# CHAPTER ONE
# INTRODUCTION

## 1.0 Study Background

Continuous depletion of valuable timber species in Nigerian forests as a result of increased population explosion, urbanization, agricultural activities, over exploitation, and other human factors is a challenge to sustainable supply of wood for various purposes. Studies have been conducted on the physical, chemical and mechanical properties of various species of bamboo as substitutes to wood (Razak*et al,* 2018, Abdullah *et al,* 2014*)*. Utilisation of bamboo as substitute for wood is being recognised globally as a result of declining availability of timber species. *Bambusa vulgaris* is among the species that can be used as substitute to wood to meet increasing demand for wood products (Rogerson *et al.,* 2014, Adebayo and Ogunsanwo, 2014).

Bamboo is a cylindrical pole with jointed stem known as a culm. Bamboo culms in the plant fibres category belong to the grass family Poaceae*,* subfamily Bambusoideae, and Bambuseae tribe. Bamboo grows naturally in diverse climates and has more than 1000 species from 70 genera that are found in abundance in Asia and South America (Zakikhani *et al.* 2014). There are over 1500 identified bamboo species in the world (Xu *et al*, 2014). It has been the focus of research in recent years. This is to ensure that it can be utilized widely in the wood-based industry to reduce the rate of decrease in the wood raw materials (Rogerson, *et al*, 2014). It has good potential to substitute wood-based materials especially in wood-based composite industry. Apart from being fast growing, bamboo also has good mecahnical properties Rogerson *et al*, (2014).

*Bambusa vulgaris* is a lingo-cellulosic non-timber material which grows abundantly in most of the tropical countries. Itis one of the most popular tropical bamboo species and is easy to cultivate. It is easily cultivated through vegetative propagation of stem cutting and rhizomes. This bamboo possesses thick culms walls and has uniform sizes between the nodes and internodes. These properties make them suitable as materials for industrial usage (Razak*et a.l,* 2018). *Bambusa vulgaris* is one of the most preferred species of tropical bamboo for plantation because of its fast growth rate. The fast growingcharacteristics of bamboohas made it the best possible alternatives to replace timber in the future (Rogerson *et al.*, (2014). It takes a short period of time to mature and can been harvested for utilization within 3 to 4 years (Anokye, *et al*, 2014) unlike wood which matures at the about eight to ten years (depending on the silvicultural treatments and objects of management). Hence, the rotation period is short and good for sustainable forest management for supply of cellulosic raw materials for various uses. This makes it suitable as materials for industrial usage.

Bamboo is the longest, evergreen giant perennial, hollow stem plant (Pooja*et al*, 2018). It is found in many places; either grows naturally or cultivated deliberately (Abdullah *et al*, 2016). It is commonly found along the river and other moist areas because of high demand for water for growth and development. When fully matured a bamboo culm may attain a height of twenty metres when cultivated under favorable conditions. Where there is regular and abundant supply of water, a bamboo stand spread rapidly and the culms attain maturity within a short period of years. In Nigeria, *Bambusa vulgaris* grows abundantly in Mangrove Swamp Forest, Fresh Water Forest, and Lowland Rain Forest. It is rarely found in Southern Guinea Savanna vegetation and totally absent in Sudan and Sahel Savannas and Montane vegetation because of scarcity of water.

All bamboo species have a similar anatomy, which consists of nodes, internodes, and diaphragm (Awalluddin *et a*l, 2017). Each species can be identified according to their root system, in which there are three known root systems including, sympodial, monopodial, and amphodial (Sharma *et al*, 2014). The thickness of a bamboo decreases along the height of the culm, while the fibres density increases from the bamboo culm's inner wall to outer wall (Awalluddin *et al*, 2017).

The various traditional uses of bamboo vary from one locality to another. In most countries where it is available, it is used for scaffolding, yam stakes, fencing, and building and as fuel wood. Bamboo has become a very versatile material nowadays.In China, contractors have utilized bamboo as scaffoldings, while in Bali; bamboo is used to construct a Green School (Syeda*et al*, 2014). Contrarily, in other developing country, the utilization of bamboo as a construction material is limited, even with an abundance of bamboo source. Lack of study concerning the mechanical properties of bamboo is known to be one of the factors that are associated with a low utilization of bamboo in construction (Awalluddin *et al*, 2017).

Bamboo can be harvested in a short period of time, in addition to having a high rate of carbon absorption as compared to timber (Awalluddin *et al*, 2017). It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. Traditional bamboo crafts such as handicraft, basketry, and high – value-added products of panels, parquets, furniture and low technology construction materials are utilized extensively in the rural areas (Razak *et al,* 2018). In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs, etc.

Bamboos have been used for centuries in several countries, especially in Asia (China, India and Thailand), Central America (Costa Rica, Mexico and Honduras) and South America (Peru, Ecuador and Colombia), (Silveira2017). It was estimated that bamboos may be used for at least three thousand purposes, including food (both human and animal feeds), construction material and handicrafts, energy and industrial raw material in several products, such as ethanol (Kuttiraja *et al,* 2013), composites (Chaowana, 2013), panels (Liu, 2016), textiles (Nayak and Mishra, 2016 ) and cellulose (Tripathi, 2018).The species used are generally from Asia, both tropical and subtropical. This climatic range allows that bamboo species reach satisfactory growth rates when adapted to different soil and climate conditions in the Brazilian territory, especially the *Bambusa* genus (156 species), which originates in Asia, Oceania and Madagascar. Other genera are equally explored, such as *Dendrocalamus* (Asia and Oceania; 66 species), better known for its usually large-sized species.

Another important genus is *Guadua* (33 species), occurring from Mexico to Uruguay, being particularly common in the Amazon region (Rusch2019**)**. It is possible to cite *Ochlandra* (10 species), originating in Asia, especially in India and Sri Lanka Vorontsova, 2017).More than 1000 species from 70 genera are found in abundance in Asia and South America (Zakikhani *et al.* 2014).The industrial potential of these species occurs not only because of their rapid growth, but also because they show physical-mechanical characteristics good enough to be explored in constructions, in their structural form, coatings and production of laminated floors and panels (Rusch*et a.,l*2019).

Bamboo forest has a higher harvest cycle. This means that bamboo can be harvested in a short period of time. The biomass productivity of bamboo can also be extremely high with a high rate of carbon absorption as compared to timber(Awalluddin *et al*, 2017). In the atmosphere, carbon dioxide ($CO^2$) occurs only ina very small fraction (currently around 400 ppm; ppmDparts per million, ratio of the number of moles CO2 ina given volume of dry air to the total number of moles of allconstituents in this volume, IPCC, 2013).Species such as *Guadua angustifolia* can produce *ca.* 500cm$^3$ cell wall substances per day. This results in a total of about 0.1 m$^3$ for the entire culms (Ogunsanwo *et al,* 2015).

**1.1 Statement of Problems**

Continuous and uncontrolled uses of forest resources in Nigeria contribute to decrease in phytogenetic resources and forest ecosystems decline. Timber production from the natural tropical forests will continue to be on the decline as a result of increase in the world population and sustained high market demand by the wood-based industry in Nigeria. As a consequence of the growing world population and the accompanying rising demand for resources, we are progressively reaching the stage of an advanced overuse of the natural resources. The total global land surface amounts to 13.4 billion hectares (ha); 37% of the global land surface, approximately 5 billion hectares, is farmland **(**Almut *et al*., 2013).

The largest proportion of the available land surface is therefore utilized for agriculture. The world‘s forests cover around 3.9 billion hectares, 36% of these forests are primary forests. Worldwide, around 30% of the land surface is covered by forests. In Latin America and Europe including the Russian Federation, the volume of forest cover is above average with 49% and 45%, respectively. Asia (19%), Oceania (23%) as well as Africa (19%) is below the average in terms of forest cover (FAO, 2010). Whilst the timber extracted from forests in Africa, Asia and Oceania is used mainly as firewood, it is clearly used predominantly for industrial purposes in Europe and North America (FAO, 2011).

Between 1970 and 2009, the rate of timber extraction in Africa and Latin America also increased significantly, whereas volumes have remained more or less constant or have declined slightly in the other global regions .Therefore, the timber supply from the plantation could not cope with the growing demand for timbers. On the trends of demand for wood products, there would be an increase in demand of the order of 20% by 2010 (FAO, 1997). Consequently, utilization of bamboo as wood substitute is of great importance.

Bamboos species show a variability of their properties at the intra specific level, as well as at inter specific level which could be related to the geographical origin and the genetic factors (Soeprayitno *et al.* 1990). Internodal variations in physical and mechanical properties of *Bambusa vulgaris* glulam affect application of glulam technology for its various uses.

Bamboo like other plants is affected by the environment during phases of growth and development. Plant growth and distribution are limited by the environment. These environmental factors are water (humidity), light, relative humidity, soil,temperature, carbon dioxide concentration and wind. If anyone of environmental factors is less than ideal it will become a limiting factor in plant growth.Empirical relationships between tree rings and climate have been investigated at the intra-annual level, e.g., for reconstructing summertime precipitation by means of latewood-width chronologies (Stahle *et al.*, 2009; Griffin et al., 2013).There was a positive relationship between temperature and wood density of eucalypts(Thomas *et al.*, 2006). Limiting factors are also responsible for the geographical distribution of *Bambusa vulgaris* just like other plants. For example, only plants adapted to limited amounts of water can live in deserts. Most plant problems are caused by environmental stress, either directly or indirectly.

The long gestation period of forest (trees) also contributes to insufficient availability of preferred tree species for structural wood despite the increase in the world population and the market demand by the wood-based industry (Wahab *et al.*, 2012). Trees managed for timber production attain maturity between 20 to 25 years. In a forest managed on a rotation age of 25 years, this implies that after harvesting an annual coup, a forest manager has to wait for another 25 years before he could return to the same annual coup. This is not efficient for wood production to sustain wood based industries in Nigeria.

### 1.2 Aim and Objectives

The aim of this work is to evaluate the technical properties of glulam*Bambusa vulgaris* as affected by internodal variations and ecological zones with a view to maximizing its utilization potential as wood substitute.

#### 1.2.1 Specific Objectives

The specific objectives were to

i. produceglulam*Bambusa vulgaris* boards from three Nigerian ecological zones

ii. investigate internodal variation in selected physical propertiesand mechanical properties of glulam*Bambusa vulgaris*

iii. correlate absolute density with selected physical and mechanical properties of glulam*Bambusa vulgaris*

iv. carry out regression analysis, develop model and then predict the selected physical and mechanical properties of glulam*Bambusa vulgaris*.

**1.3 Justifications**

Information on the internodal and ecological variations in the physical and mechanical properties of glulam*Bambusa vulgaris* is very essential to its utilization potentials. Many studies had been carried out in order to highlight axial variations of these fundamental characteristics, as well as to maximize bamboo utilization However; they did not provide information on the internodal variability of these properties in glulam bamboo in Nigerian ecozones.

The use of non timber forest products as substitute to wood products has been advocated because of imminent shortage of wood materials for use. As a result of this, it is essential that substitute species be found. Development of unknown forest resources such as bamboos is one of the important ways to reduce the dependence on the traditional timber species for large scale production of wood products (Kokutse *et al*., 2013). Bamboo is a vast growing timber produce with gestation period of between 3-5 years. It can therefore be used to reduce the declining supply of valuable timber species.

Nigeria is a country of diverse ecological zones and the variation in these ecological zones influence the physical and mechanical properties of glulam *Bambusa vulgaris*. The ecological zones in Nigeria are based on Keay (1949), and are defined from South to North as follows: Mangrove Swamp and Coastal Vegetation, Freshwater Swamp Forest, Lowland Rain Forest, Derived Savanna, Guinea Savanna, Sudan Savanna, and Sahel Savanna. A few mountainous areas are found in the Jos Plateau, Adamawa, Taraba and Northern part of Cross-River State. It is important to study selected physical and mechanical properties of *Bambusa vulgaris* glulam in the Mangrove swamp, Lowland Rain Forest and Guinea Savanna ecological zones of Nigeria.

The mechanical properties of wood and other lingo-cellulosic materials are their fitness and ability to resist applied or external forces. The ability and capacity of bamboo to withstand the force applied onto it is very important. The strength properties of the bamboo are among the most important factors, which determine both ability and capacity of full bamboo culm (Awalluddin *et al*, 2017).External force means, any force outside of a given piece of material which tends to deform it in any manner. It is largely such properties that determine the use of wood and bamboo for structural and building purposes, and innumerable other uses of which furniture, vehicles, implements, and tool handles are a few common examples. Knowledge of these properties obtainable through experimentation is essential to determine the use of glulam bamboo for various uses.

This research study therefore provided information on the effects of intermodal and ecological variability on selected physical and mechanical properties glulam of bamboo (*Bambusa vulgaris*) with a view to maximizing its potential as a wood complement.

**1.4 Scope of the Study**

This study focused on laboratory evaluation of inter-nodal and eco-spatial variability of selected physical and mechanical properties of *Bambusa vulgaris* in Nigeria. The physical properties of *Bambusa vulgaris* are restricted to density (Kg/m$^3$) and percentage volumetric shrinkage (%) while the mechanical properties studied in this work are Modulus of Rupture (MOR, Nmm$^2$), Modulus of Elasticity (MOE, N/mm$^2$), Maximum Compressive Strength Parallel to Grain (N/mm$^2$),Maximum Compressive Strength Perpendicular to Grain (N/mm$^2$) and Shear Strength(N/mm$^2$) Test samples used for this study were produced in the wood work workshop,department of Forest Production and Products, Faculty of renewable Natural Resources, the University of Ibadan. Density, radial and tangential shrinkage and shear strength along the glue line were studied in theForestry Research Institute of Nigeria, Ibadan. Modulus of Rupture, Modulus of Elasticity, Maximum Compressive Strength Parallel and Perpendicular to grain were examined in theDepartment of Wood Products Engineering, Faculty of Technology,the University of Ibadan.

**1.5 Limitation of the Study.**

This study is limited to the use of Top bond adhesive to bind *Bambusa vulgaris* laminates . This study was also limited to the use of hand brush in the application of Top bond adhesive. Clamps were also used to press laminate members together during adhesive application.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Taxonomyof Bamboo

The bambusoid taxa isregarded as the most "primitive" grasses, especially because of the presence of bracts,indeterminate inflorescences, pseudospikelets (units of inflores cence or flower clusters) and glumes or leaf-like structures in woody bamboos which is similar to spikelets or clumps of grass( botanicus.org) and flowers with three lodicules (tiny scale-like structure at the bottom of a florets or clump of grass flowers, found between lemma, the lowest part of spikelets, and sexual organs of the flower), six stamens, and three stigmas (Clark *et al*.,1995). Bamboos are some of the fastest growing plants in the world (Farrelly, 1984).

Bamboo is a perennial, giant, woody grass and it belongs to the group angiosperms (Chapman, 1996). It belongs to the order monocotyledon (Abd.Latif *et al.,* 1990). The grass family Poaceae (or *Gramineae)*is divided into one subfamily, *Centothecoideae,* and five large sub-families, *Arundinaceae, Pooideae, Chloridodeae, Panicoideae, and Bambusoideae*. Bamboos are classified under the sub-family *Bambusoideae* (Chapman, 1996, Chapman, 1997). Wang and Shen, (1987) stated that there are about sixty to seventy genera. *Bambusa, Chusquea, Dendrocalamus, Phyllostachys, Gigantochloa* and *Schizostachyum*) are among these genera and there are over 1,200 –1,500 species of bamboo in the world. Grosser and Liese, (1971) reported that about half of these species grow in Asia, most of them within the Indo-Burmese region.

*Bambusa vulgaris* is a species of the large genus Bambusa of the clumping bamboo tribe Bambuseae (Kew, 2012) that are found largely in tropical and subtropical areas of Asia, especially in the wet tropics (Farrelly, 1984). The pachymorph (sympodial or superposed in such a way as to imitate a simple axis) rhizome system of clumping bamboos expands horizontally by only a short distance each year. The shoots emerge in a tight or open habit (group), depending on the species; common bamboo has open groups.

## 2.1 Morphological Characteristics of Bamboo

*Bambusa vulgaris* produces moderately loose clumps and possesses no thorns (flora of North America editorial committee, 2007). It possesses lemon-yellow culms (stems) with green stripes and dark green leaves (Bambusa vulgaris archive, 2007). It does not have straight stems, and the stems are not easy to split, inflexible, thick-walled, and initially strong. The densely tufted culms can attain a height of 10–20 m and thickness of 4–10 cm thickOhrnberger, 1999; Rao *et al*, 1998). Culms at the base are straight or flexuose, drooping at the tips. Culm walls are thick ranging between 7-15 mm (Schröder, 2011). Nodes are slightly inflated and are 20–45 cm.Several branches develop from mid-culm nodes and above. Culm leaves are deciduous with dense pubescence (Flora of North America Editorial Committee, 2007). Leaf blades are narrowly lanceolate.

Flowering does not common and there are no seeds. Fruits are rare due to low pollen viability caused by irregular meiosis (Louppe *et al.,* 2008). At the interval of several decades, the whole population of an area blooms at once (Whistler, 2000) and individual stems bear a large number of flowers (Louppe *et al.,* 2008). Vegetative propagation is through clump division, of rhizome, stem and branch cutting, layering, and marcotting (Rao *et al*, 1998; Louppe *et al.,* 2008) and when a stem dies, the clump usually survives. A clump can emerge from the stem used for poles, fences, props, stakes, or posts. Its rhizomes extend up to 80 cm before turning upward to create open, fast-spreading clumps (Meredith, 2009).

Wong, (1995), and Dransfield, (1992) illustrate the morphological characteristics of bamboo. Bamboo is divided into 2 major portions, the rhizomes and the culms. The rhizome is the underground part of the stem and is mostly sympodial or, to a much lesser degree, monopodial. This dissertation is concerned with the upper ground portion of the stem, called the culm. It is the portion of the bamboo tree that contains most of the woody material. Most of bamboo culms are cylindrical and hollow, with diameters ranging from 6.35mm (0.25 inch) to 304.80mm (12 inches) and height ranging from 0.3048m (1 foot) to 36.576m (120 feet), (Lee *et al.*,1994). It is without any bark and has a hard smooth outer skin due to the presence of silica (Tewari, 1992). Bamboo is distinguishable from one another by the differences of these basic features, along with the growth style of the culm, which is either strictly erected with pendulous tips, ascending, arched or clambering. Several published materials extensively described the morphology and structure of bamboo (McClure, 1967;

Dransfield, 1992; Farrelly, 1984; Tewari, 1992; Kuma and Dobriyal, 1992). Bamboo is a fast growing species and a high yield renewable resource. Bamboo growth depends on species, but generally all bamboo matures quickly.

Aminuddin, and Abd.Latif (1991) stated that bamboo might have 40 to 50 stems in one clump, which adds 10 to 20 culms yearly. Bamboo can reach its maximum height in 4 to 6 months with a daily increment of 15 to 18 cm (5 to 7 inches). Wong, (1995) stated that culms take 2 to 6 years to mature, which depends on the species. It is suggested that with a good management of the bamboo resource, the cutting cycle is normally 3 years. According to Lee *et al*., (1997) bamboo matures in about 3 to 5 years, which means it grows more rapid than any other plant on the planet. Some bamboo species have been observed to surge skyward as fast as 48 inches in one-day (Farrelly, 1984). The fast growth characteristic of bamboo is an important incentive for its utilization. Due to the fact that it is abundant and cheap, bamboo should be used to its fullest extent.

**2.2 Habitat of Bamboo**

Most of the bamboos need a warm climate, abundant moisture, and productive soil, though some do grow in reasonably cold weather (below $-20^{o}C$). According to Grosser and Liese (1971), bamboos grow particularly well in the tropics and subtropics, but some taxa also thrive in the temperate climate of Japan, China, Chile and the USA. Lee *et al.,* (1994) stated that the smaller bamboo species are mostly found in high elevations or temperate latitudes, and the larger ones are abundant in the tropic and sub-tropic areas. Bamboo is quite adaptable. Some bamboo species from one country have been introduced to other countries. The most popular and valuable bamboo species in Asia, *Phyllostachy pubescences* or the Moso bamboo has been grown successfully in South Carolina and some other South-eastern states in America for more than 50 years (Lee *et al*, 1997). Bamboos are also adaptable to various types of habitat. They grow in plains, hilly and high altitude mountainous regions, and in most kinds of soils, except alkaline soils, desert, and marsh (Wang, and Shen, 1987). Abd.Latif and Abd.Razak (1991) mention that bamboo could grow from sea level to as high as 3000 meter. Bamboo is suitable on well drained sandy to clay loom or from underlying rocks with pH of 5.0 to 6.5.

## 2.3 Anatomical Structure of Bamboo

Many studies have been published on the anatomical features of bamboo (Abd.Latif, and Mohd, 1993; Abd.Latif.*et al.,* 1993; Abd.Latif *et al*., 1990; Grosser and Liese, 1971; and Janssen, 1991). Its anatomical features directly affect bamboo physical and mechanical properties. These features affect seasoning, preservation and the final application. It is expected that these anatomical features will affect the interaction between bamboo and adhesive. The bamboo culm is divided into segments by diaphragms or nodes. The nodes separate the culm into several sections termed internodes. The culm's outermost layer, the bark, consists of epidermal cells that contain a waxy layer called cutin. The innermost layer is wrapped by sclerenchyma cells. The tissue of the culm contains parenchyma cells and the vascular bundles.

Vascular bundles are a combination of vessels and sieve tubes, with companion cells and fibres (Abd.Razak, *et al,* 1995).Having only vascular bundle type I, the bamboo genera like *Arundinacea, Phyllostachys* and *Tetragonocalamus* are classified under group A. Group B is further classified into two sub-groups B1 and B2. The genera *Cephalostachyum* is classified under group B1 because it has only type II vascular bundles, whilst the genera *Melocanna*, *Schizostachyum* and *Teinostachyum* are classified in group B2 for having type II and type III vascular bundles. Group C is the classification that has only type III vascular bundles. An example of bamboo genera under group C is *Oxytenanthera*. The genera like *Bambusa, Dendrocalamus*, *Gigantochloa* and *Thyrsostachys* are classified in group D for having type III and type IV vascular bundles.The bamboo node cells are transversely inter-connected, whilst the cell at the internodes are axially oriented. Being a monocotyledon, the bamboo culm lacks the secondary thickening, and further not possessing radial cell elements like timber.

Chew *et al*., (1992) analyzed the fibre of Buluhminyak (*Bambusa Vulgaris*).The macerated fibre was stained with safranin-C and mounted on slides. They measured 300 fibres for their length, width and lumen width using a visopan projection microscope. They also observed long and slender, fibre with an arrow lumen. The average fibre length and width was found to be 2.8 mm and0.013mm, whilst the lumen width and cell-wall thickness were 0.003mm and0.005mm respectively. Abd.Latif, and Mohd,(1993) studied the anatomical properties of three Malaysian bamboo species, 1 to 3 years old *Bambusa vulgaris* (buluhminyak), *Bambusa bluemeana* (buluhduri) and *Gigantochloa scortechinii* (buluhsemantan). The bamboo was cut at about 30 cm above the ground level. Each stem was marked and cut at about 4 m intervals into basal, middle and top segments. Disks were cut and used for the determination of vascular bundles distribution and fibre dimensions respectively. This study showed that the highest mean concentration of vascular bundles was observed in the top location of the 2year old *B. bluemeana* (365 bundles/$cm^2$), *Bambusa vulgaris* (307 bundles/$cm^2$) and *G. scortechini* (223 bundles/$cm^2$).

The lowest mean concentration of vascular bundles was in the middle location of the 1 year old G. *scortechini* (132bundles/$cm^2$), 2 year old *Bambusa vulgaris* (215 bundles/$cm^2$) and 1 year old *B. bluemeana* (200 bundles/$cm^2$. The radial/tangential ratio, which was used earlier by Grosser and Liese (1971), is the ratio of radial diameter (length of vascular bundle) to the tangential diameter (width of the vascular bundle). According to this study, age does not significantly affect the radial/tangential ratio, and the trend is a decrease with height except for *G. scortechini*. It was concluded by this study that vascular bundle size is larger at the top and gradually decreases to base. The fibre length between the three species was significantly different. Age does not significantly affect fibre length. The author also observed the variation of fibre wall thickness, which is measured as the fibre diameter minus the lumen diameter divided by two. The fiber wall thickness was significantly different among the bamboo species. *G. scortechinii* was observed to be in the range of 0.006mm to 0.01mm, *Bambusa vulgaris* in the range of 0.006mm to 0.008mmand 0.004 to 0.006mm for *B. bluemeana*. From the analysis done in this study, it was observed that there is variation of the anatomical characteristics of bamboo however there are certain patterns between and within culms.

## 2.4 Effects of Anatomical Structure on Mechanical Properties of Bamboo

The anatomical Structure in relation to the mechanical properties of Malaysian bamboo has been studied by Abd.Latif *et al*., (1990). The three species, 1 to 3 year old *Bambusa vulgaris*, *Bambusa bluemeana* and *Gigantochloa scortechinii* were used again in this study. They concluded that vascular bundle size (radial/tangential ratio) and fibre length correlated positively with modulus of elasticity (MOE) and stress at proportional limit. The authors implied that the increase in the size (mature stage), and fibre length could be accompanied by an increase in strength properties. They mentioned that bamboo that possesses longer fibre might be stiffer, if it has a greater vascular bundle size. The correlation between fibre length and shear strength was negative. The fibre wall thickness correlates positively with compression strength and MOE, but negatively with modulus of rupture (MOR). There was also a correlation between lumen diameter and all of the mechanical properties, except compression strength.

Bamboo is as strong as wood in tension, bending and compression strength, but is weaker in parallel to the grain shear. Lee *et al*., (1994) determined the physical and mechanical properties of giant timber bamboo (*Phyllostachys bambusoides*) grown in South Carolina, USA. This study concluded that moisture content, height location in the culm, presence of nodes and orientation of the outer bark affect the mechanical and physical properties. This study found that the greatest shrinkage occurred in the radial direction, which was about twice as great as shrinkage in the tangential direction, while longitudinal shrinkage was negligible. Average green moisture content of the bamboo species studied was 137.6%, with a green specific gravity of 0.48. It was found that there were no significant differences of the moisture content and specific gravity between the different locations of the culm and between the different stems.

Compressive, tension and bending strengths of the giant timber bamboo was also studied. It was found that the presence of nodes, moisture content and culm location had a significant effect on strength. The presence of nodes reduced the compression, tension strength and MOR, but did not significantly affect MOE. The top location of the culm exhibited higher compression strength, tension strength, MOR and MOE. In bending, radial or tangential loading had a significant effect on MOR and MOE. Bamboo, according to Lee *et al*., (1994) is similar to wood with regard to anisotropic shrinkage. The authors compared the physical and mechanical properties of bamboo with loblolly pine, which showed a similarity.

The effects of anatomical characteristics on the physical and mechanical properties of *Bambusa bluemeana* were determined (Abd. Latif *et al*., 1993). The studies were carried out by using nine culms of 1, 2 and 3-year-old bamboo from Malaysia. This study found that the frequency of vascular bundles does not significantly vary with age and height of the culm. They observed that the highest mean concentration of vascular bundles was at the top location of the 2-year-old culm, and the lowest mean concentration was in the middle location of the 1-year-old culm.

The high density of vascular bundles at the top was due to the decrease in culm wall thickness (Liese and Grosser (1997). The size of vascular bundles was not significantly different with height and age. There was no correlation of vascular bundles with age, but there was a significant decrease with height of the culm. They explained that the reason for the higher ratio of vascular bundle size near the basal location was due to the presence of mature tissues. The radial diameter decreases faster than the longitudinal diameter of the vascular bundles within the height of the culm. The fibre length of the species of bamboo studied did not significantly differ with age and culm height. Fibre wall thickness is not significant by age or height of the culm. They observed that there is a decrease of lumen diameter with the increase of age and height of the culm.

### 2.5 Natural Durability of Bamboo

The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo against mould, fungal and borers attack is strongly associated with the chemical composition (Abd.Latif *et al*.,(1991).The natural durability of bamboo varies between 1 and 36 months depending on the species and climatic condition (Liese, 1980). It is noteworthy that even in 12 year old culms starch was present in the whole culm, especially in the longitudinal cells of the ground parenchyma (Liese and Grosser, 1997). Higher benzene-ethanol extractives of some bamboo species could be an advantage for decay résistance.

In producing material such as cement-bonded particleboard, chemical content (starch and sugar) will retard the absorption rate of $H_2O$+ ion on the cement mineral surfaces and will slow down the setting reaction. The study by Chew *et al*., (1992) found out that *Bambusa vulgaris* contains glucose 2.37%, fructose 2.07% and sucrose 0.5%. The total sugars content before and after soaking were 4.94% and 0.28%respectively. This study showed that by the technique of soaking the sugar content could be reduced below 0.5%, a permitted level for the production of cement15 bonded particleboard. This paper explained that a bamboo sample that contained more than 0.6% total sugar will produce low quality cement-bonded particleboard, unless treated.

Physical and mechanical properties of bamboo depend on the species, site/soil and climatic condition, silvicultural treatment, harvesting technique, age, density, moisture content, position in the culm, nodes or internodes and bio-degradation (Lee *et al*., 1994). The sapwood fluids are easily attacked by wood destroying agents during storage and vessel elements also serve as pathways for fungi infections in wood leading to wood deterioration (Akachuku, 1979; Onilude and Audu, 2002; Ogunwusi, 2013). Many studies had been carried out in order to highlight and observe these fundamental characteristics, as well as to maximize bamboo utilization (Abd. Latif 1990, Abd.Latif, 1993, Lee *et al*., 1994 and Janssen, 1991).

Abd.Latif *et al*., (1993) studied the effect of anatomical characteristics on the physical and mechanical properties of *B.bluemeana*. According to this study, age and height do not significantly affect moisture content. The range of green moisture content was 57% to 97%. Younger bamboo showed higher moisture content compared to an older bamboo. The paper explained that it could be the effect of the thick wall fibre and higher concentration of vascular bundle of the older bamboo. There was no significant difference for density along the culm height of the 3-year-old culm. The radial and tangential shrinkage of *B. bluemeana*, did not differ significantly through age and height. The radial and tangential shrinkage ranges from 5.4% to9.5% and 6.4% to 20.1% respectively. The older bamboo (3-year-old) is more dimensionally stable compared to the young ones (1-year-old). The 1-year-oldbamboo was observed to shrink more at an average of 15% to 22%. The radial and tangential shrinkage at basal height of a 2 -year old *B.bluemeana* culm is found to be 8% to 19% respectively, and top location at approximately 6% to 12%respectively.

### 2.6 Chemical Composition of Bamboo

The chemical composition of bamboo is similar to that of wood. The main constituents of bamboo culms are cellulose, hemi-cellulose and lignin, which amount to over 90% of the total mass. The minor constituents of bamboo are resins, tannins, waxes and inorganic salts. Compared with wood, however, bamboo has higher alkaline extractives, ash and silica contents (Tomalang *et al*., 1980; Chen *et al*., 1985).

Yusoff *et al*., (1992) studied the chemical composition of one, two, and three year old bamboo (*Gigantochloa scortechinii*). The results indicated that the holocellulose content did not vary much among different ages of bamboo. Alpha-cellulose, lignin, extractives, pentosan, ash and silica content increased with increasing age of bamboo. Bamboo contains other organic composition in addition to cellulose and lignin. It contains about 2-6% starch, 2% deoxidized saccharide, 2-4% fat, and 0.8-6% protein.

The ash content of bamboo is made up of inorganic minerals, primarily silica, calcium, and potassium. Manganese and magnesium are two other common minerals.

Silica content is the highest in the epidermis, with very little in the nodes and is absent in the internodes. Higher ash content in some bamboo species can adversely affect the processing machinery. However differences between the major chemical composition of node and internode fraction of bamboo are small (Scurlock, 2000); neither the number of nodes nor the length of internode segments would be critical to the utilization of bamboo for energy conversion, chemical production, or as a building material. Fujji *et al*., (1993) investigated the chemistry of the immature culm of a moso bamboo (*Phyllostachys pubescens Mazel*). The results indicated that the contents of cellulose, hemicellulose and lignin in immature bamboo increased while proceeding downward of the culm. The increase of cellulose in the lower position was also accompanied by an increase in crystallinity.

The culm of the bamboo is covered by its hard epidermis and inner wax layer. It also lacks ray cells as radial pathways. Several results have revealed that bamboo is difficult to treat with preservatives (Liese, 1997). Since the amount of each chemical composition of bamboo varies with age, height, and layer, the chemical compositions of bamboo are correlated with its physical and mechanical properties. Such variation can lead to obvious physical and mechanical properties changes during the growth and maturation of bamboo.

### 2.7 Physical and Mechanical Properties

The specific gravity of a substance is a comparison of its density to that of water. The specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on the anatomical structure. The moisture content of bamboo varies vertically from the bottom to the top portions and horizontally from the outer layer to the inner layers. Bamboo possesses very high moisture content. Green bamboo may have 100% percent moisture (oven-dry weight basis) and can be as high as 155 percent for the innermost layers to 70 percent for the peripheral layers. The vertical variation from the top (82%) to the bottom (110%) is comparatively less. The Fiber Saturation Point of bamboo is around 20-22 percent (Kishen *et al*., 1956). The Moisture Content range of *Bambusa bluemeana* is 57-97% (Abd.Latif *et al*, 1993).

Lee *et al*, (1994) revealed that *Phyllostachys bambusoides* has an average MC of 138% and a green SG of 0.48. Unlike wood, bamboo has no secondary growth; all gains after it reaches its full height are due to the addition of materials to cells. Wettability is the ability of a liquid to form a coherent film on a surface, owing to the molecular attraction between the liquid and the surface. Wettability of bamboo has a significant influence on adhesion and other related properties. In terms of adhesion theory, bond formation involves wetting, adsorption, and inter-diffusion of the resin with the respect to the adhered substrate. Adhesive wettability of wood is usually evaluated by contact angle measurement. Several studies have revealed wettability determined through contact angle measurement is closely associated with gluability of wood and wood based composites (Chen, 1985; Hse, 1972; Herczeg, 1965).

Aging of a bamboo culm influences physical, chemical, and mechanical properties, and consequently its processing and utilization. The physical and mechanical properties of bamboo vary with the age of the bamboo and the height of the culm (Chauhan, 2000). In general, SG and the properties of bamboo drop from the top portion to the bottom. The increase in weight is cumulative and directly related with age. Strength properties are reported to decrease in older culms (Zhou, 1981). Limaye, (1948; 1952) found that older culms of *Dendrocalamus strictus* became 40-50 percent stronger and stiffer than young ones. Maximum values were found in 3-6 year old culms. (Sekhar *et al*. 1962) found highest values in 3-4 year old culms of *Bambusa nutans*.

There is also variation in strength properties along the culm height as well. Compressive strength tends to increase with height (Espiloy, 1987; Liese, 1987; and Sattar *et al.*, 1990). The strength increases from the central to the outer part. There is more than 100 percent variation in strength from the inner to the outer layers (Narayanamurti and Bist, 1947).

### 2.7.1 Moisture Content of Green Wood

In a green wood, moisture exists in both liquid in the cell voids and lumens (free water) and as moisture in the cell wall (bound water). The moisture content of green wood is defined as the total amount of free and bound water in the living tree (Roger and Rowell 2005). It is the maximum moisture content that can exist in a living tree. It varies from one species to another and depends on the specific gravity.

### 2.7.2 Fibre Saturation Point

When a green wood is losing water, there is no change in the volume until the fibre saturation point (FSP) is reached. The fibre saturation point is the moisture content of the cell wall when there is no free water in the voids and the cell walls are saturated with water (Roger and Rowell 2005). As moisture is removed below the FSP (approximately 25-30%), the wood volume starts to shrink. Wood being anisotropic, the shrinkage in wood is different in all three growing directions. Depending on where the piece of wood is located in the log, the wood will not only become smaller as a result of loss of water, but also will become distorted as a result of the anisotropic characteristics of wood. The shrinkage of wood upon drying depends on several characteristics which include specific gravity, rate of drying and size of the piece of wood.

### 2.7.3 Volumetric Shrinkage

Hygroscopicity is one of the main distinguishing characteristics of wood. It can be defined as the ability of the wood to lose or gain moisture with a change in relative humidity (Tiryaki*et al*. 2016). Wood shrinks as a result of this natural process. Volumetric shrinkage occurs below the fiber saturation point where all of the water exists only within the cell wall (Hiziroglu 2004, Almeida and Hernández 2006). Changes in humidity below this point lead to some problems in the use of wood. For instance, the gluing problems take place because of the different dimensional changes of the glued parts (Eckelman 1998). Besides, deformations and crack formations arise depending on the development of internal stresses due to similar reasons (Rastislav *et al*, 2006). Such drawbacks adversely affect the use of wood as a building material. On the other hand, these problems can be partially reduced if the wood is dried to the moisture content compatible with its final service environment (Hiziroglu 2004, Eckelman 1998).

Heat treatment is an effective procedure that aims at improving some wood properties (Unsal *et al.* 2003, Bal, 2015). Heating the wood at high temperatures increases dimensional stability and biological durability and decreases hygroscopicity (Gunduz *et al.* 2008, Baysal *et al.* 2014). This is mainly related to the loss of the hemicellulose, which contributes greatly to water uptake due to its hydrophilic nature (Paul *et al.* 2007). In particular, the hydroxyl groups existing in hemicelluloses have a major impact on the volumetric swelling and shrinkage. Heat treatment provides a reduction in the number of these groups and thus wood absorbs less water (Inoue *et al.* 1993). As a result, the treated wood becomes less hydroscopic and more dimensionally stable compared to untreated wood (Shi *et al.* 2007, Korkut and Aytin 2015).

Shrinkage is important property that has serious effects on the service life of wood products. Heat treatment is a method that refers widely to reduce the negative effects of volumetric shrinkage. Many experimental studies for better understanding the impact of heat treatment on the amount of volumetric shrinkage of wood have been conducted (Esteves *et al.* 2007, Gunduz *et al.* 2008, Korkut and Budakci 2010).

### 2.7.4 Modulus of Rupture

Modulus of rupture is a material property, defined as the stress in a material just before it yields in a flexure test (Ashby, 2011). It reflects the maximum loadcarrying capacity of a member in bending and is proportionalto maximum moment borne by the specimen. In some wood applications, such as structural evaluation of lumber, a reliably specified strength is a fundamental need. The underlying principle of common machine stress grading of lumber is that thebending stiffness of timber is closely correlated to its strength (Schajer 2001, Oja *et al.* 2005). This close positive correlation has been shown in many works (Bodig and Jayne 1982, Karlinasari *et al.* 2005, Ravenshorst *et al.* 2008, Hein and Lima 2012).

### 2.7.5 Modulus of Elasticity

MOE is a measure of the stiffness of a body (Oklahoma 2006) and is a good overall indicator of its strength.Technically it's a measurement of the ratio of stress placed upon the wood compared to the strain (deformation) that the wood exhibits along its length.

### 2.7.6 Maximum Compressive strength parallel to grain

This is the maximum stress sustained by a stressing specimen parallel to grain.

Mechanical properties most commonly measured and represented as strength properties for design include maximum stress in compression parallel to grain, compressive stress perpendicular to grain (Adetayo and Dahunsi 2017).

### 2.7.7. Compression strength perpendicular to grain

In structural design the compression strength perpendicular to grain is an important property as it determines the bearing strength. The bearing strength depends on loading conditions and specimen (Franke and Quenneville 2011). The compression strength perpendicular to the grain is one of the important timber properties for structural design. Exceeding the strength value will not only lead to large deformations and thus a serviceability issue, but it can also lead to a failure (Franke and Quenneville (2011).

### 2.7.8 Shear Strength

The shear strength parallel to grain or "shear strength" is a fundamental mechanical property of wood and is used in general timber structural design.Shearing strength is weakened by knots and faults and cracks that appear in the wood.Various researchers have examined different test methods for obtaining the shear strength, and compared shear strength values with bending strength. (Norris, 1957)introduced a panel shear test method. Mandery, (1969) and Keenen, (1974) obtained shear strength of Douglas-fir beams by testing them under three point bending tests. Rammer *et al.* *(*1999) used a four point bending test approach on Douglas-fir and compared the results with the shear block shear strength values. Cofer *et al.,* 1998) used a finite element approach to evaluate the performance of three and five point bending tests to obtain shear strength of wood beams.

## 2.8 Ecological Zones of Nigeria

The Nigeria ecological zones have been defined by Keay (1949), from South to North as follows: Mangrove Swamp and Coastal Vegetation, Freshwater Swamp Forest, Lowland Rain Forest, Derived Savanna, Guinea Savanna, Sudan Savanna, Sahel Savannaand mountaneecologicalzone.

### 2.8.1 Mangrove Forest and Coastal Ecological Zone

Mangrove forest is found along the coastal and delta areas of Nigeria where the water is brackish. Biologically, six mangrove species make up these forests, including three species in the family *Rhizophoraceae(Rhizophora racemosa* (red mangrove; tall)*, Rhizophora harrisonii* (red mangrove; dwarf)*, Rhizophora mangle* (red mangrove; dwarf))*, and species in the family* Avicenniaceae (white mangrove) and *Combretaceae* (Aber and Ekeke 2011).Despite expansive geographic coverage, the Niger Delta mangrove forest has approximately 80% of its vegetation distributed in three states (Bayelsa, Delta, and River states) (James *et al*., 2013).  .

Although the forest is composed of six mangrove species, mangrove growth is primarily situated in brackish muddy creek banks (Aber and Ekeke 2011). Studies have indicated that *Rhizophora racemosa* (which is the tallest mangrove species) reaches its optimized growth potential when exposed to brackish water and soft mud, whereas *R. racemosa'*s relatives, *R. mangle* and *R. harrisonii,* favor higher salinity and hard mud (Aber and Ekeke 2011). In its natural state, mangrove soil or "chikoko" (a mixture of acid sulphate, silty clay, clay loam and peat), has a pH of 4 and 6 for mangroves inhabiting low-tide and high-tide locations, respectively (Adedeji *et al.,* 2016). If salinity levels shift too much from these levels, mudflats become unsuitable for mangrove production, and the process of mangrove reforestation (from infertile mangrove land to productive mangrove mudflat) can take upwards of one century (Aber and Ekeke 2011).

### 2.8.2 Freshwater Swamp Forest Ecological Zone

A freshwater swamp forest is defined as a forest that is full (inundated) of mineral-rich water (freshwater) either as a permanent, irregular or a seasonal condition. It forms a wide belt inland after the mangrove and coastal vegetation. The zone has more open canopy, which may reach 45 m in height, densely tangled, and almost impenetrable undergrowth. It is usually flooded during the wet season and dries out during the dry season leaving portions of dry forest floor interspersed with permanent pools of water. Much of this vegetation type has been converted to agricultural and urban lands, and the original swamp forest remains mostly on alluvial sites along the major rivers. Climbing palms with hooked spines are particularly characteristic as are clumps of large aroids such as *Cyrtospernia senegalense.* Large trees such as *Mitragyna ciliata, Spondianthus preussii, Lophira alata, Anthostema aubryanum* and *Alstonia congensis* occur with smaller trees such as *Nauclea gilletii, Berlinia spp., Grewia coriacea,* and *Uapaca spp (*Keay 1949).A number of tree species in this ecological zone have stilted roots. The *Raphia* palm (*Raphia hookerii*) and *Lonchocarpus griffonianus* are usually abundant in the outer fringe vegetation which seldomly exceeds 14 m in height. Behind the fringe, the trees of the freshwater swamp may reach 30 m in height.

### 2.8.3 Lowland Rain Forest Ecological Zone

Tropical rainforests are rainforests that occur in areas where there is no dry season – all months have an average precipitation of at least 60 mm.This Lowland Rain Forest is located north of the freshwater swamp forest and south of the Derived Savanna Ecological Zone to the North. It is an area of dense evergreen forest of tall trees with thick undergrowth consisting of three layers of trees: the emergent layer with trees more than 36 m high; the middle layer between 15-30 m; while the lowest layer is generally below 15m *(*Keay 1949).The understorey is a shrub stratum composed of single-stemmed shrubs. The forest in the Northern parts of the zone is characterised by a number of species belonging to the *Sterculiaceae* family, but the *Ulmaceae* and *Moraceae* families are also common. Characteristic species of the lowland rain forest are *Terminalia superba, Ricinodendron heudelotii*, *Aubrevillea kerstingii* and *Khaya ivorensis.* The families *Meliaceae* and *Fabaceae* make up a large proportion of the tree species in the wetter Southern areas of this zone (Keay 1949).In still wetter areas the *Sapotaceae* are prominent and the timber trees *Lophira alata* and *Nauclea diderrichii* are often abundant.

### 2.8.4 Derived Savanna Ecological Zone

The Derived Savanna constitutes an east-west band between the Lowland Rain Forest and Guinea Savanna ecological zones, and is characterized by dense populations. The appearance and composition of Derived savanna, apart from the vestiges of Lowland rainforest, are much the same as in the Southern areas of Guinea Savanna. However, in some areas especially where man's impact on the forests has been high, there is a considerable reduction of vegetation/plant species. The impact of man has been so intense in this area that areas left to regrow tend to grow savanna type grasses, thus creating a "derived savanna". Remnants of the high forest may be present in upland or rocky areas that are not suitable for agriculture (Keay 1949).

### 2.8.5 Guinea Savanna Ecological Zone

The Guinea savanna (or savanna woodland/wooded savanna) is the most extensive vegetation in the middle belt of Nigeria, and consist of a mixture of trees and grass (Keay 1949).Almost half of the territory of Nigeria is occupied by a moist, so-called Guinean high-grass savanna (Makinwa, 2018). Precipitation per year here is 1000-1400 mm on the average. It receives annual rainfalls between 1000 – 1500 mm with about 6-8 months of rainfall. It contains parkland savanna, gallery forests and derived savanna. The typical vegetation is open woodland with tall grasses (1 to 3m high) in open areas and trees (up to 15m high) usually with short boles and broad leaves. This vegetation is burnt almost annually by fierce fires in the dry season; therefore fire-resistant species predominate. The parkland savanna is a by-product of centuries of tree devastation by man and fire, and a continuous attempt by plants to adapt them to the climatic environment, by developing long tap roots and thick barks, which enable them to survive the long dry season and resist bush fires.

Species in the Southern areas of the Guinea Savanna zone include *Lophira lanceolate, Terminalia glaucescens, Daniellia oliveri, Hymenocardia acida, Vitex doniana, Detarium microcarpum* and *Afzelia africana.* All these species have thick bark capable of resisting grass fires. Species of the Northern Guinea Savanna show close affinities with the East African "miombo" woodlands, and include, *Isoberlinia doka, ldalzielli, Monotes kerstingii* and *Uapaca togoensis.* Open canopy is dominated by grass, shrubs (e.g., *Gardenia spp.* and *Protes elliottii)* and woody climbers (e.g. *Opilia celtidifolia* and *Uvaria chamae* (Keay 1949*).*

**2.8.6 Sudan Savanna Ecological Zone**

The Sudan savannabelt is found to the Northern parts of Nigeria, and stretches from the Sokoto Plains through the Northern section of the High Plains of Nigeria to the Chad Basin. It includes areas around Sokoto, Kaduna, Kano and Borno States of Nigeria, comprising an area over a quarter of the country. Rainfall ranges from about 600-1000 mm and the relative humidity is generally below 40%, except for the few rainy months when this can rise to 60% and above. The zone experiences a dry season of about 4-6 months.The Sudan Savanna is characterized by the coexistence of trees and grasses. Dominant tree species are often belonging to the *Combretaceae* and *Caesalpinioideae,* some *Acacia* species are also important. The dominant grass species are usually *Andropogoneae,* especially the genera *Andropogon* and *Hyparrhenia*, on shallow soils also *Loudetia* and *Aristida.*

Much of the Sudanian Savanna region is used in the form of parklands, where useful trees, such as shea, baobab, locust-bean tree and others are spared from cutting, while sorghum, maize, millet or other crops are cultivated beneath (Atangana*et al.,* 2013). The zone has the largest population density in Northern Nigeria, produces important economic crops such as groundnuts, cotton, millet, and maize and has the highest concentration of cattle in the country. Sudan savanna has consequently suffered great impact from man and livestock. The landscape has less vegetation than the Guinea savanna. Existing vegetation consist mainly of short grasses, about 1-2 m high, and some stunted tree species, such as *Acacia* species, the silk cotton *Ceiba pentandra* (silk cotton) and the *Adansonia digitata* (baobab) (Keay 1949*).*

**2.8.7 Jos Plateau Ecological Zone**

Jos Plateau Ecological Zone is based on the distinctness of the vegetation of the plateau (altitude about 1200 m) for two reasons. First, the high plateau has suffered widespread degradation by man so that only relics of Guinea woodland remain. Presently, the plateau is almost devoid of trees. Second, the flora on the Plateau is peculiar with many species of woody and herbaceous plants not found elsewhere in West Africa, alongside many typical Guinea Savanna species. The endemic species peculiar to the Jos Plateau include *Terminalia brozenii, Morea zambesiaca* and the orchids *Disperis johnstoni* and *Disa hircicornis* (Keay 1949*).*

**2.8.8 Montane Region Ecological Zone**

Montane ecosystem refers to any ecosystem found in mountains. These ecosystems are strongly affected by climate, which gets colder as elevation increases. They are stratified according to elevation. Dense forests are common at moderate elevations. However, as the elevation increases, the climate becomes harsher, and the plant community transitions to grasslands or tundra. The highlands and plateaus are characterized by grassland vegetation at the base, forest vegetation on the windward slope and grassland vegetation on the Plateaux. The lower slopes of highlands located in the forest belt such as Bamenda Highlands (in Cameroon) and the Obudu Hills are covered with forest vegetation, while the upper slopes and the plateau surfaces have grassland vegetation, which normally supports cattle population (Keay 1949*).*

This region is found along the south Eastern border of Nigeria in the Cameroon mountains. Forest vegetation extends as high as 1600 to 2400 m and ecotone with mountain grassland. There are two main types of montane forest. From about 1000 to 1800 m altitude the forest is enveloped in mist for long periods and is referred to as Mist Forest. The tree canopy is irregular and is composed of species such as *Polyscias ferruginea, Entandrophragma angolense, Turreanthus africanus* and at higher altitudes *Schefflera hookeriana* and species of *Ficus* and *Conopharyugia.* The high humidity results in a profusion of mosses and various kinds of epiphytes. Above the mist zone the forest is drier, more stunted, and more susceptible to fire.

Typical tree species include *Syzygium standtii, Schefflera abyssinica, Schefflera mannii, Lachnopylis mannii* and *Pittosporum mannii.* Masses of lichens beard the branches of the trees. At the upper limit of the forest there is a scrubby zone of *Rapanca neurophylla, Agauria saheifolia* and *Laisiosiphon glaucus.* In the lower grasslands most of the grasses are tussocky, have flat leaves, and reach 0.6 m in height, or slightly more. The family *Compositae* is well represented in this grassland. At about 3000 m there is a marked change, the flat-leaved tussocky grasses, such as *Andropogon distachvus* are replaced by grasses with more compact shorter tussocks of narrow rolled leaves, such as *Festuca abyssinica.* Trees are absent from this upper grassland, with only a few bushy plants such as *Blaeria mannii, Senecio clarenceanus* and *Helichrysum mannii (*Keay 1949*).*

### 2.8.9 Sahel Savanna Ecological Zone

The Sahel savanna is found to the extreme Northwest and Northeast of the country, where the annual rainfall is less than 600 mm and with dry seasons exceeding 8 months. Typically the vegetation consists of grasses, open thorn shrub savanna with scattered trees, 4 to 9 m in height most of them are thorny, and extensive sparse grasses. Main tree species include *Acacia raddianna, A. Senegal, A. laeta* and *Commiphora africana;* the shrubs are *Salvadora persica, Leptadenia pyrotechnica,* and four species of Grewia; while the grasses include *Aristida stipoides, Schoenefeldia gracilis* and *Chloris priean (*Keay 1949*).*

## CHAPTER THREE

## METHODOLOGY

### 3. 0 Study Areas

This study was carried out in three purposively selected ecological zones of Nigeria based on the geographical distribution of bamboo raw culm namely; Mangrove Swamp, Lowland Rain Forest and Guinea Savanna ecological zones of Nigeria. For the purpose of this study and based on logistic factor, two states were randomly selected in each ecological zone. These are: Rivers and Cross River states (Mangrove Swamp ecological zone), Oyo and Osun states (Lowland Rain Forest ecological zone) Kwara and Niger states (Guinea Savanna ecological zone).

Specifically, materials (bamboo culms) for this study were collected from Eliozu in Port Harcourt (Rivers state), Akamkpa (Cross River state), Idi Ayunre (Oyo state), Ikire (Osun state), Alapa (Kwara state) and New Bussa (Niger State, Nigeria).

### 3.1 Port Harcourt

Port Harcourt is the capital and largest city of Rivers State, Nigeria. It lies along the Bonny River and is located in the Niger Delta. The area that became Port Harcourt in 1912 was before that part of Fishing settlements (fishing ports) also called Borokiri in Okrika language and the farmlands of the Diobu village group of the Ikwerre, a tribe in the larger Igbo nation (Onwuejeogwu, 1981) . The colonial administration of Nigeria created the port to export coal from the collieries of Enugu located 243 kilometres (151 mi) north of Port Harcourt (Nigeria, Chief Secretary's Office 1933) ,to which it was linkd by a railway called the Eastern Line, also built by the British ( Williams 2008;Udo 1970).

#### 3.1.1 Geography

Port Harcourt has Coordinates of4°49′27″N7°2′1″E4.82417°N 7.03361°E.The main city of Port Harcourt is the Port Harcourt City in the Port Harcourt local government area, consisting of the former European quarters now called Old GRA and New Layout areas. The urban area (Port Harcourt metropolis), on the other hand, is made up of the local government area itself and parts of Obio-Akpor and Eleme accordingly (Ogbonna *et al*., 2007). Port Harcourt, which is the current capital of Rivers State, is highly congested as it is the only major city of the state. In 2009, a law was passed by the Rivers State House of Assembly and governor Amaechi's administration to spread development to the surrounding communities as part of the effort to decongest the Port Harcourt metropolis. The Greater Port Harcourt region, spans eight local government areas that include Port Harcourt, Okrika, Obio-Akpor, Ikwerre, Oyigbo, Ogu–Bolo, Etche and Eleme. Its total population was estimated at 2,000,000 as of 2009, making it one of the largest metropolitan areas in Nigeria. But that number has greatly increased according to recent studies (The Greater Port Harcourt Project 2012).

**3.1.2 Climate**

Port Harcourt features a tropical wet climate with lengthy and heavy rainy seasons and very short dry seasons. Only the months of December and January truly qualifies as dry season months in the city. The harmattan, which climatically influences many cities in West Africa, is less pronounced in Port Harcourt. Port Harcourt's heaviest precipitation occurs during September with an average of 367 mm of rain. December on average is the driest month of the year; with an average rainfall of 20 mm. Temperature throughout the year in the city is relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25 °C-28 °C in the city.

**3.2Akamkpa**

Akamkpa is the headquarters of Akamkpa Local Government Area of Cross River State, Nigeria. It is located is located between longitudes $8^{0}12^{1}$E to $9^{0}00^{1}$E and latitudes $5^{0}00^{1}$N to $5^{0}48^{1}$N in Cross River State, Nigeria (Theophilus*et al*, 2013). Akamkpa is the headquarters of Akamkpa Local Government Area of Cross River State, Nigeria. The soils of Akamkpa Local Government area are derived from basement complex rocks consisting of granite gneiss. Basement complex rocks are known to occur at Oban and Obudu areas in Cross River State of Nigeria (Aki *et al*., 2014). At Oban, it is known as Oban Massif which Nsan, Okomita and Old Netim are the integral parts occupying about 10,000 $km^2$ (Ekwueme, 2003; Amah *et al.,* 2012). The present study locations at Nsan, Okomita and Old Netim are underlain by basement complex rocks characterized as Biotite-Hornblende-Gneiss (Ekwueme, 2003; Amah *et al.,* 2012). The igneous and metamorphic rocks are crystalline and they weather easily and deeply under humid conditions to form deep soil (>100 cm) profiles (Olaniyan *et al*., 2010).

Studies have shown that Biotite-Hornblende-Gneiss undergoing weathering under humid tropical conditions can influence the morphological, physical and chemical as well as mineralogical properties of the soils (Wilson, 1967; Velbel, 1989). The high rainfall of the study area (>3500 m) and high soil temperature (Isohyperthermic soil temperature) (>27-31°C) can enhance hydrolytic weathering by predisposing the metamorphosed rocks (gneiss) to ferralitic pedogenesis (Amusan, 2002; Akpan-Idiok, 2012). Biotitie-Gneiss can undergo weathering with resultant formation of interstratified minerals such as vermiculite/or montmorillonite which can decompose rapidly to kaolinite; also hornblende-gneiss can weather through a pedological process of dissolution-reprecipitation to form ferruginious and aluminous weathering products (goethite, gibbsite and kaolinite) (Velbel, 1989).

**3.3 Idi Ayunre**

Idi Ayunre is the headquarters of Oluyole Local Government Area in Oyo State, Nigeria. It is a suburb of Ibadan, Oluyole Local Government, Oyo State, it lies on Latitude 7°.25N 3° and Latitude $30^0$.5E (Ogunsanwo and Akinlade 2011). The rock is of the Precambrian series shown as undifferentiated basement complex. The soil is sandy, 45cm deep with overlying clay and iron stone about 1.2m deep varying from place to place. The topography is generally gently undulating with average altitude ranging from 121.90 to 152.40m above sea level.The city has tropical rainy climate with an average annual rainfall of1265.6mm. From the estimated runoffs of the river, only one flow peak occurred in 1980 (August), and two peaks in 1990, 1999 and 2011 which occurred in July and October.The water bodies were neutraltoslightly alkaline and had pH values varying from7.6-8.19, all values fell within the tolerable limits of pH 6 –9 stipulated by Federal Ministry of Environment, for surface waters in both dry and wet seasons (Bodley Company Limited2016).

**3.4.Ikire**

Ikire is the headquatres of Irewole Local Government Area of Osun State,Nigeria.It is located between 7° 37′E and longitude 4° 10′N (Ogunsanwo and Ojo 2012 ). It is bounded in the north by Ayedire, in the south by Isokan, in the east by Ayedade and in the south east by Ife North Local Government Areas of Osun state. It also shares boundary with Egbeda Local Government of Oyo state to the west. It is bounded in the north by Ayedire, in the south by Isokan, in the east by Ayedade and in the south east by Ife North Local Government Areas of Osun state. It also shares boundary with Egbeda Local Government of Oyo state to the west (Adebayo, 2013).

The vegetation consists of high forest and derived savanna towards the north. The high forest often called tropical rainforest areas are dominated by forest tree species such as *Melicia excelsa, Terminalia ivorensis, Terminalia superba, Khaya grandifoliola,Nauclea diderichii, Lophira alata Lovoa trichiliodes, Tremaguinensis, Musanga cercrepiodes, Sterculia tragacantha* and *Ceibapentandra* among others. Savanna tree species include *Annonasenegalenses, Bridelia ferrugina, Casia sieberiana, Khayasenegalensis, Nauclea latifolia, Prosopis africana, Vitaleria paradoxum, Parkia biglobossa, Terminalia glaucean and Daniella* oliveri (Aiyeloja, and Ajewole,2006).

**3.5Alapa**

Alapa is a village in Asa Local Government Area of Kwara State, Nigeria. Afon is the headquartres of Asa Local Government Area and it is 27km away from Ilorin the State capital. It is located on latitude $8^{o}00^{1}$ and $9^{o}10^{1}$ North of the Equator and longitude $2^{o}45'$ and $4^{o}15'$ East of the Greenwich Meridian (Tunde *et al*., 2013). Asa Local Government Area has three (3) districts namely Afon, Owode and Onire. Asa LGA is one of the sixteen local government areas of Kwara state. It has an area of 1,286 and it stretches from the peri-urban fringes of the city of Ilorin by Oyo State (Ajibade, 2006). It is bounded by Moro Local Government Area to the north, Oyo State to the south, Ilorin West Local Government Area to the East and Oyun Local Government Area to the West. The average annual rainfall is between 1,000m-1,500mm. The heaviest rainfall is often recorded between the months of June and early August. The local government area falls within the tropical hinterland with wet and dry climate. Trees found here are mainly deciduous that shed their leaves during the dry season so as to reduce moisture loss to transpiration, while they are fresh and luxuriant during rainy season. Grasses here are very good for grazing and therefore support cattle rearing. The vegetation of the area comprises of Guinea Savannah, derived savannah and rainforest.

**3.6 New Bussa**

New Bussa is the headquarters of Borgu Local Government Area of Niger State, Nigeria.It lies between latitudes $9^{0}$ $4^{/}$ Nand $10^{0}$ 23’ and longitudes 30 30 and 50 50’ E (Tuna Wildlife Consultants and NARDES, 1983). The average temperature in New Bussa is 27.2 °C. The average annual rainfall is 1109 mm. The least amount of rainfall occurs in December. The average in this month is 1 mm. The greatest amount of precipitation occurs in September, with an average of 234 mm. The vegetation of New Bussa is a transitional one between the Sudan and Northern Guinea Savanna types, while that of the Zugurma sector is typically Northern Guinea Savanna woodland (Child 1974, DRB 2004, Milligan 1979). The vegetation of the Borgu sector is differentiable by hydrological as well as soil factors into six major types viz; the *Afzelia africana* woodland, the *Isoberlinia* woodland, the *Terminalia macroptera* woodland, the *Acacia* complex, the *Burkea Africana, Detarium microcarpum* wooded savanna and the riparian or fringing forest (Child 1974).

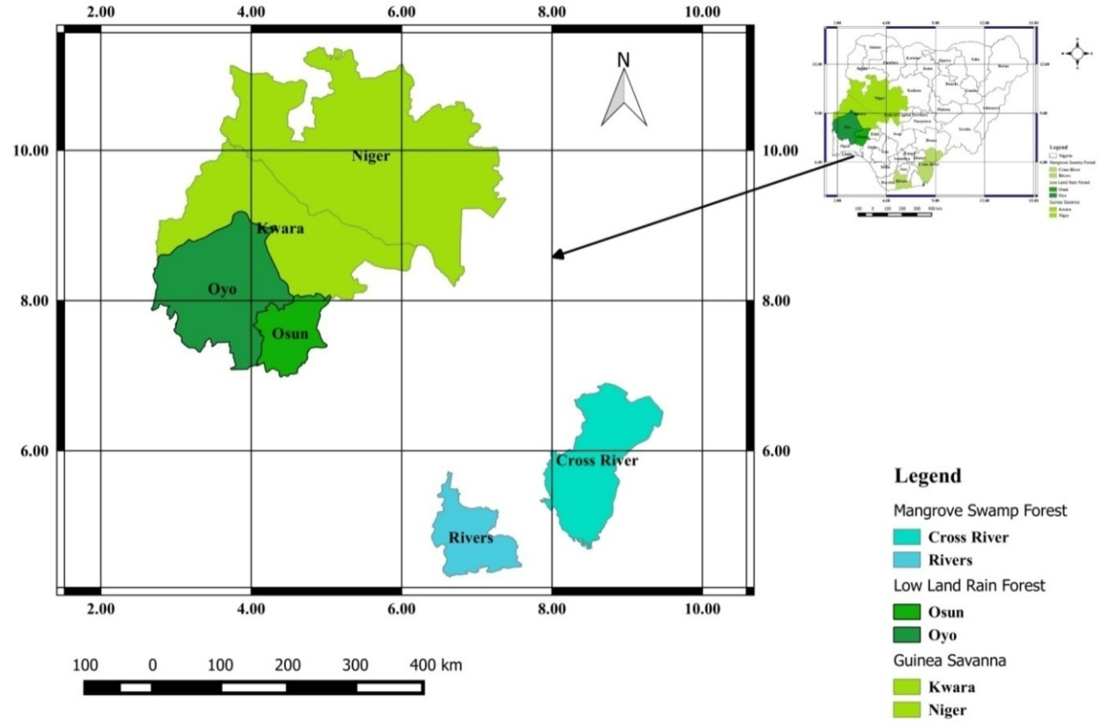


Figure 3.1: Ecological Map of the Study Area.

### 3.7 Metho

### 3.7.1 Sample Collection

In each site, 10 five-year old bamboo culms (about 15 – 20m height, 25– 30mm Diameter at the Breast Height (DBH) and wall thickness of about 3-5mm) were selected and then harvested from a bamboo stock making a total of 20 culms per zone. The culms were then cross cut with a cross cutting saw. Along each culm, ten sampling points (SP1−lowest basal point to SP10−topmost point) at 3- internode intervals were systematically selected from base to top for glulam bamboo boards production.

### 3.7.2 Preparation of Glulam*Bambusa vulgaris* Board Samples

Figure 3.7.2.1 is the flow chartof the preparation of glulam*bambusa vulgaris* board samples. The harvested bamboo culms from each bamboo stock were converted primarily to four equal bamboo splits with circular saw.Bamboo splits were then air-dried for two months. After air-drying for two weeks, bamboo splits were preserved in a solution of sodium metaborate ($Na_2Bo_3$) for two months. They were then air-dried for another two weeks. Bamboo splits were then edged and cut. The inner and outer parts of the bamboo splits were planed on a multi-purpose planing machine for proper penetration of top bond adhesive. After planing, top bond adhesive was applied to both inner and outer surfaces of bamboo laminate members and then pressed together on clamps for proper adhesion of laminate members for five day using cold press method. They were then trimmed at the ends. After trimming, they were sanded to achieve smooth clear and plane surfaces. The bamboo boards were then stacked. Preparation of samples was done in the wood workshop of the Department of Forest Production and Products, Faculty of Renewable Natural Resources the University of Ibadan, Nigeria.

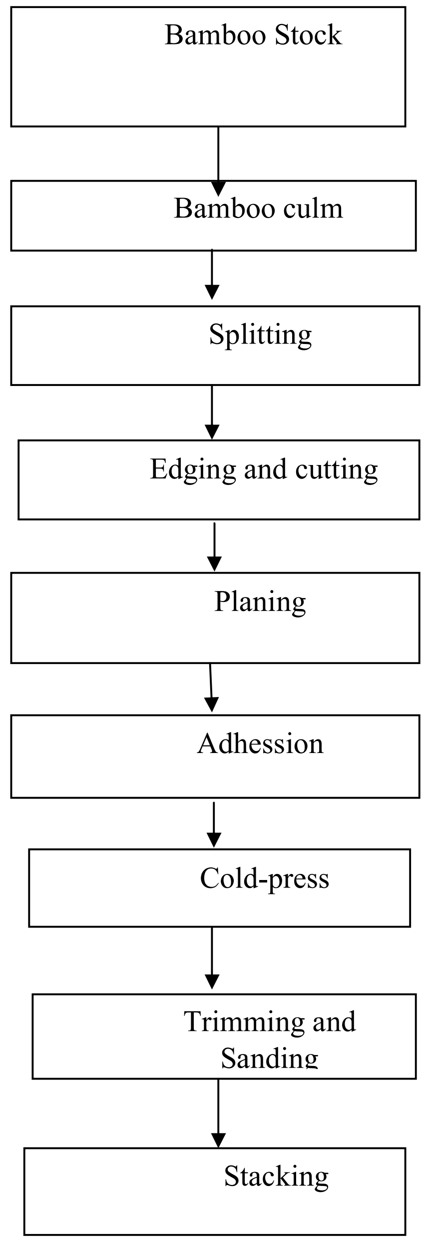


**Figure 3.7.2.1 Flow Chart of Preparation of glulam*Bambusa vulgaris* Board Samples**

### 3.7.3 Dimension of Test Sample

Figures 3.7.3 (1-6) are the different dimensions used for this study.The dimensions are: Density (60x20x20)$mm^3$, Volumetric Shrinkage (40x20x20)$mm^3$, MOR and MOE (300x20x20),MCS Parallel and Perpendicular to Grain (80x20x20)$mm^3$ and Shear Strength ( 40x20x20) $mm^3$. Ten replicates were used. The sampling strategy is as follows: 3 zones x 2 sites x 10 culms x 10 specimens= 600 samples.

10 culms x 10 specimen/10 culms

$$= \frac{100 \text{ spcimens}}{10 \text{ culms}} = 10 \text{ replicates}$$

#### 3.7.3.1 Density

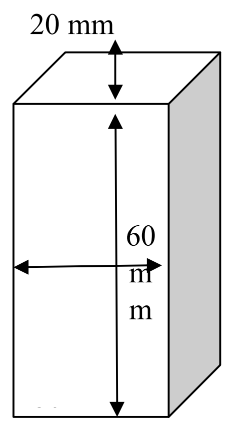


**Figure 3.7.3. 1 Density (20x20 x60) mm3**

#### 3.7.3.2Volumetric Shrinkage

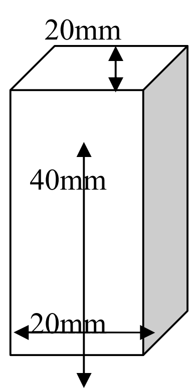


**Figure 3.7.3. 2 Percentage (%) Volumetric Shrinkage: (20x20x40) $mm^3$**

### 3.7.3. 3MOR and MOE

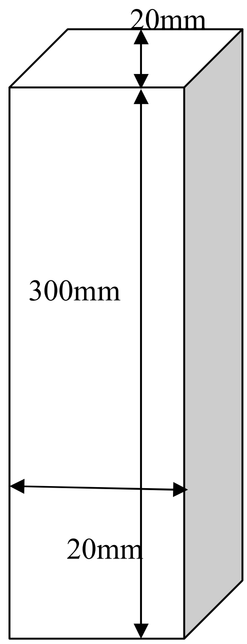


**Figure 3.7.3. 3MOR and MOE (300x20x20) mm3**

### 3.7.3. 4MCS//

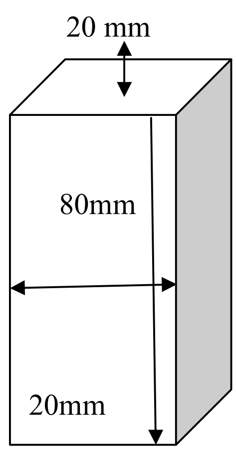


**Figure 3.7.3. 4MCS// (20x20x80) $mm^3$**

**3.7.3. 5 MCS l**

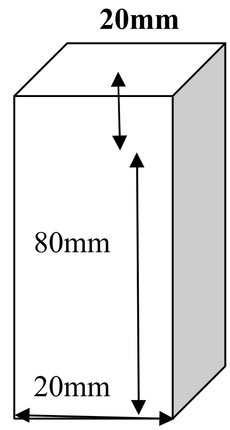


**Figure 3.7.3. 5MCS l: (20x20x80) mm$^3$**

**3.7.3. 6Shear Strength**

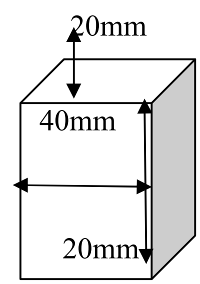


**Figure 3.7.3.6 Shear Strength(20x20x20) mm$^3$**

**Plate 3.1 A Bamboo Stand at Idi Ayunre, Ibadan.**

### 3.7.4 OKH-600KN Digital Universal Testing Machine

This type of Universal Testing Machine is a computerized electromechanical universal testing machine. It has a precision grade, testing range 0-600KN load cell capacity and Serial No: 140521.It was developed by Okhard Machine Tool Ltd.It operates at 0.01 KN/S. It was used to determine mechanical properties of glulamBambusa vulgaris in the Department Agricultural Engineering, Faculty of Technology, the University of Ibadan, Nigeria.

**Plate 3 .2OKH-600KN Digital Universal Testing Machine**

**Plate 3.3 Samples of Glulam *Bambusa vulgaris* MOR and MOE Boards**

**Plate 3.4 Failure Patterns of Some MOR and MOE Test Samples ofGlulam *Bambusa vulgaris***

**Plate 3.5 Failure patterns of Some Samples of MCS Parallel and Perpendicular to Grain of Glulam *Bambusa vulgaris* Glulam.**


**Plate 3.6 Failed Shears samples of Glulam *Bambusa vulgaris* along the glue lines**

### 3.8.0 Testing of properties

### 3.8.1 Physical Properties

Physical properties (Density and Volumetric shrinkage)were tested in the wood laboratory of the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria.

#### 3.8.1.1 Density

The densiy was evaluated in accordance with the British Standard (BS 373-1957).Ten samples were soaked in distilled water for 72 hours. Samples were then oven-dried at 103±2°C and then weighed at interval with a sensitive measuring scale until constant weights were obtained at 12% moisture content. Dry gel was used to cool the samples in desiccators after which they were weighed. The dimensions were then measured with a micro screw gauge. The density was then calculated as follows:

$þ = \frac{W_o}{V_o}$ (Kg/m$^3$)…………………………………………..equation 3.1

Where:þ =Density (gcm$^3$),$W_o$=oven-dry weight (g), $V_o$=volume of oven-dry sample (cm$^3$) as used by Simpson, 1993).

#### 3.8.1.2 Volumetric Shrinkage

Volumetric Shrinkage was determined according to theASTM- 1037 (1999) with minor modifications based on Dinwoodie (1989) and Ogunsanwo (2000). Ten Test specimens measuring (40 x20 x 20) mm$^3$ each were used. They were properly aligned and denoted 'T' and 'R' for Tangential and Radial planes respectively. They were soaked in water for 48 hrs in order to get them conditioned to moisture above Fibre Saturation Point (FSP). The FSP of bamboo is 34.05±3% (Gutiérrez *et al.,* 2015).

Specimen were then removed one after the other; their dimensions in wet condition were taken to the nearest millimetre. Percentage shrinkage along the two planes was calculated having oven-dried the samples to 12% moisture (103±2°C).

S (%) = $\frac{D_s - D_o}{D_s}$ x 100................ ...............................................equation 3.2

Where S (%) = Dimensional shrinkage (%), $D_s$= dimension at saturated condition, $D_o$= dimensionof oven dry conditionas used by Ogunsanwo and Onilude, (2000).

VS =$S_R$+$S_T$……………....................equation 3.3

Where VS= Volumetric shrinkage, $S_R$= Radial shrinkage, $S_T$= Tangential shrinkage

### 3.8.2 Mechanical properties

Mechanical properties (modulus of rupture (MOR, N/mm$^2$), modulus of elasticity (MOE, N/mm$^2$), maximum compressive strength parallel to grain (MCS//, N/mm$^2$) maximum compressive strength perpendicular to grain (MCS$\perp$, N/mm$^2$) were evaluated in the Department of Wood Products Engineering, Faculty of Technology, the University of Ibadan, Nigeria on computerized OKH-600 Digital Universal Testing Machine of range 0-600KN and Serial No 140521.Shear strength wasevaluatedin the wood laboratory of the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria using tensiometer.

#### 3.8.2.1 Modulus of Rupture (MOR)

The Modulus of Rupture was evaluated in accordance with the ASTM- D143-2014 standard. This involved the use of standard test specimens (300 x 20 x 20 x) mm$^3$. The samples were placed horizontally in-between two plates of universal testing machine and then supported. The load was applied at the initial speed of 0.01 KN/s. This was performed on computerized OKH-600 Digital Universal Testing Machine of range 0-600KN and Serial No 140521 in the Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Nigeria.

The following equation was used to calculate MOR of wood with a rectangular cross section:

For a rectangular sample under a load in a three-point bending setup,

$MOR = \frac{3PL}{2bd^2}$(Nmm$^{-2}$)…………………………… ……………..equation 3.4

Where: MOR=Modulus of Rupture, P=Force at the fracture point (N), L=length of the support span (mm), b= width (mm), d=Thickness of the board sample (mm). Unit ofMOR**:** N/mm$^2$, Where N=load, mm$^2$= area as used byJavadian *et al,* (2019).

#### 3.8.2.2 Modulus of Elasticity (MOE).

The Modulus of Elasticitywas evaluated in accordance with the ASTM- D143-2014 standard. The modulus of elasticity was calculated from the deflection values ("Δ"). There is a graduation (in mm) on the UTM from which deflection values ("Δ") were obtained at the point of failure during tests for MOR. The MOE was then calculated using the formula.

$MOE = \frac{PL^3}{4\Delta bd^3}$(Nmm$^{-2}$)…………………………………… equation 3.5

Where:P=Maximum Force (N) at failure, L=Span in (mm), b=Width in (mm), d=thickness in (mm), Δ=the deflection at beam center at proportional load,Delta (Δ) which is the deflection of beam center at proportional limit as used byJavadian*et al,* (2019).

**3.2.2.3 Maximum Compressive Strength Parallel to Grain (MCS//).**

The Maximum Compressive Strength Parallelwas evaluated in accordance with the ASTM- D143-2014. Ten test specimens of (80x 20 x 20) $mm^3$ each were used for this test. Load was placed perpendicularly in-between two plates of universal testing machine and the force was exerted at the initial speed of 0.01 mm/sec. The values of the force applied and the value of the force at the point of failure were obtained on the computer. This was then divided by the cross sectional area of the test specimen to obtain value for maximum compressive strength parallel to grain (MCS//) using the formula.

MCS// =.$\frac{Pmax}{ab}$ … … … …..…………………………. (Equation 3.6)

Where: MCS// = Maximum Compressive strength parallel to grain ($Nmm^{-2}$), P max= Maximum Force (N), a = length of sample (mm),b = breadth of sample (mm)as used byJavadian*et al,* (2019).

**3.8.2.4 Maximum Compressive Strength Perpendicular to Grain (MCSl)**

The Maximum Compressive Strength Perpendicularwas evaluated in accordance with the ASTM- D143-2014 standard. Ten test specimens of (80x 20 x 20) $mm^3$ were used for this test. Load was placed horizontally in-between two plates of universal testing machine and the force was applied. The value of the force at the point of failure was obtained from the computer connected to Universal Testing Machine. This was divided by the cross sectional area of the test specimen to obtain value for maximum compressive strength perpendicular to grain (MCSl) using the formula.

MCSl =.$\frac{Pmax}{ab}$ … … … …..…………………………………equation 3.7

Where: MCSl = Maximum Compressive strength perpendicular to grain ($Nmm^{-2}$), P max = Maximum Force (N), a =length of sample (mm), b = breadth of sample (mm)as used byJavadian*et al,* (2019).

#### 3.8.2.5 Shear Strength

The Shear Strength was evaluated in accordance with 1S0 22157 (Anonymous, 2004) standard.Test specimens of samples (40x20x20) $mm^3$were used for this test. Each test sample was placed horizontally in-between two gigs of tensiometer and the force was applied. The force at which failure occurred was read on the tensiometer and then recorded. This was divided by the cross sectional area of the test specimen to obtain value for Shear Strength using the formula:

Shear = $\frac{F}{A}$(N/$mm^2$)…………………… ………………………equation 3.8

Where:F = Force (N), A= area ($mm^2$). Unit of Shears strength is N/$mm^2$ as used by (Anonymous (2004).

### 3.9 Hypotheses Testing

#### 3.9.1 Density

1. $H_o$: Densities of glulam bamboo boards at different internodes are the same.

$H_a$: Densities of glulam bamboo boards at different internodes are different.

2. $H_o$: Densities of glulam bamboo boards in Nigerian eco-zones are the same.

$H_a$: Densities of glulam bamboo boards in Nigerian eco-zones are different.

#### 3.9.2 Volumetric Shrinkage

1. $H_o$: volumetric shrinkages of glulam bamboo boards at different internodes are the same.

$H_a$: volumetric shrinkages of glulam bamboo boards at different internodes are different.

2. $H_o$: volumetric shrinkages of glulam bamboo boards in Nigerian eco-zones are the same.

$H_a$: volumetric shrinkages of glulam bamboo boards in Nigerian eco-zones are different.

#### 3.9.3 Modulus of Rupture

1. $H_o$: Modulus of rigidity of glulam bamboo boards at different internodes is the same.

$H_a$: Modulus of rigidity of glulam bamboo boards at different internodes is different.

2. $H_o$: Modulus of rigidity of glulam bamboo boards in Nigerian eco-zones is the same.

$H_a$: Modulus of rigidity of glulam bamboo boards in Nigerian eco-zones is different.

### 3.9.4 Modulus of Elasticity

1. $H_o$: Modulus of elasticity of glulam bamboo boards at different internodes is the same.

$H_a$: Modulus of elasticity of glulam bamboo boards at different internodes is different.

2. $H_o$: Modulus of elasticity of glulam bamboo boards in Nigerian eco-zones is the same.

$H_a$: Modulus of elasticity of glulam bamboo boards in Nigerian eco-zones is different.

### 3.9.5 Maximum Compressive Strength Parallel to Grain

1. Ho: Maximum compressive strengths parallel to grain of glulam bamboo boards at different internodes are the same.

$H_a$: Maximum compressive strengths parallel to grain of glulam bamboo boards at different internodes are different.

2. $H_o$: Maximum compressive strengths parallel to grain of glulam bamboo boards in Nigerian eco-zones are the same.

$H_a$: Maximum compressive strengths parallel to grain of glulam bamboo boards in Nigerian eco-zones are different.

### 3.9.6 Maximum Compressive Strength Perpendicular to Grain

1. $H_o$: Maximum compressive strengths perpendicular to grain of glulam bamboo boards at different internodes are the same.

$H_a$: Maximum compressive strengths perpendicular to grain of glulam bamboo boards at different internodes are different.

2. $H_o$: Maximum compressive strengths perpendicular to grain of glulam bamboo boards in Nigerian eco-zones are the same.

$H_a$: Maximum compressive strengths perpendicular to grain of glulam bamboo boards in Nigerian eco-zones are different.

### 3.9.7 Shear Strength

1. $H_o$: Shear strengths of glulam bamboo boards at different internodes are the same.

$H_a$: Shear strengths of glulam bamboo boards at different internodes are different.

2. $H_o$: Shear strengths of glulam bamboo boards in Nigerian eco-zones are the same.

$H_a$: Shear strengths of glulam bamboo boards in Nigerian eco-zones are different.

**3. 10 Experimental Design**

The experimental Design adopted for this study is Randomized Complete Block Design (RCBD).

Number of Locations (Blocks) = 3

Number of internodes (treatments) = 10

Number of replicates = 10

Number of variables = 7

**3.11 Statistical models**

**3.11.1: Objective 3**

The statistical model adopted for objective 3 is:

$Yij=\mu+B_i+T_{j+}e_{ij}$…………………… …………………………….equation 3.9

Where

Yij=Individual observation

$\mu$=General mean effect of internodes

$B_i$= effect locations (blocks)

$T_j$=effect of jth height positions (treatments)

$e_{ij}$=Error term associated with the experiment.

**3.11.2: Objective 4**

The statistical model adopted for objective 4 is:

$r = \frac{\sum(y-y^{-})(x-x^{-})}{\sqrt{\sum(y-y^{-})^2(x-x^{-})^2}}$ ……………………………………………equation 3.10

Where:

r= Karl Pearson's Product Moment Correlation

x and y= individual observations of x and y, $x^{-}$and $y^{-}$= means of x and y respectively.

**3.11.3 Objective 5**

The statistical model for objective 5 is:

$Y = b_o + b_1x$…….. …………………………………………equation 3.11

Where

Y = dependent variables (physical and mechanical properties)

$b_o$= regression constant

$b_1$ = regression coefficient

x = independent variable (density)

**3.12 Statistical Analysis**

In this study, data were analyzed using descriptive and inferential statistics. Descriptive statistics used were figures. Inferential statistics used are correlation analysis, analysis of variance and regression analysis.

Descriptive statistics (figures) were used to present the inter-nodal variation in selected physical and mechanical properties of bamboo glulamin the selected eco-zones of Nigeria.

Analysis of Variance was used to analyze the inter-nodal variability in selected physical and mechanical properties of bamboo glulamin the selected eco-zones of Nigeria while Least Significant Difference (LSD) was used for further comparison and hence separation of the means.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.0 Results

### 4.1 Density

By varying the internodal sampling points, density increased significantly from the lowest basal sampling point to the topmost sampling point (Table 4.1.2). In Mangrove Swamp Forest, density increased from 35±0.09 to 56±0.05Kg/$m^3$ at the lowest basal and topmost sampling points respectively. Density increased from 40±0.01 to 61±0.01 and 47±0.01 to 64±0.00Kg/$m^3$ in Lowland Rain Forest and Guinean Savanna respectively at the lowest basal and topmost sampling points.

Also, by varying the ecological zones, significant differences were in density were observed between the ecological zones. The mean density obtained was 47±0.07, 51±0.06 and 58±0.06 Kg/$m^3$ in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively (Table 4.1.3).

Analysis of variance result showed that there were significant differences between the internodal sampling points and also between the ecological zones (DF= 29, 9; F= 59.53, P= 0.00<0.05, table 4.1.1).

Table 4.1.3 is theLSD of mean density of Glulam*Bambusa vulgaris* in Selected Nigerian Eco zones. The result showed significant differences between the ecological zones (DF= 29, 2; F= 151.39, P = 0.00<0.05). Guinea Savanna ecological zone showed most significant value (58±0.06Kg/$m^3$). This is similar to 57Kg/$m^3$ recorded by Ogunsanwo (2010 Table 4.8.1.1).

**Table 4.1.1 ANOVA Table of the Density of Glulam *Bambusa vulgaris* the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internodes** | 9 | 0.109000 | 0.012111 | 59.53 | 0.00* |
| **Ecozone** | 2 | 0.061596 | 0.030798 | 151.39 | 0.00* |
| **Error** | 18 | 0.003662 | 0.000203 | | |
| **Total** | 29 | 0.174258 | | | |

*= significant.

**Table 4.1.2 Means Densities of Glulam *Bambusa vulgaris* in Internodes (g/cm$^{3)}$**

| | Density (Kg/m$^3$) | | |
|---|---|---|---|
| **Internode** | **MF** | **LRF** | **GS** |
| 1 | 35 | 40 | 47 |
| 2 | 40 | 44 | 51 |
| 3 | 40 | 48 | 55 |
| 4 | 44 | 49 | 58 |
| 5 | 49 | 51 | 60 |
| 6 | 49 | 52 | 61 |
| 7 | 52 | 55 | 62 |
| 8 | 53 | 56 | 62 |
| 9 | 55 | 58 | 63 |
| 10 | 56 | 61 | 64 |

**Table 4.1.3 Density of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | Density ($g/cm^3$) |
|---|---|
| **MF** | 47 |
| **LRF** | 51 |
| **GS** | 58 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Foerst

**Table 4.1.4: LSD of Mean Density of Glulam *Bambusa vulgaris* in Selected Nigerian Eco zones.**

| Ecozone | Mean |
|---|---|
| Guinea Savanna | 58a |
| Lowland Rain Forest | 51b |
| Mangrove Swamp | 47c |

Note: means with the same letter are not significantly different.

## 4.2 Dimensional Shrinkage

### 4.2.1 Radial Shrinkage

Radial shrinkage significantly decreased from the lowest basal sampling point to the topmost sampling point, contrary to density. It varied from 4.37±0.00 to 4.32±0.00; 4.15±0.00 to 4.0±0.00 and 3.68±0.00 to 3.64±0.00% in the lowest sampling points and the topmost sampling points in Mangrove Swamp, Lowland Rain Forest and Guinea Savanna respectively (Table 4.2.1.2).

Radial shrinkage decreased ecologically from Mangrove Swamp to Guinea Savanna. The mean radial shrinkage obtained were 4.35±0.02; 4.08±0.05 and 3.66±0.02% in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively (Table 4.2.1.3). Mangrove Swamp Forest showed highest radial shrinkage among the ecological zones.

There were significant differences in radial shrinkage between internodes from the base to the top and between the selected ecological zones of Nigeria ($P = 0.00<0.05$, Table 4.2.1.1).

Table 4.2.1.4 is theLSD of mean radial shrinkage of Glulam*Bambusa vulgaris* in selected Nigerian Ecozones. The result showed significant differences between the ecological zones ($P = 0.00<0.05$).Guinea Savanna showed most significant value (3.66±0.02%).

**Table 4.2.1.1: ANOVA Table of the Radial Shrinkage of *Bambusa vulgaris* Glulam the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internodes** | 9 | 0.0227 | 0.003 | 6.0 | 0.00* |
| **Ecozone** | 2 | 2.3939 | 1.1970 | 2394 | 0.00* |
| **Error** | 18 | 0.0088 | 0.0005 | | |
| **Total** | 29 | 2.4264 | | | |

*= Significant (P<0.05)

**Table 4.2.1.2 Mean Radial Shrinkage of Glulam *Bambusa vulgaris* in Internodes (%) Density (g/cm$^3$)**

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 4.37 | 4.15 | 3.68 |
| 2 | 4.37 | 4.15 | 3.68 |
| 3 | 4.36 | 4.15 | 3.67 |
| 4 | 4.36 | 4.15 | 3.67 |
| 5 | 4.35 | 4.15 | 3.66 |
| 6 | 4.35 | 4.05 | 3.66 |
| 7 | 4.34 | 4.05 | 3.65 |
| 8 | 4.33 | 4.05 | 3.65 |
| 9 | 4.32 | 4.00 | 3.64 |
| 10 | 4.32 | 4.00 | 3.64 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.1.3 Radial Shrinkage ofGlulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | MeanRadial Shrinkage (%) |
|---|---|
| **MSF** | 4.35 |
| **LRF** | 4.08 |
| **GS** | 3.66 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.1.4: The LSD for Radial Shrinkage of Glulam *B. vulgaris* in Selected Nigerian Ecozones.**

| Ecozone | MeanRadial Shrinkage (%) |
|---|---|
| **Guinea Savanna** | 3.66a |
| **Lowland Rain Forest** | 4.08b |
| **Mangrove Swamp** | 4.35c |

Note: means with the same letter are not significantly different.

### 4.2.2 Tangential Shrinkage (%)

Tangential shrinkage also decreased significantly from the lowest basal sampling point to the topmost sampling point. It varied from 5.10±0.00 to 4.60±0.00% in Mangrove Swamp Forest. In lowland Rain Forest, it decreased from 4.8±0.00to 4.4±0.00%. In Guinea Savanna, it varied from 4.5±0.00; 4.10±0.00% in the lowest sampling points and the topmost sampling points respectively (Table 4.2.2.2)

It also decreased significantly ecologically from Mangrove Swamp to Guinea Savanna. The mean tangential shrinkage decreased from 4.87±0.19, in Mangrove Swamp Forest, 4.60±0.15, in Lowland Rain Forest, to 4.35±0.15% in Guinea Savanna (Figure 4.2.2.3).

The ANOVA showed that there were significant differences in tangential shrinkage between internodes from the base to the top and between the selected ecological zones of Nigeria (P = 0.00<0.05, Table 4.2.2.1).

Table 4.2.2.4 is theLSD of mean tangential shrinkage of Glulam*Bambusa vulgaris* in selected Nigerian Ecozones. The result showed significant differences between the ecological zones (P = 0.00<0.05).Guinea Savanna showed most significant value 4.30±0.15%).

**Table4.2.2.1 ANOVA Table of the Tangential Shrinkage of Gluelam *Bambusa vulgaris* in the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 0.7070 | 0.0786 | 101 | 0.00* |
| **Ecozone** | 2 | 1.6260 | 0.8130 | 1045.30 | 0.00* |
| **Error** | 18 | 0.0140 | 0.0008 | | |
| **Total** | 29 | 2.3470 | | | |

Note:*= significantly different.

**Table 4.2.2.2 Mean Tangential Shrinkage of Glulam *Bambusa vulgaris* in Internodes (%)**

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 5.10 | 4.80 | 4.50 |
| 2 | 5.10 | 4.80 | 4.50 |
| 3 | 5.00 | 4.70 | 4.40 |
| 4 | 5.00 | 4.70 | 4.40 |
| 5 | 4.90 | 4.60 | 4.30 |
| 6 | 4.90 | 4.60 | 4.30 |
| 7 | 4.80 | 4.50 | 4.20 |
| 8 | 4.70 | 4.50 | 4.20 |
| 9 | 4.60 | 4.40 | 4.10 |
| 10 | 4.60 | 4.40 | 4.10 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.2.3 Tangential Shrinkage of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | Mean Tangential Shrinkage (%) |
|---|---|
| **MSF** | 4.87 |
| **LRF** | 4.60 |
| **GS** | 4.30 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.2.4: The LSD for Tangential Shrinkage of Glulam *Bambusa vulgaris* in Selected Nigerian Ecozones.**

| Ecozone | MeanTangential Shrinkage (%) |
|---|---|
| **Guinea Savanna** | 4.30a |
| **Lowland Rain Forest** | 4.60b |
| **Mangrove Swamp** | 4.87c |

Note: means with the same letter are not significantly different.

### 4.2.3 Volumetric Shrinkage (%)

Volumetric shrinkage of glulam*Bambusa vulgaris* decreased significantly from 9.47±0.00 to 8.92±0.00% in the lowest basal sampling point and the top the topmost sampling point in Mangrove Swamp Forest. InLowland Rain Forest, it decreased from 8.95±0.00 to 8.40±0.00%.It also decreased significantly from 8.18±0.00 to7.74±0.00% in the lowest basal sampling point and the top the topmost sampling pointrespectively in Guinea Savanna (Table 4.2.3.2).

It also varied significantly across the ecological zones. In Mangrove Swamp Forest, it was 9.22±0.21%. It was 8.68±0.20 and 7.96±0.16% in Lowland Rain Forest and Guinea Savanna respectively (Table 4.2.3.3).

The ANOVA of volumetric shrinkage is shown in table 4.2.3.1. The ANOVA showed that there were significant differences from lowest basal internodes and the topmost internodes and also between the ecological zones of Nigeria (P=0.00<0.05). Table 4.2.3.4 is theLSD of mean volumetric shrinkage of Glulam*Bambusa vulgaris* in selected Nigerian Ecozones.

There was negative correlation between density and volumetric shrinkage (r = -0.82, P<0.05, table 4.2.3.5).The negative relationship indicates decrease in volumetric shrinkage with culm height.

**Table 4.2.3.1: ANOVA Table of the Volumetric Shrinkage ofGlulam *Bambusa vulgaris* the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 0.979 | 0.109 | 113 | 0.00* |
| **Ecozone** | 2 | 7.950 | 3.975 | 4142 | 0.00* |
| **Error** | 18 | 0.017 | 0.001 | | |
| **Total** | 29 | 8.94 | | | |

Note: means with the same letter are not significantly different.

**Table 4.2.3.2 Mean Volumetric Shrinkage of Glulam *Bambusa vulgaris* in Internodes (%)**

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 9.47 | 8.95 | 8.18 |
| 2 | 9.47 | 8.95 | 8.18 |
| 3 | 9.36 | 8.88 | 8.07 |
| 4 | 9.36 | 8.88 | 8.07 |
| 5 | 9.25 | 8.87 | 7.96 |
| 6 | 9.25 | 8.65 | 7.96 |
| 7 | 9.14 | 8.55 | 7.85 |
| 8 | 9.03 | 4.55 | 7.85 |
| 9 | 8.92 | 8.40 | 7.74 |
| 10 | 8.92 | 8.40 | 7.74 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.3.3 Volumetric Shrinkage of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | MeanVolumetric Shrinkage (%) |
|---|---|
| **MSF** | 9.22c |
| **LRF** | 8.68b |
| **GS** | 7.96a |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.2.3.4: Pearson's Correlation of Volumetric Shrinkage and Density of Glulam *B. vulgaris* in Nigerian Ecological zones.**

| Variable | Pearson`s Correlation Sig. (2-tailed) | N |
|---|---|---|
| Volumetric Shrinkage | - 0.82* | 30 |

Marked correlation is negatively significant at $p < .05$

**Table 4.2.3.5 ShrinkageProperties of *Bambusa vulgaris* Glulam Compared to Athel (*Tamarix aphylla*) Wood**

| Properties | *Athel wood | Bambusa vulgaris |
|---|---|---|
| Tangential shrinkage (%) | 7.13 | 4.30 |
| Radial shrinkage (%) | 4.14 | 3.66 |
| Volumetric shrinkage (%) | 13.23 | 7.96 |

*Abasali *et al*., (2012).

### 4.3 Modulus of Rupture (MOR)

Modulus of rupture significantly increased from 531.56±0.01 to 565.65±0.01; 533.24 ±0.01 to 572.86±0.01 and 541.35±0.00 to 702.09±0.19N/$mm^2$ in the lowest basal internodes and the topmost internodes in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively (Table 4.3.2).

Variation was also significant between the ecological zones. In Mangrove Swamp Forest, the mean MOR was 543.68±11.60. It was 555.11±11.29 and 600.64±53.42N/$mm^2$in Lowland Rain Forest and Guinea Savanna respectively (Table 4.3.3).Guinea Savanna had the highest MOR value. This is higher than 120.90 N/$mm^2$ recorded by Ogunsanwo (2010, Table 4.8.1.1). This may be as a result more adhesive absorbed by the bamboo laminates.

The ANOVA and LSD showed significant differences in MOR between internodes from the basal internodes to the topmost internodes (P=0.02<0.05) and also between the ecological zones (P=0.00<0.05, Table 4.3.1).

Table 4.3.3 is theLSD of mean MORof Glulam*Bambusa vulgaris* in Nigerian Ecozones.There was correlation between density and MOR (r =0.92, Table 4.3.4).

**Table 4.3:1: ANOVA Table of the Modulus of Rupture (MOR) of the Glulam *Bambusa vulgaris* in the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 0.0088 | 0.0010 | 3.30 | 0.02* |
| **Ecozone** | 2 | 0.0097 | 0.0048 | 16.20 | 0.00* |
| **Error** | 18 | 0.0054 | 0.0003 | | |
| **Total** | 29 | 0.0239 | | | |

Note: * = significant

**Table 4.3.2 Mean MOR of Glulam *Bambusa vulgaris* in Internodes** ($N/mm^2$)

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 531.56 | 533.25 | 541.35 |
| 2 | 533.25 | 543.94 | 551.38 |
| 3 | 534.38 | 546.75 | 560 |
| 4 | 536.06 | 551.81 | 568.75 |
| 5 | 539.44 | 559.13 | 575.04 |
| 6 | 544.50 | 559.69 | 582.50 |
| 7 | 546.75 | 560.81 | 620.05 |
| 8 | 549.00 | 561.38 | 650.00 |
| 9 | 556.25 | 561.49 | 655.22 |
| 10 | 565.65 | 572.86 | 702.09 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.3.3 MOR of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | MeanMOR(N/$mm^2$) |
|---|---|
| **MSF** | 543.68 |
| **LRF** | 555.11 |
| **GS** | 600.64 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.3.4: The LSD for MOR of Glulam *Bambusa vulgaris* in Selected Nigerian Ecozones.**

| Ecozone | Mean MOR (N/$mm^2$) |
| --- | --- |
| **Guinea Savanna** | 600.64a |
| **Lowland Rain Forest** | 555.11b |
| **Mangrove Swamp** | 543.68c |

Note: means with the same letter are not significantly different.

**Table 4.3.5: Pearson`s Correlation of MOR and Density of Glulam *Bambusa vulgaris* bamboo boards in Nigerian Ecological Zones.**

| Variable | Pearson`s Correlation Sig. (2-tailed) | N |
|---|---|---|
| **MOR** | 0.92* | 30 |

*= significant

### 4.4 Modulus of Elasticity (MOE)

Modulus of elasticity increased significantly from 6535.60±0.05 to 9255.81±0.05; 7271.51±0.00 to 9650.1±0.32 and 7877.66±0.08 to 9841.3±0.68N/mm$^2$ in the lowest basal internodes and the topmost internodes in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively (Table 4.4.2).

There were significant variations between the ecological zones. In Mangrove Swamp Forest, it was 7883.22±909.71N/mm$^2$. It was 8744.17±725.96 and 9090.16±53.42N/mm$^2$ in Lowland Rain Forest and Guinea Savanna respectively (Table 4.4.3). Guinea Savanna had the highest value of MOE (9090.16±53.42N/mm$^2$, Table 44.4).Thisresult lower than9995.16 N/mm$^2$ recorded by Ogunsanwo (2010, Table 4.8.1.1**)**. This may be as a result more adhesive absorbed by the bamboo laminates.

Analysis of variance showed that there were significant differences in MOE from the basal internodes to the topmost internodes (P=0.02<0.05) and between the ecological zones (P=0.00<0.05, Table 4.4.1).Analysis of variance and LSD showed that there were significant differences in MOE from the basal internodes to the topmost internodes (P= 0.00) and also between the ecological zones (P= 0.00, tables 4.4.1).

Table 4.4.4 is theLSD of mean MOEof Glulam*Bambusa vulgaris* in Nigerian Ecozones.The ecological zones were significantly different (P = 0.00<0.05). There was correlation between density and MOE (r= 1, Table 4.4.5).

**Table 4.4.1: ANOVA Table of the Modulus of Elasticity (MOE) of Glulam *Bambusa vulgaris* in the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 0.0422 | 0.0047 | 32 | 0.00* |
| **Ecozone** | 2 | 0.0215 | 0.0108 | 75 | 0.00* |
| **Error** | 18 | 0.0026 | 0.0001 | | |
| **Total** | 29 | 0.0663 | | | |

*= significant

**Table 4.4.2 Mean MOE of Glulam *Bambusa vulgaris* in Internodes (N/mm$^2$)**

| Internode | MF | LRF | GS |
|---|---|---|---|
| 1 | 6535.60 | 7271.51 | 7877.66 |
| 2 | 6895.47 | 7999.70 | 8226.62 |
| 3 | 7031.25 | 8368.62 | 8595.70 |
| 4 | 7445.31 | 8505.52 | 9015.29 |
| 5 | 7780.35 | 8810.22 | 9273.04 |
| 6 | 8007.81 | 9010.00 | 9365.00 |
| 7 | 8324.73 | 9120.00 | 9473.01 |
| 8 | 8650.00 | 9205.00 | 9585.00 |
| 9 | 8905.89 | 9501.00 | 9650.00 |
| 10 | 9255.81 | 9650.10 | 9840.30 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.4.3 MOE of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | Mean MOE (N/mm$^2$) |
|---|---|
| **MSF** | 7883.22 |
| **LRF** | 8744.17 |
| **GS** | 9090.16 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.4.4: The LSD for MOE of Glulam *Bambusa vulgaris* Glulam in Selected Nigerian Ecozones.**

| Ecozone | MeanMOE ($N/mm^2$) |
|---|---|
| **Guinea Savanna** | 9090.16a |
| **Lowland Rain Forest** | 8744.17b |
| **Mangrove Swamp** | 7883.22c |

Note: means with the same letter are not significantly different.

**Table 4.4.5: Pearson`s Correlation of MOE and Density of Glulam *Bambusa vulgaris***

| Variable | Pearson`s Correlation Sig. (2-tailed) | N |
|---|---|---|
| **MOE** | 1* | 30 |

Note: * = significant

### 4.5 Maximum Compressive Strength Parallel to Grain (MCS//)

Maximum compressive force parallel to grain increased significantly from 16.00±0.08 to 21.78±0.08; 16.50±0.00 to 23.41±0.03; and 19.01±0.03 to 26.89±0.03N/mm$^2$ in the lowest basal internodes and the topmost internodes in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively,(Table 4.5.2).

There were also significant variations between the ecological zones. In Mangrove Swamp Forest, it was 18.52±1.89N/mm$^2$. It was 19.57±2.35 and 22.91±2.81N/mm$^2$ in Lowland Rain Forest and Guinea Savanna respectively figure 4.5.3). The highest value of MCS// was recorded in Guinea Savanna (22.91±2.81N/mm$^2$, Table 4.5.4). This value is lower compared to what was recorded by Ogunsanwo (2010, Table 4.8.1.1). The ANOVA showed significant differences in MCS// between internodes from the basal internodes to the topmost internodes (P=0.02<0.05) and also between the selected ecological zones (P=0.00<0.05, Table 4.5.1).

Table 4.5.4 is theLSD of mean MCS// of Glulam*Bambusa vulgaris* in selected Nigerian Ecozones. The ecozones were significantly differences (P = 0.00<0.05). Density correlated positive and the maximum compressive force Parallel to grain(r= 0.96, Table 4.5.5).

**Table 4.5.1: ANOVA Table of the MCS// of Glulam *Bambusa vulgaris* the Selected Ecological zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 146.52 | 16.28 | 47.21 | 0.00* |
| **Ecozone** | 2 | 105.08 | 52.54 | 152.37 | 0.00* |
| **Error** | 18 | 6.21 | 0.34 | | |
| **Total** | 29 | 257.81 | | | |

*= significant

**Table 4.5.2 Mean MCS//of Glulam *Bambusa vulgaris* in Internodes (N/mm²)**

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 16.04 | 16.50 | 19.01 |
| 2 | 16.61 | 17.11 | 19.50 |
| 3 | 17.02 | 17.88 | 20.00 |
| 4 | 17.37 | 18.12 | 21.31 |
| 5 | 17.60 | 18.50 | 23.02 |
| 6 | 17.78 | 19.80 | 23.80 |
| 7 | 19.50 | 20.30 | 24.60 |
| 8 | 20.0 | 21.60 | 25.20 |
| 9 | 20.54 | 22.50 | 25.80 |
| 10 | 21.78 | 23.41 | 26.89 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.5.3MCS//of Glulam *Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| **Ecozone** | **MeanMCS//(N/mm$^2$)** |
|---|---|
| **MF** | 18.52 |
| **LRF** | 19.57 |
| **GS** | 22.91 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.5.4: The LSD for MCS// of Glulam*Bambusa vulgaris* Glulam in Selected Nigerian Ecozones.**

| Ecozone | MeanMCS//($N/mm^2$) |
|---|---|
| **Guinea Savanna** | 22.91a |
| **Lowland Rain Forest** | 19.57b |
| **Mangrove Swamp** | 18.52c |

Note: means with the same letter are not significantly different.

**Table 4.5.5: Pearson`s Correlation of MCS// and Density of Glulam *Bambusa vulgaris* Nigerian Ecological zones.**

| Variable | Pearson`s Correlation Sig. (2-tailed) | N |
|---|---|---|
| MCS Parallel | 0.96* | 30 |

*= significant

**4.6 Maximum Compressive Force Perpendicular to Grain (MCSl)**

Maximum Compressive Force Perpendicular to Grain significantly increased from 3.34±0.00 to 6.40±0.00 in lowest basal internodes and the topmost internodes in Mangrove Swamp Forest. In Lowland Rain Forest and Guinea Savanna, it increased from 4.21±0.0 to 6.82±0.00 and 5.38±0.00 to 7.51±0.03$N/mm^2$ in the lowest basal internodes and the topmost internodes respectively (Table 4.6.2). Maximum Compressive Force Perpendicular to Grain significantly increased from 5.14±0.87, (Mangrove Swamp Forest), 5.80±5.0 (Lowland Rain Forest) to 6.09±0.53$N/mm^2$ (Guinea Savanna).

Also, the MCSl increased ecologically from 5.14±0.87$N/mm^2$, 5.80±0.50 to 6.09±0.53$N/mm^2$ in Lowland Rain Forest and Guinea Savanna respectively, (Table 4.6.2). The highest MCSl was recorded in Guinea Savanna (6.09±0.53$N/mm^2$, Table 4.6.4.). This result is similar to themean range of 3.4- 5.8 (MPa) recorded by Serrano, and Enquist, (2010, Table 4.6.5). It is different from 32.1, 34.7 and 39.$N/mm^2$recorded by Schröder, (2015) at base, middle and top of 5-year Guadua agustifolia (Table 4.6.6).The ANOVA and LSD showed significant differences in MCSl between internodes from the basal internodes to the topmost internodes (P=0.02<0.05) and also between the selected ecological zones (P=0.00<0.05, Table 4.6.1). Table 4.6.4 is theLSD of mean MCSl of Glulam*Bambusa vulgaris* in selected Nigerian Ecozones. The ecozones were significantly differences (P = 0.00<0.05). Density correlated positively with the maximum compressive force Parallel to grain (r= 0.96, P= 0.00<0.05, table 4.6.4).

**Table 4.6.1: The ANOVA of the Maximum Compressive Strength Perpendicular to Grain (MCS⊥) of Glulam *Bambusa vulgaris* inthe Selected Eco-zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 10.7647 | 1.1961 | 25.09 | 0.00* |
| **Ecozone** | 2 | 4.7192 | 2.3596 | 49.50 | 0.00* |
| **Error** | 18 | 0.8580 | 0.0477 | | |
| **Total** | 29 | 16.3419 | | | |

*= significant

**Table 4.6.2 Mean MC⊥ of Glulam *Bambusa vulgaris* in Internodes (N/mm$^2$)**

| Internode | MF | LRF | GS |
|---|---|---|---|
| 1 | 3.34 | 4.88 | 5.06 |
| 2 | 4.34 | 5.21 | 5.38 |
| 3 | 4.57 | 5.50 | 5.85 |
| 4 | 5.0 | 5.74 | 6.05 |
| 5 | 5.11 | 5.79 | 6.11 |
| 6 | 5.42 | 5.89 | 6.22 |
| 7 | 5.61 | 5.94 | 6.32 |
| 8 | 5.85 | 6.23 | 6.58 |
| 9 | 6.00 | 6.37 | 6.59 |
| 10 | 6.17 | 6.44 | 6.68 |

**Table 4.6.3 MCSl of Glulam*Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | Mean MCSl ($N/mm^2$) |
|---|---|
| **MF** | 5.14 |
| **LRF** | 5.80 |
| **GS** | 6.09 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.6.4: The LSD for MCSl of Glulam*Bambusa vulgaris* Glulam in Selected Nigerian Ecozones.**

| Ecozone | MeanMCSl ($N/mm^2$) |
|---|---|
| **Guinea Savanna** | 6.091a |
| **Lowland Rain Forest** | 5.80b |
| **Mangrove Swamp** | 5.14c |

Note: means with the same letter are not significantly different.

**Table 4.6.5: Pearson`s Correlation of Maximum Compressive Strength Perpendicular to Grain and Density of Glulam *Bambusa vulgaris* in Nigerian Ecological Zones.**

| Variable | Pearson`s Correlation | Sig. (2-tailed) | N |
|---|---|---|---|
| MCSl | 0.99* | 30 | |

*= significant

**Table 4.6.6 Maximum Compressive Strength Perpendicular to Grain (MCS l)**

| Test series | Mean (MPa) | COV |
|---|---|---|
| A | 3.3 | 7.4% |
| B1 | 4.4 | 9.8% |
| B2 | 5.8 | 5.3% |
| C1 | 2.9 | 4.7% |
| C2 | 4.9 | 5.5% |

Serrano and Enquist (2010).

**Table 4.6.7 Compressive Strength Perpendicular to Grain of *Guadua agustifolia***

| **Compressive Strength ($N/mm^2$)** | **Age of Bamboo (Year)** | | | |
|---|---|---|---|---|
| | **2** | **3** | **4** | **5** |
| Bottom | 39.9 | 38.1 | 37.6 | 32.1 |
| Middle | 27.2 | 42.1 | 41.5 | 34.7 |
| Top | 20.4 | 42.6 | 42.1 | 39.0 |

Schröder, (2015)

### 4.7 Shear Strength

Shear strength also varied significantly from the lowest basal internodes to the topmost internodes. It increased from 2.46±0.00 to 6.02±0.0; 3.22±0.06 to 6.62±0.06 and 4.51±0.03 to7.51±0.03N/mm$^2$ in the lowest basal internodes and the topmost in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna respectively. It also varied significantly between the ecological zones.

In Mangrove Swamp Forest, it the mean Shear strength was 4.33±1.21N/mm$^2$. It was 4.89±1.15 and 5.96±1.09N/mm$^2$ in Lowland Rain Forest and Guinea Savanna respectively (Table 4.7.1). The highest value of shear strength was recorded in Guinea Savanna ( Table 4.7.4) This value is lower compared to 7.6, 7.4 and 7.8 N/mm$^2$ recorded by Juanand Juliana (2010, Table 4.7.6).There was increase in shear strength from the lowest basal internodes to the topmost internodes.

The ANOVA and LSD showed significant Shear Strength differences between internodes from the lowest basal internodes to the topmost internodes ($P=0.02<0.05$) and also between the selected ecological zones ($P=0.00<0.05$, Table 4.7.1).

Density correlated positively with the Shear Strength ($r= 0.98$, $P= 0.00<0.05$, Table 4.7.4).

**Table 4.7.1: ANOVA Table of the Shear Strength ofGlulam*Bambusa vulgaris* in the Selected Ecological Zones of Nigeria.**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Internode** | 9 | 35.4910 | 3.9434 | 382.06 | 0.00* |
| **Ecozone** | 2 | 13.7833 | 6.8916 | 667.70 | 0.00* |
| **Error** | 18 | 0.1858 | 0.0103 | | |
| **Total** | 29 | 49.4601 | | | |

*= significant

**Table 4.7.2 Mean Shear Strengthof Glulam*Bambusa vulgaris* in Internodes ($N/mm^2$)**

| Internode | MSF | LRF | GS |
|---|---|---|---|
| 1 | 2.46 | 3.30 | 4.50 |
| 2 | 2.89 | 3.53 | 4.70 |
| 3 | 3.41 | 3.81 | 4.89 |
| 4 | 3.81 | 4.41 | 5.41 |
| 5 | 4.11 | 4.71 | 5.78 |
| 6 | 4.51 | 5.21 | 6.11 |
| 7 | 5.02 | 5.50 | 6.51 |
| 8 | 5.25 | 5.69 | 6.89 |
| 9 | 5.79 | 6.21 | 7.31 |
| 10 | 6.02 | 6.22 | 7.51 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.7.3 Shear Strengthof Glulam*Bambusa vulgaris* in Selected Ecological Zones of Nigeria**

| Ecozone | MeanShear Strength (N/mm$^2$) |
|---|---|
| **MF** | 4.33 |
| **LRF** | 4.89 |
| **GS** | 5.96 |

Note: MSF= Mangrove Swamp Forest, LRF= Lowland Rain Forest, GS= Guinea Savanna

**Table 4.7.4: The LSD for Shear Strength of Glulam *Bambusa vulgaris* Glulam in Selected Nigerian Ecozones.**

| **Ecozone** | **MeanShear Strength (N/mm$^2$)** |
|---|---|
| **Guinea Savanna** | 5.96a |
| **Lowland Rain Forest** | 4.89b |
| **Mangrove Swamp** | 4.33c |

Note: means with t`he same letter are not significantly different.

**Table4.7.5 Pearson`s Correlation of Shear Strength and Density of Glulam *Bambusa vulgaris* in Nigerian Ecological Zones.**

| Variable | Pearson`s Correlation Sig. (2-tailed) | N |
|---|---|---|
| Shear Strength | 0.98* | 30 |

*= significant

**Table 4.7.6Shear Strength (MPa) of*Guadua angustifolia* Bamboo**

| Age | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Bottom** | 7.2 | 7.4. | 7.5. | 7.6 |
| **Middle** | 7.5 | 8.2 | 8.0 | 7.4 |
| **Top** | 7.2 | 8.1 | 7.6 | 8.0 |

Juan and Juliana (2010).

**Table 4.7.7 Strength Properties of Glulam *Bambusa vulgaris* Boards Compared to Selected Tropical Hardwoods.**

| Species | Density ($Kg/m^3$) | MOE ($N/mm^3$) | MOR ($N/mm^3$) | MCS// ($N/mm^3$) |
|---|---|---|---|---|
| **M*$_1$*.excelsa* | 60 | 7910 | 833 | 55.09 |
| **K. se galensis* | 68 | 8120 | 860 | 50.40 |
| **M*$_2$*. Altisima* | N/A | 110 | 60.00 | 66 |
| ***S. rhinopetala* | 65 | 8840 | 135.20 | 65.30 |
| ***H. grandis* | 53 | 7331 | 995.5 | 53.70 |
| ***B. vulgaris* | 57 | 9925.16 | 120.90 | 57.17 |
| *B. vulgaris* | 58 | 9090.16 | 600.64 | 22.91 |

Note: *= CIRAD (2009), **= Ogunsanwo (2010), *M*$_1$*. = Melicea*, *K. Khaya, M*$_2$*. = Mansonia, S. = Sterculia, H. = Holoptelia, B. = Bambusa*

**Table 4.7.8 Specific Strength (SS) of Glulam *Bambusa vulgaris* Boards in Relation to Other Tropical Hardwoods.**

| Species | Density (Kg/cm$^3$ | MOR ($N/mm^2$) | MOE ($N/mm^2$) | MCS// ($N/mm^2$) |
|---|---|---|---|---|
| **M. excelsa* | 60 | 13.88 | 131.83 | 0.92 |
| *K. segalensis | 68 | 12.65 | 119.41 | 0.74 |
| **M. altisima* | 66 | 1.67 | N/A | 0.91 |
| ***S. rhinopetala* | 65 | 2.08 | 136 | 1.01 |
| ***H. grandis* | 53 | 18.78 | 138.32 | 1.01 |
| ***B. vulgaris* | 57 | 19.30 | 174.13 | 1.00 |
| *B. vulgaris* | 58 | 10.36 | 156.72 | 0.40 |

Note: *= CIRAD (2009), **= Ogunsanwo (2010), *$M_1$. = Melicea*, *K. Khaya*, *$M_2$. = Mansonia, S. = Sterculia, H. = Holoptelia, B. = Bambusa*

### 4.8 Regression Analysis and Prediction of Physical and Mechanical Properties

Simple linear regression model was used to analyse and predict dependent variables (volumetric shrinkage, MOR, MOE, maximum compressive strength parallel and perpendicular to grains in Mangrove Swamp Forest, Lowland Rain Forest and Guinea Savanna ecological zones. Density was used as the independent variable. Test statistics: modeling efficiency ($R^2$) standard error of estimate (SEE), correlation analysis(r), standard error of estimate (SEE), probability test ($\alpha_{0.05}$) and scatter plot statistics were computed to test the validity of the regression models.

#### 4.8.1 Mangrove Swamp Forest Ecological Zone

##### 4.8.1.1 Regression Analysis and Prediction of Volumetric Shrinkage

Simple linear regression was used to establish functional relationship between volumetric shrinkage and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.1)

Where;

Y= volumetric shrinkage

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.1.1.1 is the result of the of regression analysis. The ANOVA showed functional relationship between volumetric shrinkage and absolute density of *Bambusa vulgaris* glulam ($F$ 1, 8 = 197.50, $P<0.05$). Table 4.8.1.1.2: is the regression summary for dependent variable: volumetric shrinkage.

**Table 4.8.1.1.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.3461 | 0.3461 | 65.49 | 0.00* |
| Residual | 8 | 0.0428 | 0.0053 | | |
| Total | 9 | 0.3889 | | | |

*= significant

**Table 4.8.1.1.2: Regression Summary for Dependent Variable: Volumetric Shrinkage**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | 10.50 | -2.71 | -0.94 | 0.89 | -14.13 | 0.00* | 0.17 | 0.07 |

*= significant

### 8.1.2 Regression Analysis and Prediction of Modulus of Rupture

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOR) and absolute density.

$LnY= b_o+b_1x$……………….. (Equation 4.8.2)

Where;

Ln = Natural log,

Y= MOR

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.9.1.2.1 is the result of the of regression analysis. The ANOVA showed that there was functional relationship between MOR and density of glulam*Bambusa vulgaris* (F (1, 8 = 35.29, P<0.05).

**4.8.1.2.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Regression** | 1 | 0.00064 | 0.000640 | 101.98 | 0.00* |
| **Residual** | 8 | 0.00005 | 0.000006 | | |
| **Total** | 9 | 0.00069 | | | |

*= significant

**Table 4.8.1.2.2: Regression Summary for Dependent Variable: MOR**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | 2.68 | 0.11 | 0.91 | 0.93 | 6.02 | 0.00* | 0.00 | 0.00 |

*= significant

#### 4.8.1.3: Regression Analysis and Prediction of Modulus of Elasticity

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOE) and density.

$LnY = b_o + b_1x$……………….. (Equation 4.8.3)

Where,

Ln = natural log,

Y= MOE

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= absolute density

Table 4.9.1.3.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MOE and density of *Bambusa vulgaris* glulam(F (1, 8 = 77.26, P<0.05).

**4.8.1.3.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.022848 | 0.022848 | 77.25788 | 0.00* |
| Residual | 8 | 0.001177 | 0.000147 | | |
| Total | 9 | 0.024020 | | | |

*= significant

**Table 4.8.1.3.2Regression Summary for Dependent Variable: MOE**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | 3.57 | 0.69 | 0.99. | 0.99 | 15.08 | 0.00* | 0.17 | 0.02 |

*= significant

**4.8.1.4 Regression Analysis and Prediction of Maximum Compressive Force Parallel to Grain (MCS//)**

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MCS//) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.4)

Where;

Y= MCS//

$b_{o}$ = regression constant

$b_{1}$ = regression coefficient

x= density

Table 4.9.1.4.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MCS// and absolute density of glulam *Bambusa vulgaris* (F (1, 8 = 62.63, P<0.05).

**4.8.1.4.1 ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 28.50 | 28.50 | 62.63 | 0.00* |
| Residual | 8 | 3.64 | 0.46 | | |
| Total | 9 | 32.14 | | | |

*= significant

**Table 4.8.1.4.2: Regression Summary for Dependent Variable: MCS parallel to Grain**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | 6.89 | 24.63 | 0.94. | 0.89 | 0.82 | 0.00* | 1.49 | 0.67 |

*= significant

#### 4.8.1.5 Regression Analysis and Prediction of Maximum Compressive Force Perpendicular to Grain (MCS<u>l</u>)

Simple linear regression was used to establish functional relationship between MCS and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.5)

Where;

Y= MCS<u>l</u>

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.1.5.1 is the result of the of regression analysis. The analysis of variance shows that there was functional relationship between MCS<u>l</u> and density of glulam *Bambusa vulgaris* (F (1, 8 = 169.89, P<0.05).

**4.8.1.5.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Regression** | 1 | 6.52 | 6.52 | 169.89 | 0.00* |
| **Residual** | 8 | 0.31 | 0.40 | | |
| **Total** | 9 | 6.83 | | | |

*= significant

**Table 4.8.1 Regression Summary for Dependent Variable: MCS<u>l</u> Grain**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | 0.43 | 11.78 | 0.98. | 0.95 | 12.54 | 0.00* | 0.43 | 0.20 |

*= significant

#### 4.8.1.6 Regression Analysis and Prediction of Shear Strength

Simple linear regression was used to establish functional relationship between Shear Strength and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.11)

Where;

Y= Shear Strength

$b_{o}$ = regression constant

$b_{1}$= regression coefficient

x= density

Table 4.8.1.6.1 is the result of the of regression analysis. The analysis of variance shows that there was functional relationship between Shear Strength and density of glulam*Bambusa vulgaris* (F (1, 8 = 192.00, P<0.05).

**4.8.1.6.1 ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 12.56 | 520.59 | 192.00 | 0.00* |
| Residual | 8 | 0.52 | 0.07 | | |
| Total | 9 | 13.08 | | | |

*= significant

**Table 4.8.1.6.2Regression Summary for Dependent Variable: Shear Strength**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|
| | -3.40 | 16.35 | 0.98. | 0.96 | 14.01 | 0.00* | 0.56 | 0.26 |

*= significant

**Table 4.8.1.7 Summary of Regression Equations Showing Relationship between Density and Selected Physical and Mechanical Properties of Glulam*Bambusa vulgaris* in Mangrove Swamp Forest**

| Dependent | $b_0$ | $b_1$ | r | $R^2$ | t | P | SE | SEE | F |
|---|---|---|---|---|---|---|---|---|---|
| VS | 10.50 | -2.71 | -0.94 | 0.89 | -14.13 | 0.00 | 0.17 | 0.07 | 63.14 |
| MOR | 2.68 | 0.11 | 0.91 | 0.93 | 6.20 | 0.00 | 0.00 | 0.00 | 36.84 |
| MOE | 3.57 | 0.69 | 0.99 | 0.99 | 15.08 | 0.00 | 0.00 | 0.02 | 350.31 |
| MCS// | 6.89 | 24.63 | 0.94 | 0.89 | 0.82 | 0.00 | 1.49 | 0.67 | 62.63 |
| MCSl | -0.43 | 11.78 | 0.98 | 0.95 | 12.54 | 0.00 | 0.43 | 0.20 | 169.89 |
| SS | -3.40 | 16.35 | 0.98 | 0.96 | 14.01 | 0.00 | 0.56 | 0.26 | 191.97 |

Note: RS = Radial Shrinkage, TS =Tangential Shrinkage, MOR = Modulus of Rupture, MOE = Modulus of Elasticity, MCS// = Maximum Compressive Force Parallel to Grain, MCSl = Maximum Compressive Force Perpendicular to Grain, SS = Shear Strength.

**Table 4.8.1.8 Prediction of Physical and Mechanical Propertie of Glulam Bambusa vulgaris in Mangrove Swamp Forest**

VS= 10.50 -2.71(x)

MOR= 2.68 + 0.11(x)

MOE = 3.57 + 0.69(x)

MCS// = 6.89 +24.63 (x)

MCSl = -0.43 +11.78 (x)

SS= -3.40 +16.35(x)

Note: x= predictor (density).

#### 4.8.1.9 Scatter Plot

In addition to the above statistics used to assess the fitness of candidate regression model, Expected and Observed table (table 4.8.1.8) and scatter plot (figure 4.9.1) were used to complement these statistics. Scatter plot of expected and observed was used to identify potential clusters of cases that were not well predicted. The graph had no cluster. This shows that the regression models were valid.

**Table 4.8.1.9.1 Expected and Observed Variables in Mangrove Swamp Eco-zone of Nigeria**

| Variable | Expected | Observed |
|---|---|---|
| Vol. Shrinkage | 9.23 | 9.22 |
| MOR | 2.75 | 2.74 |
| MOE | 3.89 | 3.81 |
| MCS// | 18.47 | 18.32 |
| MCS⊥ | 5.11 | 5.14 |
| Shear Strength | 4.29 | 4.33 |

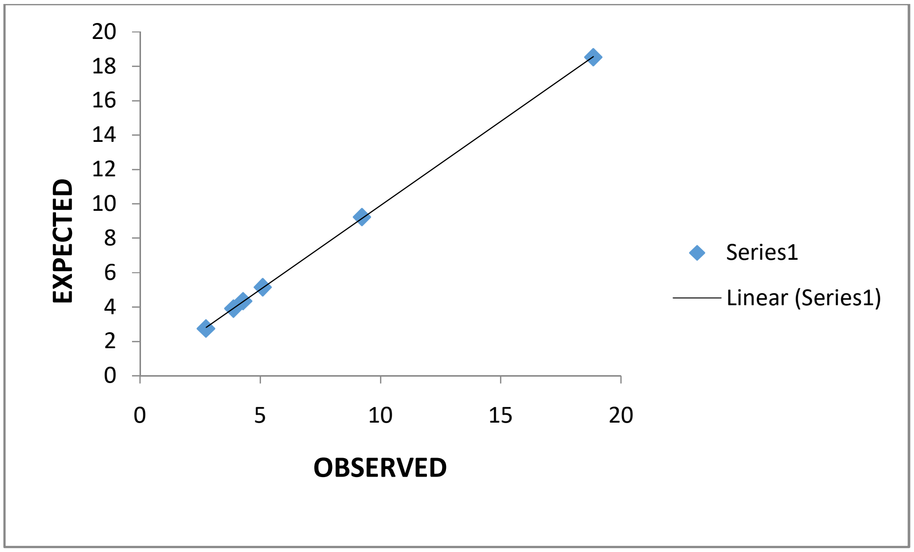


**Figure 4.8.1.9.1Scatter Plot of Expected and Observed Physical and Mechanical Properties of Glulam *Bambusavulgaris* in Mangrove Swamp Ecological Zone.**

## 8.2 Lowland Rain Forest Ecological Zone

### 4.8.2.1 Regression Analysis and Prediction of Volumetric Shrinkage

Simple linear regression was used to establish functional relationship between volumetric shrinkage and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.13)

Where;

Y= %volumetric shrinkage

$b_o$ = regression constant

$b_1$ = regression coefficient

x= densit

Table 4.8.2.1.1 is the result of the of regression analysis. The ANOVA showed functional relationship between volumetric shrinkage and density ofGlulam*Bambusa vulgaris* (F (1, 8 = 341.30, P<0.05).

**Table 4.8.2.1.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.3503 | 0.3503 | 175.25 | 0.00* |
| Residual | 8 | 0.0160 | 0.0020 | | |
| Total | 9 | 0.3663 | | | |

*= significant

**Table 4.8.2.1.2: Regression Summary for Dependent Variable: Shear Strength**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 10.25 | -3.05 | -0.98. | 0.96 | 17.14 | 175.25 | 0.00* | 0.12 | 0.05 |

*= significant

#### 4.8.2.2 Regression Analysis and Prediction of Modulus of Rupture

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOR) and density.

$LnY = b_o+b_1x$……………….. (Equation 4.8.15)

Where;

Ln= natural log

Y= MOR

$b_{o} =$ regression constant

$b_{1}=$ regression coefficient

x= density

Table 4.8.2.2.1 is the result of the of regression analysis. The analysis of variance shows that there was functional relationship between MOR and density ofglulam (*Bambusa vulgaris* F (1, 8 = 105.20, P<0.05).

**4.8.2.2.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.000629 | 0.000629 | 61.80 | 0.00* |
| Residual | 8 | 0.000081 | 0.000001 | | |
| Total | 9 | 0.000710 | | | |

*= significant

**Table 4.8.2.2.2: Regression Summary for Dependent Variable: MOR**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | F | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|---|
| | 2.68 | 0.13 | 0.96. | 0.93 | 10.46 | 103.86 | 0.00* | 0.03 | 0.01 |

*= significant

### 4.8.2.3 Regression Analysis and Prediction of Modulus of Elasticity

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOE) and density.

$LnY= b_o+b_1x$……………….. (Equation 4.9.17)

Where; Ln = Natural log,

Y= MOE

$b_{o =}$ regression constant

$b_{1=}$ regression coefficient

x= absolute density

Table 4.8.2.3.1 is the result of the of regression analysis. The analysis of variance shows that there was functional relationship between MOE and density of *Bambusa vulgaris* glulam ($F (1, 8 = 295.60, P<0.05$).

**4.8.2.3.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.011364 | 0.011364 | 77.25788 | 0.00* |
| Residual | 8 | 0.001177 | 0.000147 | | |
| Total | 9 | 0.012541 | | | |

*= significant

**Table 4.8.2.3.2Regression Summary for Dependent Variable: MOE**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 3.65 | 0.57 | 0.98 | 0.91 | 16.81 | 192.49 | 0.00* | 0.02 | 0.01 |

*= significant

**4.8.2.4 Regression Analysis and Prediction of Maximum Compressive Force Parallel to Grain (MCS//) and Density**

Simple linear regression was used to establish functional relationship between Maximum Compressive Force Parallel to Grain (MCS //)
(MCS//) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.19)

Where;

Y= MCS//

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.2.4.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MCS// and density of glulam*Bambusa vulgaris* ($F$ (1, 8 =114.63, $P<0.05$).

**Table 4.8.2.4.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 46.38 | 46.38 | 114.63 | 0.00* |
| Residual | 8 | 3.24 | 0.40 | | |
| Total | 9 | 49.62 | | | |

*= significant

**Table 4.8.2.4.2Regression Summary for Dependent Variable: MCS// to Grain**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.5 | 35.12 | 0.97 | 0.94 | 10.39 | 114.63 | 0.00* | 0.64 | 1.70 |

*= significant

### 4.8.2.5 Regression Analysis and Prediction of Maximum Compressive Strength Perpendicular to Grain (MCSl)

Simple linear regression was used to establish functional relationship between Maximum Compressive Strength Perpendicular to Grain (MCSl) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.21)

Where;

Y=MCSl

$b_o =$ regression constant

$b_1 =$ regression coefficient

x= density

Table 4.8.2.5.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MCSl  and density of *Bambusa vulgaris* glulam($F$ (1, 8 =295.05, $P<0.05$).

**Table 4.8.2.5.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 2.18 | 2.18 | 295.05 | 0.00* |
| Residual | 8 | 0.06 | 0.01 | | |
| Total | 9 | 2.24 | | | |

*= significant

**Table 4.8.2.5.2Regression Summary for Dependent Variable:⊥MCS  to Grain**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.89 | 7.61 | 0.99 | 0.97 | 17.08 | 295.05 | 0.00* | 0.23 | 0.09 |

*= significant

### 4.8.2.6 Regression Analysis and Prediction of Shear Strength

Simple linear regression was used to establish functional relationship between Maximum Compressive Strength Perpendicular to Grain (MCS) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.23)

Where;

Y= Shear Strength

$b_{o}$ = regression constant

$b_{1}$ = regression coefficient

x= density

Table 4.8.2.6.1 is the result of the of regression analysis. The ANOVA showed functional relationship between Shear Strength and density of glulam*Bambusa vulgaris* (F (1, 8 =234.89, P<0.05).

**Table 4.8.2.6.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 11.59 | 11.59 | 234.89 | 0.00* |
| Residual | 8 | 0.05 | 0.01 | | |
| Total | 9 | 12.49 | | | |

*= significant

**Table 4.8.2.6.2Regression Summary for Dependent Variable: Shear Strength**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | t | F | P | SE | SEE |
|---|---|---|---|---|---|---|---|---|---|
| | -4.14 | 17.56 | 0.99 | 0.97 | 14.77 | 234.89 | 0.00* | 0.22 | 0.59 |

*= significant

**Table 4.8.2.7 Summary of Regression Equations Showing Relationship between Density and Selected Physical and Mechanical Properties of Glulam*Bambusa vulgaris* in Lowland Rain Forest**

| Dependent | $b_0$ | $b_1$ | r | $R^2$ | t | P | SE | SEE | F |
|---|---|---|---|---|---|---|---|---|---|
| VS | 10.25 | -3.05 | -0.98 | 0.96 | 17.14 | 0.00 | 0.12 | 0.12 | 175.25 |
| MOR | 2.68 | 0.13 | 0.96 | 0.93 | 10.46 | 0.00 | 0.01 | 0.00 | 103.86 |
| MOE | 3.65 | 0.57 | 0.98 | 0.91 | 16.81 | 0.00 | 0.22 | 0.01 | 192.49 |
| MCS// | 1.50 | 35.12 | 0.97 | 0.94 | 10.39 | 0.00 | 0.17 | 0.64 | 114.63 |
| MCSl | 1.89 | 7.61 | 0.99 | 0.97 | 17.08 | 0.00 | 0.23 | 0.09 | 295.05 |
| SS | -4.14 | 17.56 | 0.99 | 0.97 | 14.77 | 0.00 | 0.59 | 0.22 | 234.89 |

Note: RS = Radial Shrinkage, TS =Tangential Shrinkage, MOR = Modulus of Rupture, MOE = Modulus of Elasticity, MCS// = Maximum Compressive Force Parallel to Grain, MCSl = Maximum Compressive Force Perpendicular to Grain, SS = Shear Strength.

**Table 4.8.2.8 Prediction of Physical and Mechanical Propertie of Glulam Bambusa vulgaris in Lowland Rain Forest**

| |
|---|
| VS= 10.25 -3.05 (x) |
| MOR= 2.68 + 0.13(x) |
| MOE = 3.65 + 0.57(x) |
| MCS// = 1.50 +35.12 (x) |
| MCSl = 1.89 +7.61 (x) |
| SS= -4.14 +17.56(x) |

Note: x= predictor (density).

**Table 4.8.2.9: Expected and Observed Variables in Mangrove Swamp Eco-zone of Nigeria**

| Variable | Expected | Observed |
|---|---|---|
| Vol. Shrinkage | 8.69 | 8.68 |
| MOR | 2.75 | 2.74 |
| MOE | 3.94 | 3.94 |
| MCS// | 19.45 | 19.57 |
| MCSl | 5.77 | 5.80 |
| Shear Strength | 4.82 | 4.89 |

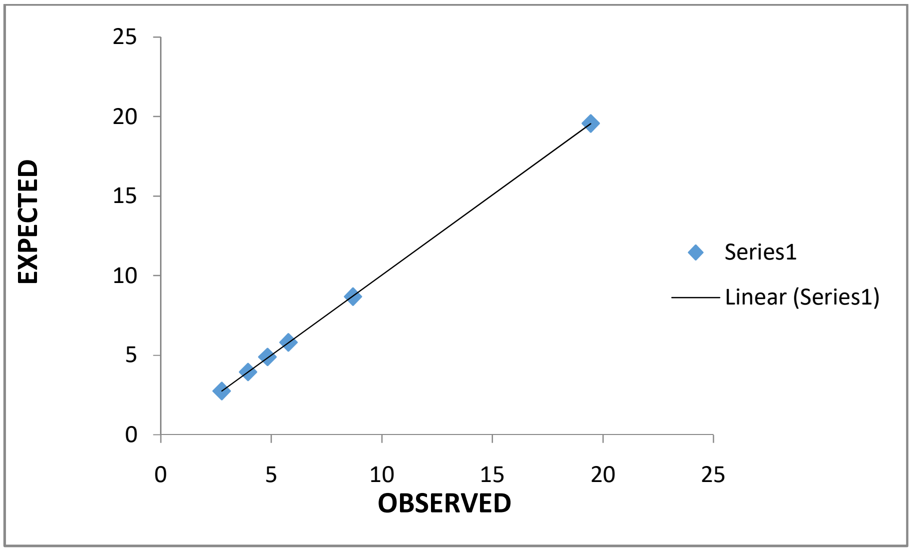


**Figure 4.8.2.1 Scatter Plot of Expected and Observed Physical and Mechanical Properties of Glulam *Bambusavulgaris* in Lowland Rain Forest Ecological Zone.**

### 4.8.3 Guinea Savanna Ecological Zone

#### 4.8.3.1 Regression Analysis and Prediction of Volumetric Shrinkage

Simple linear regression was used to establish functional relationship between volumetric shrinkage and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.25)

Where;

Y= volumetric shrinkage

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.3.1.1 is the result of the of regression analysis. The ANOVA showed functional relationship between volumetric shrinkage and density of glulam*Bambusa vulgaris* (F (1, 8 = 78.01, P<0.05).The r (-0.94) of the predictor (density) was negatively significant indicating inverse correlation between volumetric shrinkage and density (volumetric shrinkage decreased as the density increased (Table4.8.3.1.2).

**4.8.3.1.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.3503 | 0.3503 | 175.25 | 0.00* |
| Residual | 8 | 0.0160 . | 0.0025 | | |
| Total | 9 | 0.3663 | | | |

. *= significant

**Table 4.8.3.1.2: Regression Summary for Dependent Variable: Volumetric Shrinkage**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 9.25 | -2.67 | -0.92 | 0.84 | -8.91 | 41.36 | 0.00* | 0.24 | 0.07 |

*= significant

#### 4.8.3.2: Regression Analysis and Prediction of Modulus of Rupture

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOR) and density.

$LnY= b_o+b_1x$……………….. (Equation 4.8.27)

Where;

Ln= natural log

Y= MOR

$b_{o}$ = regression constant

$b_{1}$ = regression coefficient

x= density

Table 4.8.3.2.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MOR and density of glulam*Bambusa vulgaris* (F (1, 8 = 14.80, P<0.05).

**4.8.3.2.1: ANOVA Table for MOR Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.011910 | 0.011910 | 106.36 | 0.00* |
| Residual | 8 | 0.000896 | 0.000112 | | |
| Total | 9 | 0.012806 | | | |

*= significant

**Table 4.8.3.2.2Regression Summary for Dependent Variable: MOR**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 2.45 | 0.55 | 0.82 | 093 | 3.89 | 16.61 | 0.00* | 0.08 | 0.02 |

*= significant

#### 4.8.3.3 Regression Analysis and Prediction of Modulus of Elasticity (MOE)

Simple linear regression was used to establish functional relationship between Modulus of Rupture (MOE) and density.

$LnY= b_o+b_1x$……………….. (Equation 4.8.29)

Where;

Ln= natural log

Y= MOE

$b_o$ = regression constant

$b_1$= regression coefficient

x= density

Table 4.8.3.3.1 is the result of the of regression analysis. The analysis of variance showed that there was functional relationship between MOE and density of glulam*Bambusa vulgaris* ($F$ (1, 8 = 295.60, $P<0.05$).

**4.8.3.3.1: ANOVA Table for MOE Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Regression** | 1 | 0.008350 | 0.008350 | 71.13 | 0.00* |
| **Residual** | 8 | 0.000939 | 0.000117 | | |
| **Total** | 9 | 0.009289 | | | |

*= significant

**Table 4.8.3.3.2 Regression Summary for Dependent Variable: MOE**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 3.62 | 0.58 | 0.99 | 0.90 | 27.65 | 125 | 0.00* | 0.01 | 0.00 |

*= significant

**4.8.3.4 Regression Analysis and Prediction of Maximum Compressive Force Parallel to Grain (MCS//)**

Simple linear regression was used to establish functional relationship between Maximum Compressive Strength Parallel to Grain (MCS//) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.31)

Where;

Y= MCS//

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.3.4.1 is the result of the of regression analysis. The ANOVA showed functional relationship between MCS// and density of *B. vulgaris*glulam($F$ (1, 8 =114.63, $P<0.05$).

**Table 4.8.3.4.1: ANOVA Table for Regression Model**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 46.38 | 46.38 | 114.63 | 0.00* |
| Residual | 8 | 3.24 | 0.40 | | |
| Total | 9 | 49.62 | | | |

*= significant

**Table 4.8.3.4.2 Regression Summary for Dependent Variable: MCS parallel to Grain**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | -4.41 | 0.58 | 0.93 | 0.87 | 7.39 | 53.71 | 0.00* | 1.07 | 1.70 |

*= significant

#### 4.8.3.5 Regression Analysis and Prediction of Maximum Compressive Force Perpendicular to Grain (MCSl)

Simple linear regression was used to establish functional relationship between Maximum Compressive Strength Perpendicular to Grain (MCSl) and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.33)

Where;

Y= MCSl

$b_{o}$ = regression constant

$b_{1}$ = regression coefficient

x= density

Table 4.8.3.5.1 is the result of the of regression analysis. The analysis of variance shows that there was functional relationship between MCSl and density of glulam*Bambusa vulgaris* (F (1, 8 =301.5, P<0.05).

**Table 4.8.3.5.1: ANOVA Table for Regression Model for MCSl**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 2.49 | 2.49 | 301.51 | 0.00* |
| Residual | 8 | 0.07 | 0.01 | | |
| Total | 9 | 2.56 | | | |

*= significant

**Table 4.8.3.5.2 Regression Summary for Dependent Variable: MCSl**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.60 | 9.42 | 0.99 | 0.97 | 17.50 | 1301.51 | 0.00* | 0.32 | 0.09 |

*= significant

#### 4.8.3.6: Regression Analysis and Prediction of Shear Strength

Simple linear regression was used to establish functional relationship between shear stength and density.

$Y= b_o+b_1x$……………….. (Equation 4.8.35)

Where;

Y= Shear Strength

$b_{o\,=}$ regression constant

$b_{1=}$ regression coefficient

x= density

Table 4.8.3.6.1 is the result of the of regression analysis. The ANOVA showed functional relationship between Shear Strength and density of *Bambusa vulgaris* glulam (F (1, 8 =40.31, P<0.05).

**Table 4.8.3.6.1ANOVA Table for Regression Tests of Significance for Shear Strength**

| SV | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 8.86 | 8.86 | 40.31 | 0.00* |
| Residual | 8 | 1.76 | 0.22 | | |
| Total | 9 | 10.62 | | | |

*= significant

**Table 4.8.3.6.2 Regression Summary for Dependent Variable: Shear Strength**

| N=10 | $b_o$ | $b_1$ | r | $R^2$ | tF | P | SE | SEE | |
|---|---|---|---|---|---|---|---|---|---|
| | -4, 38 | 17.76 | 0.93 | 0.83 | 6.39 | 40.31 | 0.00* | 1.6 | 0.47 |

*= significant

**Table 4.8.3.7 Summary of Regression Equations Showing Relationship between Density and Selected Physical and Mechanical Properties of Glulam*Bambusa vulgaris* in Guinea Savanna**

| Dependent | $b_0$ | $b_1$ | r | $R^2$ | t | P | SE | SEE | F |
|---|---|---|---|---|---|---|---|---|---|
| VS | 9.52 | -2.67 | -0.92 | 0.84 | -8.91 | 0.00 | 0.24 | 0.07 | 41.36 |
| MOR | 2.45 | 0.55 | 0.82 | 0.93 | 3.89 | 0.00 | 0.01 | 0.00 | 16.61 |
| MOE | 3.62 | 0.58 | 0.99 | 0.90 | 27.65 | 0.00 | 0.01 | 0.00 | 125 |
| MCS// | -4.41 | 46.89 | 0.93 | 0.87 | 7.39 | 0.00 | 1.70 | 1.07 | 53.71 |
| MCS | 0.60 | 9.42 | 0.99 | 0.97 | 17.51 | 0.00 | 0.32 | 0.09 | 130 |
| SS | -4.38 | 17.76 | 0.93 | 0.83 | 6.39 | 0.00 | 1.60 | 0.47 | 40.31 |

Note: RS = Radial Shrinkage, TS =Tangential Shrinkage, MOR = Modulus of Rupture, MOE = Modulus of Elasticity, MCS// = Maximum Compressive Force Parallel to Grain, MCSl = Maximum Compressive Force Perpendicular to Grain, SS = Shear Strength.

**Table 4.8.3.8 Prediction of Physical and Mechanical Propertie of Glulam Bambusa vulgaris in Guinea Savanna**

| |
|---|
| VS= 9.5 -2.67(x) |
| MOR= 2.45 + 0.55(x) |
| MOE = 3.62 + 0.58(x) |
| MCS// = -4.41 + 46.89(x) |
| MCS⊥ = 0.60 + 9.42(x) |
| SS= -4.38 + 17.76(x) |

Note: x= predictor (density).

**Table 4.8.3.9 Expected and Observed Variables in Guinea Savanna Ecological Zone of Nigeria**

| Variable | Expected | Observed |
|---|---|---|
| Vol. Shrinkage | 8.02 | 7.96 |
| MOR | 2.77 | 2.78 |
| MOE | 3.96 | 3.96 |
| MCS// | 22.79 | 22.91 |
| MCS⊥ | 6.06 | 6.09 |
| Shear Strength | 5.92 | 5.96 |

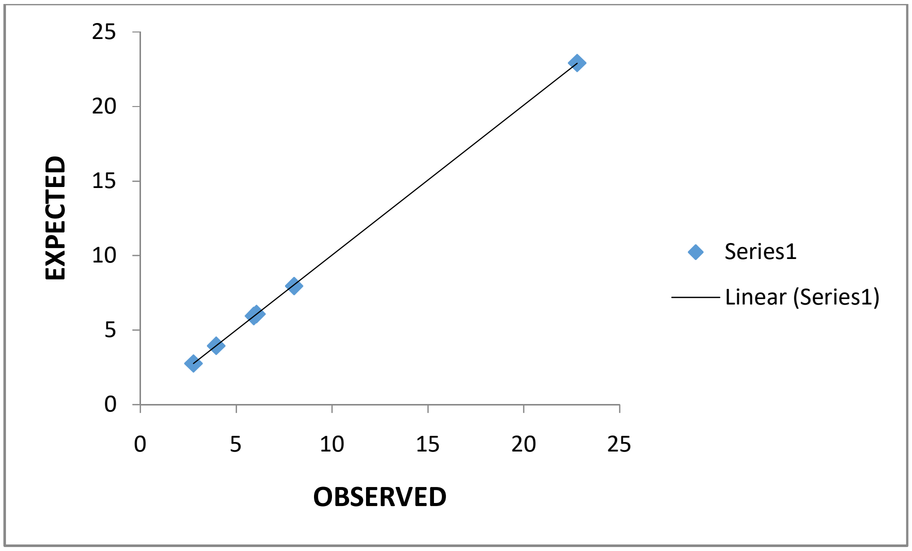


**Figure 4.8.3.1: Scatter Plot of Expected and Observed Physical and Mechanical Properties of Glulam *Bambusa vulgaris* in Guinea Savanna Ecological Zone.**

## 4. 9 Discussion

### 4. 9.1 Variability of Physical Properties

#### 4.9.1.1 Density

Density is one of the most important indicators of both physical properties of glulam *Bambusa vulgaris*. Density is considered to be an important factor in determining the suitability of bamboo for various applications. Density is important because it reflects the amount of cell wall material per unit volume of culms and relates directly to strength properties. Thus, increase in density results in decrease in moisture content and volumetric shrinkage and increase in all mechanical properties. Density of a glulam*Bambusa vulgaris* does not vary only with age but also with internodal position within clums. Different values of density of glulam*Bambusa vulgaries* were achieved by varying the locations of internodes from i.e. linear relationships have been established between density and intermodal locations.

In this study, density of glulam *Bambusa vulgaris* varied significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 2; F= 59.53; P= 0.00, <0.05, Table 4.1.1). It increased from35±0.09 to 56±0.05Kg/cm$^3$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.1.2). In the Lowland Rain Forest, it increased significantly from 40±0.01 to 61±0.01Kg/cm$^3$ at the lowest basal internode and the topmost internode respectively (Table 4.1.2). In Guinea Savanna, it increased from 47±0.07 to 64±0.00 Kg/cm$^3$ at lowest basal internode and the topmost internode respectively (Table 4.1.2). This could be due to the absorption of more adhesive by the porous cells in the upper internodes. The lowest and the highest values of density were observed in Mangrove Swamp Forest and Guinea Savanna respectively (Table 4.1.4).

Density of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 151.39; P= 0.00, <0.05, F=, table 4.1.1). There were significant differences in the mean densities of glulam*Bambusa vulgaris* obtained from the three ecological zones used for this study. The mean density were 47±0.07 Kg/cm$^3$ (Mangrove Swamp Forest) 51±0.06Kg/cm$^3$ (Lowland Rain Forest) and 58±0.06Kg/cm$^3$ (Guinea Savanna, table 4.1.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best density property than those from other ecological zones (Table 4.1.4). This could be attributed to variation in the environmental factors between the ecological zones. Environmental stress increases the density and decreases the moisture content of *Bambusa vulgaris*.

**4. 9.1.2 Radial Shrinkage (%)**

Radial shrinkage of glulam *Bambusa vulgaris* varied significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 6.00, P= 0.00, <0.05, Table 4.2.1.1). It decreased from 4.37±0.00 to 4.32±0.00 % at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4 2.1.2). In the Lowland Rain Forest, it decreased significantly from 4.15±0.00 to 4.00±0.00 at the lowest basal internode and the topmost internode respectively (Table 4 2.1.2). In Guinea Savanna, it decreased from3.68±0.0 to 3.64±0.00 at lowest basal internode and the topmost internode respectively (Table 4 2.1.2). The lowest and the highest value of radial shrinkage were observed inGuinea Savanna and Mangrove Swamp Forest respectively (Table 4.2.1.4)

Radial shrinkage of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; = 2394, P= 0.00, <0.05, Table 4.2.1.1). There are significant differences in the mean radial shrinkage of glulam*Bambusa vulgaris* obtained from the three ecological zones used for this study. The mean radial shrinkage was 4.35±0.07, (Mangrove Swamp Forest), 4.08±0.05, (Lowland Rain Forest) and 3.66±0.02 % (Guinea Savanna, table 4.2.1.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best radial shrinkage than those from other ecological zones (Table 4.2.1.4). This could be attributed to variation in the environmental factors between the ecological zones. Environmental stress decreases the moisture content of *Bambusa vulgaris*.

### 4. 9.1.3 Tangential Shrinkage (%)

Inverse relationship was also observed between tangential shrinkage and internodal location. Tangential shrinkageof glulam *Bambusa vulgaris* varied significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 101, P= 0.00, <0.05, Table 4.2.2.1). It decreased from 5.10±0.00 to 4.6±0.00 at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.2.2.2). In the Lowland Rain Forest, it decreased significantly from 4.8±0.00 to 4.4.±0.00 at the lowest basal internode and the topmost internode respectively (Table 4.2.2.2). In Guinea Savanna, it decreased from 4.5±0.00 to 4.1±0.00 at lowest basal internode and the topmost internode respectively (Table 4.2.2.2).

Tangential shrinkage of glulam *Bambusa vulgaris* also varied significantly with ecozones (df= 29, 2; F= 1045.30, P= 0.00, <0.05, Table 4.2.2.1). There were significant differences in the mean tangential shrinkage of glulam*Bambusa vulgaris* obtained from the three ecological zones used for this study. The mean tangential shrinkage was4.87±0.19, (Mangrove Swamp Forest), 4.60±0.15, (Lowland Rain Forest) and 4.30±0.15 % (Guinea Savanna, Table 4.2.2.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best tangential shrinkage than those from other ecological zones (Table 4.2.2.4). This could be attributed to variation in the environmental factors between the ecological zones. Environmental stress decreases the moisture content of *Bambusa vulgaris*.

### 4. 9.1.4 Volumetric Shrinkage (%)

Inverse relationship was also observed between volumetric shrinkage and internodal location. Volumetric shrinkageof glulam *Bambusa vulgaris* decreased significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 113, P= 0.00, <0.05, Table 4.2.3.1). It decreased from 9.47±0.00 to 8.92±0.00 at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.2.3.2). In the Lowland Rain Forest, it decreased significantly from 8.95±0.00 to 8.40±0.00 at the lowest basal internode and the topmost internode respectively (Table 4.2.3.2). In Guinea Savanna, it decreased from 8.18±0.00 to 7.74±0.00 at lowest basal internode and the topmost internode respectively (Table 4.2.2.2).The mean volumetric shrinkage was 9.22±0.21, (Mangrove Swamp Forest), 8.68±0.20, (Lowland Rain Forest)and 7.96±0.16 % (Guinea Savanna, Table 4.2.3).

The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best volumetric shrinkage than those from other ecological zones (Table 4.2.3.4). This could be attributed to variation in the environmental factors between the ecological zones. Environmental stress decreases the moisture content of *Bambusa vulgaris*.

Density correlated negatively with Volumetric shrinkage in all the ecozones -0.94 (Mangrove Swamp Forest, table 4.8.1.7), -0.98 (Lowland Rain Forest, table 4.8.2.7) and -0.92 (Guinea Savanna, Table 4.8.3.7). This indicates inverse relationship between density and volumetric shrinkage. The inverse relationship shows that density increases with decrease in volumetric shrinkage.

The coefficient of determination ($R^2$) of Volumetric shrinkage was high in all ecozones: 0.89 (Mangrove Swamp Forest, table 4.8.1.7), 0. 96 (Lowland Rain Forest, table 4.8.2.7), and 0.84 (Guinea Savanna, Table 4.8.3.7). This shows that density is the principal predictor of volumetric shrinkage in Nigerian ecozones.

### 4. 9.2 Mechanical Properties

#### 4. 9.2.1 Modulus of Rupture (MOR)

MOR of glulam *Bambusa vulgaris* varied significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 3.30, P= 0.02<0.05, table 4.1.1). It increased from 531.56±0.01 to 565.65±0.01N/mm$^2$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.3.1). In the Lowland Rain Forest, it increased significantly from533.25±0.01 to 572.86±0.01 N/mm$^2$at the lowest basal internode and the topmost internode respectively (Table 4.3.2). In Guinea Savanna, it increased from541.35±0.0 to 702.09±0.19N/mm$^2$ at lowest basal internode and the topmost internode respectively (Table 4.3.2).

MOR of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 16.20, P= 0.0, <0.05, Table 4.3.1).

There were significant differences in the mean MOR of glulam*Bambusa vulgaris* obtained from the three ecozones used for this study. The mean MORwas543±68, (Mangrove Swamp Forest), 555.11±11.30 (Lowland Rain Forest) and

600.64±53.42N/mm$^2$ (Guinea Savanna, Table 4.3.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best MOR property than those from other ecological zones (600.64±53.42N/mm$^2$, Table 4.3.4).

Density correlated positively with MOR in all the ecozones 0.91 (Mangrove Swamp Forest, table 4.8.1.7), 0.96 (Lowland Rain Forest, table 4.8.2.7) and 0.82 (Guinea Savanna, Table 4.8.3.7). This indicates inverse relationship between density and volumetric shrinkage. The inverse relationship shows that density increases with decrease in volumetric shrinkage.

The coefficient of determination ($R^2$) of MOR was high in all ecozones: 0.93 (Mangrove Swamp Forest, table 4.8.1.7), 0. 93 (Lowland Rain Forest, table 4.8.2.7) and 0.93 (Guinea Savanna, Table 4.8.3.7). Density is therefore the principal predictor of MOR in Nigerian ecozones.

**4. 9.2.2 Modulus of Elasticity (MOE)**

The MOEof glulam *Bambusa vulgaris* alsovaried significantly from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 32, P= 0.02<0.05, table 4.4.1). It increased from 6535.60±0.05 to 9255.81±0.03N/mm$^2$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.4.1). In the Lowland Rain Forest, it increased significantly from 7271.51±0.00 to 9650±0.32 N/mm$^2$at the lowest basal internode and the topmost internode respectively (Table 4.4.2). In Guinea Savanna, it increased from7877.66±0.08 to 9841±0.68N/mm$^2$ at lowest basal internode and the topmost internode respectively (Table 4.4.2).MOE of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 16.20, P= 0.0, <0.05, Table 4.4.1).

There were significant differences in the mean MOE of glulam*Bambusa vulgaris* obtained from the three ecozones used for this study. The mean MOEwas7883.22±909.71, (Mangrove Swamp Forest), 8744.17±725.96 (Lowland Rain Forest)and 9090.16±653.41N/mm$^2$ (Guinea Savanna, Table 4.3.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best MOE property than those from other ecological zones 9090.16±653.41N/mm$^2$, Table 4.4.4).

Density correlated positively with MOEin all the ecozones 0.99 (Mangrove Swamp Forest, Table 4.8.1.7), 0.98 (Lowland Rain Forest, table 4.8.2.7) and 0.99 (Guinea

Savanna, Table 4.9.3.7). This indicates mutual relationship between density and MOE. The coefficient of determination ($R^2$) of MOE was high in all ecozones: 0.99 (Mangrove Swamp Forest, Table 4.8.1.7), 0. 91 (Lowland Rain Forest, Table 4.8.2.7), and 0.90 (Guinea Savanna, Table 4.8.3.7). Density is therefore the principal predictor of MOE in Nigerian ecozones.

**4. 9.2. 3Maximum Compressive Force Parallel to Grain (MCS//)**

There were significant variations in MCS//of glulam *Bambusa vulgaris*from the lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 47.21, P= 0.00<0.05, table 4.5.1). It increased from 16.04±0.08 to 21.78±0.63N/mm$^2$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.5.2). In the Lowland Rain Forest, it increased significantly from 16.50±0.00 to 23.41±0.03N/mm$^2$at the lowest basal internode and the topmost internode respectively (Table 4.5.2). In Guinea Savanna, it increased from 19.01±0.03 to 26.89±0.03N/mm$^2$ at lowest basal internode and the topmost internode respectively (Table 4.5.2).The MCS//of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 152.37, P= 0.0, <0.05, Table 4.5.1).

There were significant differences in the mean MCS//of glulam*Bambusa vulgaris* obtained from the three ecozones used for this study. The mean MCS//was 18.52±1.89 (Mangrove Swamp Forest), 19.57±2.35 (Lowland Rain Forest)and 22.91±2.81N/mm$^2$ (Guinea Savanna, Table 4.3.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best MCS//property than those from other ecological zones (22.91±2.81N/mm$^2$, Table 4.5.4).

Density correlated positively with MCS//in all the ecozones 0.94 (Mangrove Swamp Forest, Table 4.8.1.7), 0.97 (Lowland Rain Forest, table 4.8.2.7) and 0.93 (Guinea Savanna, Table 4.8.3.7). This indicates mutual relationship between density and MOE. The coefficient of determination ($R^2$) of MCS//was high in all ecozones: 0.89 (Mangrove Swamp Forest,table 4.8.1.7), 0.94 (Lowland Rain Forest, Table 4.8.2.7), and 0.87 (Guinea Savanna, Table 4.8.3.7). Density is therefore the principal predictor of MCS//in Nigerian ecozones.

**4. 9.2.4 Maximum Compressive Force Perpendicular to Grain (MCSl)**

The MCSl also varied significantly fromthe lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 25.09, P= 0.00<0.05, table 4.6.1). It increased from 16.3.34±0.00 to 6.40±0.01N/mm$^2$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.6.2). In the Lowland Rain Forest, it increased significantly from 4.21±0.00 to 6.82±0.00N/mm$^2$at the lowest basal internode and the topmost internode respectively (Table 4.6.2). In Guinea Savanna, it increased from 5.38±0.00 to 7.51±0.03N/mm$^2$ at lowest basal internode and the topmost internode respectively (Table 4.6.2).

The MCS**l** of glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 49.50, P= 0.0, <0.05, Table 4.6.1). There were significant differences in the mean MCSlof glulam*Bambusa vulgaris* obtained from the three ecozones used for this study. The mean MCS//was 5.14±0.87 (Mangrove Swamp Forest), 5.80±2.05 (Lowland Rain Forest)and 6.09±0.53N/mm$^2$ (Guinea Savanna, Table 4.6.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best MCS//property than those from other ecological zones (22.91±2.81N/mm$^2$, Table 4.5.4).

Density correlated positively with MCSl in all the ecozones 0.98 (Mangrove Swamp Forest, Table 4.8.1.7), 0.99 (Lowland Rain Forest, table 4.8.2.7) and 0.99 (Guinea Savanna, Table 4.8.3.7). This indicates mutual relationship between density and MCSl.

The coefficient of determination ($R^2$) of MCSl was high in all ecozones: 0.98 (Mangrove Swamp Forest, table 4.8.1.7), 0. 99 (Lowland Rain Forest, Table 4.8.2.7), and 0.99 (Guinea Savanna, Table 4.8.3.7). Density is therefore the principal predictor of MCSl in Nigerian ecozones.

**4. 9.2.5 Shear Strength**

This also varied significantly fromthe lowest basal internodes to the topmost internodes. Analysis of Variance shows significant difference (DF= 29, 9; F= 382.06, P= 0.00<0.05, table 4.6.1). It increased from 2.46±0.01 to 6.02±0.06N/mm$^2$ at the lowest basal internode and the topmost internode respectively in the Mangrove Swamp Forest (Table 4.7.2). In the Lowland Rain Forest, it increased significantly from 3.22±0.06 to 6.62±0.06N/mm$^2$at the lowest basal internode and the topmost internode respectively (Table 4.7.2). In Guinea Savanna, it increased from 4.51±0.03 to 7.51±0.03N/mm$^2$ at lowest basal internode and the topmost internode respectively (Table 4.6.2).

The Shear Strengthof glulam *Bambusa vulgaris* also varied significantly with ecozones (DF= 29, 2; F= 667.70, P= 0.0, <0.05, Table 4.7.1). There were significant differences in the mean MCSlof glulam*Bambusa vulgaris* obtained from the three ecozones used for this study. The mean Shear Strengthwas 4.33±1.21 (Mangrove Swamp Forest), 4.89±1.15 (Lowland Rain Forest)and 5.96±1.09N/mm$^2$ (Guinea Savanna, Table 4.7.3).The glulam bamboo boards of *Bambusa vulgaris* from the Guinea Savanna had the best MCS// property than those from other ecological zones (5.96±1.09N/mm$^2$, Table 4.7.4).

Density correlated positively with Shear Strength in all the ecozones 0.98 (Mangrove Swamp Forest, Table 4.8.1.7), 0.99 (Lowland Rain Forest, table 4.8.2.7) and 0.93 (Guinea Savanna, Table 4.8.3.7). This indicates mutual relationship between density and MCSl. The coefficient of determination ($R^2$) of Shear Strength was also high in all ecozones: 0.96 (Mangrove Swamp Forest, table 4.8.1.7), 0. 97 (Lowland Rain Forest, Table 4.8.2.7), and 0.93 (Guinea Savanna, Table 4.8.3.7). This shows that density is an indepent variable that predicts Shear Strength in Nigerian ecozones.

## 4.10 Properties of Glulam *Bambusa vulgaris* Boards Compared to Selected Tropical Woods

The Shrinkage Properties ofglulam *Bambusa vulgaris* Compared to Athel (*Tamarix aphylla*) wood were shown in table (4.2.3.5). The tangential, radial, and volumetric shrinkages (%) were 4.30, 3.66 and 7.96% respectively. Compared to *Tamarix aphylla*,these values were lower than 7.13, 4.14 and 13.23% recorded by Abasali *et al.,* (2012) for the tangential, radial, and volumetric shrinkages respectively (Table 4.2.3.5). This shows that glulam *Bambusa vulgaris* boards is better than *Tamarix aphylla* and can favorablely substitute it.

Specific strength ofglulam *Bambusa vulgaris* boards and those other tropical hardwoods were shown in Table 4.7.8. The specific gravity for MOR was 10.36Nmm$^2$. This was lower than the values recorded for *Melicia excelsa*, *Khaya senegalensis*, *Holoptelia grandis* but higher than the values recorded for *Sterculia rhinopetala* and *Mansonia altisima* recorded by CIRAD (2009) and Ogunsanwo

(2010). The higher value shown by *Bambusa vulgaris* compared to *Sterculia rhinopetala* and *Mansonia altisima* (Table 4.7.8.) has proved that *Bambusa vulgaris* could be used to replace them. The MOE of *Bambusa vulgaris*in this study is however higher than those of all selected tropical hardwoods *Bambusa vulgaris*The study further showed that glulam *Bambusa vulgaris* board could effectively function as a structural material where stiffness and flexibility is of great importance. For MCS//, specific strength of *Bambusa vulgaris* was however a little bit lower than those of the selected tropical hardwood species ((Table 4.7.8). This implies that it could effectively substitute lesser known species like *Sterculiarhinopetala* and *Mansonia altisima.*

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

This present study investigated the intermodal and ecological variability of selected physical and mechanical properties of glu- lams of *B. vulgaris*in Nigerian ecological zones. From the results of the present study, the following conclusions are drawn:

Selected physical and mechanical properties of glulam*Bambusa vulgaris* vary significantly from the bottom to the top. Therefore, sampling height of internodes along culm axis has significant effects on density, volumetric shrinkage, MOR, MOE, Maximum Compressive Strength Parallel to Grain, Maximum Compressive Strength Perpendicular to Grain and shear strength of glulam *Bambusa vulgaris*. The physical and mechanical properties of glulam bamboo boards. Glulams of *Bambusa vulgaris* produced from the culm base had lower strength properties than those obtained from the top. Upward variation resulted in improved technical potentials of glulam*B. vulgaris*.

Density increased significantly from lowest basal internodes to the topmost internodes. This may however be due to the absorption of more adhesive at the up the upper internodes because of more porous cells at the upper internodes.

There was significant reduction in volumetric, radial and tangential shrinkages as the sampling points increased from the lowest basal internodes to the topmost internodes. Increase in density resulted in decrease in moisture content and volumetric shrinkage. This resulted in improved strength properties of glu- lams *B. vulgaris*.

Also, density, volumetric, radial and tangential shrinkages; MOR, MOE, Maximum Compressive Strength Parallel and Perpendicular to Grain and Shear Strength of glulam*Bambusa vulgaris* varied significantly from one ecological zone to another. The most significant ecozone was Guinea Sananna This is as a result of variation in quality, quantity, intensity and duration of environmental factors such as light, temperature, water, relative humidity, wind and soil fertility. This implied that environmental factors could influence selected physical and mechanical properties of glulam*Bambusa vulgaris* in Nigeria. Also, Glulams from dryer ecological zones were superior to those produced from wetter zones.

There was significant correlation between density and volumetric shrinkage,MOR, MOE MCS//, MCS<u>l</u> and shear strength of glulam*Bambusa vulgaris*. While correlation was mutual with density andall mechanical properties of glulam*Bambusa vulgaris*, the reverse was the case in the relationship between density and volumetric shrinkage. The coefficient of determination was very high for volumetric shrinkage, MOR, MOE, Maximum Compressive Strength Parallel and Perpendicular to Grain and Shear Strength of glulam*Bambusa vulgaris;* density being the independent factor.Density is therefore the principal property that influences physical and mechanical properties of glulam*Bambusavulgaris* boards.

The specific strengths of glulam*Bambusavulgaris* boards haven shown that*Bambusavulgaris* could serve as subdtitute to *Sterculiarhinopetala,Mansonia altisima*and other lesser used species.

**5.2 Recommendations**

1. Glulam*Bambusa vulgaris* has technical properties similar to those of medium density wood. It should therefore be used as substitute for them.
2. It should also be laminated with wood products to reduce dependence on wood.

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# APPENDICES

## Appendix 1: Prediction of Percentage Volumetric Shrinkage in Mangrove Swamp Forest

To predict percentage volumetric shrinkage in Mangrove Swamp Forest, data were fitted into a simple linear regression model:

V= 10.25+ (-3.05D) ……………….. (Equation 4.9.1.2)

Where `

V=Volumetric Shrinkage (%)

D= Density = (0.47cm$^{-3}$)
V= 10.50+ (-2.71x0.47) %
V= 9.23%.

**Appendix 11: Prediction of MOR in Mangrove Swamp Forest**

To predict MOR in Mangrove Swamp Forest, data were fitted into a simple linear regression model:

Ln MOR = 2.70+0.11D (N/mm$^2$) ………………Equation4.9.1.4

Where
D= Density
Ln MOR= 2.70+ (0.11x0.47) %
= 2.75N/mm$^2$
Table 4.8.1.2.2: is the regression summary for dependent variable: volumetric shrinkage

**Appendix 111: Prediction of MOE in Mangrove Swamp Forest**

To predict MOE in Mangrove Swamp Forest, data were fitted into a simple linear regression model:

Ln MOE = 3.57+0.69D …………….. (Equation 4.9.1.6)

Where

Ln = natural log

MOE= Modulus of elasticity

D= density (= 0.47)

MOE= 3.89N/$m^2$

**Appendix 1V: Prediction of MCS//in Mangrove Swamp Forest**

To predict MCS// in Mangrove Swamp, data were fitted into a simple linear regression model:
MCS // = 6.89+24.63D …………………….. (Equation 4.9.8)

Where

MCS // = Maximum Compressive Force Parallel to Grain

D= Density (= 0.47)

MCS // = 18.47N/$m^2$

**Appendix V: Prediction of MCSl in Mangrove Swamp Forest**

To predict MCSl in Mangrove Swamp Forest, data were fitted into a simple linear regression model:

MCSl = -0.43+11.78D…………………. (Equation 4.9.10)

Where

MCSl = Maximum Compressive Force Perpendicular to Grain

D= Density.

MCSl = -0.43+ (11.78 x0.47) $N/mm^2$

MCSl = 5.11$N/mm^2$

**Appendix V1: Prediction of SS in Mangrove Swamp Forest**

To predict shear strength in mangrove swamp therefore, data were fitted into a simple linear regression model:

$SS = -3.40+16.35D$ ………………….. (Equation 4.9.12)

Where

SS = Shear Strength

D= Density.

$SS = -3.40+ (16.35 \times 0.47)\ Nmm^2$

$SS = 4.29 Nmm^2$

**Appendix V11: Prediction ofVolumetric Shrinkage in Lowland Rain Forest**

To predict volumetric shrinkage in Lowland Rain Forest, data were fitted into a simple linear regression model:

V= 10.25 + (-3.05D) ……………….. (Equation 4.8.14)

Where

V=Volumetric Shrinkage (%)

D= Density

V= 10.25 + (-3.05D) ……………….. (Equation 4.8.14)

Where

V=Volumetric Shrinkage (%)

D= Density.

V= 10.25 + (-3.05x0.51)

V=8.69(%).

**Appendix V111: Prediction of** MOR **in Lowland Rain Forest**

To predict MOR in Lowland Fain forest, data were fitted into a simple linear regression model:

Ln MOR = 2.68+0.0.13D ………………….. (Equation 4.8.16)

Where Ln = natural log,

MOR = modulus of rupture.

D= Density.

MOR = 2.68+ (0.13x0.51) $N/mm^2$

MOR =2.75$N/mm^2$.

**Appendix 1X: Prediction ofMOEin Lowland Rain Forest**

To predict MOE in Lowland Rain Forest, data were fitted into a simple linear regression model:

LnMOE = 3.65+0.57D ………………….. (Equation 4.8.18)

Where,

Ln = natural log,

MOE = modulus of elasticity.

Density.

MOE = 3.65+ (0.57x 0.51)N/mm$^2$.

MOE = 3.94N/mm$^2$.

**Appendix X: Prediction ofMCS//** in **Lowland Rain Forest**

To predict MCS// in Lowland Rain Forest, data were fitted into a simple linear regression model:

MCS // = 6.89+24.63D …………………….. (Equation 4.8.20)

Where

MCS // = Maximum Compressive Force Parallel to Grain

D= Density

MCS // = 6.89+ (24.63x0.51)Nmm$^2$

MCS // = 19.45)Nmm$^2$

**Appendix X1: Prediction of MCSl in Lowland Rain Forest**

To predict MCSl in Lowland Rain Forest, data were fitted into a simple linear regression model:

MCSl = 1.89+7.61D ………………….. (Equation 4.8.22)

Where

MCSl= Maximum Compressive Strength Perpendicular to Grain

D= Density.

MCSl = 1.89+ (7.61x0.51)

MCSl = 5.77N/mm$^2$

**Appendix X11: Prediction of Shear Strengthin Lowland Rain Forest**

To predict shear strength in Lowland Rain Forest, data were fitted into a simple linear regression model:

SS = -4.14 +17.56D ………………….. (Equation 4.8.24)

Where

SS =Shear Strength

D= Density.

SS = -4.14 + (17.56x0.51)

SS = 4.82N/mm$^2$

**Appendix X111: Prediction of Volumetric Shrinkage in Guinea Savanna**

To predict volumetric shrinkage in Guinea Savanna, data were fitted into a simple linear regression model:

V= 9.52+ (-2.67D) ……………….. (Equation 4.8.26)

Where

V=Volumetric Shrinkage (%)

D = Density.

D = 9.52+(-2.6X0.58)

D= 8.02%

**Appendix X1V: Prediction of MOR inGuinea Savanna**

To predict MOR in Guinea Savanna, data were fitted into a simple linear regression model:

Ln MOR= 2.45+0.55D ………………….. (Equation 4.8.28)

Where,

Ln= natural log,

MOR =Modulus of Rupture

D= Density.

Ln MOR= 2.45+(0.55x0.58)

MOR = 2.77Nmm$^2$

**Appendix XV: Prediction of MOE inGuinea Savanna**

To predict MOE in Guinea Savanna, data were fitted into a simple linear regression model:

Ln MOE = 3.62+0.58D ………………….. (Equation 4.9.30)

Where,

Ln = natural log

MOE = modulus of elasticity.

D= density

MOE= 3.62+ (0.58x0.58)

MOE= 3.96N/mm$^2$

**Appendix XXV: Prediction of MCS//inGuinea Savanna**

To predict MCS// in Guinea, data were fitted into a simple linear regression model:
MCS// = -4.41+46.89D ………………….. (Equation 4.8.32)

Where

MCS// =Maximum Compressive Force Parallel to Grain

= -4.41+(46.89x0.58)

= 22.79N/mm$^2$

**Appendix XV1: Prediction of MCSl inGuinea Savanna**

To predict Maximum Compressive Force Perpendicular to Grain in Guinea Savanna ecological zone, data were fitted into a simple regression model:

MCSl= 0.60+9.42D ………………….. (Equation 4.8.34)

Where

MCSl = Maximum Compressive Force Perpendicular to Grain

D= Density

MCSl = 0.60+(9.42x0.58)

MCSl = 6.06N/mm$^2$

**Appendix XV11: Prediction of SS inGuinea Savanna**

To predict Shear Strength in Guinea Savanna, data were fit into a simple linear regression model:

SS = -4.38+17.76D ………………….. (Equation 4.8.36)

Where

SS = Shear Strength

D= Density.

SS= -4.38+ (17.76x0.58)

SS= 5.92N/$mm^2$