview of Timber Portal Frame

Timber portal frame are generally low rise structure columns and horizontal or pitched rafters connected by moment resisting connectors. Resistance to lateral and vertical actions is provided by the rigidity of the connectors and bending stiffness of the member which is increased by a suitable haunch depending on the rafter sections. (Ubani, 2020). Timber portal frame is a continuous frame with moment- resisting connections. If the connection between the column and the rafter is not rigid, the frame will be unstable in plane. The continuous nature of timber portal frame provides in-plane stability and resistance to lateral loads such as wind load. As a result, the stability of the frame and its resistance to deformation depends on the stiffness of the column and rafters which are the primary members of the frame (Ubani, 2020). According to (Kumar and Kumar, 2014) timber portal frame consist of two dimensional rigid frames having a basic characteristics of a rigid joint between column and beam. The main objective of this form of design is to reduce bending moment in the beam which allows the frame to act as one structural unit. Portal frame are generally used for single storey construction requiring a large unobstructed floor spaces like factories, shopping centers, warehouse, industrial complexes, place of worship, leisure house and sport complex (Omotoriogun, 2018). They are very efficient for enclosing large volumes making them useful for commercial and industrial purposes.

The functionality of this type of structure is usually influenced by factors such as the usage of the building, property developments law, availability of spaces and the desired quality of the finished building (Omotoriogun, 2018). By using framed structures, large spaces can be built with the minimum quantity of materials and some of the advantages are: ease of construction, effectiveness in construction, less maintenance cost, less weight and aesthetically pleasing appearance.

This section will review literatures relevant to experimental and analytical assessment of timber portal frame structures using Euro code 5.

## **2.2 Review of Structural Properties of Timber**

### **2.2.1 Charpy Energy Impact**

Unlike most engineering materials, Timber is an organic material that is anisotropic, hygroscopic and exhibits high variability of mechanical properties Nwokoye, (2015). These mechanical / structural properties include the elastic, plastic and elasto-plastic (viscoelastic) properties this timber species possess, which forms the basis of the timber design. The combined elastic and plastic energy of a material gives the toughness energy of that material Toughness of a material is defined as the ability of the material to absorb energy and plastically deform before failure occurs. It is the ability of a material to absorb sudden shock without breaking or shattering. Toughness of a material is also a measure of the plasticity and plasticity of a material in terms of energy absorbed. Toughness of timber material is inversely proportional to the temperature of the timber material; this can be attributed to the decrease in moisture content of the material when exposed to high temperature. The toughness of a material can be determined using two main methods; by finding the area under a stress-strain curve of the material and from an impact energy test of the material Charpy impact test is used to obtain the impact strength of timber materials. These impacts strength obtained in the form of toughness energy gives the amount of energy the timber can absorb before undergoing plastic deformation.

Nwokoye, (2015) wrote that the behaviours of timber material on the application of load can be explained as follows; Timber does not behave in a truly elastic mode, rather its behaviour is time dependent, the magnitude of the strain is influenced by a wide range of factors. Some of these are property dependent, such as density of the timber, angle of the grain relative to direction of load application and angle of the micro fibrils within the cell wall. Others are environmentally dependent, such as temperature and relative humidity.

On the application of load timber deforms, these deformations can be divided into the elastic, delayed elastic and viscous-deformation. The elastic deformation appears directly after loading, after which the deformation increase slowly under a constant load. This increase in deformation is made up of delayed elastic and viscous deformation. The difference between these two is that the delayed elastic deformation is recoverable after unloading, but the viscous-deformation is permanent (Marie, 2015). The delayed elastic deformation together with the viscous deformation is called creep. The viscous deformation which is a permanent deformation is also termed a plastic

deformation since its effect is irreversible. In materials such as timber where such behaviours are observed, they are treated as viscoelastic (elastic-plastic) material.

Ezeagu and Onwunduba, (2019), investigated the Charpy Energy Impact on Variable Nigerian Timber species short beams. Charpy impact test method was used to determine the impact energy/toughness of twenty locally available timber species, comprising of ten hardwoods and ten softwoods. Three sets of specimen (having dimension 125 mm by 12.5 mm by 12.5 mm) were obtained from each of the timber species. The findings indicate that the toughness energy obtained for the different softwood species was 1.49Kgfm/cm<sup>2</sup> for Obia, 2.89Kgfm/cm<sup>2</sup> for Okwe, 1.08Kgfm/cm<sup>2</sup> for Avu, 2.2Kgfm/cm<sup>2</sup> for Akpu, 2.4Kgfm/cm<sup>2</sup> for Anyasualo, 2.26Kgfm/cm<sup>2</sup> for Egba, 1.6Kgfm/cm<sup>2</sup> for Owen, 1.23Kgfm/cm<sup>2</sup> for Ojoo, 1.08Kgfm/cm<sup>2</sup> for Yellow man, 1.4Kgfm/cm<sup>2</sup> for Marima. While for the hardwood specimen, the following range of result was obtained; 2.22Kgfm/cm<sup>2</sup> for UghiMmanu, 2.4Kgfm/cm<sup>2</sup> for Ukpi, 2.62Kgfm/cm<sup>2</sup> for UburuMmiri, 1.85Kgfm/cm<sup>2</sup> for Iroko, 1.08Kgfm/cm<sup>2</sup> for Oha, 1.6Kgfm/cm<sup>2</sup> for Mango nkiti, 1.42Kgfm/cm<sup>2</sup> for Egbu, 1.46Kgfm/cm<sup>2</sup> for Meligna, 2.0Kgfm/cm<sup>2</sup> for Obala and 1.6Kgfm/cm<sup>2</sup> for Mahogany. A comparison of the toughness energy of the twenty timber specimen was made, which showed that *Cordiamilleni* (Okwe) possessed the highest impact energy/toughness which occurred when the grain orientation was parallel to the longitudinal axis of the specimen.

### **2.2.2 Bending Stiffness**

Bending stiffness (K) is the resistance of a member against bending deformation. It is a function of elastic modulus (E), the area of moment of inertia (I) of the beam cross section about the axis of interest, length of the beam and beam boundary condition. The load bearing capacity of glulam under bending is highly related to the material properties and the tensile capacity of the timber boards used. The glulam timber has more uniform mechanical properties mainly due to the intent of minimizing the influence or defects in timber (e.g. nodes, cracks, misalignment of fibbers) with the production process Helder et al, (2013).

Ioakar, et al., (2022) worked on the Analysis of Stiffness and Bending Strength of Green *Isobertia Doka* Timber Specie Grown in North Central Nigeria. The specimens for the experiment were obtained from log of *Isobertia doka* specie at green condition. Test specimens were prepared and tested in accordance with ASTM D198, (2018), ASTM D143, (2014) and BS

373 (1957). The mean values of moisture content and density obtained were 62.62% and 687kg/m<sup>3</sup> respectively. Three-point bending test was conducted at Civil Engineering Laboratory of the Ahmadu Bello University, Zaria using Universal testing machine of 250KN capacity. The mean values of bending strength and MOE recorded at green condition were 34.07N/mm<sup>2</sup> and 6035.19N/mm<sup>2</sup> respectively. The green grade bending stress and MOE computed were 6N/mm<sup>2</sup> and 345N/mm<sup>2</sup> respectively. While the corresponding dry grade stress were 19.31N/mm<sup>2</sup> and 8369.32N/mm<sup>2</sup> respectively. The green grade bending stress and MOE did not conform with that in Table 9 of NCP 2, (1973). The 18% moisture content grade bending and modular of elasticity conform to that of Wilson et al., (2021). The green strength obtained in this study could be used in designing and constructing timber structures that intends to use green *Isobertia doka* in construction.

Rahmon, et al., (2017) investigated the strength characterization and grading of Eku (*brachystegia eurycoma*) timber grown in Kwara State, Nigeria in accordance to BS 5268. Specimens used in the experiment were obtained from sawmills in Kwara State, Nigeria. The samples were seasoned naturally for seven months and prepared according to British Standard BS 373 (1957) Methods of Testing Small Clear Specimen of Timber. Test carried out on the prepared specimens were bending, tension, compression and shear parallel to grain, compression perpendicular to grain, moisture content and density. The timber properties determined were adjusted to the values at 12% and 18% moisture content in conformity with BS 5268 (2002) and NCP 2 (1973) for application in the Northern part of Nigeria. All the results were analyzed statistically. Eku has an average moisture content of 11.78% and mean air-dried density of 1148.25kg/m<sup>3</sup>. The Basic and grade stresses were computed using experimental failure stresses. The material properties showed that, Eku (*Brachystegia eurycoma*) can be graded and assigned to strength class D40. Therefore Eku timber has been successfully characterized and graded in accordance to British Standard and thereby recommended for load bearing structure like bridge beams.

Alake and Ekundayo, (2018), evaluated the suitability of *Funtumia africana*, *Alstonia congensis* and *Antiaris toxicaria* Nigerian timber species in the production of glue-laminated timber elements using adhesive (polyvinyl acetate glue) otherwise known locally as top bond. "The glue ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. The findings showed that the timber species were glue able and the bending strength across the species

were: *Funtumia Africana* solid and glue laminated beams at 65.22N/mm<sup>2</sup> and 36.44 N/mm<sup>2</sup>; *Alstonia congensis* solid and glulam beams at 26.15N/mm<sup>2</sup> and 25N/mm<sup>2</sup>; and *Antiaris toxicaria* beams at 14N/mm<sup>2</sup> and 20N/mm<sup>2</sup> in edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glue able using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated Nigerian timber species were of structural importance given the bending strength of 36.44 N/mm<sup>2</sup>, 25 N/mm<sup>2</sup> and 20 N/mm<sup>2</sup> in *Funtumia africana* (Ire), *Alstonia congensis* (Awun) and *Antiaris toxicaria* (Oriro)". It also goes to show that the kind of adhesive used for experiments should be taken into cognizance as regards when the load is applied to the members. The stronger the adhesives in grade the better the glulam in resisting load, thus making it a better structural member.

Jimoh and Ibitolu, (2018) conducted a study on characterization and grading of three selected timber species grown in Kwara state Nigeria according to EN 338 (2009) for structural use. The timbers namely *Vitex doniana*, *Ceiba pentandra* and *Pseudocedrela kotschy* were obtained in Ilorin, Kwara State of Nigeria. Physical and Mechanical properties of the selected timber species were determined in accordance with EN 13183-1 (2002) and EN 408 (2003) for structural timbers. Four point bending tests based on EN 408 (2003) with specimen 50x50x1000 mm were carried out using a Universal Testing Machine (UTM) to determine the bending strength and Modulus of Elasticity of the each timber specie. Characteristic values of Bending strength, Modulus of Rupture and Density were determined using EN 384(2004). The timber species; *Vitex doniana*, *Ceiba pentandra* and *Pseudocedrela kotschy* had equilibrium moisture content (EMC) of 15.70%, 13.71 % and 24.28 % respectively. Strength grading of timber species was then conducted by adjusting the material properties values of species to 12 % moisture content using the required adjustment factors. The timber were then graded according to EN338 (2009). *Pseudocedrela kotschy* had the highest density of 813 kg/m<sup>3</sup> followed by *Vitex doniana* (706 kg/m<sup>3</sup>) while *Ceiba pentandra* had the lowest density of 402 kg/m<sup>3</sup>. *Vitex doniana*, *ceiba pentandra* and *Pseudocedrela kotschy* were assigned to strength class D30, C16 and D35 respectively in accordance with EN338(2004).

Anshari et al. (2016) proposed a new approach to strengthen glulam beams which was tested under bending. Teles et al. (2013) performed a nondestructive test to assess the deflection of glulam beams made from hardwood. Rohanova and Lagana (2015) made a description on quality

parameters and the according requirements of structural timber. Fink et al. (2105) proposed and illustrated a probabilistic method for simulating the capacity of glued-laminated timber.

An important feature of glued-laminated timber is that the bonding of lamina can result in sections of higher strength than the strength of the single lamina from which they are constructed (1995).

Osuji and Inerhunwa, (2017) investigated the Characterization and Strength Classification of Timber Species in Akwa Ibom State, Nigeria for Structural Engineering Applications. In the study, determination of the physical and mechanical properties of timber species in Akwa Ibom state in southern Nigeria was carried out using methods defined in BS EN 1193:1998, BS EN 384:2016, BS EN 408:2010 and BS 373:1957, while strength classification of the timber species was in accordance with BS EN 338:2016. Twenty-five (25) samples each of five common timber species in Akwa Ibom namely: IyipOkoyo (*Stauditiastipitata*), Owen (*Mitragyna* spp.), Mkpeneke (*Uapacaguineensis*), Atarabang (*Xylophia* spp.) and Ata (*XanthoxylonSenegalensis*) were selected for the study. Results of physical properties indicated that the timber species have low susceptibility to fungal degradation and high durability but prone to dimensional change. Of the five timber species, Atarabang (*Xylophia* spp.) was the only softwood specie, suggesting that Akwa Ibom is dominated by hardwood species. Mechanical properties obtained were consistent with properties of strength class assigned to each timber specie and are useful parameters for structural engineering design process. The study further showed that the timber species have moderate to high densities and find application in general construction such as for flooring, formwork systems, cladding, joinery and paneling.

Shan et al. (2019) investigated the Mechanical Properties of Glued-Laminated Timber with Different Assembly Patterns. The bending stiffness and reliability of the beams were assessed according to the experimental results. The influence of the assembly pattern on the bending behavior of glued-laminated timber was investigated by finite element models. The results show that the assembly pattern of the section has little influence on the failure mode of glued-laminated timber.

Aguwa, (2015), assessed the structural reliability of the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. The study was conducted to ascertain the structural performance of Abura as a timber bridge beams. Samples of the Nigerian grown Abura timber were bought from timber market, seasoned naturally and their structural/strength properties were

determined at a moisture content of 18%. The determined strength properties were subjected to statistical analysis to determine some statistical parameters used in the design. Structural analysis and deterministic design of a timber bridge beam using the Nigerian grown Abura timber in accordance with BS 5268 were carried out under the Ultimate Limit State of loading. A computer programme in FORTRAN language was developed and used for reliability analysis of the Nigerian grown Abura timber bridge beam so designed, to ascertain its level of safety using First-Order Reliability Method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the Abura timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian grown Abura timber is a satisfactory structural material for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are  $0.23 \times 10^{-3}$  and  $0.27 \times 10^{-15}$  respectively, under the design conditions.

Carlos et al. (2020) conducted a study on the Assessment of Bending Properties of Sawn and Glulam Blackwood in Portugal. The valuation of Blackwood for structural applications has been considered through the non-destructive and destructive assessment of their mechanical properties as sawn wood. Their potential was also assessed for a more technologically engineered wood product, the glulam. The dynamic modulus of elasticity (MOE) was estimated through the Longitudinal Vibration Method (LVM) and the Transformed Section Method (TSM); the static MOE and bending strength were assessed through a four-point bending test. Agreement was obtained between both approaches. Sawn Portuguese Blackwood showed a density of  $647 \text{ kg/m}^3$ ,  $13,900 \text{ N/mm}^2$  of MOE and a bending strength of  $65 \text{ N/mm}^2$  (mean values). The glulam beams fabricated with this raw material had improved properties relative to sawn wood, most obviously concerning the bending strength, with an improvement of 29%.

Wdowiak and Brol (2020) tested beams manufactured from glued pine timber type c (combined), of which each was composed of four lamellas. Bending reinforcement CFRP tapes were glued to the bottom face of the beam or between the two bottom lamellas. This provided a 23% increase in load-bearing capacity and a 36.29% increase in rigidity. Moreover, reinforcement had a positive effect on the structural durability of the beams. Additionally, an analytical model was proposed as

a useful tool in calculations for such beams, showing high consistency with empirical testing results.

Idris and Muhammad, (2014) carried out a study on Bending Strength Classification of Some Common Nigerian Timber Species *Strombosia pustulata*, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Entandrophragma cylindricum*. Twelve (12) timber planks from the selected species were supplied from Ekiti state in the southern part of Nigeria. The specimens for experimental measurements were prepared from the obtained timber planks. Laboratory experiments were conducted to determine the physical and mechanical properties of the selected timber species in accordance with EN408 (2003). The mechanical properties were determined using four point bending test. The generated properties were used to obtain the characteristic values of the material properties in accordance with EN384 (2004). The selected timber species were then graded in accordance with EN 338 (2009). *Strombosia pustulata*, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Entandrophragma cylindricum* were assigned to strength classes D35, C14, D30 and D18, respectively. Other properties such as tensile and compressive strengths parallel and perpendicular to grains, shear strength as well as shear modulus were computed from the empirical relationships given in EN 338.

Jimoh and Chabi, (2017) evaluated the Physical and Mechanical Properties of *Daniellia Ogea* Harms Green Timber Species. The study presents some physical and mechanical properties of *Daniellia ogea* (Iya) green timber specie freshly felled from matured trees in forests around Ilorin Local Government, Kwara-State, Nigeria and cut into structural sizes within the Wood workshop of University of Ilorin premises according to BS EN 408: 2003. The moisture content and the density were the physical properties tested while the mechanical properties were the modulus of rupture and the local modulus of elasticity in bending strength, the apparent modulus of elasticity, the compressive strength perpendicular to grain then the compressive strength and tensile strength parallel to grain using the Universal Testing Machine of 300kN capacity of the food laboratory of the department of Agriculture of the University. Then the basic and grade stresses were determined and found to conform to the BS 5268 codes of practice. The results obtained post-tests for the moisture content and the density had respectively average values of 140.45% and 854.67 kg/m<sup>3</sup>.

Wilson, et al., (2017) conducted a review of mechanical strength properties of some selected timbers in Nigeria. Species of timber adopted for the study are: Iroko (*Chlorophora excelsa*), Mahogany (*Khaya ivorensis*), Fanpalm (*Borassus aethiopicum*), Ekki (*Lophira alata*), Opepe (*Nauclea diderrichii*), Apa (*Afzelia, bipindensis*), Ayin (*Anogeissus leiocarpus*), Afara (*Terminalia superba*). The Annual Book of ASTM Standard Section 4, (D143), method of testing small clear specimens of timber was adopted to evaluate the variation of strength properties of the species from standard speed and dimension specifications. The strength properties reviewed were, compression parallel to grain, compression perpendicular to grain, static bending (flexure) and tensile strength parallel to grain. From the review, it was found that strength of timbers along the grain is far greater than across or perpendicular to grain showing the anisotropic nature of timber. Prior soaking of the specimen before test accounts for reduction in strength. Also deviations from the specified dimensions and speed of testing of specimen will in one way or the other affect the accuracy of strength obtained in the test. It is therefore recommended that strict adherence to the test procedure and specifications should be followed so as to achieve the exact strength values of timbers and that further research work be done on other timbers in order to maximize their usefulness as a construction material.

Rahmon and Jimoh, (2020) investigated the strength characterization and grading of less-used nigerian grown timber species for structural applications. Ayunre (*Albizia zygia*), Eku (*Brachystegia eurycoma*) and Ire (*Funtunia elastica*) timber species were obtained from different sawmills in Ilorin, Nigeria and preparation of various test specimens are in accordance with British Standards BS 373: 1957. A total of 300 specimens were used in determining the strength characteristics of the timber species a 300kN capacity Testometric Universal Testing Machine (UTM) at Agricultural and Biosystems Engineering Laboratory, University of Ilorin. Twenty (20) specimens for each timber species were tested for structural/strength properties according to the British Standard. Results show that the timber species had average moisture contents of 12.47, 11.78 and 12.71% for Ayunre, Eku and Ire, respectively. For density classification, Ayunre and Eku were classified as heavy wood and Ire as light wood. The results obtained provided quantitative details of the strength properties of selected timber species which can be used in determining the application of these timber species for structural applications. The timber species were, therefore graded according to NCP 2 (1973), EN 338 (2009) and BS 5268 (2002).

Ekundayo, (2015) conducted a study on comparative assessment of the strengths of solid and glued laminated timber. The research therefore conducted laboratory experiments on selected timber species namely; Ire (*Funtumia africana*), Awun (*Alstonia congensis*) and Oriro (*Antiaristoxicaria*) being readily available and widely used species with no information on Oriro and Ire in NCP 2 of 1973. The aim was to assess their strength properties as glulam elements with the view to improving their structural capacity. It also set out to determine their glueability, the effects of temperature variation on compressive strength parallel to grain for glulam short columns by subjecting specimens of equal dimension for the three species to different temperatures of 0 °C, 40 °C, 50 °C, 70 °C, 100 °C and room temperature for 4 hours in an electric oven prior to testing; to compare the mechanical properties of solid and glulam elements. In furtherance, specimens were prepared and tested for; static bending strength, compression parallel and perpendicular to grain, density and moisture content in line with ASTM D193, EN 408(2003) and EN13183-1(2002). The research established that the species are; structurally glueable, that due to temperature increase compressive strength is lost in glulam columns from control temperature (30°C and 27.9°C) to 100 °C was 41% 14.4% and 21.6% in Ire, Awun and Oriro. Results showed that glulam elements developed 55%, 95% and 143% of clear solid wood bending strength and that bending strength of 65.22N/mm<sup>2</sup>; 36.44N/mm<sup>2</sup>, 26.15N/mm<sup>2</sup>; 25N/mm<sup>2</sup> and 14N/mm<sup>2</sup>; 20N/mm<sup>2</sup> in solid and glulam in the species are structurally significant. The study has therefore demonstrated that the timber species studied can be engineered to load bearing glued laminated structural elements using polyvinyl acetate glue without severe loss of strength below and above room temperature.

### **2.2.3 Flexural Strength**

Ezeagu et al., (2015) defines Flexural strength or modulus of rupture for a material as the strength of the material in bending, expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure. Flexural strength as discussed by (Ekundayo and Alake, 2018), is commonly known as modulus of rupture and it is ‘defined as the bending stress in a flexural member at the failure load and is computed assuming an elastic stress distribution. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Flexural rigidity is the stiffness of a material when subject to bending also defined as the force couple required to bend a rigid structure to a unit curvature. In

other words, Flexural strength of a material can be defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen in bending.

Thuc, (2018), investigated the flexural behaviour of hardwood and softwood beams with glue laminated connectors, the experiment include strengthening and testing of a total of 91 beam (51 hardwood and 41 softwood). Each beam was loaded above it service load until complete failure. The findings obtained indicate that the flexural strength of the hardwood laminate was relatively higher than that of the softwood with the value for hardwood ranging from 60.03N/mm<sup>2</sup> to 76.64N/mm<sup>2</sup> while the softwood ranges from 38.89N/mm<sup>2</sup> to 51.29N/mm<sup>2</sup>.

Aguwa, J. I., (2015), assessed the structural reliability of the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. The study was conducted to ascertain the structural performance of Abura as a timber bridge beams. Samples of the Nigerian grown

Abura timber were bought from timber market, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%. The determined strength properties were subjected to statistical analysis to determine some statistical parameters used in the design. Structural analysis and deterministic design of a timber bridge beam using the Nigerian grown Abura timber in accordance with BS 5268 were carried out under the Ultimate Limit State of loading. A computer programme in FORTRAN language was developed and used for reliability analysis of the Nigerian grown Abura timber bridge beam so designed, to ascertain its level of safety using First-Order Reliability Method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the Abura timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian grown Abura timber is a satisfactory structural material for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are  $0.23 \times 10^{-3}$  and  $0.27 \times 10^{-15}$  respectively, under the design conditions.

Okafor and Ezeagu, (2020) conducted a study on analysis of Bending Stiffness and Strength of Glue Laminated Nigerian Timber. Five hardwoods and five softwoods were investigated, namely: *Mansonia*, Mahogany, Orji, Ukpi, Ufi mmanu, White Afara, Owen, Melina, Akpu and Ubia. The dimensions of the wood specimens are 100mm×50mm×20mm. The wood samples were tested for flexural strength using a Universal Testing Tensile Machine. The results obtained shows that Owen

has the highest ultimate wood strength of 46.806N/mm<sup>2</sup> for the softwood glulam. Ukpi has the highest wood strength of 73.375N/mm<sup>2</sup> for the hardwood glulam, and highest MOE at 2412.93N/mm<sup>2</sup>. Akpu recorded the weakest sample with bending strength values for glulam at 11.929 N/mm<sup>2</sup>.

Yusof and Rahman, (2017) conducted a study on flexural strengthening of timber beams using carbon fibre reinforced polymer. Five timber beams of Yellow Meranti species were tested. One of the beams was used as a control beam (un-strengthened) while the remaining four beams were strengthened before tested to failure under four point loading. The results showed that the strengthened beams performed better than the control beam. The ultimate and service load of the strengthened beams were increased between 31.8 – 44.5% and 27.1 – 80%, respectively when the CFRP area was between 0.15 – 0.42%. The strengthening of timber beams with CFRP has enhanced their stiffness. The stiffness of the beams was increased between 32.6 – 87.6%. The tensile crack and crushing occurred simultaneously (balanced reinforced) when the CFRP was about 0.16%. Modification factors for bending strength and stiffness for timber beam strengthened using CFRP plates were proposed from this research

Jimoh and Chabi, (2017) determined the strength class of Daniellia Ogea Harms green timber species and the results conform with BS 5268. Classification of four seasoned Timber species grown in Nigeria including Isoberlinia doka was carried out by Wilson, et al. (2021) and the results revealed that Isoberlinia doka is a hardwood and assigned class N3 in line with NCP 2, (1973). Characterization of two commonly used timber species in Nigeria; Isoberlinia doka and Anogeissus leiocarpus for structural use was carried out by Jimoh, et al., (2018) in accordance with BS 5268:2002 and NCP2:1973. The study assigned class N7 to Isoberlinia doka.

Ekundayo and Alake, (2018) conducted a study on the bending strength of solid and glue laminated timber from three selected Nigerian Timber species. Three species of timber namely: Funtumia africana, Alstonia congensis and Antiaris toxicora were investigated and used for the production of glue laminated timber elements using polyvinyl acetate glue. The glue-ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. Results showed that the timber species were glueable and bending strength across the species was 65.22N/mm<sup>2</sup> vs 36.44N/mm<sup>2</sup>; 26.15N/mm<sup>2</sup> vs 25N/mm<sup>2</sup>; 14N/mm<sup>2</sup> vs 20N/mm<sup>2</sup> in solid vs glued laminated Funtumia Africana, Alstonia congensis and Antiaris toxicaria beams respectively in

edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glueable using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated Nigerian timber species were of structural significance given the bending strength of 36.44N/mm<sup>2</sup>, 25N/mm<sup>2</sup> and 20N/mm<sup>2</sup> in *Funtumia africana* (Ire), *Alstonia congensis*(Awun) and *Antiaris toxicaria* (Oriro).

Aguwa and Sadiku, (2014). Conducted a reliability study on the Nigerian Ekki timber as bridge beam in bending under the ultimate limit state of loading. The study was carried out to ascertain the structural performance of the timber bridge beam. Samples of the Nigerian Ekki timber were collected, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%, in accordance with the British Standard BS 373, methods of testing small clear specimens of timber. Statistical analysis was carried out using the structural/strength properties determined. Structural analysis and design of a timber bridge beam using the Nigerian Ekki timber in accordance with BS 5268 were carried out under the ultimate limit state of loading. Reliability analysis of the Ekki timber bridge beam so designed to ascertain its level of safety was carried out using first-order reliability method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian Ekki timber is a satisfactory structural material for timber bridge beams at depth of 400 mm, breadth of 150 mm and span of 5000 to 7000 mm under the ultimate limit state of loading. Its probability of failure in bending under the specified operating conditions is  $1.1 \times 10^{-7}$ , that is, one in ten million.

Tunkut, et al., (2014), investigated the physical and mechanical properties of laminated wood panels manufactured with Nanoparticles Filled Poly (vinyl acetate) Adhesive. PVAc adhesive was prepared with adding of SiO<sub>2</sub>, TiO<sub>2</sub> and nano clays for 0.5%, 1%, and 2% loadings. Spruce (*Picea orientalis* L) and Oak (*Quercus robur*) wood species were used to produce the panels. The prepared adhesive was applied to wood layers, and then all layers were combined to obtain laminated wood panels which have 5 layers. The panels having 12% moisture content (MC) were tested to determine the physical properties such as water absorption, thickness swelling; and the mechanical properties such as flexural strength and modulus of elasticity in flexure and compression strength. The results showed that the density and moisture content between wood species was found to be slightly different to each one, but water absorption and thickness swelling were determined to

increase with increasing of loading rates. The mechanical properties were found to increase with nanoparticles and the maximum increasing of mechanical properties were determined to panels with nanoclays at 2%. Nanoclays at 2% can be advised to the production of laminated wood panels due to improving the mechanical properties more than 50%.

Zziwa et al. (2016) evaluated the basic strength indicators of *Mangifera Indica* Timber specie to ascertain its suitability for furniture construction. Thirty five small clear test samples for static bending and 50 samples for basic density tests was prepared according to standard methods. Static bending tests were carried out in accordance with BS 373 (1957) using a Testometric AX M500 25KN Universal Testing Machine at a loading rate of 6.6 mm min<sup>-1</sup>. MOE and MOR results were adjusted to their 12% equilibrium moisture content equivalents. Basic density was determined by the water displacement method. The mean basic density of *Mangifera indica* ranged from 534 kg/m<sup>3</sup> to 585kg/m<sup>3</sup>. The mean MOE and MOR of *M. indica* ranged from 5,617.0 N/mm<sup>2</sup> to 8,027.8N/mm<sup>2</sup> and 46.6 N/mm<sup>2</sup> to 74.2 N/mm<sup>2</sup> respectively.

Abubakar, et al., (2020) carried out structural reliability based assessment of Nigerian *Anogeissus schimperi* timber bridge beam in shear and bearing forces. Specimens for laboratory tests were prepared using the timber specie in accordance with BS 373 (1957). Tests were carried out to determine the physical and mechanical properties at 12% moisture content in line with BS 5268 (2002). Statistical analysis was carried out using strength properties obtained and the specie was classified to strength class D60, confirmed to be Hardwood. *Anogeissus schimperi* timber bridge beam was designed in accordance to BS5268 (2002), using deterministic approach. While, reliability analysis to confirm the safety level of the timber bridge beam designed was carried out using constant failure rate model in accordance with Jimoh, (2018). Sensitivity analysis to ascertain the safety margin of a simply supported timber bridge beam subjected to Shear and bearing by varying the span, depth, width and live load was carried out. Results of reliability analysis showed that *Anogeissus schimperi* met the minimum reliability index of 0.5 under ultimate state of loading in Shear and bearing. Safety index was found to be directly proportional to the depth and width but inversely proportional to the span and live load of the timber bridge beam during Sensitivity Analysis. The result confirmed that *Anogeissus schimperi* specie from north western Nigeria at 400mm depth, 150mm breadth and 5000mm span under ultimate limit state loading in Shear and bearing can be used as a reliable timber bridge beam material.

## **2.3 Strength Class of Timber**

Solid timber for structural application has to be strength graded prior to its use (Kisito et al, 2014). In order to remain economic, the grading process usually focuses on the most important physical and mechanical properties; density, modulus of elasticity (MOE) and bending strength (JCSS, 2006). Timber is assigned to its appropriate strength class based on respective limits given in EN 338 (Kisito et al, 2014). Additional mechanical properties such as tensile and compressive strength parallel and perpendicular to the grain are derived from the basic property values by standard empirical relationships (EN 384, 2004; JCSS, 2006).

### **2.3.1 Timber Strength Classification System**

Prior to April, 2010 the structural design of timber members in the United Kingdom is related to Part 2 of BS 5268, and is based on permissible stress design philosophy. Elastic theory is used to analyse structures under various loading conditions to give the worst design case. Then timber sections are chosen so that the permissible stresses are not exceeded at any point on the structure. BS 5268 par 2, on which the design of structural timber is based, was originally published as CP 112 in 1952, revised later in 1967 and, extensively revised in 1971.

The 'basic stresses' introduced in CP 112 were determined from carrying out short-term loading tests on small timber specimens free from all defects. The data was used to estimate the minimum strength which was taken as the value below which not more than 1% of the test results fell. These strengths were multiplied by a reduction factor to give basic stresses. The reduction factor made an allowance for the reduction in strength due to duration of loading, size of specimen and other effects normally associated with a safety factor, such as accidental overloading, simplifying assumptions made during design and design inaccuracy, together with poor workmanship.

Basic stress was defined as the stress that could be permanently sustained by timber free from any strength-reducing characteristics. Since 1967 there have been continuing and significant changes affecting the structural use of timber. Research studies in the UK and other countries had shown the need for a review of the stress values and modification factors given in the original code. With the introduction of BS 5268 in 1984, the concept of 'basic stresses' was largely abandoned and the new approach for assessing the strength of timber moved somewhat in line with limit states' design philosophy.

In 1996, Part 2 of BS 5268 was revised with a clear aim to bring this code as close as possible to, and to run in parallel with, Eurocode 5: Design of timber structures, Part 1.1 General rules and rules for buildings. The overall aim has been to incorporate material specifications and design approaches from Eurocode 5, while maintaining a permissible stress code with which designers, accustomed to BS 5268, will feel familiar and be able to use without difficulty.

The concept of grouping timber into strength classes was introduced into the UK with BS 5268: Part 2 in 1984. Strength classes offer a number of advantages both to the designer and the supplier of timber. The designer can undertake his design without the need to check on the availability and price of a large number of species and grades which he might use. Suppliers can supply any of the species/grade combinations that meet the strength class in a specification. The concept also allows new species to be introduced onto the market without affecting existing specifications for timber. The latest strength classes used in BS 5268: Part 2: 1996 relate to the European strength classes which are defined in EN 338 Structural timber strength classes.

There are a total of 16 strength classes, C14 to C40 for softwoods and D30 to D70 for hardwoods as given in Table 7 of BS 5268: Part 2 (1996). The number in each strength class refers to its 'characteristic bending strength' value, for example, C40 timber has a characteristic bending strength of 40N/mm<sup>2</sup>. Characteristic values larger than the grade stress values used in BS 5268: Part 2, as they do not include effects of long-term loading and safety factors.

One benefits of using characteristic value of material properties rather than grade stress is that it will make it easier to sanction the use of new material properties and component for structural purposes, since such values can be utilized immediately, without first having to determine what reduction factors are needed to convert them to permissible or working values. In Table 2.1, typical grade stresses and characteristic values for timber strength class D70 are presented.

**Table 2.1: Strength Properties of D70 Timber Based on BS 5268 and EN 338 Source: BS 5268 (1996); EN 338 (2009)**

Material Property	Strength Class D70	
	Grade Stress (BS 5268)	EN 338
Tension Parallel to Grain	13.8	42.0
Bending Strength Parallel to Grain	13.0	70.0
Compression Parallel to Grain	13.8	34.0
Shear Strength	2.6	6.0

## 2.4 Load Duration on Timber Structures

Wood experiences a significant loss of strength and stiffness when loaded over a period of time. The effect of ten years load duration may amount to a strength loss of approximately 40 % for solid wood (Toratti, 2014). This phenomenon is known as creep-rupture – often called the duration of load (DOL) effect. The issue has been a subject of particular interest for everyone in the timber engineering community concerned with safe and efficient engineering design. Research on both clear wood and structural timber (Hoffmeyer, 2014) sustaining long-term constant load is well documented in the literature.

### 2.4.1 Euro code 5 Load Duration Factor (Kmod)

Load duration factors to account for timber design under sustained load are given in Eurocode. The kmod is based on timber service and load duration classes. The service classes are defined in clause 2.3.1.3 of the Eurocode 5 as follows;

Service class 1 refers to timber used internally in a continuously heated building. The average moisture content likely to be attained in service condition is 12%. Service class 2 refers to timber used in a covered building. The average moisture content likely to be attained in service condition if building is generally heated is 15%, and if unheated, 18%. Service class 3 refers to timber used externally and fully exposed. The average moisture content likely to be attained in service condition is over 20%.

**Table 2.2: Euro code 5 Load Duration Class Source: Eurocode 5: Part 1.1 (2004)**

<b>Load Duration Class</b>	<b>Order of Accumulated Duration of Characteristic load</b>	<b>Example of Loading</b>
Permanent	Greater than 10 years	Self weight
Long-term	6 month to 10 years	Storage
Medium-term	1 week to 6 month	Imposed floor load
Short-term	Less than 1 week	Snow maintenance
Instantaneous	Instantly	Wind, impact

## **2.5 Review of Selected Timber Species**

*Swietenia macrophylla* are the botanical name with which Mahogany is identified with. It is a tropical evergreen or deciduous tree that can attain heights of 150 feet. Mahogany is a member of the Meliaceae, which includes other trees with notable wood for cabinet making. *Swietenia macrophylla* is world renowned for its beautifully grained, hard, red-brown wood. It has been harvested since 1500 A.D. for its wood, with large branches being in higher demand than the trunk. This is due to the closeness of the grain in the branch's wood. Mahogany is used for furniture, fixtures, musical instruments, millwork, cars, ships, boats, caskets, airplanes, foundry patterns, veneer, and plywood (Hill, 1952).

The history of the term Mahogany raises a taxonomic controversy. When the Yoruba tribe was brought from Nigeria to Jamaica as slaves, they recognized a tree in Jamaica just like one back home. The American mahogany, *S. mahogani*, looked identical to the African Mahogany, *Khaya sengalensis*. For this reason the Yorubas referred to American Mahogany as they did African Mahogany, M'Oganwo. Over time the term was changed to M'Ogani by the Yorubas. Americans spelled it how they heard it, and thus M'Ogami became Mahogany. The controversy is that the Yorubas believed African and American Mahogany to be the same tree, but French botanist Adrien de Jussieu (1830) insisted that they were from two different genera. He based this on his African Mahogany specimens having four parted flowers instead of the five parts displayed by American Mahogany.

Triplochiton Scleroxylon (Obeche), is a large deciduous forest tree commonly attaining 45m in height and 1.5m in diameter (Martins, 1984). The specie is geographically distributed in Benin, Cameroon, Central Africa Republic, Congo, Cote d'voire, Democratic Republic of Congo, Equatorial Guinea, Ghana, Guinea, Liberia, Sierra-Leone, Togo and Nigeria (Cirad, 2009). Although, the main uses of the specie are for timber, it is also used for fibreboard and particleboard. The heartwood and sapwood are not clearly differentiated. There is usually an unpleasant odour when the specie is freshly cut, but the smell disappears after it is seasoned. The sapwood is permeable. It respond well to hand and machine tools in moulding and most operations.

The specie has good gluing qualities. It is light yellow in colour. It appeared in EN 350-2 (1994). It is a class 5 (non-durable) material, susceptible to termite attack, thereby requiring preservative treatment. It is produce poor connection with nails but good with glue. Based on the work at Cirad (2009), at 12% moisture content, the specie has a density of 380kg/m<sup>3</sup>, crushing strength of 30MPa, static bending strength of 52MPa and modulus of elasticity of 7260MPa.

Lophira Alata (Ekki) occurs in evergreen and moist decidous forest in freshwater swamp forest (NCP 2, 1973). The tree may attain a height of 50m. Trunk diameter range from 1.5 to 2.5m, without buttress (Martin, 1884). Lophira Alata (Ekki) is dark red in colour. The specie appeared in the EN 350-2 (1994). It is a class 2 (durable), highly resistant to termite attack. It is non-permeable to preservative treatment. It has a good embedment to nails, but pre-boring is required when driving. Based on the study conducted at Cirad (2009), the species has a density of 1006kg/m<sup>3</sup>, crushing strength of 96MPa, static bending strength of 162MPa and Modulus of elasticity of 21420MPa; all at 12% moisture content. The tree is used for heavy duty construction work, such as harbour works, heavy-duty flooring, rail road cross ties.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Material Collection and Preparation

A total of three timber samples were dimensioned, this samples were cut into a dimension of 150mm x 100mm x 50mm for the determination of it structural properties. These materials were procured from a timber shed at Head Bridge in Onitsha Anambra State Nigeria.



**Plate 3.0: Sample of Obeche (*Triplochiton scleroxylon*) used for the Study**



**Plate 3.1: Sample of Mahogany (*Swietenia macrophylla*) used for the Study**



**Plate 3.2: Sample of Ekki (*Lophira Alata*) used for the Study**

**Table 3.1: List of Timber Species Dimension and Classification.**

<b>Botanical Names</b>	<b>Classification</b>	<b>Other Names</b>	<b>Dimension</b>
Swietenia macrophylla	Hardwood	Mahogany	150mm x 100mm x 50mm
Triplochiton scleroxylon	Hardwood	Obeche	150mm x 100mm x 50mm
Lophira Alata	Hardwood	Ekki	150mm x 100mm x 50mm

### **3.2 Method of Study**

The laboratory test and procedure used to obtain the research findings are highlighted below:

#### **3.2.1 Bending Strength Test**

Bending stiffness test is performed to determine the resistance of a member against bending deformation. It is a function of elastic modulus  $E$ , the area of moment of inertia  $I$  of the beam cross section about the axis of interest, length of the beam and beam boundary condition. The load bearing capacity of glulam under bending is highly related to the material properties and the tensile capacity of the timber boards used. The glulam timber has more uniform mechanical properties mainly due to the intent of minimizing the influence or defects in timber (e.g. nodes, cracks misalignment of fibbers) with the production process Helder et al, (2013).

#### **Apparatus Employed**

1. M500 – 25CT universal testometric testing machine
2. Dial gauge deflector
3. Calibrated steel roller beam supports
4. Metal plate
5. Steel roller loading device



**Plate 3.3: Testometric Universal Testing Machine**

### **Test Procedure**

1. The specimen was measured and weighed.
2. The centre loading point and supports were marked, such that the orientation of the test species ensured perpendicularity to the direction of loading.
3. The test piece was then stabilized with an initial load, after which the dial gauge is mounted and adjusted to zero to monitor deflection.
4. The test piece was supported at the ends while unrestrained to allow bending action throughout the member and ensure failure due to flexure.
5. The speed of the machine was set to load the test piece and allow adequate monitoring of the dial gauge.
6. Reading on the dial gauge was then taken at intervals within the elastic limit before failure.

## **Computation of Bending Stiffness**

The bending Stiffness is calculated as follows:

$$F_m = \frac{3F_{max}l}{2bh}$$

Where  $F_m$  is the bending strength (in Newton),  $F_{max}$  is the maximum Load (in Newton),  $b$  is the width of cross section in bending test (mm),  $h$  is the depth of cross section in bending test (mm) and  $l$  is the length of test specimen between supports (mm)”.  
and  $l$  is the length of test specimen between supports (mm)”).

### **3.2.2 Charpy Impact Test**

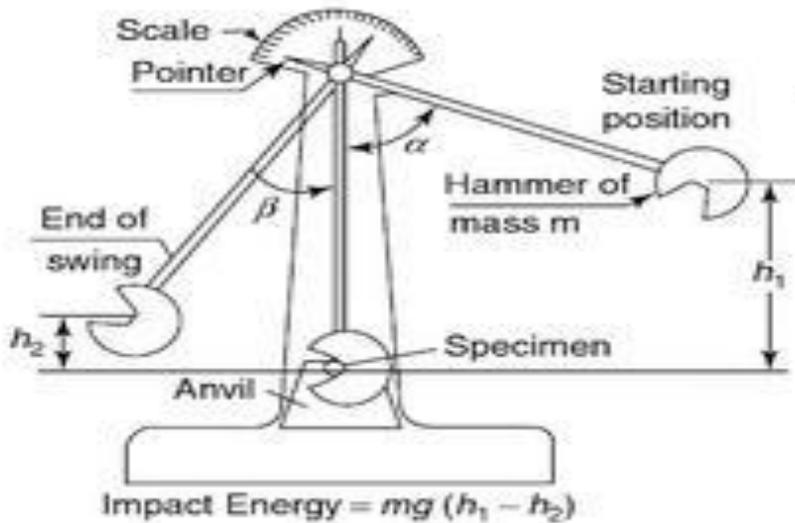
Impact test determines the amount of energy absorbed by a material during fracture. This energy absorbed indicates the toughness of the material which can be defined as the capacity of materials to absorb energy and deform plastically before fracturing. The toughness of a material is related with both the strength and ductility of the material.

Impact testing of material involves the sudden and dynamic application of the load. Generally a pendulum is made to swing from a fixed height and strike the standard impact specimen. In the Charpy test, the specimen is placed in a horizontal position with the notched (U or V shape) side facing a way from the pendulum.

#### **Apparatus Employed**

The apparatus used for this test include:

1. A single blow impact testing machine with a calibrated dial so as to give direct reading of energy absorbed in breaking specimen on a single blow as schematically illustrated.
2. A calibrated dial gauge to give direct reading of angle covered.
3. Ruler
4. Specimen setting fixtures



**Plate 3.4: Charpy impact testing machine**

### Test Procedure

The test procedure was done in accordance to specification by M.LGambhir, (2014) and this are enumerated as follows:

1. Measure the dimensions of the timber specimen.
2. Set the latching mechanism in the upper position.
3. Lift the pendulum to its upper position and secure it with the safety latching mechanism.
4. Check whether the testing machine has been adjusted accurately,
5. Using positioning gauge place the Charpy V-notch test specimen horizontally across supports on the anvil in the path of a pendulum with the V-notch test specimen with the notch facing away from the hammer make sure the specimen is centered within the anvil jaws and tightened firmly in the position.
6. Slide the indicator pointer to the left until it indicates the maximum energy range on the upper Charpy tension scale.
7. Raise the pendulum arm to the right until it is firmly supported by the latching mechanism.

**Caution: make sure the safety latch is clear when raising the pendulum arm into this test position.**

8. The test conductor or laboratory instructor shall then release the pendulum by pushing up on the release knob. The hammer will drop striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator will move and stop when peak swing through is registered, providing a direct reading of the energy absorbed by the test specimen. Read the indicated value from the charpy scale and record.
9. Apply the hand brake when the pendulum has returned to its stable hanging vertical position.
10. Remove the specimen from the testing area and examine the failure surface.
11. Leave pendulum in the down hanging vertical position until another test is to be performed

### **3.2.3 Moisture Content Determination for Assigning of Strength Class**

Moisture content (MC) is the amount of water contained in the wood, usually expressed as a percentage of the mass of the oven-dried wood. The species MCs were determined in accordance with EN 13183-1. The MC of each slice was determined by first measuring its initial mass before drying using weighing balance. The test slices were then oven dried at a temperature of 103°C until constant mass is reached. The initial and final mass of each slice were recorded and the MC was then computed from the equation:

$$\text{Moisture Content (\%)} = \frac{\text{Original Mass} - \text{Oven Dried Mass}}{\text{Oven Dry Mass}} \times 100$$

#### **Apparatus for Moisture Content Determination**

1. An Electric Oven
2. Digital Weighing Balance
3. Recording Sheet

### **3.3 Adjustment of Moisture Content and Allocation of Strength Class**

According to Graham (2001), there is no definite formula for adjusting for moisture content of timber specie. This is due to the vast number of species, with each having its own inherent variability. There have been two main schools of thought on the derivation of a suitable generalized formula for adjusting for moisture content; one being driven by the wood scientists while the other

has been developed by the wood engineers. For sawn timber the European Standard used to correct strength parameter measurement for varying moisture contents is BS EN 384 (2004).

Strength class values according to EN 338(2009) are derived from timbers at about 12% moisture content, which is taken as a reference moisture content. Thus the strength characteristics of timber were adjusted to 12% reference moisture content using equation 3.1 and then these results are converted to their equivalent moisture content of 18% by interpolation which is the acceptable moisture content of timber to be used in Northern Nigeria using equation 3.1.

$$F_{12} = F_w (1 + \lambda (W - 12)). \tag{3.1}$$

$F_{12}$  = the ultimate strength at 12% moisture content.

$W$  = the moisture content at the time of testing.

$F_w$  = the ultimate strength at the moisture content at the time of testing.

$\lambda$  = the adjustment factor for moisture content, equivalent to the percentage change in strength values for 1% change in moisture content shown in Table 3.2.

**Table 3.2 Adjustment Factor for Wood State of Stress**

State of Stress	Adjustment Factor	Reference
Modulus of Elasticity	0.02	BS 384:2004
Bending Strength (Modulus of Rupture MOR)	0.04	Zziwa <i>et al.</i> (2020)
Shear Parallel to grain	0.03	Karlsen and Slitskouhov (2015)
Compression Parallel/Perpendicular to grain	0.03	BS 384:2004
Tensile parallel to grain	0.05	Karlsen and Slitskouhov (2015)

Density	-0.005	Abubakar and Nabade (2014)
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$$\text{Moisture Content} 18\% = \frac{F_{12\%} \times 18}{12} \quad (3.2)$$

According to EN 338 (2009), a solid timber can be allocated a strength class if its characteristic values of bending strength and density are equal to or greater than the values for that strength class given in Table 1 of EN 338(2009), and its characteristic mean MOE in bending equals or exceeds 95% of the value given for that strength class.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

This chapter presents key findings obtained from experimental investigation of selected species of timber commonly used in portal frame construction and also the proposed allocation of strength class to the selected species of timber.

#### 4.1 Results of the Experiment

**Table 4.1: Modulus of Elasticity Test Results for Selected Species of Timber Test Pieces**

Test Piece Number	Modulus of Elasticity (N/mm <sup>2</sup> )		
	Mahogany	Obeche	Ekki
1	7986.6	4638.2	24687.4
2	8009.6	5452.5	22250.4
3	8419.2	6245.3	16998.5
4	7294.3	3459.2	21894.6
5	9245.4	4602.5	21570.4
6	8342.2	5453.2	22815.1
7	8786.4	6538.4	19386.4
8	8665.2	4811.2	23562.8
9	8452.3	4523.8	18271.4
10	8468.5	5453.2	19487.8
11	8388.2	4482.4	18271.4
12	7986.2	5732.9	24186.4
13	7794.5	3854.2	22919.5
14	8045.8	4428.6	25060.4
15	8225.4	4752.8	21894.6

**Table 4.2: Bending Strength Test Results for Selected Species of Timber Test Pieces**

Test Piece Number	Bending Strength (N/mm <sup>2</sup> )		
	Mahogany	Obeche	Ekki
1	46.5	65	53.4
2	49.6	64.3	68.3
3	51.6	58	90.2
4	45.6	58.6	57.9
5	47.5	53.1	48.5
6	58	36.8	70.6
7	55.8	70.2	79.4
8	58.4	54.3	68.1
9	46.9	48.4	61.9
10	42.1	40.3	72.8
11	51.8	62.8	68.8
12	50	72.4	72.4
13	53.5	40.9	75.6
14	50.1	55.6	58.9
15	55.9	59	70.1

**Table 4.3: Charpy Impact Test Results for Selected Species of Timber**

Grain angle	Energy Absorbed (Joules/cm <sup>2</sup> )		
	Mahogany	Ekki	Obeche
45	1.4	1.53	1.39
60	1.27	1.4	1.16
90	1.97	1.79	1.68
120	2.34	2.14	1.92
150	2.5	2.45	2.3
180	2.64	2.86	2.72

**Table 4.4: Proposed Allocation of Strength Class for Mahogany (*Swietenia macrophylla*)**

<b>Reference Material Properties</b>	<b>12% Adjusted Value</b>	<b>18% Moisture Content Adjusted Values</b>	<b>Allocated Strength Class EN, 338 (2009)</b>
Bending Strength (N/mm <sup>2</sup> )	45.63 (Characteristic)	50.41 (Mean)	D18
Modulus of Elasticity (kN/mm <sup>2</sup> )	6.59 (Mean)	5.95 (Mean)	

**Table 4.5: Proposed Allocation of Strength Class for Obeche (*Triplochiton scleroxylon*)**

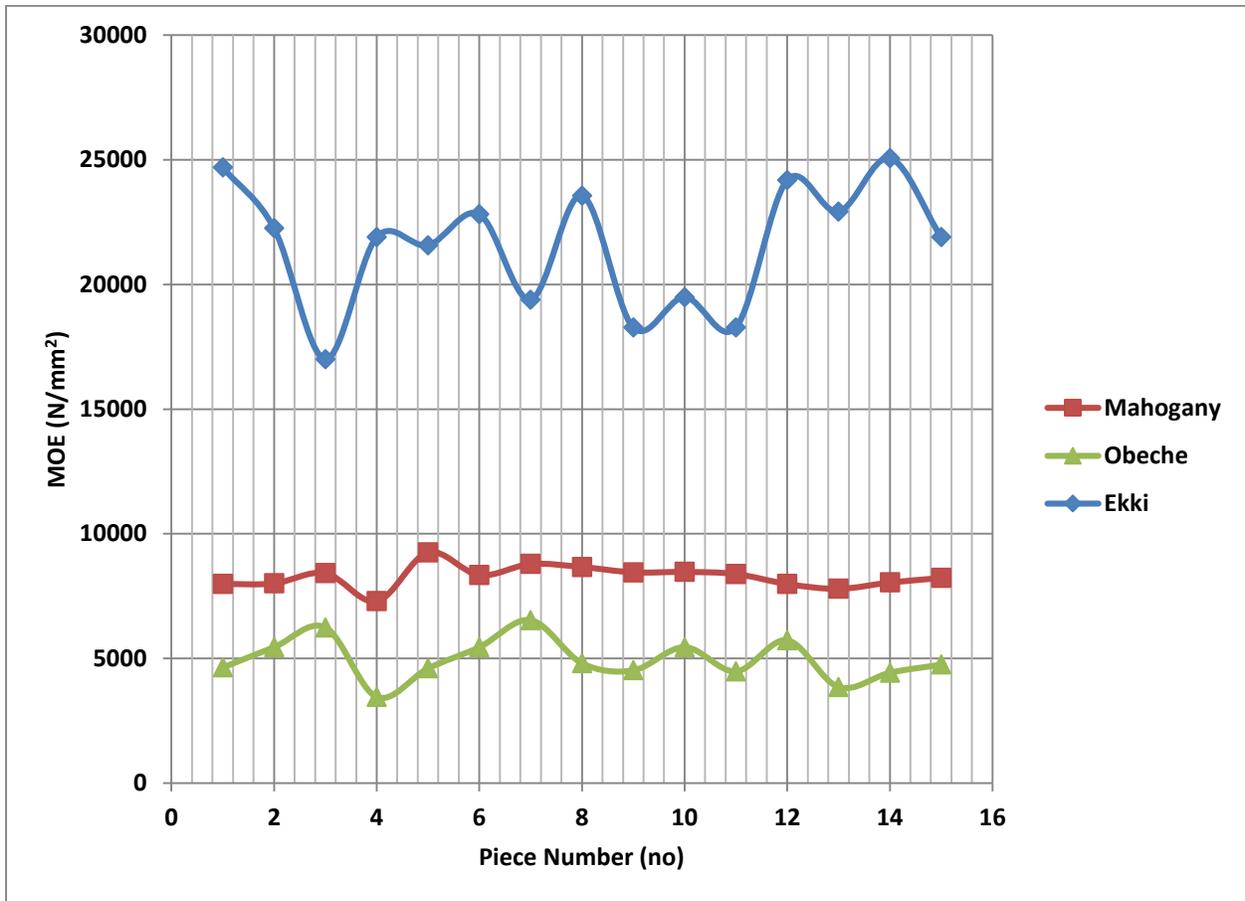
<b>Reference Material Properties</b>	<b>12% Adjusted Value</b>	<b>18% Moisture Content Adjusted Values</b>	<b>Allocated Strength Class EN, 338 (2009)</b>
Bending Strength (N/mm <sup>2</sup> )	50.13 (Characteristic)	71.79 (Mean)	D18
Modulus of Elasticity (kN/mm <sup>2</sup> )	13.56 (Mean)	12.25 (Mean)	

**Table 4.6: Proposed Allocation of Strength Class for Ekki (*Lophira Alata*)**

<b>Reference Material Properties</b>	<b>12% Adjusted Value</b>	<b>18% Moisture Content Adjusted Values</b>	<b>Allocated Strength Class EN, 338 (2009)</b>
Bending Strength (N/mm <sup>2</sup> )	83.54 (Characteristic)	86.62 (Mean)	D60
Modulus of Elasticity (kN/mm <sup>2</sup> )	23.08 (Mean)	20.08 (Mean)	

## 4.2 Discussion on Findings

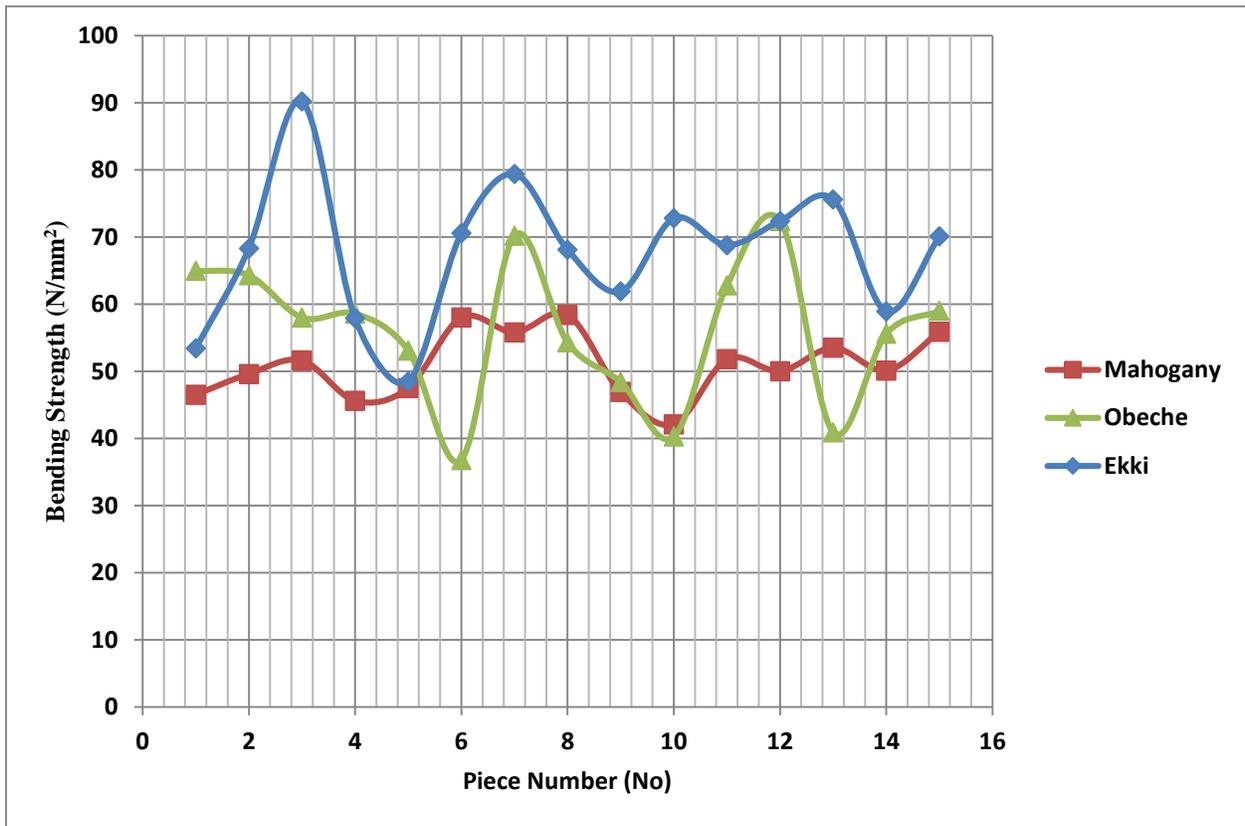
### 4.2.1 Bending Stiffness



**Figure 4.1: Chart Showing the Modulus of Elasticity of Selected Species of Timber**

The bending stiffness of a member is the resistance of the member against bending deformation otherwise referred to as modulus of elasticity (Ezeagu, et al. 2015). The average modulus of elasticity of Ekki, Obeche and Mahogany were  $21550.8\text{N/mm}^2$ ,  $4961.8\text{N/mm}^2$  and  $8270.5\text{N/mm}^2$  respectively. These results suggest that Ekki produced the highest value of bending stiffness and as a result can resist deflection to a considerable limit than Obeche and Mahogany. Obeche yielded the lowest value of bending stiffness and as a result will offer small amount of resistance to deflection during service. Therefore, it can be deduced that portal frame constructed with extract from Ekki can resist considerable amount of deflection than extract from Obeche and Mahogany.

### 4.2.2 Bending Strength



**Figure 4.2: Chart Showing the Bending Strength of Selected Species of Timber**

Figure 4.2 depicts the bending strength for the selected species of timber. The bending strength test was done to evaluate the maximum stress that the timber species can withstand before failure. Result obtained shows that Ekki with an average bending strength of  $67.8\text{N/mm}^2$  while Mahogany with an average bending strength of  $50.9\text{N/mm}^2$  produced the least bending strength. This result implies that timber extract obtained from Ekki can withstand significant amount of stress before failure especially when used in the construction of portal frame than Obeche and Mahogany.

### 4.2.3 Charpy Impact Energy

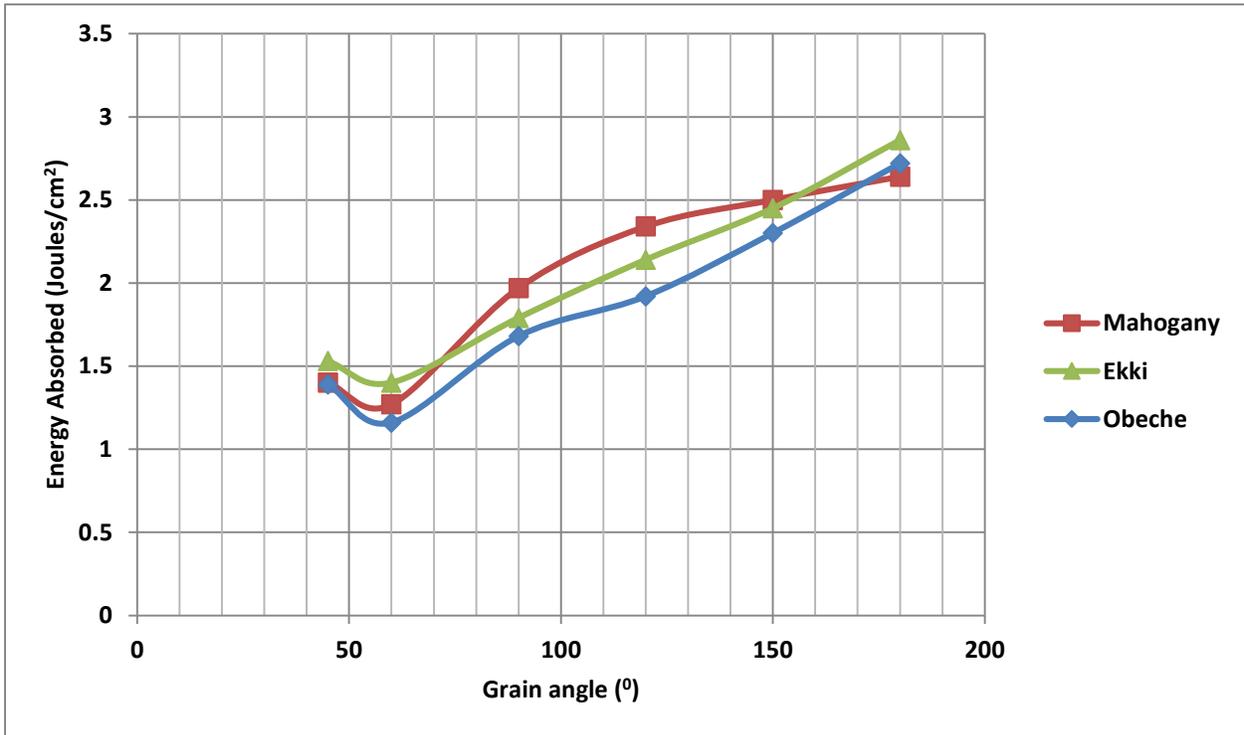


Figure 4.3: Chart Showing the Energy Absorbed against Grain angle for Selected Species of Timber

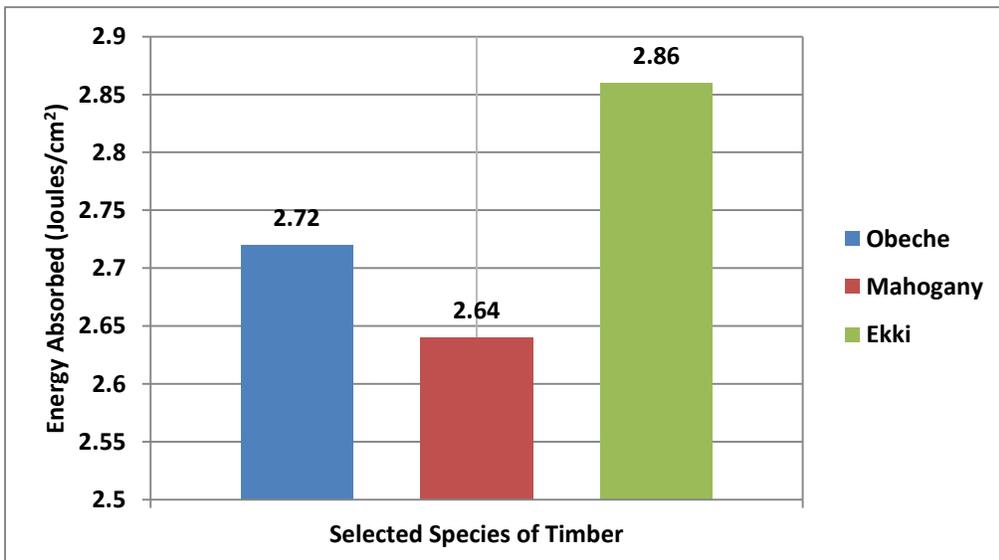


Figure 4.4: Chart Showing the Impact Value for Selected Species of Timber Species

Figure 4.3-4.4 depicts a collective plot of impact energy (toughness) against grain angle for the selected species of timber used in the study. The grain angle generally have the same shape with the impact energy varying as the grain angle relative to the longitudinal axis as the samples varies from  $0^{\circ}$  to  $180^{\circ}$ . The highest strength for the solid timber species were observed at a grain angle of  $180^{\circ}$  (when grain is parallel to the longitudinal axis of the samples). The lowest impact strength was observed at  $60^{\circ}$  for all selected species of timber. The timber species with the highest impact energy was Ekki while Mahogany produced the lowest impact strength. This implies that Ekki offer more resistance to shock during service than Mahogany and Obeche while Mahogany offers less resistance to shock when utilized in the construction of portal frame.

#### **4.2.4 Strength Class**

Evaluation of the strength class of selected species of timber shows that Ekki with a strength class of D60 was allocated the highest strength class while the strength class of Obeche and Mahogany was the same. The highest strength class of Ekki is a confirmation of the inherent structural properties of the timber specie.

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 Conclusion**

The study carried out experimental and analytical assessment of selected species of timber used in portal frame construction, from the findings obtained; it was observed that the Ekki produced the highest bending strength, bending stiffness and impact energy than extract from Mahogany and Obeche. Assessment of the strength class of the timber species in accordance with EN 338, (2009) revealed that the highest strength class was allocated to Ekki while the strength class of Mahogany and Obeche were the same. The study concluded that extract from Ekki has better structural properties than extract from Mahogany and Obeche and will perform satisfactorily during service especially when used in the construction of portal frame.

#### **5.2 Recommendation**

The study recommends the use of extract from Ekki as structural members in the construction of portal frame as extract from Ekki can with considerable amount of load over long duration owing to their inherent structural properties.

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# APPENDIX

BS 5268: Part 2 (1996) BS 5268-2:2002

