CHARACTERISATION OF SELECTED WOOD PROPERTIES OF THERMAL-MODIFIED *Bambusa vulgaris* SCHRAD.EX J.C.WENDL

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ABSTRACT

The preservative treatment of non-durable lignocellulosic materials, such as *Bambusa vulgaris* (bamboo) enhances its service life. Thermally modified lignocellulosic biomaterial is better than chemically treated products because it is environmentally friendly. However, there is a dearth of information on the characterisation properties of thermally modified *Bambusa vulgaris*. This study was therefore conducted to characterise the properties of thermally modified *Bambusa vulgaris.*

One thousand and eighty (30 cm x 2 cm x 0.5 cm) bamboo strips were thermally modified in a heat-chamber at 100, 110, 120, 130 and 140 °C each, for 10, 20 and 30 minutes, under constant pressure (220 N/m^2) in factorial arrangement in completely randomised design with 5 replicates. Untreated strips served as control. The strips were laminated into boards using cold press for 24 hours and Fibre Diameter (FD), Fibre Cell Wall (FCW), Fibre Lumen Width (FLW), Fibre length (FL) were measured. The Specific Gravity (SG), Equilibrium Moisture Content (EMC), Radial Shrinkage (RS), Water Absorption (WA), Compressive Strength (CS$\perp$), Modulus of Elasticity (MOE), Modulus of Rupture (MOR), Shear Strength (SS) and Impact Bending (IB), chemical characteristics (cellulose, hemicellulose, lignin and ash contents) were determined using standard procedures. Samples were thereafter inoculated with *Sclerotium rolfsii* (Brown rot) and *Pleurotus florida* (White rot) using accelerated durability test procedure for 12 weeks and assessed for Weight Loss (WL). Samples were also assessed in Timber Grave Yard (TGY) using Weight Loss (WL) procedure. Data were analysed using descriptive statistics, ANOVA and regression at $\alpha_{0.05}$.

The FD ranged from 11.51±2.07 μm (140°C/30 minutes) to 17.62±3.65 μm (control), FCW ranged from 5.96±2.13 μm (140°C/30 minutes) to 12.03±3.66 μm (control), FLW ranged from 2.64±0.12 μm (140°C/30 minutes) to 2.80±0.22 μm (control), while FL ranged from 2.05±0.28 mm (140°C/30 minutes) to 2.52±0.39 mm (control). The SG (0.6±0.1 and 0.5±0.1), EMC (10.5±1.3 and 6.8±1.2), RS (3.7±1.1and 1.6±0.6) and WA (46.6±13.5% and 32.7±2.2) were obtained in control and 140°C/30 minutes thermal-modified samples, respectively. The RS and WA at 100, 110, 120 and 130°C/30 minutes were 0.9±0.3, 1.2±0.4, 0.6±0.1, 0.6±0.1 and 38.4±5.3, 31.1±4.7, 26.4±3.8, 29.9±4.5%, respectively. The CS$\perp$, MOE, MOR, SS and IB varied from 7.41±0.24, 5461.83±594.86, 18.39±2.01, 1.07±0.26 N/mm^2 and 1.68±0.03 KJ/m^2, respectively in 140°C/30 minutes to 36.14±0.11, 29,703.50±4192.77, 56.29±1.86, 3.88±0.50N/mm^2 and 2.30±0.02 KJ/m^2, respectively for untreated samples. The cellulose (46.46±0.11% and 42.19±0.18%), hemicellulose (35.59±0.10% and 31.80±0.01%), lignin (29.11±0.12% and 26.17±0.13%), ash (0.92±0.02% and 0.63±0.01%) were obtained in control and 140°C/30 minutes thermal-modified samples, respectively. The highest WL was obtained from untreated samples inoculated with *Sclerotium rolfsii* (6.1±0.3%) and *Pleurotus florida* (5.1±0.9%), while the least WL of 1.8±0.2% and 1.1±0.2%, respectively was recorded for samples modified at 140°C/30 minutes. The WL of untreated samples in TGY was 28.2±14.1%, while the least WL (25.1±2.9%) was observed for 140°C/30 minutes thermal-modified samples. The IB and EMC accounted for 83.9 and 53.8% variation of chemical characteristics.

Thermal modification at 140°C for 30 minutes improved dimensional stability and durability of *Bambusa vulgaris*. Increase in temperature and time of thermal modification reduced strength properties and chemical characteristics of *Bambusa vulgaris.*

Keywords: Thermal modification, Wood dimensional stability, Wood durability, *Bambusa vulgaris*.

Word count: 499

DEDICATION

I dedicate this piece of work to Author and Finisher of my faith, Alpha and Omega, the beginning and the last of all things, unto him be all the glory, power, honour, dominion, authority and adoration forever and ever. Amen.

CERTIFICATION

I certify that this project work was carried out by Mr. Oladele Bernard, OLAJIDE under my supervision in the Department of Forest Resources Management, University of Ibadan

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ACRONYMS

ANOVA	Analysis of Variance
EMC	Equilibrium Moisture Content
FCW	Fibre Cell Wall
FD	Fibre Diameter
FL	Fibre Length
FLW	Fibre Length Width
FPD&U	Forest Product Development and Utilisation
FRIN	Forestry Research Institute of Nigeria
FSP	Fibre Saturated Point
GYT	Grave Yard Test
IB	Impact Bending
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
RS	Radial Shrinkage
S.G	Specific Gravity
SEM	Scanning Electron Microscope
SS	Shear Strength
TEM	Transmission Electron Microscope
TM	Thermal-Modified
WA	Water Assumption
WL	Weight Loss

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CHAPTER ONE

INTRODUCTION

1.1 Background Study

Bamboo culms as well as processed bamboo in the form of laminates, cuts, splits, slices and sticks provide excellent raw material for a number of value added products and applications in structural and non-structural segments (Jang, 2008). Both processed and unprocessed bamboo products face the problem of biological degradation while untreated with preservative measures. Though a wide range of protective measures and processes are known to prevent such degradation, in recent years; the productions of heat-treated wood and allied products have increased rapidly (Ewert and Scheiding, 2005, Olajide *et al.*, 2013b).

Thermal treatment has been found to be an environmental friendly-wood preservation technique (Kocaefe *et al.*, 2008). Thermal modification is used to improve the durability and dimensional stability of bamboo, though thermal modification causes many changes related to the physical properties of bamboo such as Mass, Colour and Equilibrium Moisture Content (EMC). All these changes are dependent on the modification conditions (modification temperature and duration). However, most bamboos used for structural purposes in rural and tribal housing deteriorate in a couple of years, therefore, putting heavy pressure on the resource, because of the increase demands for frequent replacements of deteriorated ones, this adversely affects the supplies of bamboo, even in bamboo rich regions. Considerable research work has been carried out in bamboo producing countries in the Asian region, as a result of which the service life of bamboo can be increased.

In Nigeria, the current patterns of development in the forest industry which rely solely on diminishing forest resources are undoubtedly unsustainable (Ogunwusi and Jolaoso, 2012 and Ogunwusi, 2012). A number of studies; Larinde, (2010); Ogunsanwo, (2010) and Ogunwusi, (2012b) recently reported the timber resources in Nigeria to be dwindling in availability. There is therefore need to search for more sustainable, climate friendly alternatives that have potentials for alleviating the social and environmental problems the world is currently facing. Bamboo is a promising non-timber forest product in the world that can substitute timber in many applications, the history of bamboo's utilization can be traced back to 5000 to 6000 years ago (Zhaohua, 2004). Although, most of the earlier developments in bamboo utilization and processing took place in China (Zhaohua, 2004), the increasing realization of the roles of bamboo in climate change Mitigation, Adaptation and Development (MAD) has made it a pride that most countries are depending on the development of local industries (Schellnhuber, 2009). According to Wooldridge, (2012), bamboo is being hailed as a new super material with uses ranging from textiles to construction. With advancement in technology, nearly 4000 commercial products made out of bamboo or its products are available and in use daily in the world (Singh, 2008). Despite this, bamboo usage is still undergoing transformation, making experts to call the plant the timber of the 21st century (Wooldridge, 2012). This coupled with continual development of new technologies and processing techniques enables bamboo to compete effectively with wood products.

Anatomically, bamboo is quite different from wood coming from gymnosperms and dicotyledonous angiosperms (Ghosh and Negi, 1959). All the growth in bamboo occurs longitudinally and there is no lateral or radial growth as in trees. Characteristically, bamboo has a hollow stem, or culm which is closed at frequent intervals called nodes. The anatomy and physical properties of bamboo culms have been known to have significant effects on their durability and strength (Abd. Latif and Mohd Tamizi 1992; Liese 1985; Razak 1998), therefore, bamboo microstructures of bamboo has a great influence on the strength and service life of bamboo.

In general, hydrothermal treatments of wood induce a temporary or permanent change and improve some wood characteristics. The actions of steam and heat on wood are complex because they involve changes in the physical and chemical nature of the wood micro nature and in the cell wall components. Steam causes swelling of the material accompanied by hydrolysis of certain compounds and salvation of various extractives. On the other hand, thermal modification causes progressive degradation of the constituents of the wood cells, leading to the formation of numerous substances whose nature depends on the wood species, the sample size, and the process conditions (Todaro *et al*., 2013). The changes in chemical composition of wood and bamboo structures in the thermal processes are mainly caused by degradation of hemicelluloses, cellulose, and lignin, which directly influences the physical and chemical properties of the wood (Stamm 1956, Mazela *et al*., 2004). Esteves and Pereira (2009) reported changes that result to include; increased lignin content, increased dimensional stability due to cross-linking in lignin, the destruction of some of the hydroxyl groups, improved durability, undesirable decreased mechanical properties such as static and dynamic bending strength and tensile strength, lower Equilibrium, Moisture Content and darker colour (Esteve and Pereira, 2009).

Several studies have reported that equilibrium moisture, swelling and shrinkage of modified-wood with heat treatment (Stamm *et al.,* 1946; kollmann and Schneider, 1963; Burmester, 1975 and Hillis, 1984). Also several studies reported increasing resistance to fungal attack by heat treatment (Dirol and Guyonnet, 1993; Troyal and Navarrette, 1994; Leithoff and peek, 2001; Mazela *et al*., 2004), but literature is still lacking on the physical properties and anatomical structures of thermal-modified bamboo. Olajide *et al,* (2013b) reported that the inventory of *Bambusa vulgaris* in terms of location, quantity and anatomical quality of bamboo be further assessed. Therefore in this study, the general anatomical structure, physical and mechanical properties of *Bambusa vulgaris* in relation to thermal modification at different treatment temperature and time variations and sample heights will be determined, and the durability of the thermal-modified bamboo will be investigated.

1.2 Statement Problem

The increasing scarcity of commonly used species of Non Timber Forest Products, (NTFPs) in tropical forests has made in-depth research into utilization potentials of lesser used wood species or alternative woody materials inevitable in order to increase demand for their industrial products. High rate of deforestation and the increasing rate of downward movement of the desert conditions have seriously reduced wood availability in Nigeria. Efforts have to be geared towards promoting the utilization of lesser used wood species or other woody plant materials as substitute raw materials in the industrial sector in Nigeria. Badejo *et al,* (2013) reported that the excessive timber harvest has caused a marked reduction in the supply of wood; the extent of reduction is currently affecting wood position as a prime choice among the conventional construction methods for varying applications.

In recent times the use of bamboo as substitute for wood is on the increase. However, efficient processing and preservation techniques are also major areas of concern as well as product development and promotion in bamboo. However, bamboo is easily attacked by fungal or insect infestation. The properties of bamboo will deteriorate rapidly if material is not treated with preservatives (Liese, 1985). The use of preservative in bamboo has been recognised as necessary, if it has to be considered for utilization in furniture and construction purposes, However, the use of preservatives is not always effective as bamboo is not easily treated (Liese, 1985). Bamboo is a natural material of organic origin, without any protective treatment its durability is less than five years. Unlike varieties of timber which are naturally durable, bamboo structure is void of toxic deposits. The presence of starch makes it more attractive to microorganisms; biological degradation can affect the usage, strength, utility and value of the bamboo (Liese, 1998, Wang *et al*., 1998).

The preservative treatments applied to timber wood species are often not applicable to bamboo due to the different internal structure of the bamboo culm. Treatability of bamboo varies along the height of the culm and across the culm wall thickness (Gnanaharan, 2000). Bamboo culms are divided into nodes and internodes and are composed of two types of tissue; parenchyma cells and vascular bundles. Obstacles between these cells reduce an easy flow. Some vessels at the nodes do, however, run straight through into the following vessel. Additionally, the outside and inside membranes are covered by hard cuticles that offer considerable resistance to the absorption of water particularly when dry, even after the application of pressure these anatomical features help to explain the refractory nature of bamboo to preservatives (Ding and Liese, 1995).

Furthermore, bamboo has very low resistance to biological degrading agents. Several techniques to enhance its durability have, therefore, been challenging. Durability of bamboo against mold, fungal and borers attack is strongly associated with its chemical composition (Ssemaganda *et al*, 2011). The natural durability of bamboo is relatively short, varies between 1 and 36 months depending on the species and climatic condition (Liese, 1980). Recent project on some important Indian Bamboo species showed that the average life of untreated bamboos is less than two years; this confirmed the observations on natural durability of bamboo reported by Purushotham *et al*, (1954), Anon, (1982) and Lee *et al*, (1994). The thermal modification technique used recently is based on empirical knowledge; there is no fundamental examination of the relationship between thermal treatment and changes in properties until recently (Nguyen *et al*., 2012).

1.3 Aim and Objective

The aim of the study is to characterise some selected wood properties of thermal-modified *Bambusa vulgaris* with a view to determine the influence of heat modification on selected properties of bamboo. The objectives are to;

(i) assess the anatomical characteristics of thermal-modified *Bambusa vulgaris.*

(ii) determine the selected physical and mechanical properties of thermal-modified bamboo laminates

(iii) assess the chemical components of thermal-modified bamboo.

(iv) determine the durability of thermal-modified *Bambusa vulgaris.*

1.4 Scope of the Study

The Bamboo harvesting and conversion was carried out at the Forestry Research Institute of Nigeria, Jericho, Ibadan. Nigeria (FRIN). The Scanning Electron Microscope (SEM) of the Kwazulu-Natal, South Africa was used. The physical properties were carried out at FRIN; mechanical properties at FRIN, Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife chemical properties were carried out at Nigerian Institute of Science Laboratory Technology, Ibadan, Oyo State (NISLT).

1.5 Justifications

The importance of bamboo in the world economy as one of the Non-Timber-Forest products (NTFPs) cannot be over emphasized. Considering the concerns about natural forest resources and growing demand for sustainable timber resources, which is leading to the dwindling of these unsustainable resources, thus, bamboo resources is a good candidate that can substitute for many timber products. Bamboo products are particularly hard and durable, which is why bamboo represents a good substitute for hardwood products (Hunter, 2003). According to Ogunsanwo and Terziev, (2010) bamboo has higher specific strength than *Milicia excelsa, Khaya senegalensis and Mansonia altisima*. The perception and evaluation of non-wood forest products is changing due to alarming rates of deforestation and decreased timber yields (Kigomo, 2007), Non-wood forest products are known to generate substantial foreign exchange and are increasingly being regarded as valuable commodities around the world.

Unfortunately, utilization of bamboo particularly for structural application is associated with rapid bio-deterioration in service. Olajide *et al*, (2013b) reported that thermal treatment is an effective method of bamboo preservation, as it reduces the infestation of insects attack, notwithstanding the relative and undesirable decrease in the strength properties. Bruno *et al*, (2009) reported that, the culms exhibit different chemical composition in the contents of extractives, holocellulose, Alpha-cellulose, lignin and ash between the bamboo species, location in the culms and position at the nodes and internodes. Heat treatment reduces sugar content of wood and can therefore enhance wood adhesion; the comprehensive knowledge of the chemical components in the bamboo species will facilitate the use of the materials in the forestry industrial sector and help to enhance their utilization in the chemical and bio-chemical related industry.

Wood thermal treatment is useful and environmental friendly, the heat treatment process only uses steam and heat, and no chemicals or agents are applied to the material during the process. It is a mechanism that can improve some wood properties like dimensional stability, durability, and some colour (Bazyar, 2012). The action of heat can be relatively intense on wood, on account of the structural changes that occur during combustion (Brito, 1992). It is important to identify various benefits derivable from heat treatment on wood and other lignocellulosic materials, this study is therefore necessary in order to assess the potential impact of heat treatment on the properties of bamboo.

Little is known of relative effect of thermal treatment on the anatomical structure of *Bambusa vulgaris*; the effect of heat treatment on the arrangement of vascular bundles cells, the cells composition, cells sizes; which are all functions of wood quality and the end use of woody materials. Most often, emphases are laid on the strength properties and physical properties with little consideration on the anatomical structures of bamboo, meanwhile, the strength of wood is embed in its microstructures, on completion of this project, the result will serve as baseline information for the anatomical characteristics of thermal-modified *Bambusa vulgaris.*

One of the most important stages in wood thermal treatments is selecting the temperature range (Pessoa *et al.*, 2006). The wood chemical changes due to heating depend on the duration and temperature of the treatment, the temperature being the main factor (Bourgois *et al*, 1989). The heat treatment method for modifying wood increases dimensional stability, durability and it is more environmentally friendly than methods that use chemical treatments (Poncsak *et al.,* 2006; Kocaefe *et al.*, 2008; Gunduz *et al.,* 2009 and Garcia *et al.,* 2012). Heat treatment results in significant changes in the properties of the wood. Different species of trees are affected differently by heat treatment so it's important to determine the optimal conditions (e.g. duration and temperature) for heat treatment to achieve the best balance of physical and mechanical (Bal and Bektas, 2012).

In recent years many studies on thermal modification of different wood species have been carried out in Europe, North America, Asia to analyse the changes in physical properties (Kamdem *et al.*, 2002, Militz, 2002; Alen *et al.*, 2002; Esteve *et al.*, 2008; Schnabel *et al.*, 2007; Borrega and Lampi, 2007; Pfriem *et al.*, 2009; 2010 and Boonstra and Tjeerdsma, 2006) Todorovic *et al*, 2012, and chemical composition (Tjeerdsma *et al*, 1998 and Windeisten *et al*, 2009) and to improve the dimensional stability and biological durability of wood (Burmester, 1975; Edvardsen and Sandland, 1999; Militz, 2002; Kamden *et al.*, 2002; Hill, 2006; Dubey *et al.*, 2011), Recent works on bamboo focus on quality control, modelling, and studying of the reasons for the wood improvement through thermal modification (Esteve and Pereira, 2009). But for *Bambusa vulgaris*, there exist few results in this field; this study will therefore investigate the effect of the heat modification on the selected wood properties of thermal-modified bamboo *Bambusa vulgaris.*

CHAPTER TWO

LITERATURE REVIEW

2.1 Bamboo as Lignocellulosic Material

Bamboo is woody, herbaceous plant belonging to the grass family, with over 700 classified species being distributed across 50 distinct genera (Hidalgo, 2003). It is a perennial plant reasonably easy to cultivate, with a long useful life and capable of promoting great soil regeneration, having accompanied mankind from the beginning of time, providing shelter, food, household utensils, charcoal, paper, fabric, irrigation, musical instruments as well as other artifacts (Wandivaldi *et al*., 2011). Bamboo is a grass that is the fastest growing plant currently known (Liese, 1987). In the United States, it is not officially recognised as a structural building material owing to the absence of any standard building code, preventing it from being accepted freely by the construction industry. It is mainly used for non-structural applications such as flooring, fencing, furniture, crafts, and ornamental (Mahdavi1 *et al*., 2011). As resource availability declines and resource demands increase in today's modern industrialised world, it is becoming increasingly necessary to explore opportunities for new, sustainable building materials (Meadows *et al*., 1992). Wood, for example, has recently gained popularity in the green building community because of its environmentally beneficial characteristics: wood is promoted as renewable, biodegradable, sequestering carbon from the atmosphere, low in embodied energy, and creating less pollution in production than steel or concrete (Falk, 2009). Bamboo has similar environmental characteristics (Van der Lugt *et al*., 2006; Lee *et al*., 1994; Rittironk and Elnieiri, 2007; Nath *et al*., 2009). Most notably, it is highly renewable; bamboo stalks reach maturity in eight years and its strength is comparable to that of wood (Mahdavi1 *et al*., 2011).

2.1.1 *Bambusa vulgaris*

Bambusa vulgaris is a group of plants that belong taxonomically to the sub-family of Bambusoideae under the family of Gramineae B. vulgaris is a species of the large genus Bambusa of the clumping bamboo tribe Bambuseae, which are found largely in tropical and subtropical areas of Asia, especially in the wet tropics. 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. *Bambusa vulgaris* forms moderately loose clumps and has no thorns. It has lemon-yellow culms (stems) with green stripes and dark green leaves. Stems are not straight, not easy to split, inflexible, thick-walled, and initially strong. The densely tufted culms grow 10–20 m (30–70 ft) high and 4–10 cm (2–4 in) thick. Culms are basally straight or flexuose (bent alternately in different directions), drooping at the tips. Culm walls are slightly thick. Nodes are slightly inflated. Internodes are 20–45 cm (7.9–17.7 in). Several branches develop from mid-culm nodes and above. Culm leaves are deciduous with dense pubescence. Leaf blades are narrowly lanceolate, (Ohrnberger, 1999).

2.1.2 Macroscopic Characteristic of Bamboo

The bamboo culm is the upper ground part of bamboo that contains most of the woody material. The culm is straight, hollow and cylinder-formed with nodes and internodes which are the parts between nodes. In the internodes, the cells are strongly oriented axially. No radial cell elements exist and therefore, the transversal interconnection is provided only by the nodes with their solid cross wall, called diaphragm. The variation between internode and node is not desirable characteristics which have an effect on the penetration of liquid adhesive used for bonding the bamboo elements together; the diameter of bamboo culm is smaller than those of wood species.

The smallest bamboo species, *Raddiella vanessiae*, can grow as little as 2 cm in height while the largest known *D. giganteus* grows up to 60m in height and 20cm in culm diameter (Ramanatha-Rao and Williams, 1998). Additionally, the culm diameter extremely varies along the culm length. The culms taper towards the top with a gradual decrease in diameter. Then, the bamboo processing might be applied with the high efficient method and equipment of woodworking industry. On both sides of bamboo culm wall are covered by a special tissue. The outermost skin of the bamboo culm consists of epidermal cells that are covered with a waxy layer poor affinity of water and adhesives. The innermost skin or pith is the part of culm wall next to culm cavity. It is composed of sclerenchyma cells. Such this characteristic leads to negative influences on adhesion (Chaowana, 2013).

Plate 1: ***Bambusa vulgaris*** **culms**

Bamboo is a group of perennial evergreens in the true grass family Poaceae and includes the largest members of the grass family. There are more than 70 genera of bamboo divided into about 1,450 species, of which only around 50 species are routinely cultivated (Hunter, 2003). Native bamboo grows in many parts of the world, including East Asia, Sub-Saharan Africa and the Americas. Bamboo is not limited to tropical climates, with some species able to withstand frost and survive in Northern Europe. Bamboo is an extremely fast growing plant, with some species obtaining growth surges of 100cm per 24 hour period. Most bamboo species grow to their full height within a single growing season. Over the following seasons the walls of each culm (or stem) dry and harden, reaching maturity within 3 to 5 years. After a maximum life, which varies by species and climate, the individual bamboo culm will collapse and decay, although the plant itself may survive. Furthermore bamboo tolerates poor soils, which makes it useful for planting on degraded land (Hunter, 2003). Another peculiarity of bamboo is that most species flower very infrequently, with intervals as long as 60 to 120 years. These species exhibit what is called 'mass flowering' where all plants in the population flower at the same time (Hunter, 2003). This phenomenon has restricted the commercialisation of many species, as flowering causes the bamboo plant to die. In vegetatively propagated plants, it is almost impossible to predict the flowering pattern. However, if a flowering event occurs and seedlings are utilised, flowering is not expected for another 60-120 years depending upon the species. Bamboo shoots and culms grow from the dense root rhizome system. There are two main categories of rhizomes: monopodial and sympodial. Monopodial rhizomes grow horizontally, often at a surprising rate, thus their nickname of 'runners' or 'running bamboo'.

The rhizome buds develop either upward, generating a culm, or horizontally, with a new tract of the rhizomal net. Monopodial bamboos generate an open clump with culms distant from each other and can be invasive. They are usually found in temperate regions and include the genera Phyllostachys and Pleioblastus. Sympodial rhizomes are short and thick, and the culms above ground are close together in a compact clump, which expands evenly around its circumference. These are known as 'clumping' bamboo and the development of culms around the core of the plant is predictable. Their natural habitat is tropical regions and they are not invasive. The clump size is self limiting and will not continue to increase past a certain size, dependent on species and growing conditions.

The plants can therefore be easily controlled. Sympodial bamboos include the genera Bambusa and G. angustifolia (FAO, 2005).

Sustainable use of existing bamboo stands, education, and the creation of national bamboo policy are the surest way to combat the growing trend of deforestation and social inequality. Thus, there should be regular inventory of natural bamboo stands for the resource to be managed on sustainable basis. Efforts should also be geared towards the protection and conservation of rich biodiversity associated with bamboo forests and bamboo growth areas, sustainable development, and utilization of bamboo resources through scientific management, promotion of local traditional bamboo craft, and art with value-addition for local and export market, promotion of awareness, and understanding of bamboo with a view of utilizing its full potential to galvanize the rural and national economy. Bamboo is a sustainable natural resource in many countries of the world. It prefers lowland humid habitats, but tolerates a wide range of climatic conditions and soil types (United Nations, 1972). A culm can reach its full maturity in a matter of two to three months which make it one of the fastest growing highest yielding renewable natural resources (Lessard and Chouinard, 1980; United Nations, 1972). Bamboo is used for construction of houses, huts, boats, fences, props and furniture; as raw material for paper pulp; planted as ornamental or boundary marker; used to support banana plants; split stems used for brooms, baskets (Ohrnberger, 1999). In rural Tanzania, a bamboo pipe network is being used for providing safe and constant water supply to a large rural population (Lipangile, 1991) "Due to new developments in the industrial bamboo sector, virtually any wood product can be produced from bamboo. Therefore the market for wood products can be considered as an analogous substitute market" (Inga and Camille, 2010).

As focus is drawn toward more sustainable construction practices, use of bamboo as a structural building material is growing as a topic of interest. It is highly renewable, has low-embodied energy, and has the highest strength-to-weight ratio of steel, concrete, and timber. Composite lumber made from bamboo, termed laminated bamboo lumber (LBL), has gained the particular interest of researchers and practitioners of late, since it has bamboo's mechanical properties but can be manufactured in well-defined dimensions, similar to commercially available wood products (Mahdavi1 *et al.*, 2011). Compared with wood, bamboo has many advantages; greater strength, more tenacity, strong rigidity, treatability, and has better physical-mechanical performance, bamboo's static bending, rigidity and strength of extension can be up to twice that of other hardwood flooring (Olajide *et al*., 2013b).

Bamboo is seismically resisting material and for sustainable environment development without harming our global environment since it absorbs a lot of nitrogen and carbon dioxide from the atmosphere during its growth (Nathaniel. *et al.,* 2011). Its utilization is not restricted to any geographical area or culture; hence bamboo has over the years been subjected to different degree of local and scientific exploitations and quarry, both in urban and rural communities. Alenso *et al*, (2001) estimated that about 4.5 billion people (40% of world population) still use bamboo as their primary source of roofing sheet. Bamboo has been used for handicrafts and building material in India, China, America, and Costa Rica for thousands of years, yet its potential contribution to sustainable natural resource management has only recently been recognised. Unfortunately, most bamboo is harvested from forest stands at a rate which exceeds natural growth, so current utilization is anything but sustainable (IFAR/INBAR, 1991; Tewari, 1992). Bamboo, regarded as 'The Green Gold' of the 21st century and commonly known as 'poor man's timber', played a significant role in human society since time immemorial and today contributes to the subsistence needs of over a billion people worldwide (Salam, 2008); and plays a vital role in the socio-economics of the rural population (Prasad, 1990)

RMRDC, (2004) reported that bamboo is widely distributed in the south and middle belt regions of Nigeria. According to the report, distribution of bamboo is related to ecological conditions with the rainforest areas having the most abundant. Bamboo is found in abundance in all the States of Southern Nigeria except Lagos and Bayelsa where the distribution is considered relatively less. The most endowed states in terms of bamboo occurrence are observed to be Ogun, Oyo, Osun, Ondo, Edo, Delta, Rivers, Akwa Ibom, Cross River, Abia, Ebonyi, Enugu, Anambra and Imo States. The report indicated that at least 10% of the natural vegetation in these states is dominated by bamboo, with existing bamboo clumps showing appreciable gregarious growth that is contiguous over large areas. In Lagos, Ekiti, Bayelsa, Kogi, Kwara, Benue and Nasarawa States bamboo distribution was observed to be frequent, indicating that between 6.0 to 9.0% of the natural vegetation is occupied by bamboo. Pockets of bamboo clumps were also reported in Niger, Taraba and Plateau States as well as within the Federal Capital Territory. There are 12 states where bamboo occurrence is rare; these are Adamawa, Bauchi, Borno, Gombe, Kano, Kaduna, Katsina, Kebbi, Sokoto, Jigawa, Yobe and Zamfara (Ogunwusi, 2011).

The average diameter of bamboo culms in Nigeria varied from 3.2-9.1cm while the largest sized bamboo was observed to occur in the South-South and the smallest in the North- East (RMRDC, 2004). The report indicated that the relative diameter of bamboo that exists in Nigeria is lower than some of those reported in literature. For instance, Naixum (2001) reported the average diameter of *Dendrocalamus sinicus* growing in India as 30cm. The average diameters of *D. giganteus* and *Phyllostachys heterocycla* were also reported as 30cm and 10- 20cm respectively. The diameter of the Nigerian species is however, larger than what was reported for *Shibataea chinesis* (0.2-0.3cm), *Brachystachyum densiflorum* (1-3cm), respectively. As some of the small diameter bamboo resources such as those observed in Nigeria are currently being used at industrial levels, the bamboo resources of Nigeria can adequately be used as industrial raw materials (RMRDC, 2004).

2.1.3 Uses of Bamboo

From time immemorial, man has used bamboo for construction purposes (poles, rafters, and trusses), fence, scaffolding, woven products (mats, baskets), agricultural implements, ladders, props, etc. As bamboo was cheaper than expensive construction materials like timber, steel, etc., it was referred to as 'poor man's timber'. Now, efforts are being made to bring out a bamboo building code so as to promote bamboo as an engineering material. Bamboo, in general, is not durable. It should be treated with either preservative chemicals or thermal treatment, especially when it is to be used as an engineering material in structures (Gnanaharan, 2000). Bamboo can be used in a variety of ways ranging from little processed culm based products to newly developed industrial products as a substitute for traditional hardwoods.

Another dimension to the rapidly growing bamboo market is the wide range of uses from low-cost products such as cheap housing (such as the growing use of bamboo based disaster relief housing) to high-end products such as parquet flooring and decking. Bamboo has received increasing attention over the last two decades for its economic and environmental values. In Africa, Asia and Latin America it is closely associated with indigenous culture and knowledge and is widely used for housing, forestry, agroforestry, agricultural activities and utensils. In countries undergoing economic development, traditional bamboo culture gradually disappears. However, industrial development of bamboo is offering a new opportunity to younger generations to retain and continue developing cultural traditions related to the cultivation, harvesting and use of bamboo (FAO, 2005).

Bamboo use and trade have been growing rapidly in recent years. It is important to exploit the versatility of bamboo in middling and top grade building construction, architecture decorating, and other major applications. Its high valued utilization not only promotes the economic development in bamboo areas where people are in low-income, but also saves forest resources to protect our ecological environment as a wood substitute (Olajide *et al.*, 2013b). Adewole and Bello, (2013) opined that, an interest is growing daily on the utilization of bamboo as a reliable supplement to wood in furniture production to mitigate the scarcity of wood raw material supply to an extent that bamboo recovered from its use as scaffold material is been put into use as intermediate raw material for the production of indoor furniture.

2.1.4 World Bamboo Resources

The total bamboo area in the world is approximately 36 million hectares or an average of 3.2% of the total forest area. It is naturally distributed in the tropical and subtropical zone at latitudes from approximately 46° North to 47° South latitude, and from sea level to as much as 3,000metres in elevation where has a warm climate, abundant moisture, and productive soil. In nature, bamboo is mostly distributed in the tropics, subtropical and temperate zones of all continents except Europe and North America. In recent years, bamboo is introduced into North America, Europe and Australia (Lobovikov *et al*., 2007; Zhang *et al*., 2002; Jiang, 2007).

2.1.5 Bamboo in Africa

Africa has the smallest bamboo area covering an area of 2.7 million hectares or 7% of the total bamboo area in the world. There are totally about 40 species within 13 genera which are mostly distributed in tropical rainforest and evergreen broadleaved mixed forest. The main species are *Arundinaria alpine*, *B. vulgaris* and *Oxytenanthera abyssinica*. In Africa, approximately 66 percent of bamboo area is classified as private system. Compared with Asia, the level of bamboo utilization and development in Latin America and Africa are far lower. It can be represented by the consistence rate of bamboo area during 1990 to 2005 (Lobovikov *et al*., 2007). It seems to be that bamboo could be a non-wood alternative material for the tropical and subtropical regions. There are 2.5 billion people in Asia, over 40% of the world's population, use bamboo for fibre and food in everyday life Moreover, it has becomes the substitute materials in place of wood for the wood composite industries (Chaowana, 2013)**.**

2.2 Glulam products

Laminated wood products are becoming popular in various applications such as construction, furniture units and indoor decorations due to the utilization of raw materials with alternative approach. Compared with sawn lumber, laminated lumber can be used to create wood products that are free from defects and are much larger in size than pieces of wood sawn. They are also advantageous in that they are dimensionally more stable, have a variable cross-section and are more attractive than wood products manufactured from solid wood (Dilik, 1997; Kurtoglu, 1978) heat treatment affected the bonding strength properties of laminated bamboo positively (Ordu, *et al*., 2013).

2.2.1 The Gluability Properties of Bamboo Culm

In wood composite manufacture, adhesive is required to bond wood element together. The adhesive is not only a significant cost factor in wood composite production but also it is the key factor for some of the product properties. The gluability of bamboo is influenced by its surface properties, such as wettability, pH value, buffering capacity etc. Ahmad and Kamke, (2003); Chaowana, *et al*, (2013) reported that the average contact angle of *D. strictus*, *Gigantochloa scortechinii* and *D. asper* is 52, 14 and 35°, respectively (Chaowana, 2013).

2.3 Natural durability

Bamboo, in general, is not durable, unlike durable timbers; it does not possess toxic extractives to impart natural durability. It is highly prone to attack by biological organism; Results from the graveyard test conducted by the Forest Research Institute, Dehradun have shown that the average life of untreated bamboos is less than two years (Kumar and Dobriyal, 1992). Among different species, there is little variation in durability, even though some species have shown to be more resistant than others. Round bamboo is more resistant than split bamboo. Outer part of the culm is more resistant than the inner part.

2.4 Treatments to enhance durability in service

The search for effective bio-control methods for wood preservation is continuing, generally the attack by biological organisms is severer in tropical regions than in temperate regions. For structural uses, whether indoor or outdoor, whether in tropical or temperate region, bamboo should be treated with preservative chemicals to provide adequate service life. For outdoor applications, bamboo should be treated with fixed-type preservative chemicals which are resistant to leaching. Generally, the treatment of bamboo is divided into two categories, viz; (a) treatment of green bamboos and (b) treatment of dry bamboos. In addition to the established methods of treatment for wood, some traditional methods are also in use for the treatment of bamboos (Satish *et al*., 1994). In India, insect pests of standing bamboo were never considered important and not much work has been done, bamboo stem beetles (Roonwal, 1977), weevil borers (Chatterjee and Sebastian, 1964, 1966) and sap suckers have been occasionally observed (Beeson, 1941).

The most serious borers of felled bamboos are three species of Dinoderus (celluris, minutes, and brevis) and Lyctus, which attack bamboo rich with starch (Casin and Mosteiro, 1970; Sandhu, 1975). They cause immense damage during drying, storage, and subsequent use. Carpenter bees and termites also attack bamboo (Beeson, 1938; Sensarma and Mathur, 1957) Bamboos are attacked by marine organisms as well (Anon, 1945) for practical purposes, it is recommended that bamboo needed to be oil-cured at temperature of 180^0C and above for effective protection against fungi and insects attack. Apart from increasing the durability of bamboo, the oil curing process can also be applicable in rapid drying and improving the colour of matured bamboo prior to utilization. Oil-curing process can be used as an alternative in treating bamboo and other woody materials in prolonging their service life span to human usage (Razak *et al*., 2004).

2.5 Wood thermal modification

2.5.1 The heat treatment process

A popular ThermoWood heat treatment method was developed by VTT in Finland (Viitaniemi *et al.,* 1996). The process can be performed on green as well as pre-dried wood. The treatment is performed in an environment with superheated steam at atmospheric pressure in order to create an inert atmosphere, since presence of oxygen will lead to an oxidative degradation. How this displacement of oxygen is solved is the major difference between ThermoWood and other treatment methods found today (Dennis, 2008).

Plato Process: The Plato process (Ruyter, 1989; Tjeerdsma and Groeneveld, 1998) is a two-step process. The first step is performed on wood saturated with water in a hydrothermal treatment at 160°C–190°C at super atmospheric pressure. The second step is a curing step performed at 170°C–190°C at atmospheric pressure without air present, but before this step the wood has to be dried to about 10% MC.

Retification: The Retification process is performed at 210°C–240°C in a nitrogen atmosphere containing no more than 2% oxygen and is done on pre-dried (12% MC) wood (Vernois, 2000).

Les Bois Perdure: The Les Bois Perdure process starts with a drying step for green wood. After initial drying, the wood is heated in a steam environment generated by the water in the wood (Vernois, 2000).

Oil heat treatment: In this method, the treatment is performed in a hot oil bath. Typical treatment temperature is 180°C–220°C (Rapp and Sailer, 2001). Tests are being performed on how this process can be further improved by using oil with chemically active groups added and thereby performing a combination of both chemical modification and heat treatment (Tjeerdsma *et al.*, 2005).

2.5.2 Kiln Drying and Air Drying of Bamboo

Kiln drying of round bamboos is not feasible. Even under mild drying conditions, higher temperatures enhance the incidence of cracking and collapse (Rehman and Ishaq, 1947). Split bamboos can, however, be kiln dried. Air drying takes 6-12 weeks, depending on the initial moisture content and wall thickness. Collapse may be a major problem in some species, owing to excessive and non-uniform shrinkage of the culm. However, problems are mostly seen in drying of immature culms. It is recommended that only mature culms are used (Sharma, 1988). Split bamboos do not pose any problems in air drying and can be dried even in the open sun. Split bamboos standing upright dry faster than horizontal stacking. Round bamboos can also be dried standing upright or in stacks, using bamboo crossers of appropriate diameter (Satish *et al.*, 1994).

2.6 Environmental aspects of treating Bamboos with Preservatives

Formulations containing arsenic and chromium have been rigorously tested for leaching in laboratory and under service conditions, and meet current safety standards. Copper Chromium Arsenic (CCA) treated material is considered absolutely safe and has been recommended for the treatment of playground equipment. Such formulations make complexes with wood substances and are rendered immobile to cause any toxicity concern. Pollution hazards do exist at formulation as well as impregnation sites. It is suggested that ready-to-use premixed formulations be used to eliminate such hazards and necessary safety precautions as suggested by the manufacturers be followed. Treatment effluents, if generated on a large scale, should be adequately treated before disposal. Pentachlorophenol is another chemical being viewed cautiously.

The present technology of manufacture of this compound claims that no dioxins are produced in the process. Nevertheless, disposal of all treated wood products and residues have to meet the toxicity characteristic leaching procedure limits (TCLP) proposed by the Environmental Protection Agency (EPA) of the USA. Guidelines for tropical timber are recorded in Willeitner and Liese (1992) and it provided useful pointers for institutes engaged in developing such programs. Boric-acid: borax, Cu/Zn naphthenates/abietates are among the safest wood preservatives being promoted the world over. Many new chemicals considered being environmentally safe such as Tebuconazole, IPBC (3-iodo 2-propanyl butyl carbamate), chloro-thalonil, isothiozolones and synthetic pyrethroides are under various stages of adoption as wood preservatives. Apart from being expensive, such chemicals need to be tested for their efficacy on bamboos (Satish *et al*., 1994).

Another bothering issue is the disposal of preservative treated bamboo after prolonged service causes problems in several countries. In some, it is not considered a hazardous waste, but in others it has to be brought to special dumping places. Proper safety garments such as gloves, aprons, and eye protective glasses should be used while handling preservative solutions or freshly treated material. Any spillage of chemicals should be immediately attended to by soaking in wood dust and disposed appropriately. Freshly treated material should be stored under cover during drying to avoid rain leaching of chemicals.

2.7 Relationship among the Physical, Anatomical and Mechanical Properties of Bamboo

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). Many studies had been carried out in order to highlight and observe these fundamental characteristics, as well as to maximise bamboo utilisation (Abd.Latif *et al*., 1993, Lee *et al*., 1994, 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. He also explained further the effect of the thick wall fibre and higher concentration of vascular bundle of the older bamboo, 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% to 9.5% and 6.4% to 20.1% respectively. The older bamboo (3-year-old) is more dimensionally stabled compared to the young ones (1-year-old), the 1-year-old.

Tewari, (1992) explained that bamboo start to shrink both in the wall thickness and diameter as soon as it starts to lose moisture. This behaviour is unlike wood, where most of the properties will start to change when it reaches the fibre saturation point. Lee *et al*, (1994) claimed that the average specific gravity of bamboo ranged from 0.3 to 0.8 (Lee *et al*., 1994). Chew *et al*, (1992) gave the density of *B.vulgaris* at 630 kg/m^3, which is relatively light compared to other bamboo samples. This behaviour is similar to mechanical properties of wood. Vascular bundle distribution is positively correlated with all the strength properties except for MOR, Abd.Latif *et al*, (1993) implied that this behaviour may be due to the increase of the number of sclerenchyma and conductive cells, and thus results in an increase in density.

Vascular bundle size (radial/tangential ratio) and fibre length are positively correlated with compression strength, bending stress at proportional limit and MOE. The decrease in tangential size of the vascular bundle (mature stage or higher radial/tangential ratio) was accompanied by an increase in strength properties. Abd.Latif *et al*, (1993) suggested that longer fibres will decrease the shear strength, which was due primarily to cell wall thickness or density rather than the percentage of the parenchyma fibres. The cell wall thickness has a positive correlation with compression strength, bending stress at proportional limit and MOE, but negatively correlated to MOR. This study found out that fibre dimensions except lumen diameter correlate strongly with mechanical properties. Fibre percentage is higher in the outer one- third of the wall and in the upper part of the culm, contributing to its superior slenderness (Grosser and Liese, 1971). Most fibres have a thick polylamellate secondary wall (Parameswaran and Liese, 1976). The typical tertiary wall present in most woody cells of gymnosperms and angiosperm is not present. Similarly, bamboos do not develop reaction wood, which is most common in tree species due to aging (Satish *et al.*, 1994). Anatomical analysis of the fibres included the investigation of the fibre's length, width and length/width ratio and specific gravity they were higher in six years old culms than in the four years old culms. Similarly in physical aspects, basic density was found to be higher in six years old culms (Maya *et al*., 2013).

The physical characteristics and properties such as the culms, height, and number of internodes, per culms internodes length, internodes diameter, culms, wall thickness girth, moisture content and basic density are considered to be important factors in determining the suitability of bamboo for various application and chemical treatment. Culms of different age groups were studied in order to determine at what age influence for the bamboo treatability (Maya *et al*., 2013). The Transverse section of a bamboo culm exhibited a characterised numerous vascular bundles embedded in the parenchymatous ground tissue (Grosser and Liese, 1971). The culm tissue consists of two cell types: parenchyma cells and vascular bundles.

The bamboo culm comprises about 50% parenchyma, 40% fibres and 10% vessels and sieve tubes (Liese, 1987). The fibres contribute 60-70% of the weight of the total culm tissue. A results of an experiment showed that the six year old culms of cultivated *Oxysthenanthera monostigama* possess overall better properties compared with the four year old. The increase in the cell wall thickness in fibres was observed to be part of the maturing process in the bamboo culms. There was a little difference in vessel diameter between 4 and 6 years old culms at the middle of the culms wall thickness, anatomical structure, in bamboo have a very strong correlation with the moisture content. The physical characteristics and properties of *Oxysthenanthera monostigama* vary depending on the age and height along the culms. The culms taper from the middle portion towards the tip with a decrease in diameter and culms wall thickness. The age, height and position in the culms wall thickness influence the presence of moisture content in *Oxysthenanthera monostigama*. The basic density was higher in the 6 years old culms than in the 4 years old, and increases from lower to upper internodes exhibiting a maturation process going on between the two age-group related to the two tissue types (Maya *et al.*, 2013).

Lee *et al*, (1994) determined the physical and mechanical properties of giant timber bamboo (Phyllostachys bambusoides) grown in South Carolina, USA. The 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. The study found out 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 in the moisture content and specific gravity between the different locations of the culm and between the different stems. Compressive, tension and bending strength 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 in regard to anisotropic shrinkage.

Based on its mechanical and physical properties, bamboo has very high potential to compete with other structural materials. Companies are beginning to emerge with the capability of producing economically viable, commercial size Laminate boards. One Chinese company, Advanced Bamboo Technologies, recently developed a commercial-size product to compete with dimensional lumber called Glubam. It has been used in China in residential applications as beams and columns, replacing other construction materials with bamboo were considered from a supply perspective. In this study, a scenario was quantitatively analyzed in which bamboo would be used as a “modern” material; a material that would replace construction materials such as brick, concrete, and wood. Using production data and the mechanical properties of bamboo, it was approximated that one hectare of bamboo was required to produce one medium-sized (175 m^2 total floor area) bamboo-frame house (Mahdavi *et al.*, 2011).

Test results show that the strength and stiffness of bamboo are comparable to those of wood, making bamboo capable of replacing wood in structural applications from a load-carrying standpoint. Also, the strength-to-weight ratio of bamboo is far better than those of structural steel, aluminium alloy, cast iron, timber, and concrete, showing that it has a very efficient load-bearing capability. Use of bamboo in structural applications has been shown to have the least environmental load and cost (excluding additional costs such as assembly/disassembly, maintenance, and material disposal) by large margin. It is reasonable to conclude that it could be economically, environmentally, and, perhaps, structurally beneficial to use bamboo as a wood alternative. Challenges must be considered and dealt with appropriately (Mahdavi1 *et al*, 2011). The physical and mechanical properties of some important bamboo species have been evaluated. The complexity is due to uneven distribution of vascular bundles, variation in moisture content, differences in the physico – mechanical properties of the node and internode parts, most especially with age. The physico – mechanical properties of bamboo material in all the three directions are also different. Nevertheless, the development of improved processing techniques including the newly developed Ecology Diversity Synergy (EDS) technique invented in Japan (UNIDO, 2009).

This variation could be 20-25 percent in thick-walled bamboos like *Dendrocalamus strictus* (Sharma and Mehra, 1970). In thin- walled bamboos, the differences in density are much less (Sekhar and Bhartari, 1960). Moisture also varies from the bottom to the top and from the innermost layers to the periphery. Green bamboo may have up to 150% moisture (oven-dry weight basis) and the variation reported is 155% for the innermost layers to 70% for the peripheral layers (Sharma and Mehra, 1970). The variation from the top (82%) to the bottom (110%) is comparatively low. Moisture content decreases with age while the increase in specific gravity is rather limited (Limaye, 1952). The fibre saturation point (FSP) of bamboo is around 20-22 percent (Jai Kishen *et al.*, 1956; Sharma, 1988), while Phyllostachys pubescens has a lower FSP ~13% (Ota, 1955). The FSP is influenced by the chemical/anatomical nature of tissues. Parenchyma cells, being more hygroscopic, result in raising FSP. Bamboo shrinks in diameter (10-16%) as well as in wall thickness (15-17%) (Rehman and Ishaq, 1947).

Bamboos possess excellent strength properties, especially tensile strength. Most properties depend upon the species and the climatic conditions under which they grow (Sekhar and Gulati, 1973). An increase in strength is reported to occur between 2.5 to 4 years. Thereafter, the strength values start falling (Sekhar *et al*., 1962; Sekhar and Bhartari, 1960; Sattar *et al*., 1990; Espiloy, 1994). To possess optimum strength, there is a 'maturity age'. Thus, only mature bamboos are harvested for structural or other uses. There is a variation in strength along the culm height as well. Compressive strength tends to increase with height (Liese, 1986; Sattar *et al.*, 1990), while the bending strength shows a decrease (Janssen, 1985; Limaye, 1952) the strength increases from the central to the outer part.

The dimensional stability of Moso Bamboo (*Phyllostachys pubescens* Mazel ex J. Houz) is dependent on "layer," referring to the location within the wall of the culm between the inner and outer radii. Similar to many wood species, the test results found specific gravity based on ASTM D2395 (values between 0.553 and 1.006) and tangential shrinkage from green to oven-dry (values between 4.9 and 7.8%) to be greater at the outer layers, increasing with longitudinal position or height. Conversely, they observed a decrease in longitudinal shrinkage (values from 0.30 to 0.09%) with movement from inner to outer layers. It was determined that the effects that height and layer had on all properties (specific gravity, tangential shrinkage, and longitudinal shrinkage) were statistically significant and independent of one another. Bamboo is a lignocellulosic material whose dimensional stability is dependent on its state and the prevalent surrounding environmental conditions.

Extreme variations in the surrounding conditions e.g. temperature, relative humidity (RH), moisture, among others, will always affect unprotected/untreated bamboo material in service, particularly where these variations are detrimental to certain applications. As a lignocellulosic material, it is expected that bamboo will absorb and or release moisture to the surrounding environment at the required temperature and RH, as also influenced by the species' equilibrium moisture content (EMC) and or fibre saturation point (FSP). Fluctuations in moisture absorption/desorption and volumetric/directional shrinkages in lignocellulosic material, particularly those in service, where these are disadvantageous, should be prevented or controlled to avoid situations where failure may occur as a result of these (Erakhrumen and Ogunsanwo, 2009). Lee *et al*, (1994) reported results for specific gravity and orthogonal shrinkage of giant timber bamboo (*Phyllostachys* *bambusoides* Siebold & Zucc.). Specific gravity for this species was, on average, 0.52 (irrespective of layer or height).

Radial shrinkage results were the most extreme (values between 7.1 and 27.7%), with the maximum radial shrinkage being twice as great as that of the tangential direction (values between 3.9 and 18.7%). Longitudinal shrinkage was negligible (values between 0.00 and 0.06%) (Mahdavi1*et al*., 2011). Mechanical Properties Test results provided by Yu *et al*, (2008) indicated that longitudinal Elastic modulus and tensile strength of Moso bamboo have clear dependency on radial position. It was found that elastic modulus and tensile strength at the outer layer (average, over height, of 26.9 GPa and 295.6 MPa, respectively) were almost triple those of the inner layer (average, over height, of 9.7 GPa and 113.4 MPa, respectively). Tensile modulus of elasticity had a mean increase across all layers of 12.8% as height increased from 1.3 to 4 m. The same mean change for tensile strength was only 1.25%, suggesting that tensile strength is not dependent on height.

The study by Lee *et al*, (1994) investigated the influences of moisture content, height, and the presence of nodes on mean strength and stiffness properties on giant timber bamboo. Contrary to Yu *et al*, (2008), it was found that strength properties increased with height—the dissimilarity likely being a result of the use of different bamboo species consistent with structural wood species (Mahdavi1et *et al*., 2011). Bamboo possesses excellent strength properties, especially, tensile strength. Most of the properties depend on species and on the climate condition where they grow (Sekhar and Gulati 1973). Strength varies along the along culm height. Compressive strength increases with height, while bending strength has inverse trend (Liese 1986; Kabir *et al*, 1993). An increase in strength is reported to occur at 3-4 years and thereafter decreases (Espiloy, 1994). Thus, the maturity period of bamboo may be considered at 3-4 years with respect to density and strength. Maturity of culm is a prerequisite for the optimum utilisation of bamboo in construction and other structural uses. Janssen (1991) reported that the ratio between the ultimate compression and the mass per unit volume for dry bamboo is higher than that of dry wood. The reason is attributed to the higher cellulose content of about 55% in bamboo compared with about 50% in wood (Sattar, 1990).

2. 8 Mechanical Properties of thermal modified Bambusa vulgaris

Mechanical properties of wood play an important role when used for different design applications. Wood is widely used for structural purposes.

2.8.1 Compression

Compression of wood and wood-based materials plays an important role in almost any construction projects. If the compression strength or bending strength of a 5.08-cm by 10.16-inch beam is not known, deflection due to bearing a load may cause significant deformation, which could even lead to its failure during service life. Substantial loads, Compression or shear strength of a wood beam or truss used extensively for construction can be calculated based on the following equation:

Sigma (σ) = P/A, where σ is stress, P is load and A is surface area.

In general, stress is the load per unit area and is expressed in pound per square inch (psi), kilogram per square centimeter (kg/cm^2) or any other units (CES, 2013)

2.8.2 Modulus of elasticity and Modulus of rupture (MOE and MOR)

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) are essential in order to evaluate load resistance. While MOE is a measure of the stiffness of a body, MOR is related to maximum strength that can be resisted by a member. Both are expressed as stress similar to most of the other mechanical properties of wood.

2.9 The Chemical Composition of Bamboo Culm

The chemical composition of bamboo determines its properties and influences its utilization. The main chemical constitute of bamboo are cellulose, hemicellulose and lignin, which amount to over 90% of the total mass. The minor constituents of bamboo amount to 10%, which are composed of resins, tannins, waxes and inorganic salts, (Chaowana, 2013).

Pectin is a heterosaccharide derived from the cell wall of plants. Pectins vary in their chain lengths, complexity and the order of each of the monosaccharide units. Under acidic conditions, pectin forms a gel, and it can be used as an edible thickening agent in processed foods, like jam **(**Wolfram**,** 2006) Cellulose is the principal component of the cell walls of trees. It also makes up the cell walls of other plants, including all the higher plants, most algae, and some fungi (CES, 2013)

2.9.1 Cellulose

Cellulose $(C_{6H10O5})_n$ is a long-chain, linear polymeric polysaccharide carbohydrate, of beta-glucose (a long chain of linked sugar molecules), and with lengths of 1 000 to 14 000 units. It is extremely resistant to tensile stress because of the covalent bonding between the individual units. Hemicellulose can be any of several heteropolymers (matrix polysaccharides), present in almost all cell walls along with cellulose. Hemicellulose is similar to cellulose but is less complex. The molecular weights are usually lower than that of cellulose. About 40%–50% of the wood material consists of linear polymer chains of Dglucopyranose, such as cellulose. One cellulose chain consists of 7000–15,000 monomeric units that are linked together by glycosidic bonds (oxygen bridges) (Dennis, 2008)

A bundle of cellulose chains held together by hydrogen bonding between their OHgroups is called a microfibril. The lack of side branches and the positions of the hydroxyl groups enable formation of strong crystalline regions within the microfibrils. These crystalline regions are believed to be associated with the core of the microfibril, while the outer parts contain the more hydrophilic amorphous parts (Chanzy, 1990).

2.9.2 Hemicellulose

Hemicellulose is a polysaccharide where the monomeric units are kept together by glycosidic bonds, but in contrast to cellulose, it is built up of highly branched chains of several different sugar units. Each chain contains approximately 100–400 monomeric units. The main chain of hemicellulose consists most commonly of either glucose and mannose (glucomannans) or xylose (xylans). The presence of a high number of side branches contributes to the highly amorphous structure of hemicellulose. This means that its hydroxyl groups are easily accessible. This is the reason most of the moisture in wood is bonded to the hemicellulose. Hard woods contain more pentosans and have a higher level of acetylation than softwood (Dennis, 2008).

2.9.3 Lignin

Lignin is a chemical compound that is an integral part of the cell walls of plants. It fills the spaces in the cell wall between cellulose, hemicellulose and pectin components and confers mechanical strength to the cell wall and therefore the entire plant. It is the second most abundant organic compound on earth after cellulose. Lignin is a large macromolecule with a molecular mass in excess of 10 000 atomic mass units. It is the most hydrophobic (water-repelling) component of the cell and often considered nature's adhesive.

Lignin is the compound that gives wood its stiffness, and it consists of a highly complex and amorphous network formed through radical polymerization of three different phenols. The random coupling of the different units in lignin makes it the most complex polymer in wood. The two main bonding types found in lignin are: strong carbon-carbon and weaker ether bonds (Dennis, 2008).

2.9.4 Ash

The ash content of wood is made up of inorganic minerals, primarily calcium, potassium, and magnesium. Manganese and silica are two other common minerals. If silica is found in sufficient amounts (0.5% oven-dry1 weight), it can dull machining equipment **(**CES, 2013)

2.9.5 Extractives

Extractives are all substances that are extractable from wood without damaging the wood structure. The main groups of extractives are terpenes, fats/waxes, phenolic components, sugars and salts. These extractives' main function is to protect the living tree as well as serving as backup nutrition (Dennis, 2008).

Common characteristics that are used to identify different woods with the naked eye come from extractives in the wood. Without extractives, wood would have to be identified solely by its anatomical structure. Extractives are made up of an extremely wide range of organic compounds. These chemical compounds are not part of the wood but accumulate there. The amounts and types of extractives help to determine the wood's permeability to liquids and influence other wood properties such as density, hardness, and compressive strength. Extractives give certain woods their resistance to insect or fungi attack (CES, 2013)

2.9.6 Chemical Composition and Natural Durability of bamboo

The selection of bamboo species for various applications is not only related to physical and mechanical properties but also to the chemical composition. Tomalang *et al*, (1980) in their study found that the main constituents of bamboo culms are holocellulose (60-70%), pentosans (20-25%), hemicelluloses and lignin (each amounted to about 20-30%) and minor constituents like resins, tannins, waxes and inorganic salts. The proximate chemical compositions of bamboo are similar to those of hardwoods, except for the higher alkaline extract, ash and silica contents. The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo against mold, fungal and borers attack is strongly associated with the chemical composition (Abd.Latif *et al*., 1991). 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 sugar before and after soaking was 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 cement 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. Cellulose is less affected by the heat treatments, probably because of its crystalline nature.

According to Bourgois and Guyonnet, (1988), the treatment of pine wood at 260ºC, in an atmosphere without oxygen, did not alter cellulose significantly. Similar results were reported by Yildiz *et al*, (2006). Higher resistance of cellulose in comparison to hemicelluloses was also reported by Esteves *et al*, (2008b), who observed an increase upon heating of the glucose proportion in hydrolysates due to more selective hemicellulose degradation. Cellulose crystallinity increased due to degradation of amorphous cellulose, as reported earlier, resulting in an decreased accessibility of hydroxyl groups to water molecules (Wikberg and Maunu, 2004; Bhuiyan and Hirai, 2005; Boonstra and Tjeerdsma, 2006), which contributes to a decrease of equilibrium moisture content, in addition to the major effect caused by the degradation of hemicelluloses. Lignin of Pinus pinaster increased from 28% to 41%, 54%, and 84%, respectively for 0.5, 1, and 4 hours at 260ºC (Bourgois and Guyonnet, 1988).

2.10 Dimensional stability in relation to wood heat treatment

2.10.1 Mass loss after the thermal treatment

The average weight losses of heated treated bamboo were found to vary from 5 to 34% similar results were obtained by Razak *et al*, (2004) According to a study carried out by Wandivaldi *et al*, (2011) on the thermal treatment of bamboo between the temperature ranges from 100-300 ^{o}C, the mass loss in bamboo strips was more intensified for the treatment at 300 °C, around 50% in relation to the original mass, denoting drastic changes in the bamboo structure as a result of temperature. Effects of thermal treatment on density, velocity and dynamic modulus in treatments performed at higher temperatures, the properties of thermally treated bamboo dropped dramatically. Density decreased as a result of mass loss being more intensified than volume contraction; the dynamic modulus of elasticity Ed and VPU increased because the moisture content in the bamboo thermal-modified decreased. At 300 °C, however, a marked reduction was noted in such values, indicating the presence of major structural flaws in the thermal-modified bamboo (Wandivaldi *et al*., 2011).

2.10.2 Effect of thermal treatment on swelling and absorption

According to a study carried out by Wandivaldi *et al*, (2011) on the thermal treatment of bamboo between the temperature ranges from 100-300 ^{o}C swelling after 24 hours was found insignificant in the axial direction (0.12% to 0.18%), except for the treatment at 300 °C (1.60%), indicating once again, in this case, that an important anatomical change occurring in the bamboo. Swelling was greater in the radial direction than in the tangential direction (opposite pattern to normal wood). At 220 °C, a tendency was noted toward stabilization (2%) in both anatomical directions, at higher temperatures, samples were found to become frailer, with a tendency to twist and crack (Wandivaldi *et al*., 2011). Water absorption tests, the water absorption capacity of bamboo increases with increase in nodes this may be due to presence of powder like substance at nodes. In this test a main point observed was though the water absorption capacity of bamboo was as high as 50% by weight, there was no large amount of swelling in bamboo (Harish *et al*., 2012).

2.11 The Stereological Basis

The quantitative characterisation of microstructure involves the application of the geometrical-statistical techniques and equations that relate measurements upon two-dimensional sections to three-dimensional structural quantities. This type of quantitative analysis is called "stereology" (Underwood, 1970) or "quantitative microscopy" (DeHoff and Rhines, 1968). The statistical sampling of the microstructure involves measurements upon section images formed either by reflected or transmitted radiation. Measured quantities such as point fractions, intercept and feature counts are then related to structural quantities such as volume fraction (or volume percentage), boundary or surface area per unit volume, mean chord intercept. Mean chord spacing of micro-elements, diameters, etc. The fundamental parameters of structural composition as described by Weibel and Bolender, (1973) are the Volume density, V Surface or Boundary density, **S** Numerical density, N and the mean size. The basic stereological counting measurements that may be applied to characterizing wood microstructure are described below;

Quantitative characterisation of wood microstructure can be done using the methods of stereology. The numbers so obtained may be useful for relating properties of wood to anatomical structure. It is also conceivable that a computerized probability-based system for wood identification may be developed using the quantitative data obtained with these methods. However, it remains to be determined whether or not these quantitative parameters are sufficiently species-specific to allow development of such a system. It appears that the most likely use of quantitative stereology will be in structure-property relationships especially if Instrumental techniques are introduced to collect the basic data. Information and numerical data can be extracted by image analysis of photomicrographs (Trejo-Tapia *et al*., 2003) and simple applications allow for specific measurements such as size, shape, and area fraction. Image analysis has been used for several applications, such as tomato pericarp cell structure quantification (Devaux *et al*., 2008), identification of discoloration caused by bacterial disease (Vizh´any´o and Felf¨oldi 2000), and quantification of pigments in cell suspensions (Miyanaga *et al*., 2000; Trejo-Tapia *et al*., 2007; Gonzalez *et al*., 2010).

2.11.1 Elements of Microstructure

Stereology is the science of the geometrical relationships between a structure that exists in three dimensions and the images of that structure that are fundamentally two-dimensional (2D). These images may be obtained by a variety of means, but fall into two basic categories: images of sections through the structure and projection images viewed through it. The most intensive use of stereology has been in conjunction with microscope images, which includes light microscopes (conventional and confocal), electron microscopes and other types. The basic methods are however equally appropriate for studies at macroscopic and even larger scales (the study of the distribution of stars in the visible universe led to one of the stereological rules) (Underwood, 1970)

2.11.2 Fundamental relationships of stereology

The classical rules of Stereology are a set of relationships that connect the various measures obtained with the different probes with the structural parameters. The most fundamental (and the oldest) rule is that the volume fraction of a phase within the structure is measured by the area fraction on the image, or VV = AA. Of course, this does not imply that every image has exactly the same area fraction as the volume fraction of the entire sample

2.12 Wood Fungi and termite

Research has also been carried out to clarify the effect of the high-temperature kiln drying on wood durability, and revealed it reduces fungal and termite resistance (Kurisaki *et. al.*, 2001; Yamamoto *et al.*, 2001). An alternative method in treating timber by mean of the heat treatment process has been studied by several researchers (Leithoff, 2001; Razak *et al.*, 2004a, 2004b & 2005). The findings indicated that thermal modification is effective in enhancing the timber durability against insects and fungi biodegradation. However, the effectiveness of this process is largely depending on the system used and type of solvent that is to be used as the heating medium. Wood heat treatment is described as an environment friendly wood preservation technique against wood decay and is subject of increasing interest (Esteves and Pereira, 2009).

Wood is an organic and renewable material that is subjected to biological degradation by different organisms that recognize the natural polymers in the cell wall as a source of nutrition and then metabolize them into digestible units through the action of specific enzyme systems (Paes *et al.*, 2004). Subsequently, the biological durability of wood is one of the most important properties of this versatile material (Calonego *et al.*, 2010). Bamboo is one of the strongest structural materials available; it is therefore gaining interest worldwide as one of the most important non-timber forest Products.

However bamboo, like timber wood is susceptible to microorganisms, it is often succumbs prematurely to fungal and borer attack resulting in heavy damage to structural units, such as decay fungi and xylophaegous boring insects, strongly suggesting the need for roper use and protection to maximize its use. Several treatment methods have been developed to prolong bamboo's usefulness using preservatives (Kumar *et al.*, 1994). In tropical countries the biodeterioration is very severe. Bamboos are generally destroyed in about one to two years' time when used in the open and in contact with ground while a service life of two to five years can be expected from bamboos when used under cover and out of contact with ground (Tewari, 1992).

The strength of bamboo deteriorates rapidly with the onset of fungal decay; enormous quantities of bamboo get degraded during transportation, storage in the forest depots as well as in mill yards due to stain fungi, wood rotting fungi and insects. White rot and soft rot cause more serious damage to bamboo than the brown rot. Split bamboo is more rapidly destroyed than round bamboo (Liese, 1980). The sclerenchymatous fibres of bamboo are attacked by fungi and its strength gets reduced considerably. During heat treatment, wood is heated to temperatures above 200 °C depending on the wood species and the required wood properties. The obtained product called thermally modified, torrefied or retified wood is produced by mild pyrolysis at a temperature range between 180 to 240 °C under inert atmosphere. In general, thermal treatment changes the chemical composition of wood and reduces the availability of the cell wall polymers for fungal decay. In addition, it reduces the wood hygroscopicity, its wettability (Hakkou *et al.*, 2005a, 2005b), and improves its dimensional stability (Mouras *et al.*, 2002; González-Pe´na *et al.*, 2009). The main drawbacks of heat treated wood are the mechanical brittleness (Santos, 2000; Unsal and Ayrilmis, 2005; Yildiz *et al.*, 2006) and the required protection against termite attack is not secure (Militz, 2002; Nunes *et al.*, 2004). For these reasons the heat treated wood is not recommended for use in load-bearing constructions or using alone under the termite hazard existence.

CHAPTER THREE

METHODOLOGY

3.1 Sample site

The Bamboo samples for the research work were collected from a riparian forest located at the Forestry Research Institute of Nigeria, Jericho (FRIN), is located on longitude 3.51^0 E and 7.23^0 N.

3.2 Sample Selection and Harvesting of Bamboo

Bamboo culm of good grade with no appearance of defect, between 35-40cm in diameter and 300cm-450cm were randomly selected and cut at 12 cm above the ground. Branches and tip top of culms were removed. Measurements for some basic physical characteristics were carried out on the site where the culms were taken. The culm height, internode length, internode diameter and culms wall thicknesses along the culm were measured. A total of 20 bamboo culms were harvested in 5 stands making a total of 100 culms were harvested, culms were transported to the laboratory and allowed to air-dry at 22^oC and 65% relative humidity for 60 days.

3.3 Bamboo Test Samples Preparation

Selected culms were carefully sawn with circular and vertical breakdown sawing machine longitudinally into strips. Each strip was plained on both sides; inner and outer surface, using plaining machine, in order to obtain the bamboo sample with means culm thickness of 5±0.5mm for the tests.

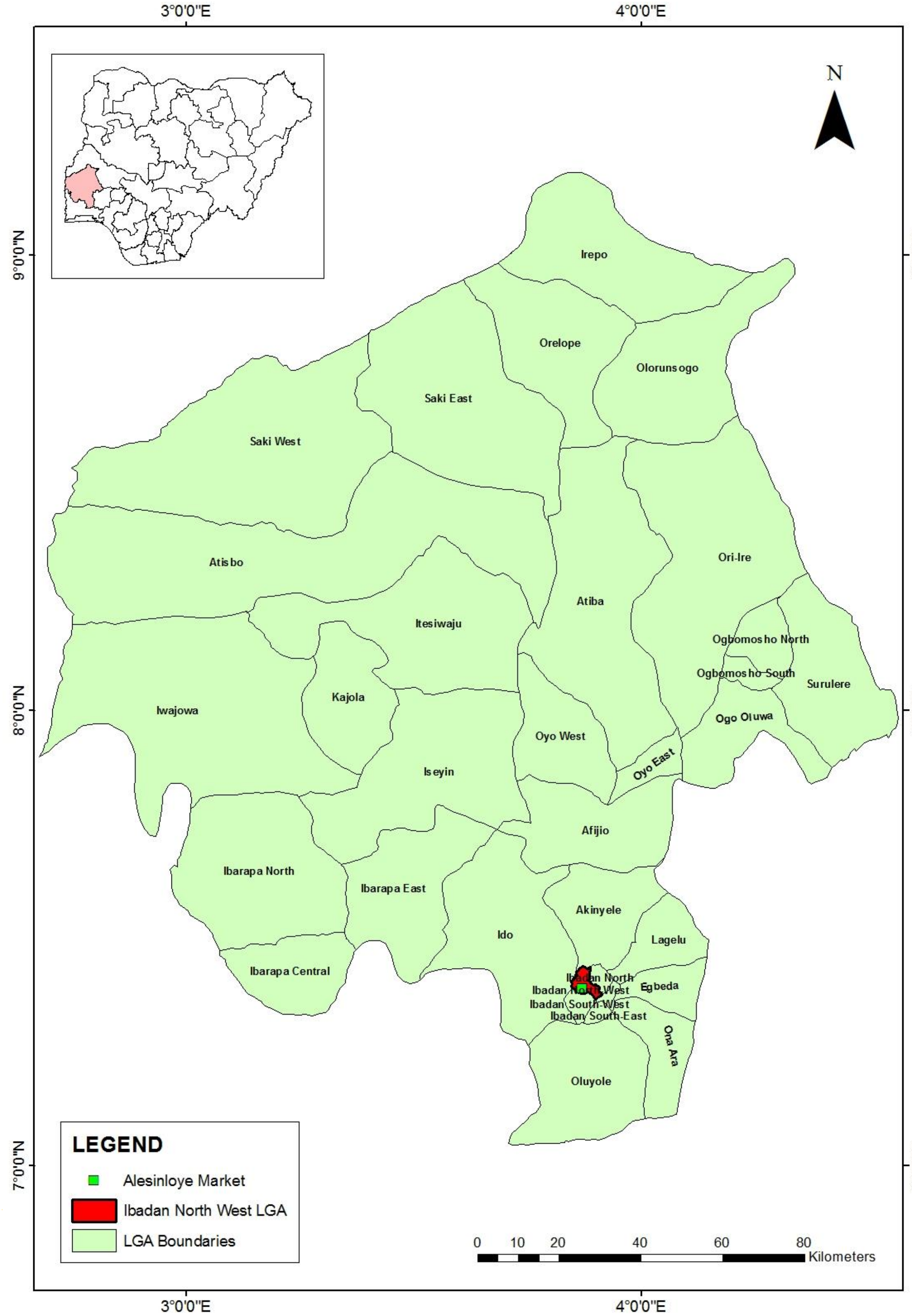


Figure 1: Map of the Bamboo site

3.4 Technological Process of Bamboo strips and Laminate

(i) One hundred bamboo culms were felled and collected from riparian river at Forestry Research Institute of Nigeria, each culm was cut into three sampling height base (10%), middle (50%) and top section (75%).

(ii) The culms in the experiment were obtained by taking out the Culms sections of 2m which were cut again into 1m to 1.5m in order to have straight pieces. Each piece was split in the axial direction into proper number of strips; the strips were dried, and were removed from wood workshop to protect it against biodegradation.

(iii) Bamboo strips with thickness of 0.5cm to 0.8cm and 2cm width dimension were bonded together with the aid of uniform application of Top bond glue on each side surface of the bamboo strip using a metal spatula; each set of bonded strip was cold pressed under hydraulic press for 24 hours. Production of the *Bambusa vulgaris* laminated board was carried out in Forestry Research Institute of Nigeria, Jericho, Ibadan (Figure 2 and 3)

3.5 Thermal Treatment of Bamboo Sample

One thousand and eighty Strips of 30cm x 2 cm x 0.5cm cm were produced. Strips were air-dried at indoor condition until moisture content value range between 20 to 25%. Thermal treatment was conducted at Biotechnology Department of National Institute of Horticulture, Ibadan inside a Vertical pressure steam sterilizer (Model LS B50L-I and JSA-100). The autoclave is equipped with a close stainless steel basket (240x190 mm in diameters and height respectively) and a microprocessor, which permitted the programming of various times and temperature (from 100 to 140 °C). The maximum capacity of the Autoclave is 50L. Strips were subjected to temperature at varying degree of Control (0^oC), 100 °C, 110 °C, 120 °C, 130^0C, 140 °C at different time interval; 10, 20 and 30minutes, and the Culm height are; base, middle and top.

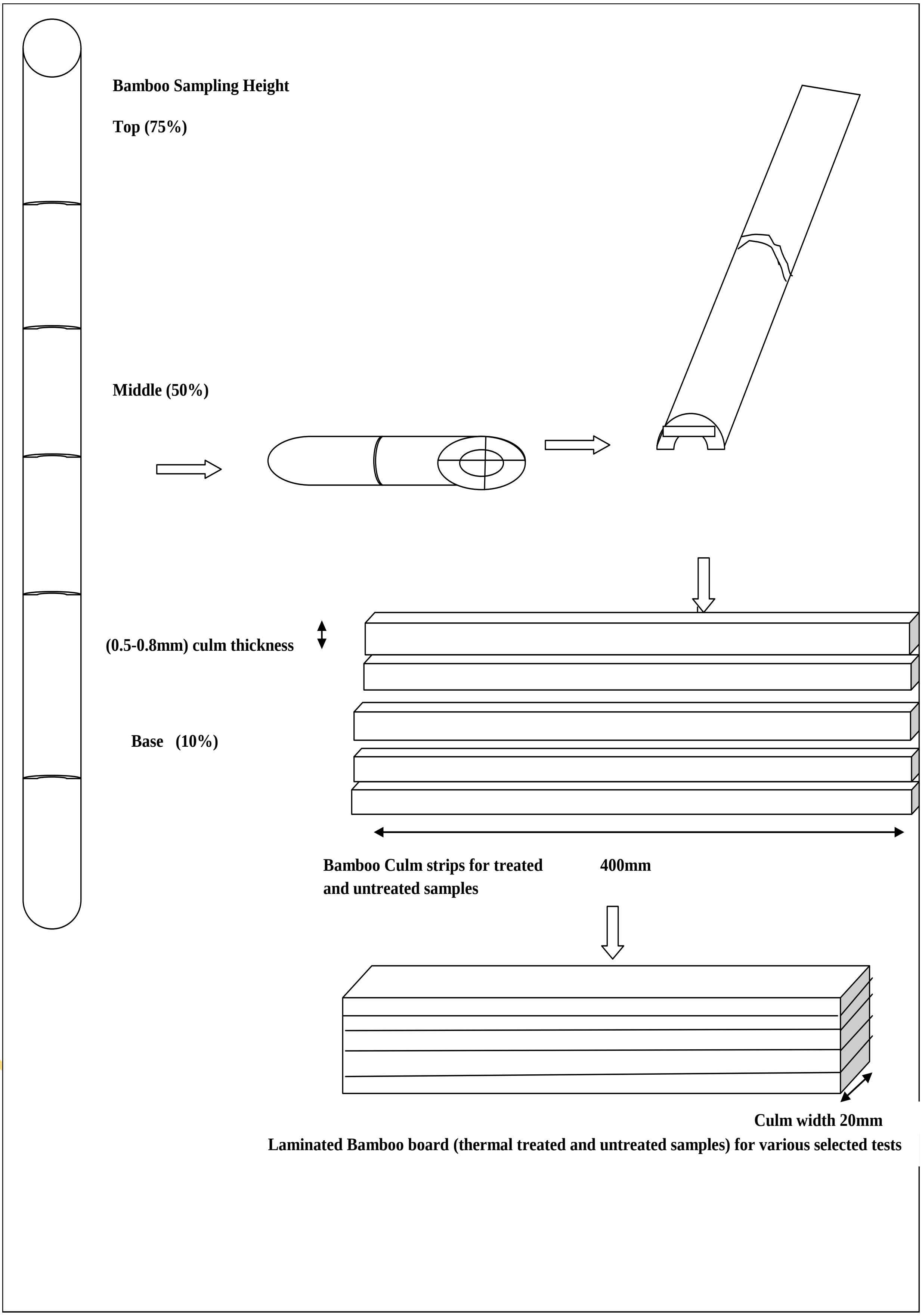
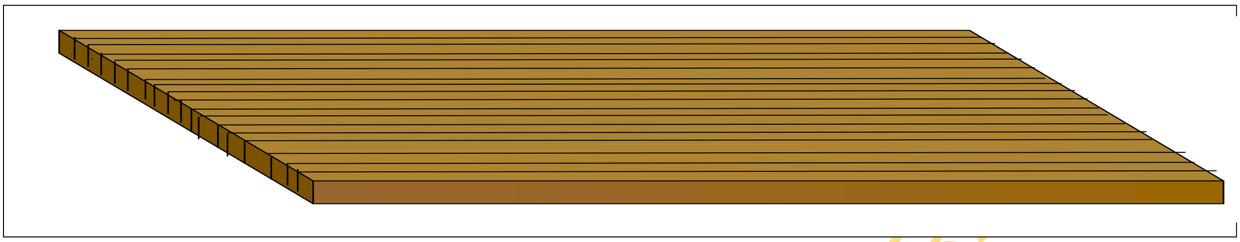


Figure 2: Schematics sampling procedure for obtaining treated and untreated Bamboo

(a) Radially glued board



(b)**Tangentially glued board**

Figure 3: Technological Process of Bamboo strips and laminated boards

Plate 2: Author performing the thermal modification process of samples

Plate 3: Thermal treated and untreated laminated bamboo boards

3.6 Bamboo Laminate Process

Heat modified and dried bamboo stems were air-dried prior to application of the adhesive chemical. The adhesive chemical (Top bond) was prepared and applied through the process of spreading method to the planned surface of the bamboo. The mats laid were left for 5 minutes in order to allow proper penetration of the adhesives before the introduction of pressure with hydraulic press machine. Fifty four (54) treatments (untreated and thermal modified) sample boards of 30x50cm dimension were produced and latter converted into different test sample sizes for all the selected mechanical properties test and grave yard tests, while non-laminated bamboo (untreated and thermal-modified) samples were employed in the physical properties test, chemical properties, anatomical test and biological accelerated test samples.

3.7 Determination of the Anatomical properties of bamboo

3.7.1 Determination of Fibre length of bamboo samples

Wood slivers were obtained from wood samples of 20 mm × 10 mm × culms wall thickness. Fibres length, fibre diameter, and fibre cell wall thickness, Fibre lumen diameter were assessed.

3.7.2 Maceration

Bamboo microscopy was performed in accordance with the ASTM D1030-95 (2007) and ASTM D1413-61. Bamboo sample from base, middle and top (Longitudinally) were prepared into slivers of 10 mm × 3 mm and macerated in equal volume of glacial acetic acid (ethanoic acid) and hydrogen peroxide (1:1) at a temperature of 100ºC. Random samples of macerated fibres were collected in the Petri's dish and examined under a microscope (Standard 25) X 140 magnification, attached to a digital camera (SVP DC-12DX). Twenty five (25) fibres were measured from each representative sample slide with 5 replicates and 54 factorial combination, resulting into total 6,750 fibre representative samples, to determine fibre characteristics namely: fibres length (mm), fibre diameter (µm), and fibre cell wall thickness (µm), Fibre lumen width (µm).

3.8 Determination of cell proportion of bamboo

3.8.1 Sectioning

Sectioning of bamboo materials were performed with a microtome sliding machine. A very sharp knife was used to cut specimens after boiling; then Softening of the bamboo samples were carried out by placing them in water inside a beaker and boiled until the samples sank under their own weight; this was also necessary to expel air in the cells before slide preparation. The bamboo samples were clamped in such a way that the sample was parallel to the direction of knife travel while the knife forms an angle of about 15^0 with the surface of the sample in the vertical plane and similar angle with line of motion. Bamboo samples were sliced in two planes namely cross sectional and radial were transferred into a dish containing methylated spirit using a soft brush. Each thin section was 20µm thick.

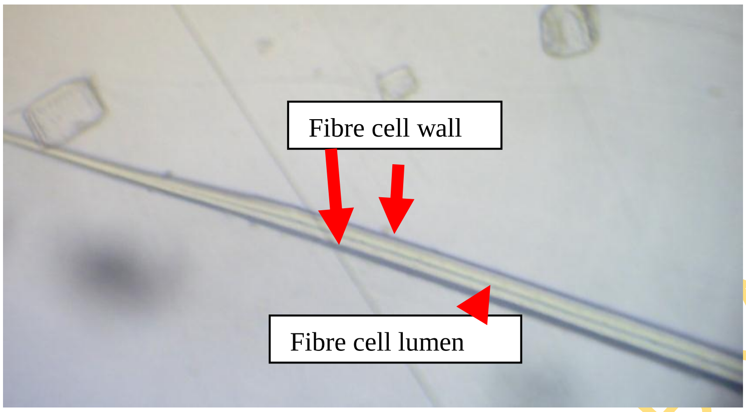


Plate 4: *Bambusa vulgaris* Fibre

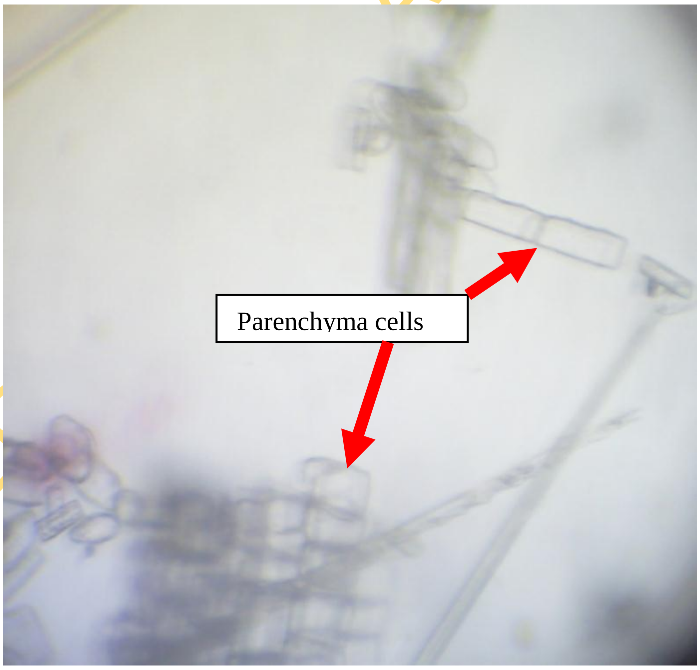


Plate 5: *Bambusa vulgaris* Axial Parenchyma

3.8.2 Mounting

Sections were washed with distilled water and covered with safranin for two minutes after which the sections were later washed with distilled water until the water became colourless. Dehydration was done by passing the bamboo sample sections through a series of bath of increasing concentrations of ethanol which replaced the water. The specimens were later covered with clove oil for 1 hour in order to drive off alcohol. The sections were placed on a clean slide, excess clove oil was drained off using filter paper; a slight amount of Canada balsam (a mounting medium and a synthetic substance) was added while the slides were covered with a cover glasses and air bubbles were removed by applying heat gently. Twenty-five complete woods cells such as; numbers of vessels/mm^2, Vessel diameter (µm), Parenchyma width (µm) and Parenchyma height were measured. The measurements were done using a flexible millimetre scale in a systematic manner to avoid duplication (Hart and Swindle, 1967; Razak *et al.*, 2007; Sulthoni, 1989; ASTM, 1974).

Further assessment of the Anatomical characteristics of thermal-modified *Bambusa vulgaris* including No. of vessels/mm^2, fibres length, fibre diameter, and fibre cell wall thickness, Vessel diameter (µm), Fibre lumen diameter (µm) Parenchyma width (µm) and Parenchyma height were carried out according to methods outlined by (Abd. Latif and Mohd Tamizi, 1992), and (Jane, 1933) Observations for anatomical structure was made using a Scanning Electron Microscope (SEM).

3.9 Stereological Analysis

Stereological counting was applied to transverse of thermal-modified and untreated *Bambusa vulgaris* for quantitative characterisation. Anatomical elements, such as the wall and lumen of vessels and fibres, were distinguished. Volume fraction, average size, and size distribution parameters were calculated according to ASTM grain size (ASTM, E122, Heyn, 1903; and Ifju, 1982).

Plate 6: Arthur performing microscopic viewing of the prepared slides

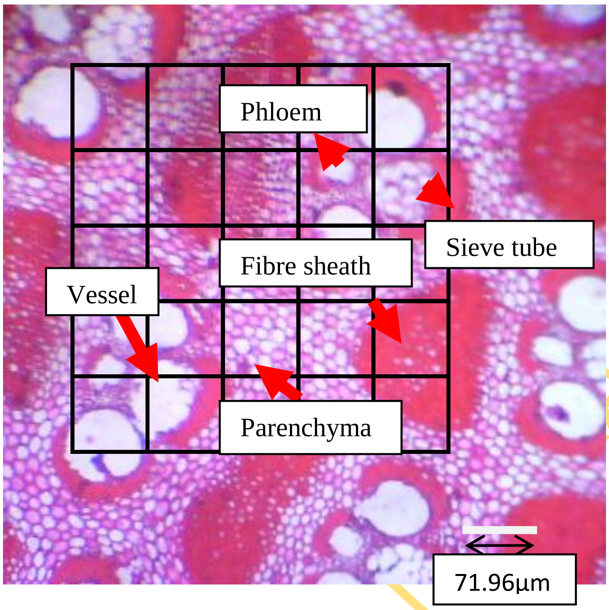


Plate 7: 25 Grid line stage Micrometer capturing bamboo Microstructures

3.9.1 Determination of Cell through Stereology Application

Fibre dimension such as fibre length, fibre diameter, fibre wall thickness and fibre lumen width, Twenty five fibres were measured per slide with five (5) replicates, with a total 54 treatment combinations; including untreated base, middle and top. Two hundred and seventy (270) test samples were used for test. The number of slides added up to 54 slides to represent all heights and treatment temperature and time variations. The slides were then displayed from the microscope through a camera onto computer screen. The 48 slides were selected systematically to represent all heights treatment temperature and time variations.

These slides were analysed using stereological techniques looking for any variations in some anatomical properties between these locations. Slides were observed under Reichert Visopan microscope X140 magnification for quantitative characterisation. This was carried out by placing twenty five 10 x 10 mm grid square, over a Visopan microscope; the actual dimension of the total grid square values is 0.36 x 0.36mm, and Sampling grids were strategically positioned across the microstructures in order to assess the anatomical variations in the microstructures. The principles of stereological counting described by (Ifju, 1983) were then applied; a calibrated stage micrometer was employed to ascertain the degree of accuracy of the grid square.

The following stereological parameters were obtained: The point count (Pp) which is the volume fraction of each cell was calculated, the number of points of intersection the horizontal test lines made for a cell per unit length of test line (PL) and the number of cell per unit test area (NA) were calculated for Parenchyma cells longitudinal and transverse, vessels and fibre sheath respectively. From the means of these three stereological fundamental parameters the structural quantities (cells perimeter) of vessel and fibre sheath were calculated. The cell Stereology structural quantities and fundamental parameter were estimated per square millimeter (mm)

Point Fraction or Point Counting (Pp) = $\bar{P}_p = \bar{V}_V = \bar{A}_A = \bar{L}_L$ --------Equation (1)

Where $\bar{P}_p$ is the average of several randomly applied point fraction

($\bar{L}_L$) = lineal fraction

$(\bar{A}_A)$ = area fraction

$(\bar{V}_V)$ = volume fraction

Intersection Counting ($\overline{P_L}$) = PL= SV/2---------------------------------Equation (2)

Where $\bar{S}_V$ = the mean boundary area per unit volume which is the area in the test volume occupied by the cell, or surface density, and is the average of the intersection counts.

Intercept Counting (N_L) = $\bar{S}_V = 2\bar{P}_L$ or $\bar{S}_V = 4\bar{N}_L$------------ Equation (3)

Therefore, $\bar{N}_L = \frac{\bar{P}_L}{2}$ --- Equation (4)

The stereological equations which relate the intersection counting (P_L), the intercept counting (N_L), to the surface area (S_V) of cells are as follows:

Since $\bar{P}_L = 2\bar{N}_L$ where $\bar{S}_V$ = the mean boundary area per unit volume which is the area in the test volume occupied by the cell, or surface density, and is the average of the intersection counts.

Feature Counting (N_A) = $N_A = (\bar{A})\ x\bar{P}_P$ ---------------------------------Equation (5)

Where N_A is the number of objects or features in a certain area of the microstructure, Determination of the quantity ($\bar{N}_A$) also all the average area ($\bar{A}$) of the cells to be calculated using the following formula:

$\bar{A} = \frac{\bar{A}_A}{\bar{N}_A} = \frac{\bar{P}_P}{\bar{N}_A}$, Thus, $\bar{A} = \frac{\bar{P}_P}{\bar{N}_A}$--- Equation(6)

Calculated Size Parameters = $\bar{L}_A = (\frac{\pi}{2})\ \bar{P}_L$ ----------------------------Equation (7)

Where $\bar{L}_A$ = is the total perimeter length per unit area of observations

$\bar{P}_L$= the average point 1ntersections per unit length of test line. In a non-space-filling system, where there are more than one type of element or cell (e.g, vessels and fibres, etc.), or when a particular element does not completely fill the whole area,

$\bar{P}_L = 2\bar{N}_L$ or $\bar{N}_L = \frac{\bar{P}_L}{2}$--Equation (8)

Thus, the average perimeter ($\bar{L}$) for circular cells can be estimated if the number of cells per unit area ($\bar{N}_A$) is determined. This equation is expressed as:

$$\bar{L} = \frac{\bar{L}_A}{\bar{N}_A} = \frac{\frac{\pi}{2}\bar{P}_L}{\bar{N}_A} = \frac{\pi}{2}\frac{\bar{P}_L}{\bar{N}_A} = \pi\,\bar{d}$$ (Underwood, 1970) ----------------------Equation (9)

Where $\bar{d}$ the average is cell diameter of a circular element and $\bar{L}$ is the average perimeter length for that cell. From equation (8) it may be seen that the mean diameter ($\bar{d}$) of anatomical elements of circular cross-sections is calculated using the simple counting of P_L and N_A.

Size Distribution Parameters

Consequently, the sample variance will:

$$\sigma^2 = M_2 - M_I^2 = d^{\bar{2}} - \bar{d}^2 = \frac{4}{\pi} - \frac{\bar{P}_P}{\bar{N}_A} - \frac{\bar{P}_L}{4\bar{N}_A}$$ ------------------------Equation (10)

3.10 Scanning Electron Microscope (SEM) imaging and sample preparation as follows:

This test was performed at Microscopy and Microanalysis Unit University of KwaZulu-Natal, South Africa. Selected experimental samples were duly prepared and analysed in order to detect any structural changes to bamboo resulting from thermal modification.

3.10.1 Resin infiltration:

1. Step 1: Thin pieces of the material were placed in 1:4 solution of resin: acetone overnight

2. Step 2: Resin solution was changed to 1:1 of acetone and resin.

3. Step 3: Resin solution was changed to 100% resin overnight

4. Step 4: Samples were placed in moulds with 100% resin and polymerized in an oven set at 70 degrees Celsius for 8 hours

3.10.2 Microtomy:

Resin blocks were cut using a Leica UC 7 ultra microtome.

Etching: The cut surface of the resin blocks were etched in a solution of potassium methoxide for 3 minutes. After etching, the etched blocks were rinsed in 100% methanol for 1 minute.

3.10.3 SEM viewing:

The etched blocks were mounted on aluminium stubs with carbon tape and gold coated in a Quorum Q150 RES sputter coater. These blocks were then viewed in a Zeiss EVO LS15 scanning electron microscope at 5KV

3.11. Determination of the physical properties of bamboo.

3.11.1 Colour of the untreated and thermal-modified *Bambusa vulgaris*.

This was physically observed both immediately and after thermal treatment at different temperature regime and treatment time, they were matched with standard colour chart and recorded.

3.11.2 Determination of moisture content of bamboo samples

Bamboo specimens of 20mmx20mmx5mm wall thickness were weighed and the weight was recorded as initial weight W_m . The test specimens were oven dried at $103^0C \pm 2^0C$ using UNISCOPE SM 9053 force air laboratory oven until a constant weight was achieved.

The formula is as shown below

$$MC = \frac{Wm - Wo}{Wo} X\ 100$$ ---Equation (11)

Where: Mc = Moisture content

Wm= Weight of specimens before oven-dry (g) and W_o= Weight of specimens after Oven-dry.

3.11.3 Determination of specific gravity

The specimen for specific gravity (SG) was carried out by obtaining a dimension of 20 X 20 X culm thickness (mm) from each treatment bamboo sample of both thermal-modified and untreated. They were subjected to a gravimetric procedure developed by Smith, (1954) with a little modification to adopt bamboo due to its nature, in which specimens were completely saturated by soaking in the water. Each treatment was removed from the water, blotted to remove excess water, weighed and oven dried to a constant weight at 103 °C. Specific gravity was determined using the formula:

$$SG = \frac{\frac{1}{Wo-Ws}}{Wo} + \frac{1}{1.53}$$ ---Equation (12)

Where

SG = specific gravity

W_s = saturated weight of wood

W_o = oven-dry weight of wood

1.53 = constant developed by Stamm (1929) as the actual weight of wood substance

3.11.4 Equilibrium Moisture Content (EMC)

For the estimation of the equilibrium moisture content, the mass of the oven dried sample (30mm x 15mm x and thickness) and the mass of the same sample at 20^{o}c and 65% were measured (5 measurements per variant). The treated wood samples were conditioned in a conditioning cabin at 20±2 °C temperatures and 70±5% relative humidity to reach EMC throughout 8 weeks (Nguyen, *et al.*, 2012**).** At the end of the 8 weeks, the dimensions of bamboo samples and weights were taken.

The EMC was determined according to Equation below

$$EMC = \frac{MF-MO}{MO} X\ 100$$ --- (Equation 13)

Where MF is the mass of the oven-dried sample before the thermal modification, and

MO is the mass of the treated and untreated samples at 20 $^\circ$C and 65% relative humidity.

3.11.5 Determination of Water absorption (WA) of bamboo samples

Shrinkage for each condition was tested on strip samples, only radial shrinkage were measure on an internodes strip of 20x20x20 wall thickness (mm) were tested for comparison. Five (5) replicates were prepared for each treatment ASTM D1037 (1999).

Water was replaced with fresh one daily for 72 hours. The samples were weighed and the Water Absorption values (WA) were calculated according to Equation 20 and 21 after each water replacement in line with the procedure adopted by Temiz *et al*, (2006).

Radial Shrinkage = $\frac{R2-R1}{R1} X\ 100$ ---Equation (14)

WA = $\frac{W2-W1}{W1} X\ 100$ --Equation (15)

Where

R1= Radial shrinkage of untreated and treated samples before soaking in the water.

R2=Radial shrinkage of untreated and treated samples after soaking in the water.

W_2=Wet weight of the specimen after soaking in water

W_1=Oven-dry weight

3.12. Selected mechanical properties of bamboo samples

3.12.1 Determination of Maximum Compressive Strength to grain (MCS$^{\perp}$)

The maximum compressive strength perpendicular to grain was determined, method of testing small clear specimen of timber, from where a test sample of 20mm x 20mm x 20mm was prepared to be used on Instron 3369 model Universal Testing Machine (UTM). The load was applied at the rate of 0.1 mm/sec with the grain perpendicular to the direction of loading, that is, specimens was loaded on the transverse face. Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine. Compressive strength was calculated using the methods in ASTM D143, (2010b)

Plate 8: Compressive testing on the test samples using Instron Universal Testing Machine

3.12.2 Modulus of Rupture (MOR)

The Modulus of Rupture was carried on test sample of 20mm x 20mm x 20mm which was prepared to be tested for on Instron 3369 model Universal Testing Machine (UTM). The load was applied at the rate of 0.1 mm/sec with the grain parallel to the direction of loading, that is, specimens was loaded on the radial face. The bending strength of wood usually expressed as (MOR) which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure was determine from the machine. Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine. Static Modulus of Rupture (MOR) was tested using UTM Instron 3369 with two points loading and calculated with the following formula:

$$MOR = \frac{3 X PMax}{2b X d^2}$$ --Equation (16)

b = width of beam (mm),

d = depth of beam (mm),

Pmax = maximum load (N)

3.12.3 Modulus of Elasticity (MOE)

The Modulus of Elasticity was carried out using Instron 3369 model Universal Testing Machine (UTM). This involves the use of standard test specimens (20mm x 20mm x 20mm), from the MOR test, the corresponding MOE was recorded. Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine. Static Modulus of Elasticity (MOE) was tested using UTM Instron 3369 with two points loading and calculated with the following formula:

$$MOE = \frac{3Pal^2b}{4\Delta lbh^3}$$ --Equation (17)

a = distance from reaction to nearest load point (mm),

Lb = length of beam that was used to measure between two load points (mm),

b = width of beam (mm),

h = depth of beam (mm),

3.12.4 Shear Strength Parallel to Grain ASTM D143-52 of 1997

Shear strength parallel to grain was performed based on the dimensions of the specimen. The load was applied continuously throughout the test at the rate of 0.6mm/min. This involves the use of standard test specimen; (20mm x 20mm x 20mm) and Ultimate shear stress was calculated.

3.12.5 Impact strength

The Impact bending test was carried out using the Hatt-Turner Impact Testing Machine at the Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan; following British Standard BS 373. In this method, standard test specimen 20 x 20 x 300mm was supported over a span of 240mm on a support radiuses 15mm, spring restricted yokes are fitted in order to arrest rebounce.

This was then subjected to a repeated blow from a weight 1.5 kg at increasing height initially from 50.8mm, and then every 25.4mm, until complete failure occurred at which point the height was recorded in meter as the height of maximum hammer drop.

3.13 Determination of chemical properties of bamboo.

This test was carried out at Nigerian Institute of Science Laboratory Technology, Ibadan, Oyo State. The internodes of each height location were cut for chemical analysis, the samples was milled in a milling mill. Milled bamboo was placed in a shaker with sieves to pass through a No. 40 mesh sieve (425-µm) or a No. 60 mesh sieve (250-µm). The resulting material was placed in glass jars labelled with appropriate code for chemical analysis. To prepare the samples of different horizontal layers of bamboo, bottom portion of the bamboo was used. The epidermis of the strips was first removed with a fine blade. The epidermis was kept for chemical analysis and the rest of the strips were divided evenly based on volume into inner, middle and outer layers along the radial direction by a fine blade. The grinding process was the same as above described. All tests were conducted under the standards of American Society for Testing and Materials (ASTM). There was a minor modification for extractive content test. Instead of benzene solutions, toluene solution was used.

3.13.1 Determination of Klason Lignin content of bamboo samples

A one-gram, oven-dried sample of extractive-free bamboo was placed in a 150 ml beaker. Fifteen ml of cold sulphuric acid (72%) was added slowly while stirring and mixing. The reaction was allowed to proceed for two hours with frequent stirring in a water bath maintained at 20 °C. When it was two hours, the specimen was transferred by washing it with 560 ml of distilled water into a 1,000 ml flask, diluting the concentration of the sulphuric acid to three percent. A condenser was attached to a flask. The apparatus was placed in a boiling water bath for four hours. The flasks were removed from the water bath and the insoluble material was allowed to settle. The contents of the flasks were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was washed free of acid with 500 ml of hot tap water and then oven-dried at 103±2 °C. Crucibles were cooled in a desiccator and weighed until a constant weight is obtained. ASTM D 110656

The following formula was used to obtain the Klason lignin content of bamboo:

Lignin content in bamboo (percent) $= \frac{(W4 - W3)}{(100 \times W2)} (100 - W1)$ --------- Equation (18)

Where,

W_1=alcohol-toluene extractive content (percent).

W_2=weight of oven-dried extractive-free sample (grams). W_3=weight of oven-dried crucible (grams).

W_4=weight of oven-dried residue and crucible (grams).

3.13.2 Determination of Holocellulose content of bamboo samples

A two-gram sample of oven-dried extractive-free bamboo was weighed and placed into a 250 ml flask with a small watch glass cover. The specimen was treated with 150 ml of distilled water, 0.2 ml of cold glacial acetic acid, and one gram of NaClO2 and was placed into a water bath maintain between 70 °C – 80 °C. Every hour for five hours 0.22ml of cold glacial acetic acid and one gram of NaClO2 was added and the contents of the flask were stirred constantly. At the end of five hours, the flasks were placed in an ice water bath until the temperature of the flasks was reduced to 10 °C. The contents of the flask were filtered into a coarse porosity fritted-glass crucible of known weight. The residue was washed free of ClO_2 with 500 ml of cold distilled water and the residue changed colour from yellow to white. The crucibles were then oven-dried at 103 ± 2 °C, then cool in a desiccator, and weigh until a constant weight was reached, ASTM D 110456.

The following formula was used to determine the holocellulose content in bamboo:

Holocellulose content in bamboo (percent) $\frac{(W4-W3)}{(100xW2)}\ \boldsymbol{X}\ (100-W1)$ ------ (19)

W_1=Alcohol-toluene extractive content (percent).

W_2=Weight of oven-dried extractive-free sample (grams).

W_3=Weight of oven-dried crucible (grams).

W_4=Weight of oven-dried residue and crucible (grams).

3.13.3 Determination of Alpha-Cellulose content of bamboo samples

A three gram oven-dried sample of holocellulose was used placed in a 250ml Erlenmeyer flask with a small watch glass cover. The flasks were placed into water bath that was maintained at 20 °C. The sample was treated with 50 ml of 17.5 percent NaOH and thoroughly mixes for one minute. After the specimen is allow to react with the solution for 29 minutes, 50ml of distilled water was added and mixed well for another minute. The reaction continued for five more minutes. The contents of the flask were filtered by aid of vacuum suction into a fritted-glass crucible of known weight. The residue was washed first with 50 ml of 8.3 percent NaOH, then with 40 ml of 10 percent acetic acid. The residue was washed free of acid with 1,000 ml of hot tap water. The crucibles were oven-dried in an oven at 103±2C, and then cool in a desiccator, and weighed until a constant weight was reached. The following formula was used to obtain the alpha-cellulose content in bamboo: ASTM D 110360.

Alpha-Cellulose (percent) =$\frac{(W4-W3)}{(100xW2)}\ X(W1)$ -------------------------Equation (20)

Where,

W_1=Holocellulose content (percent).

W_2=Weight of oven-dried holocellulose sample (grams).

W_3=Weight of oven-dried crucible (grams).

W_4=Weight of oven-dried residue and crucible (grams).

3.13.4 Determination of Ash content of bamboo samples

An empty crucible was ignited and covered in the muffle at 600 °C then later cooled in a desiccator, and weighed to the nearest 0.1 mg. Two (2) grammes sample of air-dried bamboo was placed in the crucible, then the weight of crucible plus specimen was determined, then placed it in the drying oven at 103±2^{o}C.The sample was removed with the crucible cover removed, then cooled in a desiccator and weighed until the weight was constant. The crucible and contents were placed in the muffle furnace and ignited until all the carbon was eliminated. The content was heated slowly at the start to avoid flaming and protect the crucible from strong drafts at all times to avoid mechanical loss of test specimen. The temperature of final ignition was 580 °C to 600 °C. Then the crucible with its contents was removed and place in a desiccator to cool, the cover was replaced loosely, then content was cooled and weighed accurately. The heating was repeated for 30 min periods until the weight after cooling was constant to within 0.2 mg. The following formula was used to obtain the ash content in bamboo ASTM D 110284.

Ash content (percent) $=\frac{W2/W1}{100}$ ---Equation (21)

Where,

W_1=weight of ash (grams).

W_2=weight of oven-dried sample (grams).

3.14 Determination of the durability study of thermal-modified *Bambusa vulgaris*.

This test was carried out at Forestry Research Institute of Nigeria, Ibadan, Oyo State. The bamboo samples for this test were taken from thermal-modified bamboo described earlier. These blocks were converted into 20mmx20mmx370mm wall. This test was conducted based on ASTM D 1758-74(1974) and procedure developed by Jackson 10 with some modification to suit for bamboo testing.

The test stakes was buried upright with 4/5 of their length in the ground. They were installed 200mm apart within and between rows and were distributed randomly. The test stakes were exposed to the decay hazard as well as termites. The stakes were installed during the raining season (April, 2015) the testing site for the field/grave-yard study was at Forestry Research Institute of Nigeria, Ibadan, Oyo State.

The first inspection of the stakes was done 6months after installation and some replicated treatment samples were exhumed and the weight and percentage weight loss was calculated accordingly, the second set of treatment samples for 12 months were also exhumed march 2016 at expiration of 12 months duration, the samples were examined and recorded, The criteria for testing were based on the weight loss experienced by the stakes. The stakes were oven dried before and after the ground contact tests (Razak *et al.*, 2004). Percentage weight loss of the samples were used to determine the effect of thermal treatment on the durability of *Bambusa vulgaris*

Plate 9: (a) Bamboo test samples after 1 year of Grave yard test and (b) Bamboo test samples after six months of Timber grave yard test.

3.15. Biological accelerated test

3.15.1 Culture Medium preparation

A nutrient medium of potato Dextrose Agar (PDA) in distilled water was prepared in line with the method adopted by Adegeye *et al*, (2009). First, 35 grammes of the PDA was mixed with 1 little of water in conical flask and then homogenised. After homogenising, 40 ml of the PDA was poured into McCartney bottles and sterilised by autoclaving at a pressure and temperature of 0.1 N mm^{-2} and 120^oC, respectively for a period of 20 minutes. The medium in which test fungus, was eventually cultured was first completely sterilised and the prepared PDA was poured, into it and covered with an air tight lid in preparatory for fungal inoculation.

3.15.2 Inoculation of bamboo samples

At the end of the thermal treatment period, The bamboo samples test blocks in accordance with ASTM D143-94 with had sample size 2 x 2 x culm thickness (planned to 5mm) with a slight modifications owing to bamboo nature were drained and thereafter exposed to the activities of *Pleurotus florida* (white rot) and *Sclerotium rolfsii* (Brown rot) the oven dry bamboo samples was sterilized with methylated spirit. Bamboo samples were then inoculated with decay fungi *P. Florida and Sclerotiun rolfsii* simultaneously *in* the presence of a burning spirit lamp in the disposable plastic container. The inoculation was carried out at temperature ($28{\pm}2^0C$) for the incubation of the fungi on the bamboo samples. Observations on weight loss were made on samples at an interval of two weeks until the twelfth week. Percentage weight loss was determined as shown in equation below and was used for the analysis of the effect of the fungi on the wood samples.

Plate 10: The Author inoculating the fungi into the test samples

3.15.3 Weight loss experiment

At the end of test period of twelve weeks the bamboo specimens were then harvested and the adhering mycelium scrapped off. The specimens both the control and thermal-modified samples were weighed, oven dried, weighed again and the resulting weight calculated and recorded in line with the procedure adopted by Luna *et al*, (2004) percentage weight different was determined using the equation:

Percentage weight difference= $\frac{WI-WL}{WI}$ x100--------------------Equation (22)

Where:

WI =Weight of samples before exposure to fungal attack

WL=Weight of samples after twelve weeks of exposure to fungal attack

All fungal isolates were maintained on PDA for the duration of the experiment.

3.16 Data Analysis

3.16.1 Experimental Design

The experiment was of three factors; Culm sampling height, Temperature variation and Time duration Control with their levels; Base, Middle and Top; (0 °C), 100 °C, 110 °C, 120 °C, 130 °C, 140 °C; 10minutes, 20minutes and 30minutes, respectively.

The treatment samples were experimented under the listed above factors; each experiment was run for 5 replicates with a total 270 test sample for each to; determine the selected Mechanical properties, (Shear strength, Compressive strength, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) and Impact bending), Physical properties (Moisture content, Specific gravity, Equilibrium Moisture Content (EMC) Radial shrinkage, Water absorption),

Also, to assess the anatomical properties (No. of vessels/mm^2, fibres length, fibre diameter, and fibre cell wall thickness, Vessel diameter (µm), Fibre lumen diameter (µm) Parenchyma width (µm) and Parenchyma height and bamboo Stereology) and the Chemical properties (including Hemicellulose content, Alpha-cellulose content, Klason lignin content, hot Ash content, Holocellulose content), Biological accelerated fungi test, Wood ground contact test.

3.16.2 Analysis of Variance (ANOVA).

Analysis of Variance (ANOVA) and Multiple Regressions was conducted to investigate the treatments variation and model the relationship in the selected properties of untreated and thermal-modified *Bambusa vulgaris,* Completely Randomized Design (CRD) with 5 replications was adopted, while the treatment design was adopted and was laid in 3 x 3 x 6 Factorial resulting in 54 treatment combinations. Duncan Multiple Range Test (DMRT) was used to separate the treatment means where significant differences occurred in the ANOVA.

3.16.3 The Model for three-factor (3 X 3 X 6) factorial experiment is given as;

$Y_{ijk} = \mu+A_i+B_j+C_k +AB_{ij}+AC_{ik}+ BC_{jk}+ABC_{ijk}+\varepsilon_{ijk}$ ---------------------Equation (23a)

Y_{ijk}=Individual observation

μ=General mean

A_i=Effect of culm height

B_j=Effect of Temperature

C_k=Effect of heating duration

AB_{ij}=Effect of interaction between culm height and temperature

AC_{ik}=Effect of interaction between culm height and heating duration

BC_{jk}=Effect of interaction between temperature and heating duration

$(ABC)_{ijk}$=Effect of interaction among the culm height, temperature and heating duration.

ε_{ijk}=Experimental error

3.16.4 Statement of Hypotheses:

For culm height variation levels:

H_O=There is no significant difference in the effect of the three culm height variation levels by the properties exhibited by thermal-modified and untreated bamboo samples.

For Temperature variation levels:

H_O=There is no significant difference in the effect of the six temperature variation level by the properties exhibited by thermal-modified and untreated bamboo samples.

F*or* heating duration levels:

H_O=There is no significant difference in the effects of the three heating durations by the properties exhibited by thermal-modified and untreated bamboo samples.

For the interaction:

H_O**=** the effect of interaction is not significant among the three factors.

3.16.5 Develop a relationship among all the selected properties of thermal-modified and untreated *Bambusa vulgaris*.

Multiple Regression Analysis

Multiple Regressions analysis was used to predict selected properties of thermal-modified and untreated of bamboo strips from combination of process variables: culm height, temperature (^{0}C) heating duration (minutes).

Multiple Linear Regression Model

$Y=b_0+b_1x_1+b_2x_2+ b_3x_3+e_i$---Equation (23b)

Where;

Where Y= value of the dependent variable

b_0=slope of the regression (Constant)

b_1, b_2, b_3--------b_n = coefficient of regression (Regression parameters i.e. the change in Y per unit change in X)

x=Independent variables

e_i = experimental error(Error of estimation)

b_nx_n=nth term

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Anatomical Properties of Untreated and Thermal-Modified *Bambusa vulgaris*

Table 1: Analysis of Variance (ANOVA) for fibre length for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P value
Sampling height	2.00	5.70	2.85	14.63*	0.00
Temperature variation(°C)	5.00	9.03	1.81	9.26*	0.00
Treatment time(minutes)	2.00	0.08	0.04	0.21ns	0.81
Sampling height * Temperature variation(°C)	10.00	8.75	0.88	4.49*	0.00
Sampling height * Treatment time(minutes)	4.00	0.15	0.04	0.19ns	0.94
Temperature variation(°C) * Treatment time(minutes)	10.00	1.93	0.19	0.99ns	0.46
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	9.84	0.49	2.52*	0.00
Error	216.00	42.11	0.20		
Total	270.00	1340.17			

*=significant at P<0.05

ns=not significant at P>0.05

Table 2: Mean value of fibre length (mm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	3.11±0.62	2.35±0.31	2.10±0.22	**2.52±0.39c**
100	10	2.65±0.08	2.33±0.14	2.03±0.27	**2.34±0.17a**
	20	1.68±0.14	2.32±0.03	2.90±0.31	**2.30±0.16a**
	30	2.39±0.11	2.10±0.67	1.87±0.11	**2.12±0.30a**
	Mean	**2.24±0.11**	**2.25±0.28**	**2.27±0.23**	**2.25±0.21b**
110	10	1.90±0.32	2.38±0.45	1.87±0.52	**2.05±0.43a**
	20	2.16±0.40	1.79±0.18	1.93±0.55	**1.96±0.38a**
	30	2.27±0.47	2.20±0.77	2.32±0.00	**2.26±0.41a**
	Mean	**2.11±0.40**	**2.13±0.47**	**2.04±0.36**	**2.09±0.41ab**
120	10	2.15±0.12	2.06±0.18	1.81±0.21	**2.01±0.17a**
	20	2.53±0.63	2.18±1.02	1.81±0.21	**2.18±0.62a**
	30	2.31±0.00	2.18±1.02	1.90±0.25	**2.13±0.42a**
	Mean	**2.33±0.25**	**2.14±0.74**	**1.84±0.22**	**2.10±0.40ab**
130	10	2.20±0.49	2.41±0.14	1.64±0.40	**2.09±0.34a**
	20	1.98±0.09	2.59±0.76	1.81±0.38	**2.13±0.41a**
	30	1.86±0.05	2.19±0.46	1.77±0.09	**1.94±0.20a**
	Mean	**2.01±0.21**	**2.40±0.45**	**1.74±0.29**	**2.05±0.32a**
140	10	1.73±0.18	1.76±0.36	2.06±0.71	**1.85±0.42a**
	20	2.57±1.01	1.76±0.36	1.55±0.23	**1.96±0.54a**
	30	2.18±0.32	2.03±0.41	1.94±0.11	**2.05±0.28a**
	Mean	**2.16±0.51**	**1.85±0.38**	**1.85±0.35**	**1.95±0.41a**
	Pooled mean	**2.33±0.60c**	**2.19±53b**	**1.97±0.41a**	**2.16.16±0.54**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.1 Fibre Length

The result of analysis of variance revealed that there were significant differences in the sampling height and the Temperature variation (°C), as there was no significant difference in the treatment time (minutes). The interaction effects were not significant at 5% between sampling height and time duration, also between temperature duration and treatment time (minutes) Table 1.

The mean of fibre length value for thermal-modified *Bambusa vulgaris* at base for temperature variations from 0, 100, 110, 120, 130 and 140 °C; ranged from 2.01 to 2.33mm from 1.84 to 2.27mm for middle and respective variables ranged from 1.74 to 2.27mm for the top sampling height there were inconsistency in the decreasing pattern of variation from base to top as shown in Table 2.

In this study, there were inconsistencies in the variation of fibre length to thermal modification of *Bambusa vulgaris*, notwithstanding the highest fibre length values were recorded in the untreated base samples as 3.11mm while the least fibre length mean value of 1.55mm was found at the top samples modified at temperature 140 °C-20minutes. This result had similar trend with Huang *et al*, (2015); Liese, (1998). Huang *et al*, (2015) reported in their studies on the variation in the anatomical characteristics of *Bambusa rigida* that fibre length ranged from 1.56mm to 2.11mm and from base to top, the fibre length increased initially and latter decreased. This reason may be due to the correlation between fibre length and internode length (Liese, 1998). Also, upon the height growth, the fibre elongation will cease but the fibre cell wall thickness will continue thicken until maturation (Gan and Ding, 2006). The thickening of fibre cell wall with age might be due to the second wall accumulation and maturation with the deposition of additional lamellae for fibre cell wall (Liese and Weiner, 1996). According to Grosser and Liese, (1971), fibre length of bamboo fibres with tapered ends constitute the sclerenchymatous tissue consisting of vascular bundle caps and isolated strands, playing an important role in the supporting of bamboo self-weight. The fibres are ground in fibre strand and sclerenchyma sheath around the Metaxylem vessels and phloem of bamboo. The follow up test further revealed the interaction effect between temperature variation and time (Table 3).

Table 3: Follow up test for interaction between temperature variation and time duration for fibre length

Temperature (°C)	Time (minutes)	Mean
140	10	1.85a
130	30	1.94a
110	20	1.96a
140	20	1.96a
120	10	2.01a
100	10	2.05a
140	30	2.05a
130	10	2.09a
100	30	2.12a
120	30	2.13a
130	20	2.13a
120	20	2.18a
110	30	2.26a
100	20	2.30a
100	10	2.34a
untreated	untreated	2.52c

Mean with the same alphabet are not significantly different from one another

Table 4: Analysis of Variance (ANOVA) of Fibre diameter for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P value
Sampling height	2.00	63.65	31.83	6.66*	0.00
Temperature variation(°C)	5.00	1049.72	209.94	43.96*	0.00
Treatment time(minutes)	2.00	764.23	382.12	80.02*	0.00
Sampling height * Temperature variation(°C)	10.00	254.91	25.49	5.34*	0.00
Sampling height * Treatment time(minutes)	4.00	25.08	6.27	1.31ns	0.27
Temperature variation(°C) * Treatment time(minutes)	10.00	368.58	36.86	7.72*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	75.05	3.75	0.79ns	0.73
Error	216.00	1031.47	4.78		
Total	270.00	55957.74			

*=significant at $P<0.05$

ns=not significant at $P>0.05$

Table 5: Mean value of Fibre diameter (μm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	14.53±4.27	19.69±2.34	18.65±4.34	**17.62±3.65d**
100	10	17.43±2.71	18.06±2.81	19.88±1.77	**18.45±2.43c**
	20	13.11±0.09	14.67±0.31	13.95±0.21	**13.91±0.20b**
	30	11.15±0.73	12.04±1.98	12.17±0.93	**11.79±1.21a**
	Mean	**13.89±1.17**	**14.92±1.70**	**15.33±0.97**	**14.72±1.28c**
110	10	15.92±3.54	18.54±2.34	15.47±0.00	**16.64±1.96c**
	20	11.80±1.06	14.09±1.13	12.65±1.59	**12.85±1.26b**
	30	10.72±0.14	9.87±0.04	10.27±1.37	**10.29±0.52a**
	Mean	**12.81±1.58**	**14.17±1.17**	**12.80±0.98**	**13.26±1.25b**
120	10	17.95±5.43	19.22±1.46	14.55±1.28	**17.24±2.72c**
	20	12.62±0.13	13.27±2.33	13.21±0.34	**13.03±0.93b**
	30	11.27±0.74	10.67±0.11	10.49±0.13	**10.81±0.33a**
	Mean	**13.95±2.10**	**14.39±1.30**	**12.75±0.58**	**13.69±1.33b**
130	10	13.36±0.29	15.42±1.28	14.07±2.28	**14.28±1.28c**
	20	12.37±0.71	11.89±0.50	10.92±0.51	**11.73±0.57b**
	30	10.69±0.42	10.08±0.13	9.90±0.11	**10.22±0.22a**
	Mean	**12.14±0.47**	**12.46±0.64**	**11.63±0.97**	**12.08±0.69a**
140	10	14.18±2.33	12.65±0.57	11.94±1.82	**12.92±1.57c**
	20	11.95±0.35	11.47±0.20	11.11±0.60	**11.51±0.38b**
	30	12.21±4.46	10.69±0.58	11.64±1.18	**11.51±2.07a**
	Mean	**12.78±2.38**	**11.60±0.45**	**11.56±1.20**	**11.98±1.34a**
	Pooled mean	**13.35±3.29a**	**14.54±3.89b**	**13.87±3.76a**	**13.92±3.67**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.2 Fibre diameter

The result of analysis of variance was significant in the three main factors at 5% level, the effect of the interaction was significant between sampling height and temperature variation (°C), temperature and treatment time (minutes) except between sampling height and treatment time (minutes) and among the three factors (Table 4).

The overall highest fibre diameter values were recorded in the untreated middle samples (19.69 µm) followed also, in the category of the untreated samples in the mean values ranking followed top samples with mean value 18.65µm and base with 14.53µm respectively as shown in Table 5.

The result for the mean fibre diameter of thermal-modified bamboo at base for temperature variations (°C); from 0, 100, 110, 120, 130, and 140 °C with respect to treatment time (minutes); 10, 20, and 30minutes ranged from 12.14 to 13.95µm while for middle ranged from 11.60 to 14.92µm and for top ranged from 11.56 to 15.33µm respectively (Table 5).

There were inconsistent decreases in pattern of fibre diameter of thermal-modified samples from temperature and time variations; from 100 °C-10minutes to 140 °C-30minutes, the values varied from 17.43 to 12.21, 18.06 to 10.69, and 19.88 to 11.64 for base, middle and top, respectively. This result compared favourably with the literature by Huang *et al*, (2015). In this study, the least values were recorded in the untreated base samples and the highest values were recorded at top samples in the treated categories, this is because, there was an intense level of shrinkage in the fibre cells laterally in top region because of juvenile fibre cells than the more fibrous fibre at the base. This contradicts the report by Abd. Latif and Tamizi, (1992) who stated that fibre diameter in *G. scortechinii* is not affected by age. The fibre morphology of *Bambusa vulgaris* according to this study also contradicts the observation made by Abd. Latif *et al*, (1994), this is probably due to the fact that bamboo properties are characterised by its own individual characteristics (Liese, 1985). The follow up test further revealed the interaction effect between temperature variation and time (Table 6).

Table 6: Follow up test for interaction between temperature variation and time duration for Fibre diameter

Temperature	Time(minutes)	Mean
130	30	10.22a
110	30	10.29a
120	30	10.81a
100	30	11.79a
140	30	11.51a
140	20	11.51b
130	20	11.73b
120	20	13.03b
100	20	13.91b
110	20	12.85b
140	10	12.92c
130	10	14.28c
110	10	16.64c
120	10	17.24c
100	10	18.45c
untreated	Untreated	17.62d

Mean with the same alphabet are not significantly different from one another

Table 7: Analysis of Variance (ANOVA) of Fibre Cell wall for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	47.19	23.60	4.68^{*}	0.01
Temperature variation(°C)	5.00	959.25	191.85	38.08^{*}	0.00
Treatment time(minutes)	2.00	663.19	331.59	65.82^{*}	0.00
Sampling height * Temperature variation(°C)	10.00	211.55	21.16	4.20^{*}	0.00
Sampling height * Treatment time(minutes)	4.00	34.67	8.67	1.72^{ns}	0.15
Temperature variation(°C) * Treatment time(minutes)	10.00	318.01	31.80	6.31^{*}	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	105.99	5.30	1.05^{ns}	0.40
Error	216.00	1088.27	5.04		

*=significant at P<0.05

ns=not significant at P>0.05

Table 8: Mean value of Fibre Cell wall (μm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	9.32±4.61	13.90±2.43	12.88±3.94	**12.03±3.66e**
100	10	12.41±2.86	12.41±2.88	13.82±1.77	**12.88±2.50c**
	20	8.26±0.75	8.87±0.67	8.48±0.66	**8.53±0.69b**
	30	6.11±0.99	6.73±1.66	6.79±0.60	**6.54±1.08a**
	Mean	**8.93±1.53**	**9.33±1.73**	**9.69±1.01**	**9.32±1.43d**
110	10	10.15±3.42	12.66±2.18	9.78±0.00	**10.86±1.87c**
	20	6.46±0.68	8.32±1.03	6.98±1.40	**7.26±1.04b**
	30	5.28±0.33	4.51±0.24	4.91±0.87	**4.90±0.48a**
	Mean	**7.30±1.48**	**8.50±1.15**	**7.22±0.76**	**7.67±1.13bc**
120	10	12.09±5.25	13.94±1.90	7.38±3.18	**11.13±3.44c**
	20	7.09±0.04	7.57±1.91	7.99±0.97	**7.55±0.97b**
	30	5.87±0.74	5.62±0.04	5.30±0.61	**5.60±0.47a**
	Mean	**8.35±2.01**	**9.04±1.28**	**6.89±1.59**	**8.10±1.63c**
130	10	8.42±0.75	10.04±1.34	8.95±2.32	**9.14±1.47c**
	20	7.06±0.84	6.19±0.27	5.79±0.64	**6.35±0.58b**
	30	5.38±0.62	4.96±0.27	4.64±0.04	**4.99±0.31a**
	Mean	**6.95±0.74**	**7.06±0.62**	**6.46±1.00**	**6.82±0.79ab**
140	10	9.02±2.63	7.12±0.45	7.96±1.66	**7.37±1.58c**
	20	6.44±0.59	6.54±0.36	7.01±0.99	**6.67±0.64b**
	30	6.70±4.89	5.38±0.71	5.79±0.80	**5.96±2.13a**
	Mean	**7.38±2.70**	**6.35±0.51**	**6.26±1.15**	**6.66±1.45a**
	Pooled mean	**8.04±3.38a**	**9.03±3.72b**	**8.31±3.56a**	**8.46±3.57**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.3 Fibre Cell wall

The result of analysis of variance revealed that there were significant differences in the sampling height, temperature variation (°C) and treatment time (minutes) at 5% level of probability (Table 7). There were significant interactions effect between sampling height and temperature, temperature variation (°C) and treatment time (minutes) while there was no significant interaction effect between sampling height and treatment time (minutes) and also among sampling height, temperature variation (°C) and Treatment time (minutes), (Table 7).

The average mean values for fibre cell wall of thermal-modified *Bambusa vulgaris* is presented in Table (8), The average mean value of the fibre cell wall at base for temperature variations; 0, 100, 110, 120, 130 and 140 °C with respect to treatment time (minutes); 10, 20, 30minutes ranged from 6.95 to 8.93µm while the average values for middle and top ranged from temperature variation (^{o}C) 100 to 140 °C and treatment time (minutes)10 to 30 minutes were 6.35 to 9.33µm for middle while 6.26 to 9.69µm were the value ranges for the top samples, (Table 8).

The fibre cell wall in the untreated samples of middle sampling height recorded the mean maximum value (13.90µm) and there was a consistent decrease in the mean value of fibre cell wall from 100 to 140 °C also from 10 to 30 minutes treatment time (minutes) of the treatment effect on the bamboo.

There was an inconsistency in the decreasing of mean values of thermal-modified bamboo of fibre to the temperature variation (^{o}C) and time duration. The fibre cell walls were found swollen because of the impact of the heat, hence lead to increase in the cell wall thickness within a temperature 110 to 130^{o}C and latter observed to be record lower values at 140 °C.

Random sampling techniques was not a favourable method to determine the variation in fibre cell wall thickness in response to the heat treatment and its time duration because it did not allow complete capture of the cell microstructures, cell wall responded differently to the heat treatment due to the different volume of constituent and chemical in them, the fibre cell wall varies inconsistently from the base to the top of bamboo in response to heat treatment.

There was an inconsistency in the variation of fibre wall thickness of thermal-modified bamboo, this report is a similar trend with the report of Liese, (1985); Huang *et al*, (2015) .This may be as a result of different individual characteristic of bamboo, more so, there were variation in the fibre cell walls within the sampling height. The fibre around the vessels were smaller than in the fibre sheaths, also the simple random sampling method to select the fibres for examination is not appropriate because of the heterogeneity in the fibre sizes within the sampling height, instead complete random sampling would have been appropriate to really determine the effect of heat on the cell wall of *Bambusa vulgaris* fibres. The follow up test further revealed the interaction effect between temperature variation and time (Table 9).

Table 9: Follow up test for interaction between temperature variation and time duration for Fibre Cell wall

Temperature (°C)	Time (Minutes)	Mean
110	30	4.90a
130	30	4.99a
120	30	5.60a
140	30	5.96a
100	30	6.54a
130	20	6.35b
140	20	6.67b
110	20	7.26b
120	20	7.55b
100	20	8.53b
140	10	7.37c
130	10	9.14c
110	10	10.86c
120	10	11.13c
100	10	12.88c
untreated	untreated	12.03e

Mean with the same alphabet are not significantly different from one another

Table 10: Analysis of Variance (ANOVA) of Cell lumen for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	0.42	0.21	4.28*	0.02
Temperature variation(°C)	5.00	1.15	0.23	4.73*	0.00
Treatment time(minutes)	2.00	0.42	0.21	4.32*	0.01
Sampling height * Temperature variation(°C)	10.00	1.99	0.20	4.09*	0.00
Sampling height * Treatment time(minutes)	4.00	0.24	0.06	1.23ns	0.30
Temperature variation(°C) * Treatment time(minutes)	10.00	0.40	0.04	0.83ns	0.60
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	1.40	0.07	1.44ns	0.11
Error	216.00	10.50	0.05		
Total	270.00	2014.67			

*=significant at P<0.05

ns=not significant at P>0.05

Table 11: Mean value of Cell Lumen (μm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling height Base	Middle	Top	Pooled Mean
0	Untreated	2.61±0.18	2.90±0.28	2.88±0.20	**2.80±0.22b**
100	10	2.51±0.20	2.82±0.27	3.03±0.00	**2.79±0.16b**
	20	2.42±0.33	2.90±0.26	2.74±0.24	**2.69±0.28b**
	30	2.52±0.20	2.66±0.17	2.69±0.47	**2.62±0.28a**
	Mean	**2.48±0.24**	**2.79±0.23**	**2.82±0.24**	**2.70±0.24a**
110	10	2.88±0.13	2.94±0.08	2.85±0.00	**2.89±0.07b**
	20	2.67±0.21	2.88±0.20	2.84±0.27	**2.80±0.22b**
	30	2.72±0.10	2.68±0.11	2.79±0.33	**2.73±0.18a**
	Mean	**2.76±0.15**	**2.84±0.13**	**2.82±0.20**	**2.81±0.16b**
120	10	2.93±0.10	2.64±0.22	2.79±0.52	**2.79±0.28b**
	20	2.76±0.08	2.85±0.25	2.61±0.35	**2.74±0.23b**
	30	2.70±0.21	2.52±0.03	2.59±0.24	**2.61±0.16a**
	Mean	**2.80±0.13**	**2.67±0.17**	**2.66±0.37**	**2.71±0.22ab**
130	10	2.47±0.23	2.69±0.03	2.56±0.03	**2.57±0.10b**
	20	2.65±0.07	2.85±0.12	2.57±0.08	**2.69±0.09b**
	30	2.65±0.10	2.56±0.07	2.63±0.03	**2.61±0.07a**
	Mean	**2.59±0.13**	**2.70±0.07**	**2.59±0.05**	**2.63±0.08a**
140	10	2.58±0.20	2.76±0.37	2.78±0.16	**2.71±0.24b**
	20	2.92±0.45	2.46±0.08	2.67±0.00	**2.68±0.18b**
	30	2.75±0.24	2.65±0.07	2.52±0.05	**2.64±0.12a**
	Mean	**2.75±0.30**	**2.63±0.17**	**2.65±0.07**	**2.68±0.18a**
	Pooled mean	**2.67±0.24a**	**2.75±0.24b**	**2.74±0.26b**	**2.72±0.25**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.4 Fibre cell lumen

The result of the analysis of variance revealed that there was a significant interaction effect between sampling height and temperature variation (°C), there was no significant interaction effect between sampling height and treatment time, also between temperature variation and treatment ,and among sampling height, temperature variation(°C) and treatment time(minutes) (Table 10).

The average mean value of the fibre cell lumen at base for temperature variations; 100, 110, 120, 130 and 140 °C with respect to treatment time (minutes) 10, 20, 30minutes ranged from 2.48 to 2.80µm while the average values for middle and top at the Temperature variation (°C) from 100 to 140 °C and treatment time (minutes) from 10 to 30 minutes were 2.63 to 2.84µm for middle while 2.59 to 2.82µm were the range values for the top samples (Table 11).

The fibre cell lumen of thermal-modified bamboo was found to be the maximum values at the untreated middle as 2.90µm, while least at untreated top was 2.88µm, The highest fibre cell lumen values were recorded as 2.99µm in the middle height of untreated fibre samples, as shown in Table (9), this result is supported by the claims of Huang *et al,* (2015); Liese, (1985) and Haung *et al,* (2015) who reported the maximum fibre cell wall values as 10.96 µm at middle followed by 10.51µm at base and 10.18µm at top samples of *Bambusa rigida* respectively, irrespective of the inconsistence values recorded in the fibre cell lumen of thermal-modified bamboo in this study. This study revealed lack of uniformity in sizes of fibre in the bamboo, varying from the back to inner part of culm also from base to top. The follow up test further revealed the interaction effect between temperature variation and time (Table 12).

Table 12: Follow up test for interaction between temperature variation and time duration for Fibre Cell Lumen

Temperature (°C)	Time (minutes)	Mean
120	30	2.61a
130	30	2.61a
100	30	2.62a
140	30	2.64a
110	30	2.73a
130	10	2.57b
140	20	2.68b
100	20	2.69b
130	20	2.69b
140	10	2.71b
120	20	2.74b
100	10	2.79b
120	10	2.79b
untreated	untreated	2.80b
110	20	2.80b
110	10	2.89b

Mean with the same alphabet are not significantly different from one another

4.1.5 Vessel and Parenchyma cell characteristics of untreated and thermal-modified *Bambusa vulgaris*

Table 13: Analysis of Variance (ANOVA) of Mean Tangential Diameter (MTD) for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2	48060.28	24030.1	295000.00*	0.00
Temperature variation(°C)	5	128516.8	25703.4	316000.00*	0.00
Treatment time(minutes)	2	92277.91	46139	566000.00*	0.00
Sampling height *Temperature variation(°C)	10	23705.33	2370.53	29100.00*	0.00
Sampling height * Treatment time(minutes)	4	4980.608	1245.15	15300.00*	0.00
Temperature variation(°C) * Treatment time(minutes)	10	22978.55	2297.86	28200.00*	0.00
Sampling height *Temperature variation(°C) * Treatment time(minutes)	20	8489.337	424.467	5210.00*	0.00
Error	216	17.6	0.081		
Total	270	7812042			

*=significant at P<0.05

ns=not significant at P>0.05

Table 14: Mean value of Mean Tangential Diameter (MTD) (µm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(^{o}C)	Treatment time(minutes)	Sampling Height Base	Middle	Top	Pooled Mean
0	Untreated	214.99±29.98	220.85±0.52	169.37±0.89	**201.74±10.46f**
100	10	214.62±0.00	219.11±0.89	168.97±0.52	**200.90±0.47a**
	20	210.66±0.00	199.98±0.89	168.97±0.52	**193.20±0.47b**
	30	183.32±0.00	167.37±0.89	133.82±0.52	**161.50±0.47c**
	Mean	**202.87±0.00**	**195.49±0.89**	**157.25±0.52**	**185.20±0.47e**
110	10	213.11±0.00	215.95±0.89	168.97±17.15	**199.34±6.02a**
	20	182.28±0.00	169.27±0.89	142.92±17.15	**164.82±6.02b**
	30	142.36±0.00	142.36±0.89	133.70±17.15	**139.47±6.02c**
	Mean	**179.25±0.00**	**175.86±0.89**	**148.53±17.15**	**167.88±6.02d**
120	10	195.44±29.98	199.60±0.89	168.97±17.15	**188.00±16.01a**
	20	151.02±29.98	178.43±0.89	142.92±17.15	**157.46±16.01b**
	30	131.30±29.98	134.67±0.89	133.70±17.15	**133.22±16.01c**
	Mean	**159.25±29.98**	**170.90±0.89**	**148.53±17.15**	**159.56±16.01c**
130	10	171.70±29.98	198.15±0.89	168.97±17.15	**179.61±16.01a**
	20	112.11±29.98	172.66±0.89	142.92±17.15	**142.56±16.01b**
	30	108.07±29.98	135.15±0.89	106.51±17.15	**116.58±16.01c**
	Mean	**130.63±29.98**	**168.65±0.89**	**139.47±17.15**	**146.25±16.01b**
140	10	171.70±29.98	182.26±0.89	142.92±17.15	**165.63±16.01a**
	20	112.11±29.98	162.61±0.89	139.13±17.15	**137.95±16.01b**
	30	108.07±29.98	118.45±0.8	106.51±17.15	**111.01±16.01c**
	Mean	**130.63±29.98**	**154.44±0.89**	**129.52±17.15**	**138.20±16.01a**
	Pooled mean	**169.60±40.74b**	**181.03±32.53c**	**148.80±20.95a**	**166.48±34.97**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.5.1 Mean Tangential Diameter (MTD) of Vessels of *Bambusa vulgaris*.

The result of the analysis of variance revealed that there was a significant difference in all the sources of variation adopted, while , there was a significant difference in the interaction effect among sampling height, temperature variation(°C) and treatment time(minutes) as shown in Table 13.

Vessel is an important feature in the plant, it a medium for water supply in a plant, vessel runs axially across from the base to the top of a plant, the size of a vessel is one of the pertinent indices for plant identification and classification. The mean values of Mean Tangential Diameter of vessel of thermal-modified bamboo are presented in Table (14).

The mean value ranged from 159.25 to 202.87µm for the base at temperature variations (°C); 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10, 20, 30 minutes 154.44 to 195.49µm for middle and from 129.50 to 157.25µm for top.

The MTD of thermal-modified bamboo decreased from base to the top, although there were maximum numbers of vessels found in the transverse section in the top of bamboo but with least mean diameter.

According to this study, the effect of heat treatment and its influence on the vessel was revealed against the general assertion that the fibres alone are responsible for the shrinkage and swelling phenomena in the wood physical properties. *Bambusa vulgaris* vessels demonstrated a shrinking ability after the heat treatment, the vessel path way is hollow, though surrounded with fibres tends to shrink consistently as there was increase in temperature and treatment time, until it finally collapsed. Maximum temperature variation (°C) 140 °C and treatment time (minutes) 30minutes with value 130.20µm revealed the maximum shrinkage ability on the thermal-modified *Bambusa vulgaris*.

There was a decreasing pattern in the mean values of vessels mean tangential dimension (MTD) of thermal-modified bamboo from base to top in respect to increases in temperature and time from 100 °C-10minutes to 140 °C-30minutes. The highest values of MTD was recorded at the untreated base samples (214.99µm), while the least values (129.52µm) were found at treated top samples at highest temperature and time accordingly, this result is in conformity with the reports of Abd. Latif *et al,* (1993); Grosser and Liese, (1971); Kelemwork, (2009); Huang, *et al,* (2015), also, comparing with the report of Hisham *et al,* (2006) , the *Bambusa vulgaris* MTD is relatively smaller compared with *Gigantochloa scortechinii*. All authors reported that vascular bundle size showed decreasing trend from base to top portion of all the age groups of bamboo. This may be as a result of smaller vascular bundle size located in the top portion of bamboo and tapering structure of culms. The follow up test further revealed the interaction effect between temperature variation and time (Table 15).

15: Follow up test for interaction between temperature variation and time duration for Mean Tangential Diameter (MTD)

Temperature (°C)	Time (minutes)	Mean
140	10	165.63a
130	10	179.61a
120	10	188.00a
110	10	199.34a
100	10	200.90a
140	20	137.95b
130	20	142.56b
120	20	157.46b
110	20	164.82b
100	20	193.20b
110	30	139.47c
100	30	161.50c
140	30	111.01c
140	30	116.58c
120	30	133.22c
untreated	Untreated	201.74f

Mean with the same alphabet are not significantly different from one another

Table 16: Analysis of Variance (ANOVA) of Parenchyma height for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	5582.63	2791.31	122245.40*	0.00
Temperature variation(°C)	5.00	1253.65	250.73	10980.70*	0.00
Treatment time(minutes)	2.00	17.80	8.90	389.70*	0.00
Sampling height * Temperature variation(°C)	10.00	5925.85	592.58	25952.22*	0.00
Sampling height * Treatment time(minutes)	4.00	10371.62	2592.90	113556.14*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	8420.79	842.08	36878.82*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	9745.72	487.29	21340.68*	0.00
Error	216.00	4.93	0.02		
Total	270.00	2738743.16			

***=significant at P<0.05**
ns=not significant at P>0.05

Table 17: Mean value of Parenchyma cell height (μm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	102.82±0.17	96.12±0.17	95.66±0.12	**98.20±0.15b**
100	10	88.08±0.13	82.72±0.07	103.16±0.14	**91.32±0.12a**
	20	104.56±0.08	100.62±0.14	103.30±0.26	**102.83±0.16b**
	30	116.93±0.05	107.69±0.15	102.58±0.27	**109.07±0.16c**
	Mean	**103.19±0.09**	**97.01±0.12**	**103.01±0.22**	**101.07±0.15e**
110	10	95.93±0.04	89.32±0.25	101.86±0.17	**95.70±0.16a**
	20	95.89±0.09	91.43±0.12	100.62±0.18	**95.98±0.13b**
	30	115.43±0.07	108.35±0.13	92.48±0.25	**105.42±0.15c**
	Mean	**102.42±0.07**	**96.37±0.17**	**98.32±0.20**	99.03±0.15c
120	10	94.31±0.05	79.76±0.11	100.56±0.05	**91.54±0.07a**
	20	95.71±0.00	101.84±0.13	98.50±0.05	**98.68±0.06b**
	30	116.63±0.11	130.41±0.18	55.35±0.11	**100.80±0.13c**
	Mean	**102.22±0.05**	**104.00±0.14**	**84.80±0.07**	**97.01±0.09a**
130	10	109.53±0.09	111.18±0.09	98.68±0.13	**106.46±0.10a**
	20	110.63±0.08	104.37±0.19	93.33±0.09	**102.78±0.12b**
	30	118.31±0.12	95.35±0.13	65.85±0.09	**93.17±0.11c**
	Mean	**112.82±0.10**	**103.63±0.14**	**85.96±0.10**	**100.80±0.11d**
140	10	116.27±0.13	108.25±0.05	118.64±0.36	**114.39±0.18a**
	20	110.66±0.11	97.59±0.13	96.58±0.09	**101.61±0.11b**
	30	107.30±0.23	90.44±0.15	86.64±0.25	**94.79±0.21c**
	Mean	**111.41±0.16**	**98.76±0.11**	**100.62±0.23**	**103.60±0.17f**
	Pooled mean	**105.81±8.98c**	**99.32±11.42b**	**94.73±13.80a**	**99.95±12.39**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.5.2 Parenchyma cell height

The result of analysis of variance showed that there were significant differences in all the sources of the variations adopted, there was a significant effect in the interaction effect among the sampling height, temperature variation (°C) and the treatment time (minutes) as shown in Table 16.

The mean values of parenchyma cell height ranged from 102.22 to 112.82µm for the base samples at temperature variations (°C); 0, 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10, 20 and 30 minutes, while the mean value for the middle samples also ranged from 96.37 to 104.00µm and for top samples ranged from 85.96 to 103, 01µm respectively as shown in Table (17).

There is an inconsistent pattern of variation in the mean value of parenchyma cell, Parenchyma cell are food storage cells of a plant, the capacity of the food stored in the parenchyma cells varied from time to time and from base to top. Basically, the mean value of untreated parenchyma cells increased from top to base of *Bambusa vulgaris*. The parenchyma cells of bamboo tends to swollen at certain level of temperature, the new size gained was obviously noticed from the temperature range of 100 to 130 °C while the size abruptly decreased at temperature 140 °C, this revealed the fusion reaction of parenchyma cells to heat modification and the activities of the starch content in the parenchyma cells.

The result of this study revealed that there were inconsistency in the mean values of parenchyma height from top to base, the results evidently shown as shown in figure() the swollen variations of parenchyma cell as mild temperature between 100 and 120 but noticeable decreases in parenchyma cells were recorded at highest temperature and time (140 °C/30minutes). This result is in accordance with the reports of Huang, *et al*, (2015), in their study on the variation in anatomical characteristics of *Bambusa rigida* that, the parenchyma length will cease increasing when the height growth of culms is completed. Furthermore, in all the age classes of bamboo investigated, the length of parenchyma decreased slightly from base to top portion and the middle zone had longer parenchyma cells than that for inner and outer zones. The longest mean length of parenchyma cell (82.79 µm) was observed in the middle zone in the base portion of 3 year old culms, while the shortest parenchyma cells (66.82 µm) was found in the outer zone in the top portion of 1 year old culms. The inconsistent variations in the parenchyma height of a bamboo are due to the fact that bamboo properties are characterised by its own individual characteristics (Liese, 1985). The follow up test further revealed the interaction effect between temperature variation and time (Table 18).

Table 18: Follow up test for interaction between temperature variation and time duration for Parenchyma cell height

Temperature (°C)	Time (minutes)	Mean
100	10	91.32a
120	10	91.54a
110	10	95.70a
130	10	106.46a
140	10	114.39a
110	20	95.98b
untreated	Untreated	98.20b
120	20	98.68b
140	20	101.61b
130	20	102.78b
100	20	102.83b
130	30	93.17c
140	30	94.79c
120	30	100.80c
110	30	105.42c
100	30	109.07c

Mean with the same alphabet are not significantly different from one another

Table 19: Analysis of Variance (ANOVA) of parenchyma width for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2	1681.5064	840.7532	36169.4934*	0.00
Temperature variation(°C)	5	1072.4578	214.4916	9227.50153*	0.00
Treatment time(minutes)	2	1518.0287	759.0144	32653.061*	0.00
Sampling height * Temperature variation(°C)	10	2507.481	250.7481	10787.2705*	0.00
Sampling height * Treatment time(minutes)	4	4209.8955	1052.474	45277.7911*	0.00
Temperature variation(°C) * Treatment time(minutes)	10	975.79493	97.57949	4197.90364*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20	3503.6913	175.1846	7536.50086*	0.00
Error	216	5.02088	0.023245		
Total	270	471529.56			

***=significant at P<0.05**

ns=not significant at P>0.05

Table 20: Mean value of parenchyma cell width (μm) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Mean
0	Untreated	45.31±0.09	38.78±0.14	38.32±0.14	**40.81±0.12d**
100	10	32.87±0.05	25.47±0.08	42.31±0.04	**33.55±0.06a**
	20	37.19±0.11	37.57±0.05	42.67±0.40	**39.15±0.19b**
	30	38.92±0.05	60.22±0.14	41.33±0.11	**46.82±0.10c**
	Mean	**36.33±0.07**	**41.09±0.09**	**42.10±0.18**	**39.84±0.12c**
110	10	37.96±0.05	44.31±0.26	41.53±0.13	**41.26±0.15a**
	20	45.51±0.09	46.29±0.18	40.44±0.11	**44.08±0.13b**
	30	59.30±0.08	47.45±0.18	37.15±0.18	**47.97±0.15c**
	Mean	**47.59±0.08**	**46.02±0.21**	**39.71±0.14**	**44.44±0.14f**
120	10	36.40±0.05	33.65±0.18	41.35±0.09	**37.13±0.11a**
	20	39.84±0.11	34.23±0.08	34.27±0.13	**36.11±0.11b**
	30	53.45±0.09	46.61±0.34	31.51±0.20	**43.85±0.21c**
	Mean	**43.23±0.09**	**38.16±0.20**	**35.71±0.14**	**39.03±0.14a**
130	10	38.34±0.05	43.29±0.00	40.27±0.19	**40.63±0.08a**
	20	52.57±0.11	44.25±0.15	33.21±0.22	**43.34±0.16b**
	30	63.22±0.10	44.63±0.20	27.86±0.09	**45.23±0.13c**
	Mean	**51.38±0.09**	**44.06±0.12**	**33.78±0.17**	**43.07±0.12e**
140	10	34.38±0.05	27.43±0.17	49.26±0.17	**37.02±0.13a**
	20	44.66±0.10	39.36±0.16	38.68±0.19	**40.90±0.15b**
	30	45.84±0.13	45.35±0.19	29.70±0.26	**40.29±0.20c**
	Mean	**41.63±0.10**	**37.38±0.18**	**39.21±0.21**	**39.41±0.16b**
	Pooled mean	**44.24±8.24c**	**40.91±7.80b**	**38.14a±21**	**41.10±7.58**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.1.5.3 Parenchyma cell width

There is a significant difference in all the factors variable tested as shown in Table (19). There was a significant in the interaction effect among sampling height, temperature variation (°C) and treatment time.

The mean values of parenchyma cell width ranged from 36.33 to 51.38µm for the base at temperature variations (°C); 0, 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10, 20 and 30 minutes, while the mean value for the middle also ranged from 37.38 to 46.02µm and for top sampling height ranged from 33.78 to 42.10µm respectively, as shown in Table (20).

There was an increasing trend pattern of parenchyma cell of thermal modification temperature variation(°C) from 100 to 130 °C, the parenchyma cells had swollen laterally and axially within the bamboo culm, and the cells got fused at temperature 140 °C (from 10-30minutes). The intense heat induced-fusion in the parenchyma cells systematically which lead to chemical changes, therefore, the level and hygroscopic tendency of wood reduced, hence creating a dimensional stability in the wood. Wood required a relatively optimum level of temperature to subject it to an irreversible state, to ensuring that wood cells dimensional fit and stable.

The highest parenchyma width values (45.31µm) were recorded in the untreated base and the least value were recorded at top (33.78µm) This study also revealed the ultimate variations in terms of decreases and increases in the thermal-modified bamboo, there were initial decreases in the parenchyma values from base to top between temperatures 100 to 120 °C while the increases in the parenchyma values were recorded between temperatures 120 to 140 °C. The follow up test further revealed the interaction effect between temperature variation and time (Table 21).

Table 21: Follow up test for interaction between temperature variation and time duration for Parenchyma cell width

Temperature (°C)	Time (minutes)	Mean
100	10	33.55a
140	10	37.02a
120	10	37.13a
130	10	40.63a
110	10	41.26a
100	20	39.15b
140	20	40.90b
130	20	43.34b
110	20	44.08b
140	30	40.29c
120	30	43.85c
130	30	45.23c
100	30	46.82c
110	30	47.97c
untreated	untreated	40.81d

Mean with the same alphabet are not significantly different from one another

Table 22: Analysis of Variance (ANOVA) of Vessel counts for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2	2.535	1.268	73100.00*	0.00
Temperature variation(°C)	5	4.027	0.805	46400.00*	0.00
Treatment time(minutes)	2	3.23	1.615	93100.00*	0.00
Sampling height *Temperature variation(°C)	10	0.642	0.064	3700.00*	0.00
Sampling height * Treatment time(minutes)	4	0.644	0.161	9280.00*	0.00
Temperature variation(°C) * Treatment time(minutes)	10	2.884	0.288	16600.00*	0.00
Sampling height *Temperature variation(°C) * Treatment time(minutes)	20	1.084	0.054	3120.00*	0.00
Error	216	0.004	0.00001735		
Total	270	1410.151			

*=significant at P<0.05

ns=not significant at P>0.05

Table 23: Mean value of Vessel counts/ (mm^2) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(^oC)	Treatment time(minutes)	Sampling Base	height Middle	Top	Mean
0	Untreated	2.00±0.05	2.14±0.02	2.35±0.00	**2.17±0.02b**
100	10	2.01±0.00	2.15±0.01	2.21±0.02	**2.12±0.01a**
	20	2.05±0.00	2.19±0.01	2.21±0.02	**2.15±0.01b**
	30	2.13±0.00	2.24±0.01	2.21±0.02	**2.19±0.01c**
	Mean	**2.06±0.00**	**2.19±0.01**	**2.21±0.02**	**2.16±0.01a**
110	10	2.10±0.00	2.23±0.01	2.22±0.00	**2.18±0.00a**
	20	2.10±0.00	2.29±0.01	2.25±0.00	**2.21±0.00b**
	30	2.19±0.00	2.23±0.02	2.32±0.00	**2.25±0.01c**
	Mean	**2.13±0.00**	**2.25±0.01**	**2.26±0.00**	**2.21±0.00c**
120	10	2.15±0.05	2.14±0.02	2.19±0.00	**2.16±0.02a**
	20	2.19±0.05	2.15±0.02	2.31±0.00	**2.22±0.02b**
	30	2.35±0.05	2.24±0.02	2.73±0.00	**2.44±0.02c**
	Mean	**2.23±0.05**	**2.18±0.02**	**2.41±0.00**	**2.27±0.02d**
130	10	2.10±0.05	2.20±0.02	2.14±0.00	**2.15±0.02a**
	20	2.10±0.05	2.25±0.02	2.30±0.00	**2.21±0.02b**
	30	2.41±0.05	2.29±0.02	3.10±0.00	**2.60±0.02c**
	Mean	**2.20±0.05**	**2.24±0.02**	**2.51±0.00**	**2.32±0.02e**
140	10	2.14±0.05	2.29±0.02	2.30±0.00	**2.24±0.02a**
	20	2.20±0.05	2.39±0.02	2.60±0.00	**2.40±0.02b**
	30	2.85±0.05	2.77±0.02	3.10±0.00	**2.91±0.02c**
	Mean	**2.40±0.05**	**2.48±0.02**	**2.66±0.00**	**2.51±0.02f**
	Pooled mean	**2.17±0.20a**	**2.25±0.14b**	**2.40±0.28c**	**2.27±0.24**

Mean with same superscript in the same column are not significantly different ($P<0.05$)

5.1.5.4 Vessel count (mm^2)

There is significant difference in the interaction effect among sampling height, Temperature variation (°C) and time duration (Table 22).

The mean values of vessel count per millimeter square of untreated and thermal-modified bamboo is presented in Table (23).

The mean value of the vessel count at the base ranged from 2.06 to 2.4mm^2, the value ranged from 2.18 to 2.48mm^2 at middle while at top ranged from 2.21 to 2.66 mm^2 for temperature variations (°C); 100,110,120,130 and 140 °C with treatment time (minutes) 10, 20, 30minutes respectively.

There was a significant variation in the sampling height, temperature variation (°C) and treatment time (minutes) at 5% level of probability.

A general trend in increase of vessels counts from base to top was observed. The highest values (3.10µm) of vessel count per mm^2 were recorded at the top samples modified at the highest temperature and time (140 °C/30minutes) , the least vessel count values (2.00µm) were recorded at the untreated base, this compared favourably with the findings of Grosser and Liese, (1971); Kelemwork, (2009); Nordahlia *et al*, (2012) and Haung *et al*, (2014), these observations were so because of the fact that the top portion had thinner culm wall thickness (Grosser and Liese, 1971) This finding is in well agreement with the report of Kelemwork, (2009). At the top portion, vascular bundles are smaller but more per unit area than observed in the base and middle portion of bamboo (Nordahlia *et al*., 2012). Most transfers of water, nutrients, and chemicals occur up and down in a tree through vessel. However, there is some radial transfer across the wood, generally through rays in the hard wood; rays are absent in *Bambusa vulgaris*, only vessels are responsible for transporting of water in bamboo. Sap moves down the tree through the phloem and water through the vessel, more water is expected at the top region of bamboo because of juvenile cells. The follow up test further revealed the interaction effect between temperature variation and time (Table 24).

Table 24: Follow up test for interaction between temperature variation and time duration for Vessel counts/ (mm^2)

Temperature (°C)	Time (minutes)	Mean
100	10	2.12a
130	10	2.15a
100	20	2.15b
120	10	2.16a
Untreated	untreated	2.17b
110	10	2.18a
140	10	2.24a
110	20	2.21b
130	20	2.21b
120	20	2.22b
140	20	2.40b
100	30	2.19c
110	30	2.25c
120	10	2.44c
130	30	2.60c
140	30	2.91c

Mean with the same alphabet are not significantly different from one another

4.1.6 The Stereology Structural quantities and Fundamental parameters for untreated and thermal-modified *Bambusa vulgaris*

Table 25: Mean value of volume fraction of parenchyma cell in transverse and longitudinal sections for untreated and thermal-modified *Bambusa vulgaris*

Sampling height	Temperature variation(^{o}C)	Treatment time(minutes)(minutes)	Parenchyma Longitudinal Volume fraction	Parenchyma transverse Volume fraction
	0	Untreated	0.50±0.00	0.28±0.02
Base	100	10	0.24±0.01	0.38±0.02
		20	0.39±0.00	0.39±0.01
		30	0.52±0.02	0.32±0.13
	110	10	0.67±0.00	0.58±0.00
		20	0.99±0.01	0.50±0.00
		30	0.50±0.00	0.39±0.00
	120	10	0.96±0.06	0.59±0.01
		20	0.93±0.02	0.38±0.14
		30	0.93±0.02	0.38±0.14
	130	10	0.67±0.00	0.42±0.00
		20	0.63±0.07	0.61±0.09
		30	0.63±0.07	0.39±0.02
	140	10	0.46±0.02	0.59±0.01
		20	0.67±0.00	0.74±0.02
		30	0.46±0.02	0.34±0.01
Middle	0	Untreated	0.67±0.00	0.53±0.00
	100	10	0.46±0.02	0.47±0.00
		20	1.00±0.00	0.47±0.00
		30	0.67±0.00	0.78±0.00
	110	10	0.83±0.00	0.39±0.00
		20	0.33±0.00	0.28±0.40
		30	0.33±0.00	0.28±0.40
	120	10	0.50±0.00	0.28±0.00
		20	0.44±0.14	0.28±0.10
		30	1.04±0.00	0.38±0.01
	130	10	0.98±0.01	0.44±0.00
		20	0.67±0.00	0.31±0.00
		30	0.33±0.00	0.47±0.00
	140	10	0.52±0.02	0.39±0.02
		20	1.00±0.00	0.67±0.00
		30	1.00±0.00	0.67±0.00
Top	0	Untreated	0.52±0.01	0.33±0.00
	100	10	0.85±0.02	0.64±0.06
		20	0.85±0.02	0.33±0.00
		30	0.85±0.02	0.48±0.05
	110	10	0.85±0.02	0.42±0.01
		20	1.00±0.00	0.50±0.06
		30	0.67±0.00	0.31±0.00
	120	10	0.67±0.00	0.36±0.00
		20	0.67±0.00	0.37±0.02
		30	0.50±0.00	0.53±0.00
	130	10	1.00±0.00	0.39±0.00
		20	0.25±0.00	0.50±0.00
		30	0.80±0.03	0.39±0.04
	140	10	0.44±0.00	0.33±0.00
		20	0.44±0.00	0.33±0.00
		30	0.44±0.00	0.33±0.00

4.1.6.1 Fundamental parameters

4.1.6.1.1 The parenchyma cell in Radial section of the Volume fraction

The mean volume area of longitudinal section of parenchyma of thermal-modified and untreated is presented in the Table (25) there were inconsistency in the decreasing trend of the volume area from top to base, the mean value ranged from to 0.24 to 0.96 at the base samples, 1.00 to 0.33 at middle while 1.00 to 0.25 at top samples respectively.

The highest volume fraction of parenchyma cell in the untreated samples of *Bambusa vulgaris* was recorded at the middle samples as 0.67, followed by top samples with a volume fraction value of 0.52 while 0.50 at the base samples respectively.

The result of this study revealed that there is an inconsistent trend in pattern of longitudinal parenchyma cells in response to increase in heat modification and treatment time. There were significant increases in parenchyma cells between temperature variation and treatment time 100 °C-10minutes and 120 °C-30minutes, while there were tremendous decreases in the mean values of parenchyma cells between 120^{o}C-10minutes to 140 °C-30minutes. According to this study it was obviously that the heat treatment led to the swelling of parenchyma cells which caused increase in per cell volume, while latter fused after attaining a temperature level in which the chemical constituents (starch) inside the cells could no longer resist, then lead to the decrease in cell per volume of the Parenchyma cell.

4.1.6.1.2 The parenchyma transverse Volume fraction

The mean values of the volume area of parenchyma at the transverse section of thermal-modified and untreated bamboo are presented in the Table 25. There were inconsistency in the decreasing trend of the values, at the base, the values ranged from 0.74 to 0.28, at middle also ranged from 0.78 to 0.28 and at the top the values ranged from 0.64 to 0.31 respectively.

The result in this study revealed that there is an inconsistent trend pattern in the mean value of parenchyma cells in response to heat modification with respect to treatment time, there were increases in the mean values of parenchyma cells within a treatment temperature and time between 100 °C-10minutes to 120 °C-30minutes, while there were latter decreases in the mean values between 120 °C-30minutes and 140 °C-30minutes.

The highest parenchyma cells on transverse section volume fraction mean value in the untreated samples was recorded at the middle (0.53), followed by top (0.33) and base (0.28) samples respectively.

This result is in accordance with the report of Chaowana, (2013), he reported that structure of a bamboo culm transverse section is characterised by numerous vascular bundles embedded in the parenchymatous ground tissue; with total culm tissue consists of 50% parenchyma. This is because Parenchyma cells are the food storage tissue in the plant system.

Table 26(a): Mean value of fibre and vessel Stereology structural quantities for untreated and thermal-modified *Bambusa vulgaris*

Sampling height	emperature variation(°C)	Time duration	Vessel Volume fraction	Fibre sheath Volume fraction	Vessel feature count(mm^2)	Fibre sheath feature count(mm^2)	Vessel intercept count	Fibre sheath intercept count
	0	Untreated	0.19±0.00	0.31±0.00	2.40±0.51	1.50±0.00	3.52±0.23	7.60±0.23
Base	100	10	0.07±0.02	0.36±0.39	3.80±0.45	1.50±0.00	3.52±0.25	7.50±0.21
		20	0.08±0.00	0.47±0.21	2.60±0.55	1.50±0.00	3.98±0.25	7.41±1.57
		30	0.17±0.00	0.19±0.21	2.60±0.55	1.50±0.00	3.43±0.25	9.73±1.31
	110	10	0.22±0.00	0.37±0.41	2.60±0.55	1.25±0.00	2.69±0.39	5.28±0.90
		20	0.22±0.00	0.44±0.34	3.60±0.55	1.00±0.00	2.50±0.25	6.30±0.41
		30	0.12±0.02	0.44±0.34	2.00±0.00	1.00±0.00	2.41±0.39	6.02±0.00
	120	10	0.09±0.01	0.36±0.34	2.00±0.00	1.00±0.00	1.85±0.00	6.02±0.00
		20	0.09±0.01	0.31±0.31	2.00±0.00	1.00±0.00	1.85±0.00	6.02±0.00
		30	0.09±0.01	0.39±0.35	2.40±0.55	1.34±0.15	2.78±0.00	7.41±0.00
	130	10	0.22±0.00	0.39±0.38	2.00±0.00	1.00±0.00	1.85±0.00	7.41±0.00
		20	0.20±0.01	0.31±0.17	2.00±0.00	1.40±0.55	2.78±0.00	4.82±0.84
		30	0.09±0.02	0.31±0.26	5.00±0.00	1.50±0.00	4.17±0.00	9.54±0.25
	140	10	0.18±0.02	0.34±0.39	2.00±0.00	1.00±0.00	2.69±0.21	7.87±0.00
		20	0.08±0.00	0.27±0.39	2.00±0.00	1.00±0.00	3.71±0.00	7.04±0.51
		30	0.09±0.01	0.39±0.39	4.00±0.00	1.50±0.00	2.78±0.00	8.43±0.21
Middle		Untreated	0.28±0.00	0.36±0.00	3.00±0.00	1.70±0.25	2.78±0.00	8.34±0.00
	100	10	0.14±0.01	0.34±0.05	3.00±0.00	1.70±0.27	2.78±0.00	8.34±0.00
		20	0.12±0.02	0.34±0.11	4.00±0.00	2.10±0.22	3.89±0.25	9.26±0.00
		30	0.23±0.02	0.25±0.08	2.60±0.55	1.50±0.00	1.85±0.00	6.49±0.00
	110	10	0.21±0.02	0.35±0.06	2.00±0.00	1.50±0.00	1.85±0.00	9.26±0.00
		20	0.14±0.01	0.39±0.05	2.80±0.45	1.50±0.00	3.15±0.21	6.49±0.00
		30	0.14±0.01	0.37±0.06	4.00±0.00	2.00±0.00	2.96±0.25	10.65±0.00
	120	10	0.14±0.01	0.36±0.04	3.00±0.00	2.00±0.00	3.24±0.00	8.34±0.00
		20	0.18±0.05	0.32±0.03	3.20±0.45	2.00±0.61	3.80±0.60	8.34±0.00
		30	0.12±0.01	0.28±0.13	3.00±0.00	1.50±0.00	2.78±0.00	7.87±0.00
	130	10	0.11±0.00	0.37±0.03	3.00±0.00	1.75±0.00	2.78±0.00	7.87±0.00
		20	0.19±0.00	0.27±0.07	3.00±0.00	1.60±0.22	3.71±0.33	5.10±0.00
		30	0.23±0.01	0.30±0.04	2.00±0.00	1.50±0.00	3.34±0.21	7.87±0.00
	140	10	0.22±0.00	0.31±0.09	3.20±0.45	1.50±0.00	3.89±1.01	11.30±0.41
		20	0.18±0.02	0.35±0.06	7.80±0.45	2.34±0.42	6.49±0.00	8.34±0.00
		30	0.18±0.02	0.30±0.14	7.60±0.55	2.40±0.42	6.49±0.00	8.34±0.00
Top	0	Untreated	0.23±0.04	0.28±0.00	3.20±0.41	1.50±0.00	3.34±0.43	9.26±0.00
	100	10	0.14±0.06	0.28±0.00	3.20±0.45	1.50±0.00	3.71±0.00	9.64±0.39
		20	0.10±0.02	0.33±0.00	3.60±0.55	2.00±0.00	4.08±0.21	7.13±0.96
		30	0.18±0.05	0.36±0.00	3.80±0.45	2.00±0.00	4.08±0.21	7.78±0.21
	110	10	0.18±0.06	0.28±0.00	4.00±0.00	1.80±0.45	3.71±0.00	10.19±0.00
		20	0.18±0.03	0.39±0.00	3.00±0.00	1.60±0.22	3.71±0.00	8.80±0.00
		30	0.18±0.07	0.32±0.02	3.00±0.00	1.60±0.22	3.71±0.00	8.80±0.00
	120	10	0.15±0.06	0.39±0.04	2.00±0.00	1.00±0.00	3.24±0.33	6.02±0.00
		20	0.17±0.07	0.36±0.00	4.00±0.00	2.00±0.00	4.63±0.00	6.02±0.00
		30	0.16±0.09	0.11±0.00	4.00±0.00	2.00±0.00	4.63±0.00	6.02±0.00
	130	10	0.17±0.05	0.33±0.00	3.00±0.00	1.50±0.00	3.71±0.00	6.49±0.00
		20	0.20±0.01	0.33±0.00	4.00±0.00	1.50±0.00	3.71±0.00	5.10±0.00
		30	0.17±0.06	0.33±0.00	4.00±0.00	2.00±0.00	3.71±0.00	6.02±0.00
	140	10	0.22±0.04	0.20±0.01	4.00±0.00	2.00±0.00	3.71±0.00	9.73±0.00
		20	0.18±0.08	0.39±0.01	6.00±0.00	2.00±0.00	5.56±0.00	9.91±0.25
		30	0.18±0.08	0.11±0.00	6.60±0.55	2.00±0.00	6.02±0.00	9.73±0.00

4.1.6.2 The Structural quantities of *Bambusa vulgaris* Vessels and fibre sheath cells Stereology

4.1.6.2.1 The mean value of vessel volume fraction

The mean values for the volume fraction of vessel of untreated and thermal-modified *Bambusa vulgaris* is presented in table (26a).

The mean value of vessel volume fraction for the base, middle and top samples for the adopted treatment temperature variation and treatment time ranged from 0.07 to 0.22, 0.30 to 0.39 and 0.14 to 0.22.

The mean values of untreated *Bambusa vulgaris* at base, middle and top height were; 0.19, 0.28 and 0.23 respectively.

This result is in accordance with the work of Mohammed and Nasroun, (2012) they reported that the volume fractions of vessels decreased from top height to bottom height, and also decreased from zone 1 to zone 3 and then increased in zone 4. With regards to cell dimensions, average vessel diameters decreased from top height to bottom height because more vessels are found in the top than in the base.

4.1.6.2.2 The mean of fibre sheath volume fraction

The mean value of fibre sheath volume fraction of untreated and thermal-modified *Bambusa vulgaris* is presented in Table (26a), the mean value for the fibre sheath at the base with effect to treatment temperature and treatment time; 100, 110, 120, 130 and 140 °C and treatment time 10, 20 and 30minutes, ranged from 0.27 to 0.47 at the base, while the mean value for middle ranged from 0.25-0.39, and the mean value for top also ranged from 0.11 to 0.39 for the top samples.

There is an inconsistent pattern of variation in the mean values from base to top, and from treatment temperature and time from 100 °C-10minutes to 140 °C-30minutes, the mean value increased at the treatment temperature and time from 100°C-10minutes to 120 °C-30minutes, while the mean values decreased from treatment temperature and time from 120 °C-30minutes to 140 °C-30minutes. The mean values of fibre sheath volume fraction for the untreated base, middle and top samples of *Bambusa vulgaris* were; 0.31, 0.36 and 0.26, respectively.

The result revealed that fibre sheath properties is not responsible for the higher density observed at the top, it was reported that fibrous tissues primarily act in mechanical support role. More so, Mohammed and Nasroun, (2012) reported that the average fibre length of bamboo decreased gradually from top height to bottom height. Both of which showed a gradual decrease from top height to bottom height. With regards to fibre volume fractions, Thus it can be concluded that the higher density observed at the top portion of the bamboo is mostly due to the higher fibrous tissue percentage, Photomicrograph alone cannot sufficiently address quantitative anatomy, also, the new group of design based Stereology methods has been found useful for microstructure quantification at limited levels. It seems that the conventional serial sectioning analysis may still be necessary if a more detail quantitative description of the microstructure is required (Huang *et al.*, 2015).

4.1.6.2.3 The mean value of fibre sheath intercepts count

The mean values of fibre sheath intercept count of thermal *Bambusa vulgaris* is presented at Table (26a), the mean value for base, middle and top ranged from 4.82 to 9.73mm^2, 5.10 to 11.30mm^2 and 5.1 to 10.19mm^2, respectively in Table 26a.

The result of this study revealed that there was an inconsistent variation in the mean value of fibre sheath intercept count in respect to the treatment temperature and time from 100 °C-10minutes to 140°C-30minutes. The mean value for untreated base, middle and top samples were as follows; 3.52, 2.78 and 3.34mm^2, respectively. While, the highest mean value in the untreated samples was recorded at the base because more fibre and biggest fibre sheath were recorded at the base of bamboo.

4.1.6.2.4 The mean value of fibre sheath feature count

The mean value of fibre sheath feature count of untreated and thermal-modified *Bambusa vulgaris* is presented in the Table (26a). The mean value of fibre sheath feature count at base, middle and top samples at treatment temperature variation and time; 100, 110, 120, 130 and 140 °C with; 10, 20 and 30 minutes ranged from 1 to 1.5mm^2, 1.5 to 2.40mm^2 and 1 to 2.0mm^2 respectively.

There is an inconsistent variation in the mean value of fibre feature count in respect to heat modification and time factor from 100 °C-10minutes to 140 °C-30minutes. The untreated samples; base, middle and top mean value were recorded as 1.50, 1.70 and 1.50mm^2 respectively.

The result is in line with report of Huang *et al*, (2014), they opined that the fibrous tissue proportion in cross section of bamboo increased significantly from base towards the top, ranging from 39 to 57 %. This trend in fibrous proportion along culm height is a result of the number of fibres sheath found at tapered top portion was more than other portions.

4.1.6.2.5 The mean value of vessel intercepts count

The mean value of vessel intercept count of untreated and thermal-modified *Bambusa vulgaris* is presented in Table (26a).

The mean values for the base, middle and top samples at temperature variations; 100, 110, 120. 130 and 140 °C with treatment time; 10, 20 and 30minutes ranged from 1.85 to 4.17mm^2, 1.85 to 6.49mm^2 and 3.71 to 6.02mm^2 respectively.

There is an inconsistence variation in the mean value of vessel intercept count from base to top samples and from treatment temperature and time; 100 °C-10minutes to 140 °C-30minutes.the mean values for the untreated base, middle and top samples were3.52, 2.78 and 3.34mm^2 respectively.

4.1.6.2.6 The mean value of vessel feature count

The mean value of vessel feature count of untreated and thermal-modified *Bambusa vulgaris* is presented at the Table 26a.

The mean value at base, middle and top samples with treatment temperature variations; 100, 110, 120,130 and 140 °C and treatment time 10, 20 and 30 minutes ranged from 2.00 to 3.60mm^2, 2.00 to 4.00mm^2 and from 2.00 to 6.60mm^2, respectively.

The result revealed a gradual increasing trend in mean value of vessel from base to top. The mean values for the untreated samples at base, middle and top were, 2.0, 3.0 and 3.20mm^2 respectively.

Table 26(b): Mean value of fibre and vessel Stereology fundamental parameters for untreated and thermal-modified *Bambusa vulgaris*

Sampling height	Temperature variation(°C)	Time duration	Average vessel perimeter (mm^2)	Average fibre sheath perimeter(mm^2)
	0	Untreated	314.47±79.73	1208.00±279.86
Base	100	10	191.83±35.42	1018.60±28.12
		20	320.76±51.67	1006.00±213.22
		30	279.88±70.67	1320.40±177.84
	110	10	220.13±62.89	860.13±147.08
		20	144.66±29.73	1282.60±84.36
		30	245.29±39.47	1226.10±0.00
	120	10	188.68±0.00	1226.10±0.00
		20	188.68±0.00	1226.10±0.00
		30	245.29±51.67	1136.80±121.14
	130	10	188.68±0.00	1509.00±0.00
		20	283.03±0.00	763.93±245.94
		30	169.82±0.00	1295.20±34.44
	140	10	273.59±21.10	1603.30±0.00
		20	377.37±0.00	1433.50±103.31
		30	141.51±0.00	1144.30±28.12
Middle		Untreated	188.68±0.00	1131.70±0.00
	100	10	188.68±0.00	1018.60±154.97
		20	198.12±12.92	905.40±84.36
		30	150.95±34.45	880.25±0.00
	110	10	188.68±0.00	1257.50±0.00
		20	235.86±54.47	880.25±0.00
		30	150.95±12.92	1084.60±0.00
	120	10	220.13±0.00	848.81±0.00
		20	243.72±42.34	950.67±426.10
		30	188.68±0.00	1068.90±0.00
	130	10	188.68±0.00	916.18±0.00
		20	251.58±22.24	657.04±77.33
		30	339.63±21.10	1068.90±0.00
	140	10	248.44±63.29	1534.10±56.24
		20	169.82±10.55	742.84±121.12
		30	174.53±12.92	724.32±122.68
Top	0	Untreated	239.00±26.04	1257.50±0.00
	100	10	239.00±28.13	1307.80±52.60
		20	234.28±32.13	726.21±97.79
		30	221.70±35.77	792.22±21.09
	110	10	188.68±0.00	1244.90±463.96
		20	251.58±0.00	1134.90±133.56
		30	251.58±0.00	1134.90±133.56
	120	10	330.20±33.36	1226.10±0.00
		20	235.86±0.00	613.03±0.00
		30	235.86±0.00	613.00±0.00
	130	10	251.58±0.00	880.25±0.00
		20	188.68±0.00	691.62±0.00
		30	188.68±0.00	613.03±0.00
	140	10	188.68±0.00	990.28±0.00
		20	188.68±0.00	1009.10±25.83
		30	186.89±15.99	990.28±0.00

4.1.6.3 The Structural quantities

4.1.6.3.1The mean average fibre sheath perimeter

The mean values of the volume area of fibre sheath of untreated and thermal-modified *Bambusa vulgaris* is presented in the Table (26b).

There were inconsistent variations in the mean values of thermal-modified *Bambusa vulgaris* with treatment temperature and time variations; 100, 110, 120, 130 and 140 °C and treatment time 10, 20, and 30minutes ranged from 1603.30 to 860.13µm at the base, 1534.10 to 657.04µm at the middle samples and from 1307.80 to 613.03µm at the top samples respectively.

The result revealed at the transverse section of *Bambusa vulgaris* samples the average mean values of numbers of fibre cells per fibre sheath at base, middle and top samples as 189, 240 and 140 respectively.

4.1.6.3.2 The mean average vessel perimeter

The average mean values of vessel perimeter of untreated and thermal-modified and *Bambusa vulgaris* is presented in the Table (26b). The mean values of thermal-modified *Bambusa vulgaris* with treatment temperature variations; 100, 110, 120, 130 and 140 °C and treatment time; 10, 20, and 30minutes, at base samples ranged from 144.66 to 377.37µm, at the middle samples the values ranged from 150.95 to 251.58µm while at the top samples ranged from 186.89 to 251.58µm respectively.

4.1.7 Microstructure

4.1.7.1 Photomicrograph of the Transverse sections and Radial sections of untreated and thermal-modified *Bambusa vulgaris*

The result of the Photomicrograph on Transverse section (TS) and Radial sections (RS) revealed that there were visible structural changes in the anatomical features of thermal-modified *Bambusa vulgaris;* such as swelling and shrinkage nature of parenchyma cells, fibre cells and vessels in response to heat modification. Generally, all the microcells swell gradually in response to the minimum treatment temperature and latter fused at maximum temperature, also, the heat modification gradually decreases the vessels diameters and perimeter with an increase in the treatment temperature and time.

The results also, revealed the impact of heat modification on the fibres and its shrinkage tendency and responses to heat modification were obviously and visibly noticed.

All the various anatomical structural changes were illustrated in the Plates as follows; Treated base samples Plate:11(a)-(l), Treated Middle samples, Plate 12:(a)-(l), Treated Top samples, Plate 13:(a)-(j), Control Base samples, Plate14:(a)-(b), Control Middle samples Plate 15: (a)-(b), Control Top samples Plate16: (a)-(b).

4.1.7.2 Scanning Electron Microscope (SEM)

The result of Scanning electron microscope (SEM) images are presented in Plate 17-19, the images from SEM along the transverse and radial sections revealed that the thermal modification lead to visible damage to the bamboo samples. At high treatment temperature most especially on the fibre and the parenchyma cells, there were visible distortion on the cells of fibre and parenchyma cell at highest temperature (140 °C/30minutes), while mild changes to the anatomical structures were observed at lower temperature variations. This is in agreement with the report of Colla *et al*, (2011), in their study on the effect of thermal treatment on the physicochemical characteristics of Giant Bamboo, they reported that parenchyma cells were severely contracted at temperature 140 °C and noted some fissured starch grains and burst at temperature 220 °C.

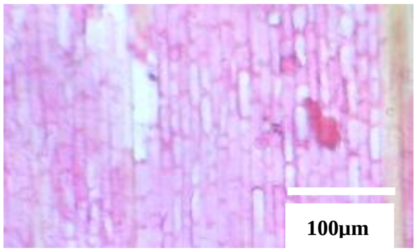


Plate 11(a): Base RS (100^{o}C-10mins) Mag.140x

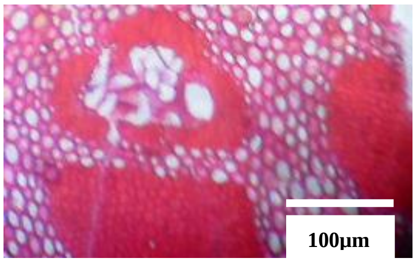


Plate 11(b): Base TS (100^{o}C-10mins) Mag.140x

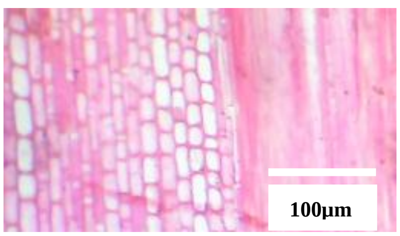


Plate 11(c): Base TS (100 ^{o}C-30mins) Mag.140x

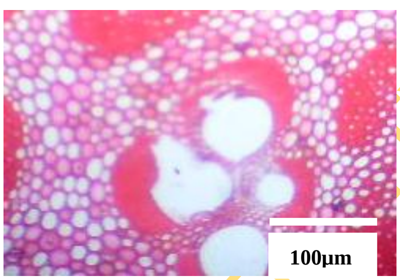


Plate 11(d): Base TS (100 ^{o}C-30mins) Mag.140x

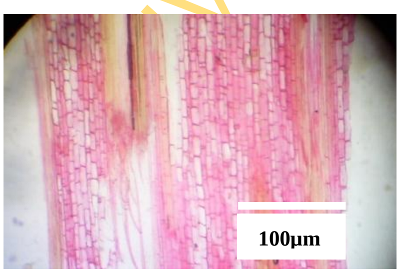


Plate 11(e): Base RS (110 ^{o}C-30mins) Mag.140x

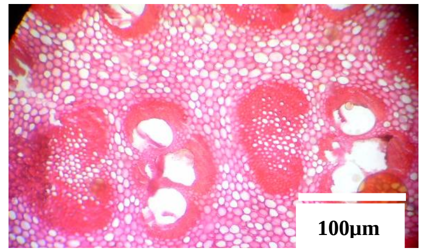


Plate 11(f): Base TS (110 ^{o}C-30mins) Mag.140x

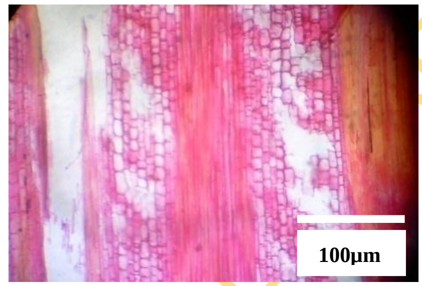


Plate 11(g): Base RS (120 ^{o}C-30mins) Mag.140x

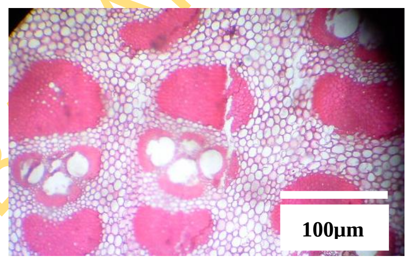


Plate 11(h): Base TS (120 ^{o}C-30mins) Mag.140x

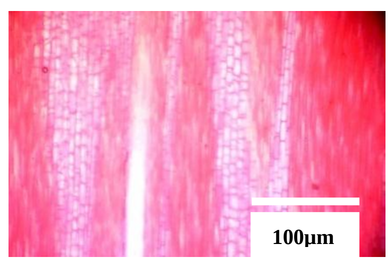


Plate 11(i): Base RS (130 ^{o}C-30mins) Mag.140x

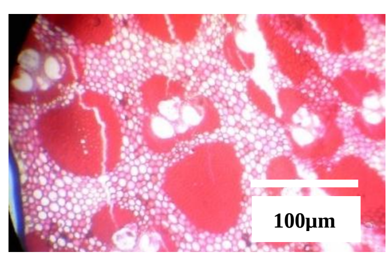


Plate 11(j): Base TS (130 ^{o}C-30mins) Mag.140x

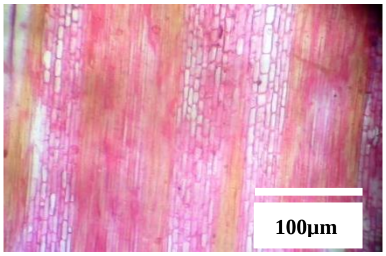


Plate 11(k): Base RS (139 ^{o}C-30mins) Mag.140x

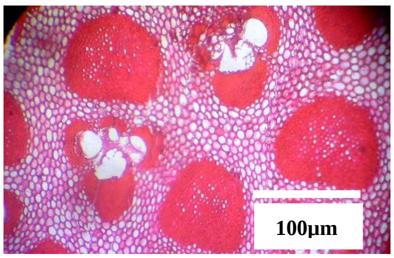


Plate 11(l): Base TS (139 ^{o}C-30mins) Mag.140x

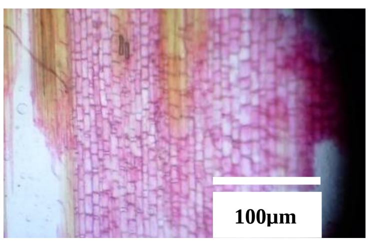


Plate 12(a): Middle RS (100 ^{o}C-10mins) Mag.140x

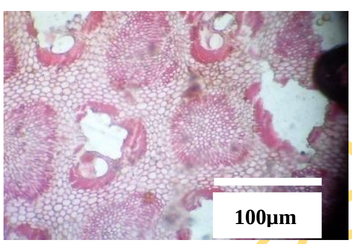


Plate 12(b): Middle TS (100 ^{o}C-10mins) Mag.140x

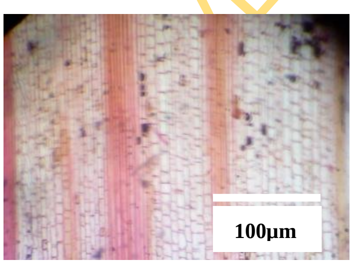


Plate 12(c): Middle RS (100 ^{o}C-30mins) Mag.140x
(b)

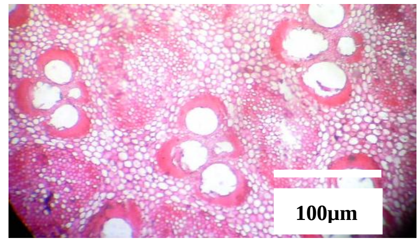


Plate 12(d): Middle TS (100 ^{o}C-30mins) Mag.140x

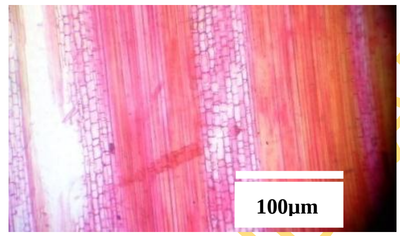


Plate 12(e): Middle RS (110 ^{o}C-30mins) Mag.140x

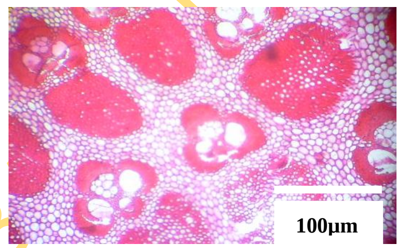


Plate 12(f): Middle TS (110 ^{o}C-30mins) Mag.140x

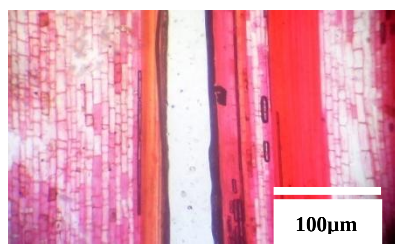


Plate 12(g): Middle RS (120 ^{o}C-30mins) Mag.140x

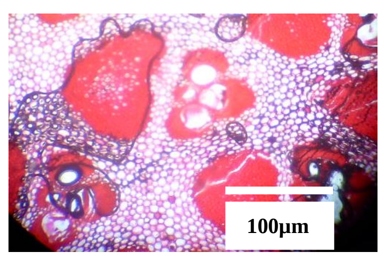


Plate 12(h): Middle TS (120 ^{o}C-30mins) Mag.140x

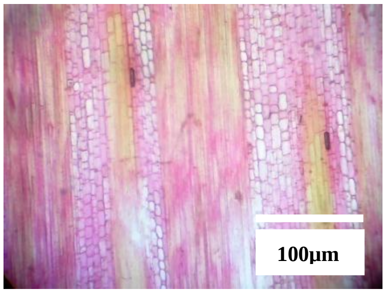


Plate 12(i): Middle R.S (130 °C-30mins) Mag.140x

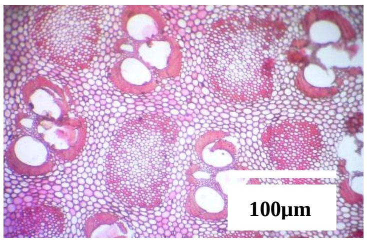


Plate 12 (j): Middle TS (130 °C-30mins) Mag.140x

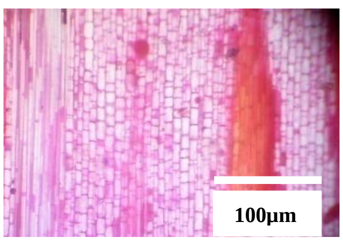


Plate 12 (k): Middle RS (139 °C-30mins) Mag.140x

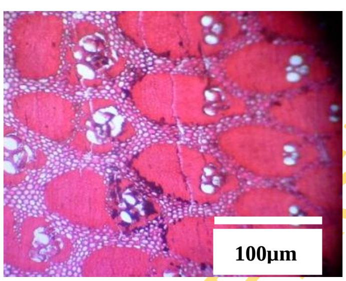


Plate 12 (l): Middle TS (139 °C-30mins) Mag.140x

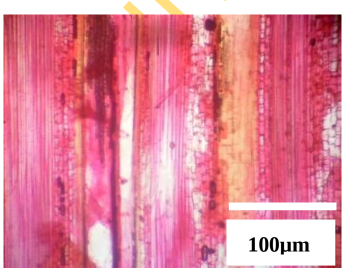


Plate 13 (a): Top RS (100 °C-10mins) Mag.140x

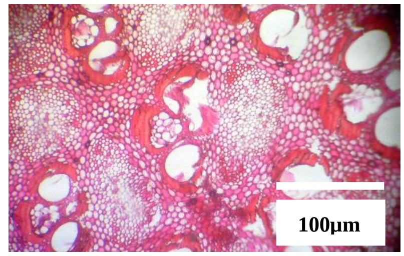


Plate 13(b): Top TS (100 °C-10mins) Mag.140x

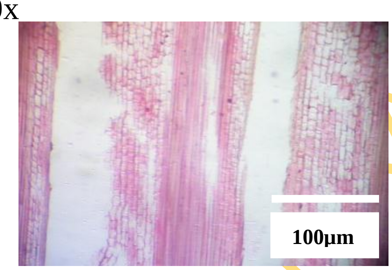


Plate 13(c): Top RS (110 °C-30mins) Mag.140x

Plate 13(d): Top TS (110 °C-30mins) Mag.140x

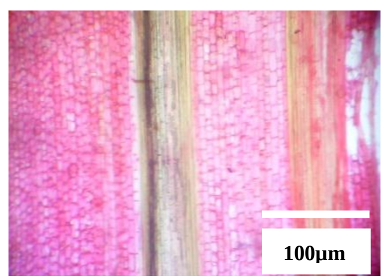


Plate 13(e): Top RS (120 °C-30mins) Mag.140x

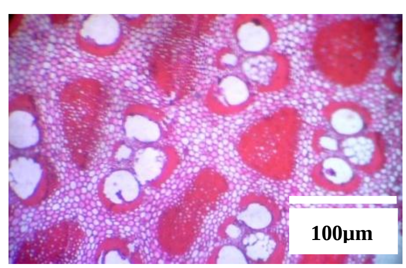


Plate 13(f): Top TS (120 °C-30mins) Mag.140x

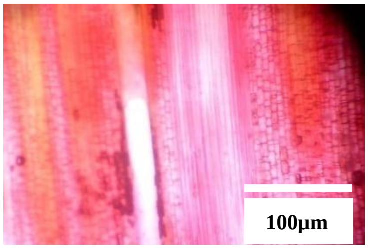


Plate 13(g): Top RS (130 °C-30mins) Mag.140x

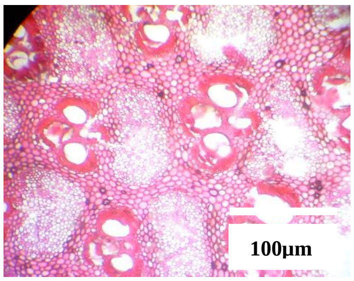


Plate 13(h): Top TS (130 °C-30mins) Mag.140x

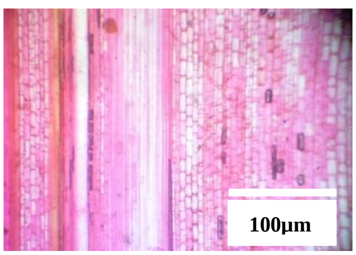


Plate 13(i): Top RS (139 °C-10mins) Mag.140x

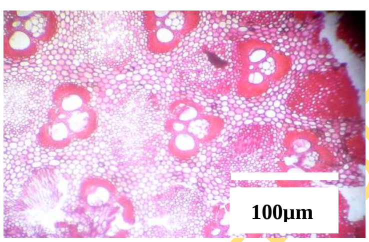


Plate 11(j): Top TS (139 °C-30mins) Mag.140x

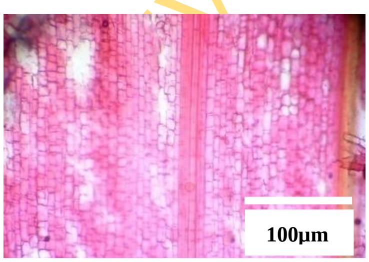


Plate 14(a): Base RS (Control) Mag.140x

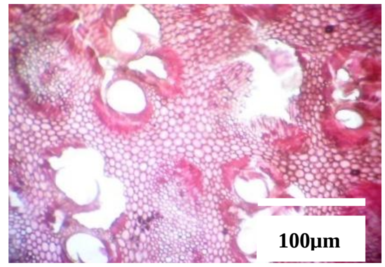


Plate 14(b): Base TS (Control) Mag.140x

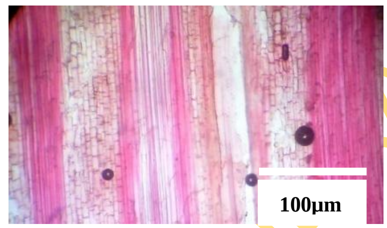


Plate 15(a): Middle RS (Control) Mag.140x

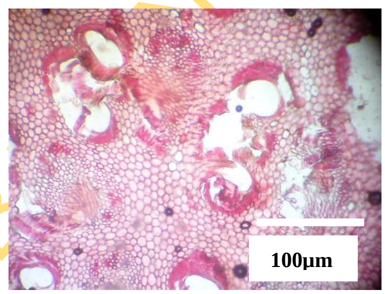


Plate 15(b): Middle TS (Control) Mag.140x

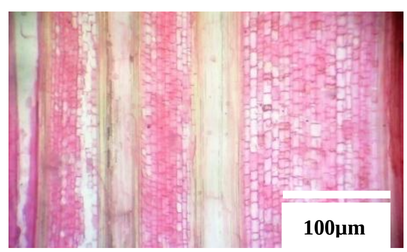


Plate 16(a): Top RS (Control) Mag.140x

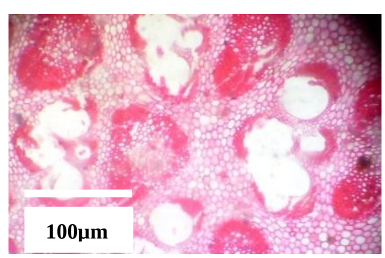


Plate 16(b): Top TS (Control) Mag.140x

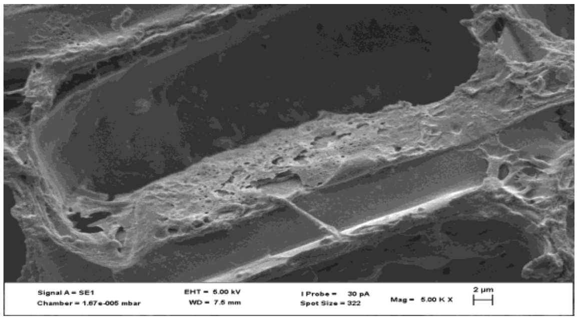


Plate17 (a): *Bambusa vulgaris* Base (Control) Mag.5000x

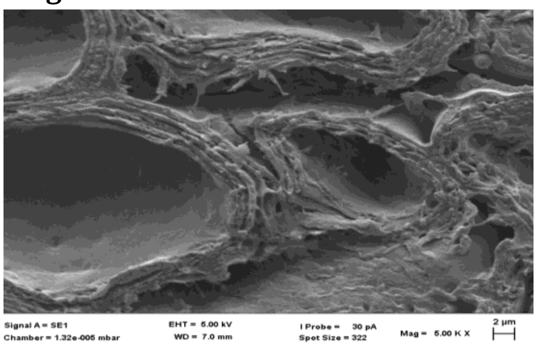


Plate17 (b): *Bambusa vulgaris* Base (140 °C-30minutes) Mag.5000x

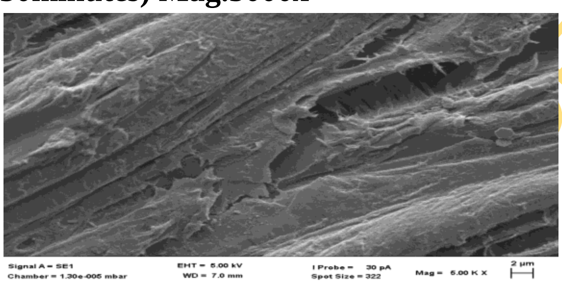


Plate 17 (c): *Bambusa vulgaris* Base (140 °C - 30minutes) Mag.5000x

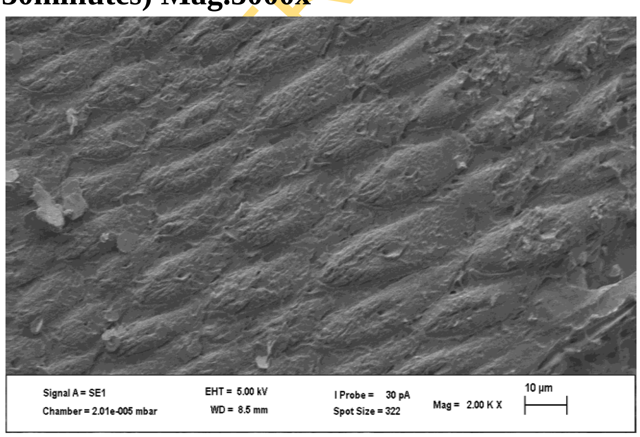


Plate17 (d): *Bambusa vulgaris* Base (140 °C-30minutes) Mag.2000x

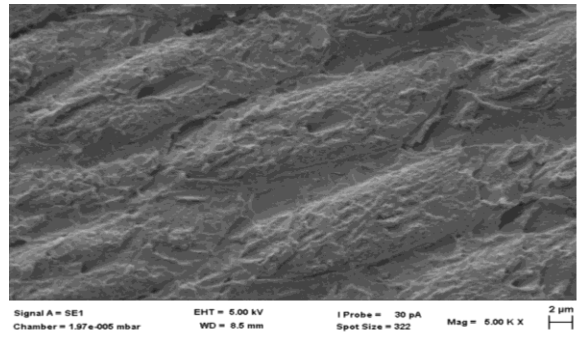


Plate18 (a): *Bambusa vulgaris* Middle (Control) Mag.5000x

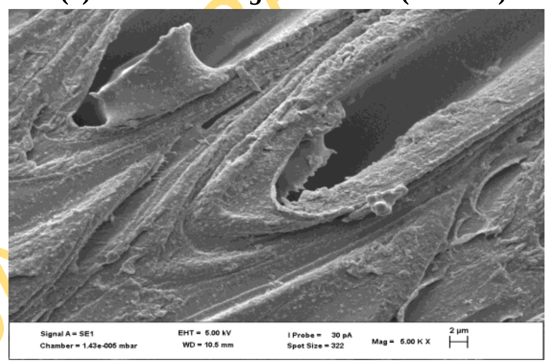


Plate 18 (b): *Bambusa vulgaris* Middle (120°C-30minutes) Mag.5000x

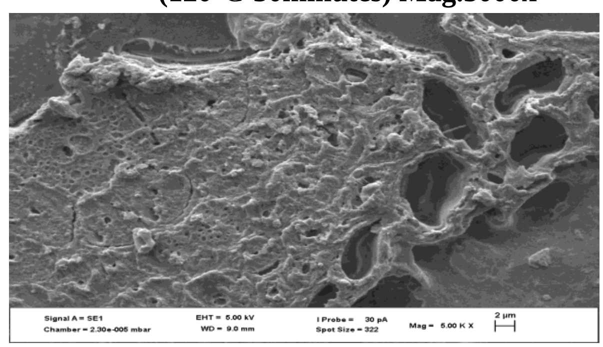


Plate19 (a): *Bambusa vulgaris* Top(Control) Mag.5000x

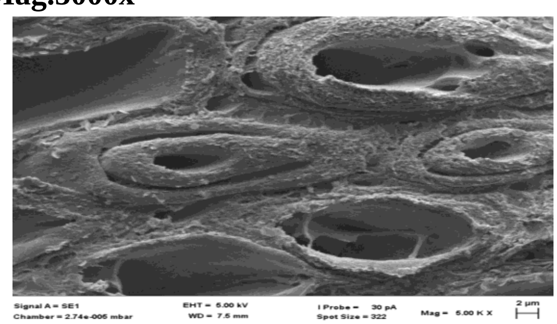


Plate 19 (b): *Bambusa vulgaris* Top (140 °C-30minutes) Mag.5000x

4.2 Physical Properties of Untreated and Thermal-Modified *Bambusa vulgaris*

4.2.1 Colour of the untreated and thermal-modified *Bambusa vulgaris*.

Colour of the untreated and the thermal-modified bamboo strips was physically observed both immediately and after thermal treatment at different temperature regime and treatment time, as shown in Plate 20

The thermal-modified *Bambusa vulgaris* tended to change in colour as showed in (figure 13) the colour changed from yellow to brown and darker brown. The untreated colour of *Bambusa vulgaris* is light yellow as revealed through the comparison with laboratory colour chart. The colour turned to brown at the temperature 120 °C-30minutes and turned darker brown at temperature 140 °C. This observation is in line with report of Natividad and Jimenez, (2015) in their study on thermal modification of *Bambusa blumena schltes*, the properties of the bamboo were altered with exposure to high temperature and long treatment duration, and the bamboo colour changed from light yellow of untreated samples to brown and latter darker brown at a steady increase in temperature variations (°C) and treatment time (minutes). Some studies have already reported that thermal modification induced wood darkening and reddening (Johansson and Morén, (2006); Lopes 2010; Aksoy *et al,* (2011). Other authors, however, reported reduction of red tonality as a function of heating (Pincelli, 1999; De-Moura and Brito, (2011). In general, heat treated wood is often appreciated for its light-brown to dark-brown appearance (Viitanen *et al.*, 1994), the variation in colour changes on heat modified specimens with untreated colour became significantly darker with increasing treatment temperature and time compared with control samples. This may also be due to an increase in lignin content with heat treatment temperature and treatment time (minutes). Coloured by-products formed during the degradation of hemicelluloses might have a contribution to this change in appearance (Kocaefe *et al.*, 2008).

Plate 20: Colour variations in the thermal modification of *Bambusa vulgaris*

Table 27: Analysis of Variance (ANOVA) of Specific Gravity for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	0.50	0.25	185.98*	0.00
Temperature variation(°C)	5.00	0.17	0.03	25.74*	0.00
Treatment time(minutes)	2.00	0.62	0.31	232.84*	0.00
Sampling height * Temperature variation(°C)	10.00	0.12	0.01	8.60*	0.00
Sampling height * Treatment time(minutes)	4.00	0.04	0.01	6.86*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	0.18	0.02	13.44*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	0.08	0.00	2.94*	0.00
Error	216.00	0.29	0.00		
Total	270.00	83.51			

*=significant at P<0.05
ns=not significant at P>0.05

Table 28: Mean value of Specific gravity (SG) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling height Base	Middle	Top	Pooled Mean
0	Untreated	0.63±0.05	0.58±0.05	0.58±0.06	**0.60±0.05d**
100	10	0.64±0.01	0.60±0.02	0.58±0.06	**0.60±0.03c**
	20	0.61±0.02	0.52±0.02	0.44±0.03	**0.52±0.02b**
	30	0.57±0.01	0.47±0.04	0.37±0.03	**0.47±0.02a**
	Mean	**0.61±0.01**	**0.53±0.03**	**0.46±0.04**	**0.53±0.03b**
110	10	0.65±0.01	0.57±0.01	0.52±0.06	**0.58±0.03c**
	20	0.65±0.01	0.51±0.03	0.46±0.02	**0.54±0.02b**
	30	0.48±0.07	0.42±0.03	0.40±0.03	**0.43±0.04a**
	Mean	**0.59±0.03**	**0.50±0.02**	**0.46±0.04**	**0.52±0.03a**
120	10	0.65±0.00	0.66±0.04	0.62±0.02	**0.64±0.02c**
	20	0.64±0.01	0.50±0.04	0.55±0.03	**0.56±0.02b**
	30	0.59±0.03	0.43±0.02	0.42±0.03	**0.48±0.03a**
	Mean	**0.63±0.01**	**0.53±0.03**	**0.53±0.03**	**0.56±0.02c**
130	10	0.65±0.02	0.59±0.02	0.59±0.03	**0.61±0.02c**
	20	0.58±0.04	0.54±0.02	0.54±0.01	**0.55±0.02b**
	30	0.52±0.02	0.46±0.06	0.45±0.09	**0.48±0.06a**
	Mean	**0.58±0.02**	**0.53±0.03**	**0.52±0.05**	**0.55±0.03b**
140	10	0.65±0.01	0.63±0.03	0.54±0.03	**0.61±0.03c**
	20	0.60±0.02	0.58±0.01	0.47±0.04	**0.55±0.02b**
	30	0.53±0.05	0.51±0.04	0.37±0.02	**0.47±0.04a**
	Mean	**0.59±0.03**	**0.57±0.03**	**0.46±0.03**	**0.54±0.03b**
	Pooled mean	**0.61±0.06c**	**0.54±0.07b**	**0.50±0.09a**	**0.55±0.09**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.2 Specific gravity (S.G)

There is a constant decrease in S.G from base to top there were significant effect in the 3effect of interaction among the sampling height, temperature variation (°C) and treatment time (minutes) as shown in Table 26.

The mean value of the specific gravity of the thermal-modified bamboo is presented in Table 27

The result of analysis of variance on the S.G as a result of the treatment effect, the sampling height temperature variation (°C) and treatment time (minutes) had significant effect on the specific gravity at 5% level of probability.

The mean value for thermal-modified bamboo at temperature variations (°C); 100, 110, 120, 130, and 140 °C with respective treatment time (minutes); 10, 20 and 30minutes at base ranged from 0.61 to 0.59, 0.57 to 0.50 at middle and decreased from 0.46 to 0.53 at the top. The specific gravity values tended to decrease along the culm from base to top, the effect of the thermal modification on bamboo samples mean values at temperature at 100 to 140 °C decreased also the treatment time from 10 to 30 minutes also decreased.

For untreated samples, the value of SG was observed at conditioned moisture content 12%. The S.G of the thermal-modified bamboo at base for temperature 100 were noticed to increase more than untreated samples, this revealed the hygroscopic nature of wood as it readily take up moisture from atmosphere until it reaches Fibre Saturated Point (FSP). The treatment effect was not significant at the temperature 100 °C, to have reduced its values compared with untreated samples.

The result of the thermal-modified bamboo revealed a decreasing trend of S.G from the base to the top, however, density of a wood is directly proportional to its specific gravity, this is in contrary to the report of Razak *et al,* (2010); Kamruzzaman *et al,* (2008), they opined that there was an increasing trend of basic density from the base toward the top of bamboo. In this study, the mean values of S.G of thermal-modified *Bambusa vulgaris* decreases from base top height, the highest value of S.G was observed in the untreated samples, while the least S.G value was recorded in the highest temperature (140 °C) adopted. Heating treatment time (minutes) between 10 to 30 minutes also had a significant effect on the S.G values of thermal modification in such that the SG recorded at 30minutes of a particular temperature is lesser than of its 10minutes. Also, the trend of thermal modification effect on the S.G of *Bambusa vulgaris* is contrary to the report of Brito *et al*, (2006), they studied the specific gravity of *Eucalyptus grandis* wood submitted to thermal treatment ranging from 120, 140, 160, 180 and 200 °C. The authors reported that the specific gravity of thermally treated wood was not different from that obtained from natural wood. However, in a previous study by Kortelainen *et al*, (2005), on samples of Scots pine and Norway spruce thermally treated at 130 and 230 °C, both weight loss and specific gravity reduction by heat were reported by Santo *et al*, (2014).

The follow up test further revealed the interaction effect between temperature variation and time (Table 29).

Table 29: Follow up test for interaction between temperature variation and time duration for Specific gravity (SG)

Temperature (°C)	Time (minutes)	Mean
110	30	0.43a
100	30	0.47a
140	30	0.47a
120	30	0.48a
130	30	0.48a
100	20	0.52b
110	20	0.54b
130	20	0.55b
140	20	0.55b
120	20	0.56b
110	10	0.58c
100	10	0.60c
130	10	0.61c
140	10	0.61c
120	10	0.64c
untreated	Untreated	0.60d

Mean with the same alphabet are not significantly different from one another

Table 30: Analysis of Variance (ANOVA) of percentage Equilibrium Moisture Content (EMC) of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	40.47	20.24	33.60*	0.00
Temperature variation(°C)	5.00	496.08	99.22	164.76*	0.00
Treatment time(minutes)	2.00	100.09	50.04	83.10*	0.00
Sampling height * Temperature variation(°C)	10.00	52.43	5.24	8.71*	0.00
Sampling height * Treatment time(minutes)	4.00	9.43	2.36	3.92*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	57.71	5.77	9.58*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	14.88	0.74	1.24ns	0.23
Error	216.00	130.08	0.60		
Total	270.00	17952.90			

***=significant at P<0.05**
ns=not significant at P>0.05

Table 31: Mean value of percentage Equilibrium Moisture Content (EMC) for untreated and thermal modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	10.84±0.74	10.42±1.20	10.18±1.83	**10.48±1.26e**
100	10	9.32±0.73	9.74±0.74	10.68±0.12	**9.91±0.53c**
	20	8.12±0.20	8.24±0.25	9.62±0.44	**8.66±0.30b**
	30	6.86±0.32	7.51±0.19	8.03±0.49	**7.46±0.33a**
	Mean	**8.10±0.42**	**8.50±0.39**	**9.44±0.35**	**8.68±0.39d**
110	10	8.29±0.55	10.30±0.17	9.66±0.47	**9.42±0.40c**
	20	6.89±0.42	7.31±1.25	8.73±0.42	**7.64±0.70b**
	30	6.09±0.29	6.30±0.00	7.31±0.78	**6.57±0.36a**
	Mean	**7.09±0.42**	**7.97±0.47**	**8.56±0.56**	**7.87±0.48c**
120	10	6.57±0.38	9.18±0.37	10.31±0.15	**8.69±0.30c**
	20	6.09±0.04	7.44±0.58	8.66±0.47	**7.40±0.36b**
	30	6.07±0.00	6.23±0.20	7.19±0.40	**6.50±0.20a**
	Mean	**6.24±0.14**	**7.62±0.38**	**8.72±0.34**	**7.53±0.29b**
130	10	6.46±0.57	7.96±0.26	7.01±0.80	**7.14±0.54c**
	20	6.03±0.04	6.42±0.41	6.09±0.13	**6.18±0.19b**
	30	6.03±0.04	6.06±0.00	6.00±0.00	**6.03±0.01a**
	Mean	**6.17±0.22**	**6.81±0.22**	**6.37±0.31**	**6.45±0.25a**
140	10	6.10±0.09	7.72±0.79	6.99±0.58	**6.94±0.49c**
	20	6.06±0.00	6.63±0.00	6.18±0.10	**6.29±0.03b**
	30	6.06±0.00	7.17±1.19	7.09±2.43	**6.77±1.21a**
	Mean	**6.07±0.03**	**7.17±0.66**	**6.75±1.04**	**6.67±0.58a**
	Pooled mean	**7.42±1.83a**	**8.08±1.70b**	**8.34±1.85c**	**7.95±1.83**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.3 Equilibrium Moisture Content (EMC)

The result of analysis of variance on EMC as a result of treatment effect in sampling height, temperature variation (°C) and treatment time (minutes) have significant on EMC at 5%, There were significant effect in the interaction of sampling height, temperature and treatment time (minutes), but there was no significant interaction among the sampling height, temperature and treatment time (minutes) (Table 30).

The average mean value of the EMC for the treated bamboo strips for 100 °C at base ranged from 6.07 to 8.10, also ranged from 6.81 to 8.50 at base while from 6.37 to 9.44 the mean values decreased from the temperature variations (°C); 140, 130, 120, 110 and 100^{o}C also from 30minutes to 10 minutes (Table 31).

The results of the EMC of thermal-modified bamboo clearly revealed the hygroscopicity and hydrophobicity tendencies of bamboo while under steam-thermal modification. The treated bamboo at temperature and time variations; 140 °C -30minutes had a lowest %EMC value while the control samples and samples at 100 °C had the relative highest values. Wood treated at high temperature lacks affinity to absorb water from atmosphere at a corresponding temperature and relative humidity. This finding is in agreement with other researches on bamboo thermal modification involving hot oil (Salim, *et al.*, 2010; Nguyen, *et al.*, 2012), and the report of thermal-modified of *Bambusa blumena* by Natividad and Jimenez, (2015), chemical and anatomical properties in the thermal-modified both contributed to the changes in the EMC, most especially the fibre cell wall; The chemical modification of bamboo cell wall components during heat treatment caused the changes in EMC level. The hemicelluloses were degraded while the amorphous regions of the cellulose were hydrolyzed breaking it to shorter chains with reduced free hydroxyl groups. Treated modified(TM) samples subjected to higher temperatures have lower free hydroxyl groups; thus, less hygroscopic or have lower EMC.

According to Nguyen, *et al*, (2012) on their study on the thermal modification of two Vietnamese bamboo species with temperature variations (°C); 130, 180 and 220 °C with 30 and 60minutes treatment time(minutes) respectively , it was noted that the lowest EMC change was observed at 150°C-30minutes with 1.55% change in EMC and the highest change was observed at 200°C-60minutes with 3.18%, The reduction of EMC (ΔEMC) due to the thermal modification was very slight at 130 °C (0.54 to 0.76 %)

much stronger at 180 °C (3.6 to 4.44%) and 220 °C and 5hours it was even higher (5.6 to 5.7%), which is a similar trend with the observation recorded in this work. The Equilibrium Moisture Content (EMC) is a steady-state level achieved when subjected to a particular relative humidity and temperature, relative humidity is strongly dependent on temperature (Wolfram, 2006), FSP and EMC values decreased with increasing temperature variations and treatment time. As presumed above, results shown that the EMC of the thermally modified bamboo is lower than the EMC of the KD control sample, as temperature level and treatment duration increased, the degree of change in EMC also increased (Ates *et al.*, 2008). The follow up test further revealed the interaction effect between temperature variation and time (Table 32).

Table 32: Follow up test for interaction between temperature variation and time duration for Equilibrium Moisture Content (EMC)

Temperature (°C)	Time (minutes)	Mean
130	30	6.03a
120	30	6.50a
110	30	6.57a
140	30	6.77a
100	30	7.46a
130	20	6.18b
140	20	6.29b
120	20	7.40b
110	20	7.64b
100	20	8.66b
140	10	6.94c
130	10	7.14c
120	10	8.69c
110	10	9.42c
100	10	9.91c
Untreated	untreated	10.48e

Mean with the same alphabet are not significantly different from one another

Table 33: Analysis of Variance (ANOVA) of percentage radial shrinkage for 24hrs for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	1.64	0.82	1.85*	0.16
Temperature variation(°C)	5.00	156.95	31.39	70.94*	0.00
Treatment time(minutes)	2.00	147.62	73.81	166.81*	0.00
Sampling height * Temperature variation(°C)	10.00	77.96	7.80	17.62	0.00
Sampling height * Treatment time(minutes)	4.00	13.68	3.42	7.73	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	117.88	11.79	26.64	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	41.38	2.07	4.68	0.00
Error	216.00	95.57	0.44		
Total	270.00	1772.44			

*=significant at P<0.05

ns=not significant at P>0.05

Table 34: Mean value of percentage Radial shrinkage for 24 hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(^oC)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	4.40±0.45	3.05±1.51	2.70±1.39	**3.70±1.12d**
100	10	4.40±0.49	4.01±0.71	2.70±1.39	**3.03±0.87c**
	20	2.49±0.89	1.99±0.58	0.50±0.37	**1.14±0.61b**
	30	0.23±0.09	0.45±0.38	0.50±0.37	**0.96±0.28a**
	Mean	**2.37±0.49**	**2.15±0.56**	**1.23±0.71**	**1.83±0.59b**
110	10	3.44±0.74	1.90±0.58	4.48±0.28	**2.85±0.53c**
	20	1.40±0.24	0.62±0.39	2.26±0.70	**1.43±0.44b**
	30	0.58±0.42	0.62±0.39	2.06±0.52	**1.23±0.44a**
	Mean	**1.81±0.47**	**1.05±0.45**	**2.93±0.50**	**2.70±0.47b**
120	10	2.59±0.59	3.35±1.21	2.81±1.20	**1.93±1.00c**
	20	0.84±0.51	0.40±0.22	0.74±0.40	**0.66±0.38b**
	30	0.13±0.00	0.40±0.22	0.22±0.02	**0.58±0.08a**
	Mean	**1.19±0.37**	**1.38±0.55**	**1.26±0.54**	**1.75±0.49a**
130	10	2.96±0.44	2.80±0.51	2.26±0.55	**1.90±0.50c**
	20	1.14±0.68	0.47±0.32	0.97±0.50	**0.86±0.50b**
	30	0.18±0.02	0.47±0.32	0.25±0.09	**0.56±0.14a**
	Mean	**1.42±0.38**	**1.25±0.38**	**1.16±0.38**	**1.51±0.38a**
140	10	2.74±0.92	1.94±1.26	3.28±1.41	**3.31±1.20c**
	20	0.79±0.30	3.90±0.15	3.62±0.32	**2.22±0.26b**
	30	0.25±0.10	2.24±0.55	1.80±1.05	**1.58±0.57a**
	Mean	**1.26±0.44**	**2.69±0.65**	**2.90±0.93**	**2.08±0.67c**
	Pooled mean	**2.08±1.67a**	**1.93±1.50a**	**2.11±1.50a**	**2.04±1.56**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.4 Radial shrinkage for 24hours

Result of analysis of variance of radial shrinkage swelling for 24 hours revealed that there were significant differences in all the variable factors adopted. There were significant differences in the effect of interaction among sampling height, temperature variation (°C) and heating treatment time (minutes) as shown in Table 33.

The mean value for radial shrinkage for 24 hours of the untreated and thermal-modified bamboo is presented in Table 34.

The average mean value of radial shrinkage swelling for 24 hours for base middle and top at temperature variations (^{o}C); 0, 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10, 20 and 30 minutes ranged from 2.37 to 1.19% for base, the average value varied from to 2.69 to1.05% for middle, while for top ranged from to 2.93 to 1.16%.

The radial shrinkage swelling for 24 hours of the thermal-modified bamboo values decreased from base to top, the mean value increased from 100 °C to 110 °C, decreased from 110 °C to 120 °C, then increased from 120 to 130 and decreased from 130 to 140 °C also decreased from 10 to 30 minutes in each temperature treatment.

The trend in the thickness swelling was proportional to Water Absorption (WA) of thermal-modified bamboo; the highest shrinkage value was recorded at the untreated middle samples, while the decreasing pattern of the thermal-modified bamboo ranged from middle, top and base, respectively. This findings is supported by the claims of Natividad and Jimenez, (2015), on the study of thermal-modified *Bambusa blumena*, that lower affinity to water or less hygroscopic structure of TM samples due to decomposition of hemicelluloses and reduction of free hydroxyl groups in the amorphous regions of the cellulose, also caused the lower swelling of samples thermally modified at higher temperatures. High dimensional stability bamboo wood is very important in their utilisation for joinery and laminated products. Loosening of joints and premature delamination of glued products are associated to raw materials with high swelling and shrinkage when used or exposed to conditions with fluctuating humidity and temperature (Natividad and Jimenez, 2015). The follow up test further revealed the interaction effect between temperature variation and time (Table 35).

Table 35: Follow up test for interaction between temperature variation and time duration for Radial shrinkage for 24 hours

Temperature (°C)	Time (minutes)	Mean
130	30	0.56a
120	30	0.58a
100	30	0.96a
110	30	1.23a
140	30	1.58a
120	20	0.66b
130	20	0.86b
100	20	1.14b
110	20	1.43b
140	20	2.22b
130	10	1.90c
120	10	1.93c
110	10	2.85c
100	10	3.03c
140	10	3.31c
untreated	untreated	3.70d

Mean with the same alphabet are not significantly different from one another

Table 36: Analysis of Variance (ANOVA) of percentage Radial shrinkage for 48hrs of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	0.37	0.18	0.33[ns]	0.72
Temperature variation(°C)	5.00	74.60	14.92	27.11*	0.00
Treatment time(minutes)	2.00	182.89	91.44	166.16*	0.00
Sampling height *Temperature variation(°C)	10.00	33.92	3.39	6.16*	0.00
Sampling height * Treatment time(minutes)	4.00	10.46	2.62	4.75*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	99.11	9.91	18.01*	0.00
Sampling height *Temperature variation(°C) * Treatment time(minutes)	20.00	74.87	3.74	6.80*	0.00
Error	216.00	118.88	0.55		
Total	270.00	1898.88			

*=significant at P<0.05

ns=not significant at P>0.05

Table 37: Mean value of percentage Radial shrinkage for 48hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	3.66±0.73	3.14±1.45	2.91±0.67	3.24±0.95c
100	10	3.66±0.79	3.85±1.28	2.91±0.67	3.47±0.91c
	20	1.54±0.51	1.05±0.69	1.08±0.87	1.23±0.69b
	30	0.58±0.07	0.30±0.00	4.79±0.25	1.89±0.11a
	Mean	**1.93±0.46**	**1.73±0.66**	**2.93±0.60**	**2.20±0.57b**
110	10	3.98±0.78	3.69±0.70	1.49±1.47	3.05±0.98c
	20	1.66±0.26	0.86±0.48	1.46±1.50	1.33±0.75b
	30	1.02±0.22	0.86±0.48	1.26±1.20	1.05±0.63a
	Mean	**2.22±0.42**	**1.80±0.55**	**1.40±1.39**	**1.81±0.79a**
120	10	3.27±0.87	3.67±0.87	4.42±0.52	3.79±0.75c
	20	1.23±0.51	1.37±0.38	2.06±1.04	1.55±0.64b
	30	0.31±0.11	0.41±0.34	0.45±0.35	0.39±0.27a
	Mean	**1.60±0.50**	**1.81±0.53**	**2.31±0.64**	**1.91±0.55a**
130	10	3.56±1.00	3.48±1.48	3.12±0.40	3.39±0.96c
	20	1.70±0.27	0.91±0.28	1.34±0.40	1.32±0.32b
	30	0.61±0.35	0.91±0.28	0.53±0.17	0.68±0.27a
	Mean	**1.95±0.54**	**1.77±0.68**	**1.66±0.32**	**1.80±0.51a**
140	10	3.30±1.05	3.89±1.22	3.46±0.89	3.55±1.05c
	20	1.19±0.36	2.46±0.04	2.08±0.53	1.91±0.31b
	30	0.50±0.19	1.97±0.46	0.55±0.18	1.01±0.28a
	Mean	**1.66±0.53**	**2.77±0.57**	**2.03±0.53**	**2.15±0.54b**
	Pooled Mean	**2.17±1.45a**	**2.17±1.54a**	**2.25±1.48a**	**2.20±1.48**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.5 Radial shrinkage for 48 hours

Result of analysis of variance of radial shrinkage swelling for 48 hours revealed that there was no significant different in the Temperature variation(°C). There were significant different in the effect of interaction among sampling height, temperature variation(°C) and heating treatment time(minutes) as shown in Table 36.

The mean value for radial shrinkage for 48 hours of the thermal-modified bamboo is presented in the Table 37. The average mean value of radial shrinkage at temperature variations (°C); 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10,20 and 30 minutes, the average mean value ranged from 1.95 to 1.60% to for base, from 1.81 to 1.73% for middle while for top ranged from 2.93 to 1.40%. This result contradicts the report of Adewole *et al*, (2017) on the characteristics of selected properties of parquet laminate produced from *Bambusa vulgaris* sourced from Cross river State, that the maximum swelling percentage (12.5%) of their bamboo treated samples thermal modified with boric was recorded at 24 hours of water soaking.

The radial shrinkage swelling for 48 hours of the thermal-modified bamboo values decreased from base to top, the mean value increased from 100 to 110 °C, decreased from 110 to 120 °C, then increased from 120 to 130 °C and then decreased from 130 to 140 °C also decreased from 10 to 30 minutes in each temperature treatment.

The follow up test further revealed the interaction effect between temperature variation and time (Table 38).

Table 38: Follow up test for interaction between temperature variation and time duration for Radial shrinkage for 48hours

Temperature (°C)	Time (minutes)	Mean
120	30	0.39a
130	30	0.68a
140	30	1.01a
110	30	1.05a
100	30	1.89a
100	20	1.23b
130	20	1.32b
110	20	1.33b
120	20	1.55b
140	20	1.91b
110	10	3.05c
untreated	untreated	3.24c
130	10	3.39c
100	10	3.47c
140	10	3.55c
120	10	3.79c

Mean with the same alphabet are not significantly different from one another

Table 39: Analysis of Variance (ANOVA) of percentage Radial shrinkage for 72hours of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-Value
Sampling height	2.00	1.66	0.83	1.27[ns]	0.28
Temperature variation(°C)	5.00	106.38	21.28	32.51*	0.00
Treatment time(minutes)	2.00	126.32	63.16	96.52*	0.00
Sampling height * Temperature variation(°C)	10.00	51.52	5.15	7.87*	0.00
Sampling height * Treatment time(minutes)	4.00	20.18	5.05	7.71*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	88.37	8.84	13.51*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	68.46	3.42	5.23*	0.00
Error	216.00	141.34	0.65		
Total	270.00	1707.69			

***=significant at P<0.05**

ns=not significant at P>0.05

Table 40: Mean value of percentage Radial shrinkage for 72hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	3.77±0.81	2.87±1.20	2.83±1.61	**3.16±1.76d**
100	10	3.77±0.88	3.52±0.73	2.83±1.61	**3.37±2.00c**
	20	1.20±0.89	1.91±0.36	1.01±0.20	**1.37±1.00b**
	30	0.30±0.17	0.48±0.53	0.37±0.23	**0.38±0.29a**
	Mean	**1.76±0.64**	**1.97±0.54**	**1.40±0.68**	**1.71±1.10ab**
110	10	3.03±0.76	3.30±1.01	2.87±1.30	**3.06±1.79c**
	20	1.72±0.36	0.96±0.76	0.37±0.30	**1.02±0.54b**
	30	0.48±0.40	0.96±0.76	0.33±0.21	**0.59±0.52a**
	Mean	**1.74±0.51**	**1.74±0.84**	**1.19±0.60**	**1.56±0.95a**
120	10	2.36±0.83	3.18±1.19	3.12±1.28	**2.89±1.76c**
	20	0.62±0.21	0.99±0.40	0.57±0.24	**0.73±0.48b**
	30	0.23±0.10	0.99±0.40	0.56±0.25	**0.59±0.45a**
	Mean	**1.07±0.38**	**1.72±0.66**	**1.41±0.59**	**1.40±0.90a**
130	10	2.49±0.41	2.87±0.74	3.89±1.01	**3.08±1.43c**
	20	1.15±0.60	1.07±0.57	1.87±0.55	**1.36±0.74b**
	30	3.83±1.10	0.28±0.16	0.50±0.30	**1.54±0.56a**
	Mean	**2.49±0.70**	**1.41±0.49**	**2.09±0.62**	**1.99±0.91bc**
140	10	0.66±0.66	3.70±0.59	3.77±0.60	**2.71±1.65c**
	20	0.15±0.00	3.24±0.13	2.28±0.50	**1.89±1.25b**
	30	2.51±1.55	2.27±1.01	0.87±0.15	**1.88±1.32a**
	Mean	**1.11±0.74**	**3.07±0.57**	**2.31±0.42**	**2.16±1.41c**
	Pooled	**1.99±1.54a**	**2.13±1.36a**	**1.95±1.60a**	**2.22±1.50**

Mean with same superscript in the same column are not significantly different ($P<0.05$)

4.2.6 Radial shrinkage for 72 hours

Result of analysis of variance of radial shrinkage swelling for 72 hours revealed that there was no significant different in the sampling height, but there was significant difference in temperature variations and treatment time. There are significant different in the effect of interaction among sampling height, Temperature variation(°C) and heating Treatment time(minutes)as shown in Table 39.

The mean value for radial shrinkage for 72 hours of the untreated and thermal-modified bamboo is presented in the Table 40.

The average mean value of radial shrinkage swelling for 72 hours at temperature variations (°C); 100, 110, 120, 130 and 140 °C with treatment time (minutes); 10, 20 and 30minutes ranged from 2.49 to1.07% for base and ranged from 3.07 to 1.41% for middle while from 2.3 to1.19% for top.

The radial shrinkage swelling for 72 hours of the thermal-modified bamboo values decreased from base to top, the mean value increased from 100 to 110 °C, decreased from 110 to 120 °C, then increased from 120 to 130 and decreased from 130 to 140 °C also decreased from 10 to 30 minutes in each temperature treatment.

The mean values of thickness swelling for 24hours, 48hours and 72hours for thermal-modified were 2.04±1.56, 2.20±1.48**,** 2.22±1.50**,** respectively. The thickness swelling test for 72hours has the highest value and the least value was found in 24hours, This is in agreement with the study of Bonigut and Stuckenberg, (2014), dimensional stability and irreversible thickness swell of thermally treated oriented strandboards (OSB), he reported that the thickness swelling value was recorded in the water immersion for 168 hours, this changes in equilibrium moisture content (EMC) and determination of dimensional changes associated with changes in relative humidity. Also, Teng, *et al*, (2017) reported that water absorption (WA), and thickness swelling (TS) values of the immersed samples were significantly influenced by the heat treatment level of the wood particles within the Wood plastic composite (WPCs). The rHDPE composites with untreated wood particles (WPCNT) had the highest water absorption (10.0%) and thickness swelling (2.1%). The follow up test further revealed the interaction effect between temperature variation and time (Table 41).

Table 41: Follow up test for interaction between temperature variation and time duration for Radial shrinkage for 72hours

Temperature (°C)	Time (minutes)	Mean
100	30	0.38a
110	30	0.59a
120	30	0.59a
130	30	1.54a
140	30	1.88a
120	20	0.73b
110	20	1.02b
130	20	1.36b
100	20	1.37b
140	20	1.89b
140	100	2.71c
120	100	2.89c
110	100	3.06c
130	100	3.08c
100	10	3.37c
untreated	untreated	3.16d

Mean with the same alphabet are not significantly different from one another

Table 42: Analysis of Variance (ANOVA) of percentage water absorption (WA) for 24hrs for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	12783.71	6391.85	114.33*	0.00
Temperature variation(°C)	5.00	1439.07	287.81	5.15*	0.00
Treatment time(minutes)	2.00	16168.77	8084.39	144.60*	0.00
Sampling height *Temperature variation(°C)	10.00	2779.61	277.96	4.97*	0.00
Sampling height * Treatment time(minutes)	4.00	1414.74	353.68	6.33*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	3755.55	375.56	6.72*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	4367.52	218.38	3.91*	0.00
Error	214.00	11964.19	55.91		
Total	268.00	548542.30			

*=significant at $P<0.05$

ns=not significant at $P>0.05$

Table 43: Mean value of percentage Water absorption (WA) for 24 hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	30.90±7.92	54.19±17.12	54.72±15.50	**46.60±13.51c**
100	10	36.61±2.41	55.31±4.17	39.18±12.12	**43.70±6.23c**
	20	31.55±2.44	46.06±2.97	62.88±8.17	**46.83±4.53b**
	30	24.87±4.20	36.52±5.77	53.94±5.84	**38.44±5.27a**
	Mean	**31.01±3.02**	**45.96±4.30**	**52.00±8.71**	**42.99±5.34bc**
110	10	53.91±14.95	56.21±6.54	58.28±1.93	**56.13±7.81c**
	20	31.70±3.60	45.85±3.55	51.92±3.66	**43.16±3.60b**
	30	24.24±3.44	37.73±2.21	31.16±8.29	**31.05±4.65a**
	Mean	**36.62±7.33**	**46.59±4.10**	**47.12±4.63**	**43.44±5.35bc**
120	10	35.21±5.79	61.77±6.04	61.45±4.96	**52.81±5.59c**
	20	29.58±1.20	40.60±8.20	42.78±5.38	**37.65±4.93b**
	30	24.22±2.53	22.94±4.85	32.01±4.00	**26.39±3.79a**
	Mean	**29.67±3.17**	**41.77±6.36**	**45.41±4.78**	**38.95±4.77a**
130	10	46.01±1.62	58.85±15.26	55.78±7.52	**53.54±8.13c**
	20	37.11±3.37	40.32±3.97	45.71±2.29	**41.04±3.21b**
	30	27.67±2.34	26.28±4.52	35.64±6.50	**29.87±4.45a**
	Mean	**36.93±2.44**	**41.82±7.92**	**45.71±5.43**	**41.49±5.27ab**
140	10	47.87±9.16	50.82±6.14	73.00±5.83	**57.23±7.04c**
	20	31.93±4.41	38.33±2.46	51.67±6.28	**40.65±4.38b**
	30	27.32±0.83	31.40±1.60	39.48±4.17	**32.73±2.20a**
	Mean	**35.71±4.80**	**40.18±3.40**	**54.72±5.43**	**43.54±4.54bc**
	Pooled mean	**33.57±9.77a**	**45.18±14.05b**	**49.95±13.52c**	**42.93±14.32**

Mean with same superscript in the same column are not significantly different ($P<0.05$)

4.2.7 Water absorption for 24 hours

Result of analysis of variance of water absorption for 24 hours revealed that there was no significant difference in the temperature variation (°C). There were significant differences in the effect of interaction among sampling height, temperature variation (°C) and heating Treatment time (minutes) as shown in Table 42.

The mean value for water absorption for 24 hours of untreated and thermal-modified bamboo is presented in the Table 43. The average mean value of water absorption for 24 hours of this study ranged from 36.93 to 31.01% for the base samples, while also ranged from 46.59 to 40.18 to % for middle, while for top ranged from 54.72 to 45.41%. The water absorption for 24 hours of the thermal-modified bamboo values decreased from base to top, the mean value increased from 100 to 110 °C, decreased from 110 to 120 °C, then increased from 120 to 130 °C and decreased from 130 to 140 °C also decreased from 10 to 30 minutes in each temperature treatment.

One of the main effects of the heat treatment of wood was reduction of wood hygroscopicity and water absorption, thermal-modified bamboo samples in this study shown decreased water absorption compared with the control samples, also there is a decreasing pattern in the mean values of WA from 100 °C to 140 °C, This result compared favorably with the report of Adewole *et al*, (2017) on the average percentage value 44% of their bamboo treated samples thermal modified with boric was recorded at 24 hours of water soaking, this also was in line with the studies of Bazyar, (2012); Colla *et al*, (2011) Bazyar, (2012) reported on the oil treated Aspen wood, he reported that oil heat treatment improved the dimensional stability by 20.5%**,** while Colla *et al*, (2011) who reported the effect of thermal treatment on a giant bamboo, at the temperature 300 °C with a better ASE value (1.60%) but with a negative effect on the mechanical properties that resulted into a poor strength properties. The affinity of wood to absorb water is distorted in thermal-modified bamboo because, thermal treatments impart mass loss of the wood material due to carbohydrates degradation, when it happens, dimensional stability and biological durability are considerably improved since reduction in shrinkage, water absorption (WA) and Equilibrium Moisture Content (EMC) had changed. Taking it into account, a useful way to evaluate the extension of the wood modification promoted by thermal treatments is to measure the mass loss of the treated material **(**Del-Menezzi *et al.,* 2009). The follow up test further revealed the interaction effect between temperature variation and time (Table 44).

Table 44: Follow up test for interaction between temperature variation and time duration for Water absorption (WA) for 24 hours

Temperature (°C)	Time (minutes)	Mean
120	30	26.39a
130	30	29.87a
110	30	31.05a
140	30	32.73a
100	30	38.44a
120	20	37.65b
140	20	40.65b
130	20	41.04b
110	20	43.16b
100	20	46.83b
100	10	43.70c
untreated	untreated	46.60c
120	10	52.81c
130	10	53.54c
110	10	56.13c
140	10	57.23c

Mean with the same alphabet are not significantly different from one another

Table 45: Analysis of Variance (ANOVA) of percentage Water absorption (WA) for 48hrs for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	20438.16	10219.08	116.93*	0.00
Temperature variation(°C)	5.00	1861.54	372.31	4.26*	0.00
Treatment time(minutes)	2.00	24610.95	12305.48	140.80*	0.00
Sampling height * Temperature variation(°C)	10.00	4608.64	460.86	5.27*	0.00
Sampling height * Treatment time(minutes)	4.00	1222.26	305.57	3.50*	0.01
Temperature variation(°C) * Treatment time(minutes)	10.00	6022.68	602.27	6.89*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	3292.17	164.61	1.88*	0.02
Error	215.00	18790.29	87.40		
Total	269.00	768242.10			

*=significant at $P<0.05$

ns=not significant at $P>0.05$

Table 46: Mean value of percentage Water absorption for 48hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	40.37±15.45	62.32±15.49	60.40±19.15	**54.36±16.70b**
100	10	42.97±2.99	62.49±5.61	83.34±5.40	**62.93±4.66c**
	20	36.20±2.65	53.45±2.23	67.55±7.04	**52.40±3.98b**
	30	30.18±2.14	36.42±7.18	43.95±7.55	**36.85±5.62a**
	Mean	**36.45±2.59**	**50.79±5.01**	**64.95±6.66**	**50.73±4.75ab**
110	10	65.07±19.38	74.39±7.59	77.69±2.37	**72.39±9.78c**
	20	33.14±5.16	57.92±5.04	61.19±6.08	**50.75±5.43b**
	30	24.53±1.45	45.63±5.98	40.21±12.22	**36.79±6.55a**
	Mean	**40.91±8.67**	**59.32±6.20**	**59.70±6.89**	**53.31±7.25b**
120	10	39.73±3.64	76.47±6.41	71.51±3.43	**62.57±4.49c**
	20	33.74±1.78	57.22±10.71	49.08±4.52	**46.68±5.67b**
	30	26.14±4.99	29.62±7.71	37.89±1.35	**31.21±4.68a**
	Mean	**33.20±3.47**	**54.44±8.27**	**52.83±3.10**	**46.82±4.95a**
130	10	52.81±2.13	67.01±16.57	60.76±3.52	**60.19±7.41c**
	20	42.98±4.67	49.39±4.98	54.85±1.68	**49.07±3.78b**
	30	33.21±3.18	38.40±3.21	41.76±4.76	**37.79±3.71a**
	Mean	**43.00±3.33**	**51.60±8.25**	**52.45±3.32**	**49.02±4.97a**
140	10	44.68±5.92	54.20±8.14	87.74±4.78	**62.21±6.28c**
	20	36.73±1.41	42.19±1.29	63.03±7.86	**47.32±3.52b**
	30	31.49±3.92	35.08±5.09	44.21±7.88	**36.93±5.63a**
	Mean	**37.63±3.75**	**43.82±4.84**	**64.99±6.84**	**48.82±5.14a**
	Pooled mean	**38.59±12.24a**	**53.71±15.83b**	**59.42±16.74c**	**50.54±17.39**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.8 Water absorption for 48 hours

Result of analysis of variance of water absorption for 48 hours revealed that there is no significant different in the temperature variation (°C). There were significant different in the effect of interaction among sampling height, temperature variation(°C) and heating Treatment time (minutes) as shown in Table 45. The mean value for water absorption for 48 hours of the thermal-modified bamboo is presented in the Table 46.

The average mean value of water absorption for 48 hours at temperature variations (°C); from 100 °C to 140 °C with treatment time(minutes) 10 to 30 minutes ranged from 43.00 to 33.20% for base, the mean value varied from 59.32 to 43.82% for middle, while for top ranged from 64.99 to 52.45%.

The anti-swelling efficiency for 48 hours of the thermal-modified bamboo values decreased from base to top, the mean value increased from 100 to 110 °C, decreased from 110 to 120 °C, then increased from 120 to 130 °C and decreased from 130 to 140 °C also decreased from 10 to 30minutes in each temperature treatment.

The more wood is exposed to moisture, the more the water-absorption affinity it becomes, because of the wood hygroscopic nature, the reasons for subjecting bamboo to numbers of hours of WA is to determine its Fibre saturated point (FSP) of treated and untreated bamboo samples, because the more the wood is exposed to moisture the more water it absorbs until the FSP is reached. Thermal-modified bamboo is further subjected to WA test for 48 hours, the highest values of WA is recorded at middle untreated samples, while least WA value was recorded at the base samples at temperature and time 140 °C-30minutes. This is similar trend to the report of Colla, *et al*, (2011), this is because, heat treatment of wood increases its moisture resistance, changes in cell wall chemistry causes the reduction of water uptake and, consequently, improvement in dimensional stability (Metsä-Kortelainen *et al.*, 2006; Vjekoslav *et al.*, 2008). Heat treatment improves dimensional stability, enhances resistance against biological deterioration, and contributes to uniform colour change from original to dark brownish tones (Kollmann *et al.*, 1975; Hill, 2006; Vjekoslav *et al.*, 2008). Higher levels of treatment temperatures yielded proportionally greater stabilisation effects. Water vapour and liquid water uptake can be reduced by 70%, and simple oiling and waxing of parquet surfaces further contributes to better performance of heat treated wood in humid conditions (Vjekoslav *et al.*, (2008). The follow up test further revealed the interaction effect between temperature variation and time (Table 47).

Table 47: Follow up test for interaction between temperature variation and time duration for Water absorption for 48hours

Temperature (°C)	Time (minutes)	Mean
120	30	31.21a
110	30	36.79a
100	30	36.85a
140	30	36.93a
130	30	37.79a
120	20	46.68b
140	20	47.32b
130	20	49.07b
110	20	50.75b
100	20	52.40b
Untreated	untreated	54.36b
130	10	60.19c
140	10	62.21c
120	10	62.57c
100	10	62.93c
110	10	72.39c

Mean with the same alphabet are not significantly different from one another

Table 48: Analysis of Variance of percentage Water absorption (WA) for 72hours for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	23073.89	11536.94	126.15*	0.00
Temperature variation(°C)	5.00	2997.45	599.49	6.56*	0.00
Treatment time(minutes)	2.00	26452.62	13226.31	144.62*	0.00
Sampling height * Temperature variation(°C)	10.00	7144.96	714.50	7.81*	0.00
Sampling height * Treatment time(minutes)	4.00	933.09	233.27	2.55*	0.04
Temperature variation(°C) * Treatment time(minutes)	10.00	6583.79	658.38	7.20*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	3772.67	188.63	2.06*	0.01
Error	216.00	19754.69	91.46		
Total	270.00	1122742.00			

*=significant at P<0.05

ns=not significant at P>0.05

Table 49: Mean value of percentage Water absorption (WA) for 72 hours for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°**C**)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	56.46±12.20	77.97±18.44	66.77±18.05	**67.07±16.23d**
100	10	52.27±3.63	78.21±9.65	92.31±1.90	**74.26±5.06c**
	20	45.48±1.79	65.17±3.40	77.27±8.50	**62.64±4.56b**
	30	40.04±1.53	54.85±3.37	55.59±11.68	**50.16±5.53a**
	Mean	**45.93±2.32**	**66.08±5.47**	**75.06±7.36**	**62.35±5.05bc**
110	10	76.45±15.87	85.97±10.78	93.97±2.61	**85.46±9.75c**
	20	42.53±8.69	64.78±4.31	79.23±4.52	**62.18±5.84b**
	30	28.63±3.82	55.98±1.37	57.62±17.46	**47.41±7.55a**
	Mean	**49.20±9.46**	**68.91±5.49**	**76.94±8.20**	**65.02±7.71cd**
120	10	46.73±3.18	88.07±4.92	85.47±4.30	**73.43±4.13c**
	20	42.37±1.28	72.74±9.55	59.66±1.92	**58.25±4.25b**
	30	37.65±1.86	39.42±9.42	47.30±3.12	**41.46±4.80a**
	Mean	**42.25±2.11**	**66.74±7.96**	**64.14±3.12**	**57.71±4.40a**
130	10	62.88±2.65	76.16±12.32	74.97±9.21	**71.34±8.06c**
	20	53.62±4.76	61.05±3.73	62.59±3.71	**59.09±4.06b**
	30	39.87±4.84	51.01±7.47	52.55±5.29	**47.81±5.87a**
	Mean	**52.12±4.08**	**62.74±7.84**	**63.37±6.07**	**59.41±6.00ab**
140	10	56.54±3.28	68.94±11.32	97.03±1.98	**74.17±5.53c**
	20	47.14±3.82	51.31±3.35	73.94±6.06	**57.46±4.41b**
	30	41.20±1.63	37.57±14.41	60.84±5.03	**46.54±7.02a**
	Mean	**48.29±2.91**	**52.60±9.69**	**77.27±4.36**	**59.39±5.65ab**
	Pooled mean	**49.04±12.67a**	**65.84±17.74b**	**70.59±16.87c**	**61.83±18.36**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.2.9 Water absorption for 72 hours

Result of analysis of variance of Water absorption for 72hours revealed that there was no significant difference in the temperature variation (°C). There were significant differences in the effect of interaction among sampling height, temperature variation (°C) and heating treatment time (minutes) as shown in Table 48.

The mean value for Water absorption (WA) for 72 hours of the thermal-modified bamboo is presented in the Table 49.

The average mean value of Water Absorption for 72 hours for base at temperature variations (°C) 100, 110, 120, 130 and 140 °C and treatment time(minutes)10, 20 and 30 minutes ranged from 52.12 to 42.25%, while, 68.91 to 52.60% for middle, and mean value for top also ranged from 77.27 to 63.37%.

The water absorption for 72hours of thermal-modified bamboo values decreased from base to top, the mean value increased from 100 to 110 °C, decreased from 110 to 120 °C, then increased from 120 to 130 °C and decreased from 130 to 140 °C also decreased from 10 to 30 minutes in each temperature treatment.

Moisture sorption behavior below the fibre saturation point is a critical aspect of wood and wood products during their service life. Loss and uptake of moisture caused by fluctuating relative humidity and temperature leads to dimension changes (Clauder and Pfriem, 2013). The increase in Water absorption due to the gradual increase of temperature and duration of treatment can be explained by the thermal effect on the degradation of cell wall components. In the temperature range of 180 °C to 220 °C, increasingly hemicelluloses are degraded, whose OH groups are responsible for the high hygroscopic behaviour of the wood. Burmester, (1975) concluded that heat treatment of wood results in a high reduction in the hemicellulose content, and is thus an improvement of the dimensional stability of the wood (Clauder and Pfriem, 2013). According to the Kocaefe *et al*, (2008); they reported that the degradation of hemicellulose, which was caused by thermal treatment, could contribute to the increase in dimensional stability.

The mean values of water absorption for 24hours, 48hours and 72hours for thermal-modified were 42.93±14.32, 50.54±17.39 and 61.83±18.36, respectively. The water absorption test for 72hours has the highest value and the least was found in 24hours, it showed that the higher the water absorption during the poorer the dimensional stability of the treated samples. Thermal modification induces the wood hygroscpicity and makes it more water resistance, but when the exposure into moisture is prolonged, this may influence negatively the hydrophilic tendency of thermal modified wood. This study is in agreement with the study of Gnatowski, (2009), it was found that Wood Plastic Composite absorbed a significant quantity of water during prolonged exposure to exterior conditions, and the water content in the material seems to increase during the exposure period. This may be associated with the loss of some mechanical properties and the presence of biological activity, including decay fungi. The follow up test further revealed the interaction effect between temperature variation and time (Table 50).

Table 50: Follow up test for interaction between temperature variation and time duration for Water absorption (WA) for 72 hours

Temperature (°C)	Time (minutes)	Mean
120	30	41.46a
140	30	46.54a
110	30	47.41a
130	30	47.81a
100	30	50.16a
140	20	57.46b
120	20	58.25b
130	20	59.09b
110	20	62.18b
100	20	62.64b
130	10	71.34c
120	10	73.43c
140	10	74.17c
100	10	74.26c
110	10	85.46c
untreated	untreated	67.07d

Mean with the same alphabet are not significantly different from one another

4.3. Mechanical properties of untreated and thermal-modified *Bambusa vulgaris*

Table 51: Analysis of Variance (ANOVA) of Compressive Strength (CS┴) of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	15362.61	7681.30	30000.00*	0
Temperature variation(°C)	5.00	27207.15	5441.43	21300.00*	0
Treatment time(minutes)	2.00	296.30	148.15	578.94*	0
Sampling height * Temperature variation(°C)	10.00	3747.96	374.80	1470.00*	0
Sampling height * Treatment time(minutes)	4.00	22.97	5.74	22.44*	0
Temperature variation(°C) * Treatment time(minutes)	10.00	229.46	22.95	89.67*	0
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	453.83	22.69	88.67*	0
Error	216.00	55.27	0.26		
Total	270.00	155253.60			

*=significant at P<0.05
ns=not significant at P>0.05

Table 52: Mean value of Compressive strength (┴) N/mm^2 for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Height Base	Middle	Top	Pooled Mean
0	Untreated	47.16±0.04	37.76±0.15	23.51±0.14	**36.14±0.11f**
100	10	42.35±0.26	30.68±0.33	20.47±0.40	**31.17±0.33c**
	20	42.80±0.00	25.96±0.64	15.12±0.31	**27.96±0.32b**
	30	42.09±0.35	25.36±0.32	9.55±0.14	**25.67±0.27a**
	Mean	**42.41±0.20**	**27.34±0.43**	**15.05±0.28**	**28.27±0.30e**
110	10	41.97±0.55	22.65±0.25	8.53±0.48	**24.38±0.43c**
	20	41.22±0.47	22.43±0.13	8.42±0.05	**24.02±0.22b**
	30	30.31±0.15	20.23±0.06	8.57±0.37	**19.70±0.19a**
	Mean	**37.83±0.39**	**21.77±0.15**	**8.51±0.30**	**22.70±0.28d**
120	10	23.28±2.50	16.25±0.56	7.31±0.01	**15.61±1.02c**
	20	21.42±0.91	16.06±0.37	7.28±0.20	**14.92±0.49b**
	30	19.66±1.01	10.42±0.26	7.63±0.27	**12.57±0.51a**
	Mean	**21.46±1.47**	**14.24±0.40**	**7.41±0.16**	**14.37±0.68c**
130	10	18.61±0.03	8.41±0.43	6.34±0.30	**11.12±0.25c**
	20	17.40±0.76	8.43±0.48	6.90±0.00	**10.91±0.41b**
	30	16.09±0.97	7.80±0.55	6.41±0.13	**10.10±0.55a**
	Mean	**17.37±0.59**	**8.21±0.49**	**6.55±0.14**	**10.71±0.40b**
140	10	12.11±0.00	7.29±0.33	5.57±0.44	**8.33±0.26c**
	20	10.51±0.18	6.14±0.02	5.81±0.10	**7.49±0.10b**
	30	10.48±0.26	6.33±0.13	5.43±0.32	**7.41±0.24a**
	Mean	**11.03±0.15**	**6.59±0.16**	**5.60±0.29**	**7.74±0.20a**
	Pooled mean	**29.54±13.84c**	**19.32±11.14b**	**36.14±9.84a**	**19.99±13.27**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.3.1 Compressive strength (┴)

Result of analysis of variance of compressive strength as a result of changing in treatment effect revealed that the sampling height, temperature variation (°C) and treatment time (minutes) were significance different at 0.05% level of probability. Also there was a significant in the effect of interaction among all the selected variable factors adopted for the study as shown in the Table 51. The mean values of compressive strength perpendicular to grain of untreated and thermal-modified *Bambusa vulgaris* are presented in Table 52.

The mean value for the temperature variation (°C); 100, 110, 120, 130 and 140 °C and treatment time(minutes) 10, 20 and 30minutes at base which ranged from 42.41 to 11.03N/mm^2, also ranged from 27.34 to 6.59N/mm^2 at the middle samples while for top ranged from 15.05 to 5.60N/mm^2. The value decreased from the maximum temperature and treatment time (140°C-30minutes) value to the least temperature and time variation (°C) (100 °C-10(minutes) adopted as stated in the Table 52.

There was a decreasing trend in the compressive strength value of thermal-modified value from Temperature variation (°C) 100 to 140 °C also, this study noted a decreasing trend of CS **(**┴) value from base to top. This result had a supported claims by the report of Ates *et al*, (2008), they opined that similarly compression strength parallel to the grain values decreased from the least temperature to the highest temperature variation (°C), In their study on the heat treatment on Calabrian pine (*Pinus brutia*) they reported a decrease in the value of all the mechanical properties except for hardness with increasing temperature and time, they claimed that maximum decreases were recorded at the treatment of 230 °C for the compressive strength while minimum decreases was observed at 130 °C ranging from 70 to 12N/mm^2 which is in conformity with this result. As maximum decreases were recorded at temperature ranges 140 °C and minimum decreases at 100 °C compared with the untreated base samples which had the highest compressive values of 47.16N/mm^2, degradation, of the hemicelluloses reduced the load sharing capacity of the lignin-hemicelluloses matrix which probably had a negative impact on the compressive strength, However, remarkable is the anisotropic effect of heat treatment on the compressive strength and hardness of bamboo. In longitudinal direction the compressive strength increased clearly, while in the radial and tangential direction a decrease (radial) was observed (Boonstra *et al.*, 2007). This may be as a result of the fibre arrangement and the chemical reaction in the wood. The follow up test further revealed the interaction effect between temperature variation and time (Table 53).

Table 53: Follow up test for interaction between temperature variation and time duration for Compressive strength (┴)

Temperature (°C)	Time (minutes)	Mean
140	30	7.41a
130	30	10.10a
120	30	12.57a
110	30	19.70a
100	30	25.67a
140	20	7.49b
130	20	10.91b
120	20	14.92b
110	20	24.02b
100	20	27.96b
140	10	8.33c
130	10	11.12c
120	10	15.61c
110	10	24.38c
100	10	31.17c
untreated	untreated	36.14f

Mean with the same alphabet are not significantly different from one another

Table 54: Analysis of Variance (ANOVA) of Modulus of Elasticity (MOE) N/mm^2 for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	3690000000.00	1840000000.00	301.96*	0
Temperature variation(°C)	5.00	13700000000.00	2740000000.00	448.87*	0
Treatment time(minutes)	2.00	255000000.00	127000000.00	20.84*	0
Sampling height *Temperature variation(°C)	10.00	515000000.00	51500000.00	8.43*	0
Sampling height * Treatment time(minutes)	4.00	8754433.00	2188608.00	0.36ns	0.838
Temperature variation(°C) * Treatment time(minutes)	10.00	117000000.00	11700000.00	1.92*	0.044
Sampling height *Temperature variation(°C) * Treatment time(minutes)	20.00	68800000.00	3439621.00	0.56ns	0.934
Error	216.00	1320000000.00	6106706.00		
Total	270.00	79700000000.00			

*=significant at P<0.05

ns=not significant at P>0.05

Table 55: Mean value of Modulus of Elasticity (MOE) N/mm^2 for untreated and thermal-modified *Bambusa vulgaris*

Temperature Variation	Time Variatio	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreate	32901.00±2947.13	26506.00±376.45	18911.00±9254.71	**29703.50±4192.77f**
100	10	30251.00±851.23	24106.00±1784.27	20130.00±3661.24	**24422.67±2098.91c**
	20	27690.00±0.00	22803.00±0.00	13682.00±892.77	**23541.00±297.59b**
	30	25409.00±1456.85	22054.00±1675.18	12510.00±713.20	**20381.67±1281.75a**
	Mean	**27783.33±769.36**	**22987.67±1153.15**	**15440.67±1755.74**	**21093.67±1226.08e**
110	10	21500.00±1784.27	18634.00±469.15	11337.00±874.52	**18524.89±1042.65c**
	20	18960.00±534.96	17266.00±892.52	9577.50±436.75	**15854.33±621.41b**
	30	17396.00±1227.61	14985.00±1784.27	8665.80±178.70	**13986.17±1063.53a**
	Mean	**19285.33±1182.28**	**16961.67±1048.65**	**9860.10±496.66**	**14970.93±909.20d**
120	10	14790.00±492.76	13030.00±0.00	7134.60±353.36	**12560.03±282.04c**
	20	13488.00±900.47	11467.00±1481.81	6515.20±0.00	**10696.53±794.09b**
	30	12546.00±0.00	9773.00±0.34	6515.20±0.00	**9611.40±0.11a**
	Mean	**13608.00±464.41**	**11423.33±494.05**	**6721.67±117.79**	**10515.51±358.75c**
130	10	12546.00±0.00	9674.90±219.02	6515.20±0.00	**9647.52±73.01c**
	20	12219.00±447.68	9153.70±72.35	6515.20±0.00	**9295.97±173.34b**
	30	11142.00±535.56	8502.40±624.50	5212.20±446.07	**8719.87±535.37a**
	Mean	**11969.00±327.75**	**9110.33±305.29**	**6080.87±148.69**	**8763.84±260.57b**
140	10	10367.00±525.12	7557.70±582.74	4788.80±218.37	**8001.86±442.08c**
	20	8860.70±582.74	6515.20±0.00	3322.90±981.54	**6721.57±521.43b**
	30	6547.40±1160.15	6515.20±0.00	1922.10±624.43	**5461.83±594.86a**
	Mean	**8591.70±756.00**	**6862.70±194.25**	**3344.60±608.12**	**5792.17±519.45a**
	Pooled ean	**19023±8983.97c**	**15642±7345.53b**	**10006±6706.42a**	**14908±8552.55**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.3.2 Modulus of Elasticity (MOE)

Analysis of variance showed the sampling height, temperature variation (°C) and treatment time (minutes) differ significantly at 0.05% level of probability. There were significant variations among the sampling height, temperature and time duration. There was no significant interaction among sampling height, temperature variation (°C) and treatment time (minutes) as shown in Table 54.

The mean value for the temperature variations (°C); 100, 110, 120 and 140 °C and treatment time (minutes) 10, 20 and 30minutes is presented at Table 55, at the base ranged from 27,783.33 to 8591.70N/mm^2. The mean values decreased from the temperature variation 100 to 140 °C and from 10 to 30minutes of the treatment time respectively, the value for middle ranged from 22, 987.67 to 6,862.70N/mm^2 , while for the top ranged from 15,440.67 to 3,344.60 N/mm^2.

There was a decreasing trend from base to top , the pattern of variation for base and middle sampling height appeared to be similar as both decreased from temperature 140 °C-30minutes to 100 °C-30minutes.

There was a decreasing pattern in the value of MOE of thermal-modified bamboo from base to top with an increase in temperature and time, there was a maximum decrease values at the temperature and time variations 140 °C-30minutes, while the minimum decrease was observed at temperature and time variations 100 °C-30minutes. This result is similar with the report given by Boonstra *et al*, (2007); Natividad and Jimenez, (2015). Boonstra *et al,* (2007) reported that there was a reduction of (MOE) after heat treatment of some softwood species namely; *Pinus radiata, Pinus sylvestris and Picea abies,* Natividad and Jimenez, (2015) also reported that bamboo sample of *Bambusa blumena* treated at the highest temperature and time duration (200 °C-60minutes) had the lowest value as MOE 3,570N/mm^2 while the highest values 4,966N/mm^2 was observed at the lowest temperature and time (150 °C-30 minutes) also, the decrease in MOE due to increased temperature level and treatment duration was also observed by Manalo and Acda, (2009) who reported a 16-22% decrease in MOE for the 3 bamboo species they studied. The effect of heat treatment on the elastic properties of wood are rather limited, although an increase of the MOE during bending test has been observed by Boonstra *et al*, (2007). Another phenomenon which can affect the strength properties of wood after heat treatment is the thermoplastic properties of wood, (Goring, 1963; Shiraishi, 2001 and Boonstra *et al.*, 2007). The thermal behaviour of lignin and hemicellulose seems to be restricted by interactions due to secondary intermolecular bonding with the cellulose (Shiraishi, 2001). Degradation of hemicelluloses during the hydro-thermolysis stage affects these secondary bonding which enables the plasticisation of the remaining hemicellulose and lignin, this probably may affect the interaction between the main components of wood affecting the strength properties (Boonstra *et al.*, 2007). The follow up test further revealed the interaction effect between temperature variation and time (Table 56).

Table 56: Follow up test for interaction between temperature variation and time duration for Modulus of Elasticity (MOE)

Temperature (°C)	Time (minutes)	Mean
140	30	5461.83a
130	30	8719.87a
120	30	9611.40a
110	30	13986.17a
100	30	20381.67a
140	20	6721.57b
130	20	9295.97b
120	20	10696.53b
110	20	15854.33b
100	20	23541.00b
140	10	8001.86c
130	10	9647.52c
120	10	12560.03c
110	10	18524.89c
100	10	24422.67c
Untreated	untreated	29703.50f

Mean with the same alphabet are not significantly different from one another

Table 57: Analysis of Variance (ANOVA) of Modulus of Rupture (MOR) for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	24539.81	12269.90	2980.00*	0.00
Temperature variation(°C)	5.00	41555.74	8311.15	2020.00*	0.00
Treatment time(minutes)	2.00	824.36	412.18	100.10*	0.00
Sampling height * Temperature variation(°C)	10.00	1140.57	114.06	27.70*	0.00
Sampling height * Treatment time(minutes)	4.00	127.41	31.85	7.74*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	394.94	39.49	9.59*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	223.31	11.17	2.71*	0.00
Error	216.00	889.39	4.12		
Total	270.00	406040.40			

*=significant at P<0.05
ns=not significant at P>0.05

Table 58: Mean value of Modulus of Rupture (MOR) N/mm^2 for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	66.36±0.21	61.96±5.37	40.55±0.00	**56.29±1.86f**
100	10	61.61±2.57	54.06±2.47	38.61±0.00	**51.43±1.68c**
	20	60.64±0.30	45.23±4.62	31.99±2.47	**45.96±2.46b**
	30	58.19±2.63	38.61±0.00	27.58±0.00	**41.46±0.88a**
	Mean	**60.15±1.83**	**45.97±2.36**	**32.73±0.82**	**46.28±1.67e**
110	10	46.34±3.02	38.61±0.00	22.41±0.32	**35.79±1.11c**
	20	44.13±0.00	36.41±3.02	22.07±0.00	**34.20±1.01b**
	30	42.10±1.85	33.10±0.00	22.07±0.00	**32.42±0.62a**
	Mean	**44.19±1.63**	**36.04±1.01**	**22.18±0.11**	**34.14±0.91d**
120	10	39.25±0.86	33.10±0.00	22.07±0.00	**31.47±0.29c**
	20	38.62±0.00	30.58±0.23	19.86±3.02	**29.69±1.08b**
	30	38.62±0.00	27.58±0.00	16.55±0.00	**27.58±0.00a**
	Mean	**38.83±0.29**	**30.42±0.08**	**19.49±1.01**	**29.58±0.46c**
130	10	38.62±0.01	27.58±0.00	16.55±0.00	**27.58±0.00c**
	20	38.61±0.00	23.17±2.47	14.34±3.02	**25.37±1.83b**
	30	35.30±3.02	22.07±0.00	11.03±0.00	**22.80±1.01a**
	Mean	**37.51±1.01**	**24.27±0.82**	**13.97±1.01**	**25.25±0.95b**
140	10	33.10±0.00	22.07±0.00	11.03±0.00	**22.06±0.00c**
	20	33.10±0.00	16.55±0.00	11.03±0.00	**20.23±0.00b**
	30	29.79±3.02	16.55±0.00	8.83±3.02	**18.39±2.01a**
	Mean	**31.99±1.01**	**18.39±0.00**	**10.30±1.01**	**20.23±0.67a**
	Pooled mean	**46.51±12.71c**	**36.17±15.10b**	**23.20±10.85a**	**35.29±16.10**

Mean with same superscript in the same column are not significantly different ($P<0.05$)

4.3.3 Modulus of rupture (MOR)

The result of analysis of variance of MOR as a result of treatment effect in sampling height, temperature variation (°C) and treatment time (minutes) were `significantly different at 5% level of probability. Effect of interaction among the sampling height, temperature and treatment time (minutes) was also significant at this level, as shown in Table 57.

The mean value of the MOR of the untreated and thermal-modified *Bambusa vulgaris* is presented in Table 58.

The mean values for the temperature variations; 100, 110, 120 and 140 °C with respect to adopted treatment time (minutes) ranged from 60.15 to 31.99N/mm^2 for the base samples, while for the middle samples ranged from 45.97 to 18.39 N/mm^2, the value ranged from 32.73 to 10.30N/mm^2 for the top.

The MOR values of thermal-modified bamboo were impacted with increasing temperature and time, the highest MOR values were observed in the untreated base samples (66.36N/mm^2). There was a decreasing trend in pattern of the MOR values from base to top with respect to relative temperature and time. More so, the lowest value (8.83N/mm^2) of MOE was observed at top samples at the highest temperature and time variations (140 °C-30minutes). This result favourably compared with the reports of Natividad and Jimenez, (2015); Manalo and Acda, (2009); and Kelemwork, (2009). Manalo and Acda, (2009) reported MOR reduction of 31-60% , finding of Kelemwork, (2009), who reported that the highest MOR was found in the bottom values of the control specimen were in the range of 170 to 214N/mm^2, while values for aged specimens ranged from 131 to 205N/mm^2. Also, this result is contrary to the bending properties for both control and aged specimens, MOR increased from the base to the top, this is as a result that bamboo has a low strength to weight ratio, it is not desirable for some applications because of its high specific gravity. All these complex features must be taken into concern for the bamboo utilisation in the wood composite manufacturing. However, its strength (bending strength) and availability may outweigh this disadvantage (Chaowana, 2013). The follow up test further revealed the interaction effect between temperature variation and time (Table 59).

Table 59: Follow up test for interaction between temperature variation and time duration for Modulus of Rupture (MOR)

Temperature (°C)	Time (minutes)	Mean
140	30	18.39a
130	30	22.80a
120	30	27.58a
110	30	32.42a
100	30	41.46a
140	20	20.23b
130	20	25.37b
120	20	29.69b
110	20	34.20b
100	20	45.96b
130	10	27.58c
140	10	22.06c
120	10	31.47c
110	10	35.79c
100	10	51.43c
untreated	untreated	56.29f

Mean with the same alphabet are not significantly different from one another

Table 60: Analysis of Variance (ANOVA) of Shear strength (//) for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	
Sampling height	2.00	129.66	64.83	100.10*	0.00
Temperature variation(°C)	5.00	65.93	13.19	20.36*	0.00
Treatment time(minutes)	2.00	276.14	138.07	213.17*	0.00
Sampling height * Temperature variation(°C)	10.00	238.66	23.87	36.85*	0.00
Sampling height * Treatment time(minutes)	4.00	22.83	5.71	8.81*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	79.98	8.00	12.35*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	60.22	3.01	4.65*	0.00
Error	216.00	139.90	0.65		
Total	270.00	3590.94			

*=significant at P<0.05

ns=not significant at P>0.05

Table 61: Mean value of Shear strength (//) N/mm^2 for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	6.50±1.02	4.17±0.23	3.98±0.25	**3.88±0.50d**
100	10	4.90±1.47	6.74±0.12	2.57±0.12	**4.74±0.57c**
	20	3.26±1.60	5.39±0.25	1.96±0.00	**3.54±0.61b**
	30	1.52±0.27	1.47±0.00	1.23±0.25	**1.41±0.17a**
	Mean	**3.23±1.11**	**4.54±0.12**	**1.92±0.12**	**3.23±0.45bc**
110	10	6.62±1.72	3.31±0.37	3.36±1.72	**4.43±1.27c**
	20	1.59±0.37	1.94±0.35	1.52±0.27	**1.68±0.33b**
	30	1.23±0.00	0.64±0.41	1.25±0.25	**1.04±0.22a**
	Mean	**3.15±0.69**	**1.96±0.38**	**2.04±0.75**	**2.38±0.61a**
120	10	6.57±3.01	3.19±0.67	3.51±0.38	**4.42±1.36c**
	20	3.78±0.77	1.77±0.50	2.62±0.16	**2.72±0.48b**
	30	2.53±1.42	1.42±0.21	1.96±0.49	**1.97±0.70a**
	Mean	**4.29±1.73**	**2.12±0.46**	**2.70±0.35**	**3.04±0.85b**
130	10	3.68±0.25	3.82±0.54	5.80±1.60	**4.43±0.80c**
	20	3.31±0.12	2.92±0.65	4.22±0.11	**3.48±0.29b**
	30	1.96±0.25	2.57±0.37	2.26±0.94	**2.26±0.52a**
	Mean	**2.98±0.20**	**3.11±0.52**	**4.09±0.88**	**3.39±0.54c**
140 °C	10	6.62±0.49	3.80±0.12	3.06±0.37	**4.49±0.33c**
	20	2.33±0.37	2.57±1.10	1.94±0.25	**2.28±0.57b**
	30	1.96±0.00	0.61±0.37	0.64±0.41	**1.07±0.26a**
	Mean	**3.64±0.29**	**2.33±0.53**	**1.88±0.34**	**2.62±0.39a**
	Pooled mean	**3.96±2.28c**	**3.04±1.63b**	**2.27±1.43a**	**3.09±1.94**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.3.4 Shear Strength (//)

The analysis of variance also revealed that there was a significant difference in sampling height, temperature variation (°C) and treatment time (minutes) at 5% level of probability; .there was also a significant effect on interactions among the sampling height, temperature variation (°C) and treatment time (minutes) as shown in Table 60.

The mean value of the shear strength at temperature variations (°C); 100, 110, 120, 130 and 140 °C with respect to treatment time (minutes); 10, 20 and 30minutes is presented in Table 43 the mean values decreased from the base to the top and ranged from 4.26 to 2.98N/mm^2 for the base, the mean value for middle samples ranged from 4.54 to 1.96N/mm^2, while the mean value ranged from 4.09 to 1.88N/mm^2 for the top samples Table 61.

The shear strength values of the thermal-modified *Bambusa vulgaris* decreased inconsistently from base samples to the top, the highest shear strength values were observed in the untreated base samples (6.11N/mm^2). The result of this study is similar to the report of Stamm, (1964), according to Stamm, (1964) this can be explained by the (partial) conversion of the polyoses, which make up about 20% of the middle lamella, into furfural polymers. Such degradation of the hemicelluloses reducing the load sharing capacity between cellulose microfibrils/ fibrils, most probably have a negative impact on the shear strength. On the other hand, an increased cross linking within the lignin polymer network could have a positive effect on the shear strength, especially because lignin is the main component of the middle lamella which plays an important role in shear strength. On the macrostructure level there is an indication that heat treatment must affect the shear strength (Boonstra *et al.*, (2006). According to the anatomical result in this study, it was revealed that bamboo posses high quantity of fibres and parenchyma cells, unlike wood, bamboo microstructure is differ from wood structures, in wood microstructure, fibres are arranged around the parenchyma cell, but reverse is the case in bamboo, where the soft parenchyma tissues are arranged around the fibres, as such, may also contribute to the cracking nature of bamboo. Softwood species with narrow annual rings and/or an abrupt transition from early wood into latewood were sensitive for tangential cracks in the latewood section. Radial cracks were also observed, mainly in wood species with an impermeable wood structure such as Norway spruce. Such defects can lead to a faster and/or increased failure when external forces, causing internal shear stresses, are applied on wood (Boonstra *et al.,* 2007). The reduction in hemicellulose content induced by heating and steaming treatment involved in the accelerated aging cycles contributed a lot to the decrease in volumetric shrinkage. Because the shear strength closely corresponded to the parenchyma cell wall components and hemicellulose is the main ingredient of parenchyma cell walls (Esteves *et al.,* 2007).

The observation during the shear test on the treated bamboo being in laminated form revealed the effect of the adhesive on the binding properties forces in the bamboo laminates board, as the shear effect were mostly observed along the glue line of the laminate, This implies the effect of stronger force of lignin binding than the adhesive (Top bond) adopted for the work, the binding force in the laminates board from Top bond adhesive is not as strong as the urea binders, but the limitation of urea binders over Top bond is its health hazard. However, concerns have been raising about the risks of cancer and bronchial health impacts from formaldehyde The follow up test further revealed the interaction effect between temperature variation and time (Table 62).

Table 62: Mean value of Shear strength (//) for untreated and thermal-modified *Bambusa vulgaris*

Temperature (°C)	Time (minutes)	Mean
110	30	1.04a
140	30	1.07a
100	30	1.41a
120	30	1.97a
130	30	2.26a
110	20	1.68b
140	20	2.28b
120	20	2.72b
130	20	3.48b
100	20	3.54b
120	10	4.42c
110	10	4.43c
130	10	4.43c
140	10	4.49c
100	10	4.74c
untreated	untreated	3.88d

Mean with the same alphabet are not significantly different from one another

Table 63: Analysis of Variance (ANOVA) of Impact bending (IB) for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	112.01	56.01	31500.00*	0.00
Temperature variation(°C)	5.00	18.16	3.63	2040.00*	0.00
Treatment time(minutes)	2.00	0.30	0.15	84.05*	0.00
Sampling height * Temperature variation(°C)	10.00	5.55	0.56	311.99*	0.00
Sampling height * Treatment time(minutes)	4.00	0.28	0.07	38.57*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	1.08	0.11	60.79*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	1.06	0.05	29.66*	0.00
Error	216.00	0.38	0.00		
Total	270.00	1024.63			

*=significant at $P<0.05$

ns=not significant at $P>0.05$

Table 64: Mean value of Impact bending (IB) KJ/m^2 for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Height Base	Middle	Top	Mean
0	Untreated	3.57±0.03	1.92±0.02	1.43±0.00	**2.30±0.02e**
100	10	3.24±0.00	1.92±0.07	1.37±0.02	**2.18±0.03c**
	20	3.03±0.01	1.78±0.05	1.33±0.00	**2.05±0.02b**
	30	2.50±0.01	1.77±0.00	1.08±0.00	**1.78±0.00a**
	Mean	**2.93±0.00**	**1.82±0.04**	**1.26±0.01**	**2.00±0.02d**
110	10	2.45±0.01	1.73±0.01	1.08±0.00	**1.75±0.01c**
	20	2.47±0.03	1.71±0.00	0.97±0.13	**1.72±0.05b**
	30	2.43±0.00	1.51±0.12	1.03±0.03	**1.65±0.05a**
	Mean	**2.45±0.01**	**1.65±0.04**	**1.02±0.05**	**1.71±0.04c**
120	10	2.38±0.04	1.61±0.00	0.94±0.05	**1.64±0.03c**
	20	2.33±0.03	1.61±0.00	0.97±0.02	**1.64±0.02b**
	30	2.36±0.05	1.58±0.08	0.93±0.07	**1.62±0.07a**
	Mean	**2.36±0.04**	**1.60±0.03**	**0.95±0.05**	**1.63±0.04b**
130	10	2.39±0.01	1.55±0.02	0.95±0.04	**1.63±0.02c**
	20	2.33±0.01	1.50±0.00	0.92±0.00	**1.58±0.00b**
	30	2.33±0.02	1.43±0.04	0.94±0.02	**1.57±0.03a**
	Mean	**2.35±0.01**	**1.49±0.02**	**0.94±0.02**	**1.59±0.02a**
140	10	2.44±0.12	1.43±0.01	0.92±0.05	**1.59±0.06c**
	20	2.36±0.01	1.46±0.00	0.98±0.04	**1.60±0.02b**
	30	2.27±0.06	1.39±0.00	1.37±0.03	**1.68±0.03a**
	Mean	**2.36±0.06**	**1.42±0.00**	**1.09±0.04**	**1.62±0.04b**
	Pooled mean	**2.67±0.47c**	**1.65±0.19b**	**1.11±0.21a**	**1.81±0.72**

Mean with same superscript in the same column are not significantly different (P<0.05

4.3.5 Impact bending (IB)

The result of analysis of variance of IB as a result of treatment effect revealed that sampling height, temperature variation (°C) and treatment time (minutes) were significantly different at 5% level. Effect of interaction among sampling height, temperature variation (°C) was significant at this level as shown in Table 63.

The result shows the mean value of Impact bending properties of the untreated and thermal-modified *Bambusa vulgaris* at temperature variation (°C); 100, 110,120,130 and 140 °C with respect to treatment time (minutes) 10, 20, and 30minutes. The mean value decreased from the base to top, from 100 to 140 °C and from 10 minutes to 30 minutes respectively. The mean value for base ranged from 2.93 to 2.35 KJ/m^2, and ranged from 1.82 to 1.42 KJ/m^2 for middle samples while from 1.26 to 0.94 KJ/m^2 for the top samples (Table 64).

This study revealed a decreasing trend in the ultimate impact bending strength values of thermal-modified *Bambusa vulgaris* from base to the top, also the highest values (3.57 KJ/m^2) of impact bending strength were recorded at the untreated base samples. There were decreases in the values of IB with an increase in temperature treatment time. The least values (1.37 KJ/m^2) of IB were recorded at top samples with the temperature; 140 °C and time; 30minutes. The results obtained is in agreement with Olajide *et al*, (2013b) who reported a decreasing trend of failure of IB because of the chemical reaction caused by heat, the hemicellulose and lignin were impacted as the cell walls were already feeble at a slightest reception of a shock would definitely result to a failure without hesitation.

The follow up test further revealed the interaction effect between temperature variation and time (Table 65).

Table 65: Follow up test for interaction between temperature variation and time duration for Impact bending

Temperature (°C)	Time (minutes)	Mean
130	30	1.57a
120	30	1.62a
130	20	1.58b
110	30	1.65a
140	30	1.68a
100	30	1.78a
140	10	1.59c
140	20	1.60b
120	20	1.64b
100	20	2.05b
110	20	1.72b
130	10	1.63c
120	10	1.64c
110	10	1.75c
100	10	2.18c
Untreated	untreated	2.30e

Mean with the same alphabet are not significantly different from one another

4.4 The Chemical Composition of Untreated and Thermal-Modified *Bambusa vulgaris*

Table 66: Analysis of Variance (ANOVA) of Cellulose for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	132.54	66.27	2850.00*	0.00
Temperature variation(°C)	5.00	617.46	123.49	5320.00*	0.00
Treatment time(minutes)	2.00	1.00	0.50	21.45*	0.00
Sampling height * Temperature variation(°C)	10.00	23.98	2.40	103.22*	0.00
Sampling height * Treatment time(minutes)	4.00	0.23	0.06	2.50*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	1.16	0.12	5.01*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	2.34	0.12	5.05*	0.00
Error	216.00	5.02	0.02		
Total	270.00	502172.10			

*=significant at P<0.05

ns=not significant at P>0.05

Table 67: Mean value of Cellulose content (%) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Mean Pooled
0	Untreated	46.37±0.04	46.45±0.01	46.56±0.30	46.46±0.11f
100	10	41.86±0.00	42.79±0.15	43.74±0.16	42.80±0.11b
	20	41.76±0.08	42.63±0.25	43.34±0.13	42.58±0.15a
	30	41.74±0.10	42.78±0.19	43.39±0.04	42.63±0.11a
	Mean	41.79±0.06	42.73±0.20	43.49±0.11	42.67±0.12e
110	10	41.80±0.03	42.64±0.05	43.39±0.08	42.61±0.05b
	20	41.58±0.16	42.65±0.07	43.34±0.08	42.52±0.11a
	30	41.49±0.04	42.45±0.09	43.32±0.03	42.42±0.05a
	Mean	41.62±0.08	42.58±0.07	43.35±0.06	42.52±0.07d
120	10	41.46±0.02	42.52±0.13	43.43±0.07	42.47±0.07b
	20	41.41±0.01	42.29±0.24	43.36±0.05	42.35±0.10a
	30	41.26±0.05	42.26±0.20	43.45±0.04	42.32±0.10a
	Mean	41.37±0.03	42.36±0.19	43.41±0.05	42.38±0.09c
130	10	41.18±0.03	42.35±0.03	43.40±0.08	42.31±0.04b
	20	41.21±0.08	42.52±0.03	43.38±0.09	42.37±0.07a
	30	41.10±0.02	42.28±0.19	43.42±0.03	42.26±0.08a
	Mean	41.16±0.04	42.38±0.08	43.40±0.07	42.32±0.07b
140	10	41.06±0.03	42.74±0.12	43.48±0.03	42.42±0.06b
	20	41.00±0.00	41.62±0.53	43.44±0.05	42.02±0.19a
	30	41.00±0.00	42.27±0.50	43.31±0.04	42.19±0.18a
	Mean	41.02±0.01	42.21±0.38	43.41±0.04	42.21±0.15a
	Pooled mean	42.22±1.88a	43.12±1.53b	43.94±1.19c	43.09±1.71

Mean with same superscript in the same column are not significantly different (P<0.05)

4.4.1 Alpha Cellulose content

There was a significant difference in all the sources of variation as shown in Table 48 There was a significant interaction effect among sampling height, temperature variation (°C) and treatment time (minutes) as shown in Table 66.

The mean value of percentage cellulose content of the thermal-modified *Bambusa vulgaris* is presented at Table 67, at the base ranged from 41.79 to 41.02%, the mean value percentage for middle samples ranged from 42.73 to 42.21% while for the top samples ranged from 43.49 to 43.41%. The heat treatment impacted the cellulose content of *Bambusa vulgaris* slightly because of the mild temperature variation (°C) adopted. The cellulose is the innermost chemical constituents in the cell wall of fibres, as such; it requires high temperature to intensely impact cellulose content in a wood. There was a percentage decrease in the cellulose content of bamboo culm from the top to the base, notwithstanding there was a slight decrease in the mean value of cellulose content from 100 to 140 °C also the treatment time (minutes) affected the cellulose content.

There is an increasing trend in the percentage of cellulose content value from base to top, the untreated bamboo top samples had the highest percentage cellulose content (46.56%). This view was reported by Bremer *et al*, (2013) on the chemical composition of thermal-modified of two Vietnamese bamboo species; namely *Dendrocalamus barbatus, Dendrocalamus asper*, at temperature variation(°C) 130, 160 and 180 °C with respective treatment time(minutes); 2hours and 5 hours, Their percentages cellulose content ranged from 50.7 to 46.13% for *Dendrocalamus barbatus*, ranged from 49.41 to 47.01% for *Dendrocalamus asper*, the modified samples showed a continuous decrease during modification in respect to increase in temperature and time variation, but only a maximum loss of 5% of cellulose was observed for both species. Cellulose is fairly impacted by thermal modification compared with the other chemical constituents in bamboo. Cellulose as the main component exhibited a higher thermal stability than hemicellulose because of its crystallinity, this could be attributed to a shortening of cellulose chains. The follow up test further revealed the interaction effect between temperature variation and time (Table 68).

Table 68: Follow up test for interaction between temperature variation and time duration for Cellulose

Temperature (°C)	Time (minutes)	Mean
140	20	42.02a
140	30	42.19a
130	30	42.26a
120	30	42.32a
120	20	42.35a
130	20	42.37a
110	30	42.42a
110	20	42.52a
100	20	42.58a
100	30	42.63a
130	10	42.31b
140	10	42.42b
120	10	42.47b
110	10	42.61b
100	10	42.80b
untreated	untreated	46.46f

Mean with the same alphabet are not significantly different from one another

Table 69: Analysis of Variance (ANOVA) of percentage Hemicellulose content for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	357.12	178.56	20100.00*	0.00
Temperature variation(°C)	5.00	472.81	94.56	10700.00*	0.00
Treatment time(minutes)	2.00	0.42	0.21	23.68*	0.00
Sampling height * Temperature variation(°C)	10.00	19.51	1.95	219.86*	0.00
Sampling height * Treatment time(minutes)	4.00	0.31	0.08	8.62*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	1.00	0.10	11.25*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	1.33	0.07	7.51*	0.00
Error	216.00	1.92	0.01		
Total	270.00	289087.50			

*=significant at P<0.05
ns=not significant at P>0.05

Table 70: Mean value of Hemicellulose content (%) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	height Middle	Top	Pooled Mean
0	Untreated	34.88±0.07	35.20±0.05	36.69±0.19	**35.59±0.10f**
100	10	30.80±0.01	32.85±0.00	33.99±0.01	**32.55±0.00b**
	20	30.74±0.05	32.52±0.29	33.98±0.00	**32.41±0.11b**
	30	30.65±0.01	32.75±0.00	33.98±0.00	**32.46±0.00a**
	Mean	**30.73±0.02**	**32.71±0.10**	**33.98±0.00**	**32.47±0.04e**
110	10	30.55±0.00	32.66±0.02	33.89±0.00	**32.37±0.01b**
	20	30.52±0.03	32.52±0.00	33.83±0.01	**32.29±0.01b**
	30	30.31±0.02	32.41±0.01	33.69±0.07	**32.13±0.03a**
	Mean	**30.46±0.02**	**32.53±0.01**	**33.80±0.03**	**32.26±0.02d**
120	10	30.21±0.19	32.32±0.01	33.44±0.04	**31.99±0.08b**
	20	30.98±0.44	32.31±0.00	33.34±0.01	**32.21±0.15b**
	30	30.39±0.13	32.27±0.01	33.22±0.01	**31.96±0.05a**
	Mean	**30.53±0.25**	**32.30±0.01**	**33.33±0.02**	**32.05±0.09c**
130	10	30.51±0.05	32.24±0.03	33.15±0.01	**31.97±0.03b**
	20	30.30±0.00	32.20±0.00	33.10±0.01	**31.87±0.00b**
	30	30.08±0.05	32.14±0.02	33.09±0.01	**31.77±0.03a**
	Mean	**30.30±0.03**	**32.19±0.02**	**33.12±0.01**	**31.87±0.02b**
140	10	30.24±0.03	32.11±0.00	33.06±0.01	**31.80±0.01b**
	20	30.22±0.02	32.10±0.00	33.02±0.00	**31.78±0.01b**
	30	30.28±0.00	32.11±0.00	33.01±0.01	**31.80±0.00a**
	Mean	**30.24±0.02**	**32.11±0.00**	**33.03±0.00**	**31.79±0.01a**
	Pooled mean	**31.19±1.68a**	**33.98±0.00b**	**33.99±1.26c**	**32.67±1.78**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.4.3 Hemicellulose content

The variation in hemicellulose percentage content in sampling height, Temperature variation (° C) and treatment time (minutes) were significant at 5% level (Table 69). There was a significant interaction effect among all the factors variable adopted as shown in Table 69.

Hemicellulose content mean values are presented in Table 70 the untreated samples at top samples recorded the highest percentage hemicellulose content 36.69%.

The values of percentage hemicellulose content of the thermal-modified *Bambusa vulgaris* at the base varied from 30.73 to 30.24%, at the middle samples the mean value ranged from 32.71 to 32.11%, while at top samples ranged from 33.98 to 33.09%.

In this study, the percentage of hemicellulose content was highest in the untreated samples, there was a decreasing pattern from top to base, and the least percentage hemicellulose content values were recorded at the temperature 140 °C-30minutes. This is a general trend with bamboo thermal-modified, according to Bremer *et al*, (2013), this is because thermal modification causes a lot of changes to physical properties of the bamboo such as Equilibrium Moisture Content (EMC), colour and mass, all of which are adversely affected by changes in chemical composition, most especially hemicellulose content (Bremer *et al.*, 2013). Species with higher hemicellulose content might present a substantial increase in hydrophobicity after treatment. In addition to changes in the hydrophobic character, the densification of lignin chain is also a factor to explain the increased resistance to fungi in thermally treated woods (Duchez and Guyonnet, 1998).

The follow up test further revealed the interaction effect between temperature variation and time (Table 71).

Table 71: Follow up test for interaction between temperature variation and time duration for Hemicellulose

Temperature (°C)	Time (minutes)	Mean
130	30	31.77a
140	30	31.80a
120	30	31.96a
110	30	32.13a
100	30	32.46a
140	20	31.78b
140	10	31.80b
130	20	31.87b
130	10	31.97b
120	10	31.99b
120	20	32.21b
110	20	32.29b
110	10	32.37b
100	20	32.41b
100	10	32.55b
Untreated	untreated	35.59f

Mean with the same alphabet are not significantly different from one another

Table 72: Analysis of Variance (ANOVA) of percentage Holocellulose for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	923.55	461.77	12700.00*	0.00
Temperature variation(°C)	5.00	2167.50	433.50	11900.00*	0.00
Treatment time(minutes)	2.00	2.28	1.14	31.21*	0.00
Sampling height * Temperature variation(°C)	10.00	67.24	6.72	184.30*	0.00
Sampling height * Treatment time(minutes)	4.00	0.98	0.24	6.69*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	2.55	0.26	7.00*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	3.43	0.17	4.70*	0.00
Error	216.00	7.88	0.04		
Total	270.00	1553104.00			

*=significant at P<0.05

ns=not significant at P>0.05

Table 73: Mean value of Holocellulose content (%) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Mean
0	Untreated	81.24±0.11	81.65±0.06	83.24±0.48	**82.05±0.22f**
100	10	72.66±0.01	75.64±0.15	77.73±0.17	**75.34±0.11c**
	20	72.50±0.13	75.15±0.04	77.32±0.13	**74.99±0.10b**
	30	72.39±0.11	75.53±0.19	77.37±0.04	**75.10±0.12a**
	Mean	**72.52±0.08**	**75.44±0.13**	**77.47±0.12**	**75.14±0.11e**
110	10	72.35±0.03	75.30±0.03	77.28±0.08	**74.98±0.05c**
	20	72.10±0.14	75.17±0.07	77.17±0.09	**74.81±0.10b**
	30	71.80±0.07	74.86±0.10	77.01±0.04	**74.55±0.07a**
	Mean	**72.08±0.08**	**75.11±0.07**	**77.15±0.07**	**74.78±0.07d**
120	10	71.67±0.17	74.85±0.14	76.87±0.02	**74.46±0.11c**
	20	72.39±0.44	74.60±0.24	76.70±0.07	**74.56±0.25b**
	30	71.65±0.18	74.53±0.21	76.67±0.04	**74.28±0.15a**
	Mean	**71.90±0.26**	**74.66±0.20**	**76.75±0.04**	**74.43±0.17c**
130	10	71.69±0.08	74.59±0.05	76.56±0.09	**74.28±0.07c**
	20	71.51±0.08	74.72±0.03	76.49±0.09	**74.24±0.07b**
	30	71.18±0.03	74.42±0.21	76.51±0.03	**74.04±0.09a**
	Mean	**71.46±0.06**	**74.58±0.10**	**76.52±0.07**	**74.18±0.08b**
140	10	71.29±0.07	74.85±0.12	76.54±0.02	**74.23±0.07c**
	20	71.22±0.02	73.72±0.53	76.46±0.05	**73.80±0.20b**
	30	71.28±0.00	74.38±0.50	76.32±0.04	**73.99±0.18a**
	Mean	**71.26±0.03**	**74.32±0.38**	**76.44±0.04**	**74.01±0.15a**
	Pooled mean	**73.41±3.55a**	**75.96±2.60b**	**77.34±2.15c**	**75.77±3.44**

Mean with same superscript in the same column are not significantly different ($P<0.05$)

4.4.4 Holocellulose content

The result of analysis of variance shown that there was a significant variation in the sampling height, temperature variation (°C) and Treatment time (minutes) at 5% level of probability as shown in table 72.

There was a significant interaction effect among all the factors variable adopted as shown in Table 72.

The mean value of Holocellulose content percentage is presented in Table 73.

The mean value of Holocellulose content percentage ranged from 72.52 to 71.26% at the base, while at the middle samples ranged from 75.44 to 74.32%, the mean value for the top samples varied from 77.47 to 76.44%.

The highest Holocellulose content percentage was recorded at the untreated top samples with percentage value 83.24%, there is a decreasing trend in the percentage holocellulose content ranging from top to base with respect to increase in temperature and time variation.

The content of holocellulose showed a continuous decrease during the thermal modification. The influence of modification variation and time seemed to be similar. Degradation of holocellulose was stronger at temperature 140 °C-20minutes this result is in agreement with the studies by Nguyen *et al*, (2012), Bamboo hemicelluloses contain about 7% acetyl groups (Liese, 1985; Kartal *et al.*, 2008). These groups were separated from the chains by thermal exposure and formed acetic acid. This compound has a catalytic effect on the decomposition of the glycosidic bonds of holocellulose. Holocellulose includes cellulose and hemicelluloses, which have different thermal stabilities. The main components; holocellulose and lignin, have an important influence on the physical and mechanical properties of *Bambusa vulgaris* (Nguyen *et al.*, 2012).

The follow up test further revealed the interaction effect between temperature variation and time (Table 74).

Table 74: Follow up test for interaction between temperature variation and time duration for Holocellulose

Temperature (°C)	Time (minutes)	Mean
140	30	73.99a
130	30	74.04a
120	30	74.28a
110	30	74.55a
100	30	75.10a
140	20	73.80b
130	20	74.24b
120	20	74.56b
110	20	74.81b
100	20	74.99b
140	10	74.23c
130	10	74.28c
120	10	74.46c
110	10	74.98c
100	10	75.34c
Untreated	untreated	82.05f

Mean with the same alphabet are not significantly different from one another

Table 75: Analysis of Variance (ANOVA) of percentage Lignin of untreated and thermal-modified Bamboo

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	45.28	22.64	4010.00*	0.00
Temperature variation(°C)	5.00	382.29	76.46	13600.00*	0.00
Treatment time(minutes)	2.00	0.10	0.05	8.44*	0.00
Sampling height * Temperature variation(°C)	10.00	2.39	0.24	42.33*	0.00
Sampling height * Treatment time(minutes)	4.00	0.02	0.01	0.84ns	0.50
Temperature variation(°C) * Treatment time(minutes)	10.00	0.02	0.00	0.32ns	0.97
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	0.14	0.01	1.22ns	0.24
Error	216.00	1.22	0.01		
Total	270.00	189459.60			

*=significant at P<0.05

ns=not significant at P>0.05

Table 76: Mean value of Klason Lignin content (%) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling height Base	Middle	Top	Mean
0	Untreated	29.69±0.17	29.13±0.03	28.50±0.16	**29.11±0.12f**
100	10	26.08±0.01	26.00±0.00	25.14±0.00	**25.74±0.00a**
	20	26.09±0.00	26.01±0.00	25.16±0.02	**25.76±0.01a**
	30	26.10±0.00	26.01±0.00	25.23±0.01	**25.78±0.00b**
	Mean	**26.09±0.00**	**26.01±0.00**	**25.18±0.01**	**25.76±0.00a**
110	10	26.10±0.00	26.01±0.00	25.35±0.00	**25.82±0.00a**
	20	26.11±0.01	26.01±0.00	25.36±0.01	**25.83±0.01a**
	30	26.15±0.02	26.02±0.00	25.38±0.00	**25.85±0.01b**
	Mean	**26.12±0.01**	**26.01±0.00**	**25.36±0.00**	**25.83±0.00b**
120	10	26.19±0.01	26.02±0.00	25.39±0.00	**25.87±0.00a**
	20	26.27±0.04	26.03±0.00	25.40±0.00	**25.90±0.01a**
	30	26.38±0.08	26.04±0.00	25.42±0.01	**25.94±0.03b**
	Mean	**26.28±0.04**	**26.03±0.00**	**25.40±0.00**	**25.90±0.02c**
130	10	26.51±0.00	26.06±0.01	25.42±0.01	**26.00±0.01a**
	20	26.53±0.01	26.07±0.00	25.44±0.01	**26.01±0.00a**
	30	26.61±0.05	26.07±0.00	25.45±0.01	**26.05±0.02b**
	Mean	**26.55±0.02**	**26.07±0.00**	**25.44±0.01**	**26.02±0.01d**
140	10	26.69±0.02	26.08±0.00	25.56±0.00	**26.11±0.01a**
	20	26.74±0.04	26.09±0.00	25.57±0.00	**26.13±0.02a**
	30	26.68±0.34	26.10±0.01	25.73±0.05	**26.17±0.13b**
	Mean	**26.70±0.13**	**26.09±0.00**	**25.62±0.02**	**26.14±0.05e**
	Pooled mean	**26.91±1.28c**	**26.56±1.16b**	**26.56±1.16a**	**26.46±1.27**

Mean with same superscript in the same column are not significantly different (P<0.05)

`4.4.5 Klason Lignin Content

Analysis of variance revealed that there is a significant variation in the sampling height, temperature variation (°C) and treatment time (minutes) adopted as shown in the Table 75.

The mean value percentage of lignin content of *Bambusa vulgaris* at base of temperature variations; 100,110, 120, 130 and 140 °C respectively with respect to the treatment time (minutes) varied from 26.09 to 26.70%, while at middle ranged from 26.01 to 26.09%, and the mean value percentage at top ranged from 25.18 to 25.62%, respectively in Table 76.

Lignin content varied consistently in decreasing order from base to top. However the trend is in reverse in the temperature variation (°C), the percentage lignin contents increased with an increase in the temperature of variation and treatment time from 100-10minutes to 140 °C-30minutes. This gain in the Lignin percentage content is as a result of hydroxyl linkage of lignin.

Based on the results, the percentage lignin variation is in contrary to the pattern of all other chemical constituents in *Bambusa vulgaris* and their response to heat modification, all the chemical constituents except the Lignin the wood decrease in the their mean values, the highest lignin content is recorded at the untreated base samples (29.69%). The increasing pattern of the percentage lignin content of thermal-modified bamboo varied from top to base, this is in line with the Bremer *et al*, (2013) finding on the chemical composition variations of the thermal-modified Vietnamese bamboo species, namely *Dendrocalamus barbatus*, *Dendrocalamus asper*, at temperature variation (^{o}C) 130, 160 and 180 °C with treatment time (minutes) 2hours and 5 hours. Their percentage cellulose content ranged from 25.19 to 37.22 % for *Dendrocalamus barbatus*, ranged from 34.89 to 24.94% for *Dendrocalamus asper*, this is because by means of Klason lignin analysis, all components are not soluble in concentrated Sulphuric acid, and bamboo lignin has a high content of unsaturated aromatic acids, as is typical for grass. These components can react with various decomposition products of hemicellulose. Furthermore, polymerisation of decomposition products of hemicelluloses is possible; the hydrophilic character will be weakened by a reduction of hydroxyl groups during decomposition of holocellulose. A decrease of Equilibrium Moisture Content with increasing temperature was detected for these samples (Nguyen *et al.*, 2012; Bremer *et al.*, 2013). The follow up test further revealed the interaction effect between temperature variation and time (Table 77).

Table 77: Follow up test for interaction between temperature variation and time duration for Klason Lignin

Temperature (°C)	Time (minutes)	Mean
100	10	25.74a
100	20	25.76a
110	10	25.82a
110	20	25.83a
120	10	25.87a
120	20	25.90a
130	10	26.00a
130	20	26.01a
140	10	26.11a
140	20	26.13a
110	30	25.85b
100	30	25.78b
120	30	25.94b
130	30	26.05b
140	30	26.17b
Untreated	Untreated	29.11f

Mean with the same alphabet are not significantly different from one another

Table 78: Analysis of Variance of percentage Ash content for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	1.17	0.59	1560.00*	0.00
Temperature variation(°C)	5.00	2.70	0.54	1440.00*	0.00
Treatment time(minutes)	2.00	0.01	0.01	15.44*	0.00
Sampling height * Temperature variation(°C)	10.00	0.36	0.04	94.30*	0.00
Sampling height * Treatment time(minutes)	4.00	0.01	0.00	3.94*	0.00
Temperature variation(°C) * Treatment time(minutes)	10.00	0.03	0.00	8.69*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	0.03	0.00	3.85*	0.00
Error	216.00	0.08	0.00		
Total	270.00	144.74			

*=significant at $P<0.05$

ns=not significant at $P>0.05$

Table 79: Mean value of Ash content (%) for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	0.93±0.02	0.87±0.02	0.95±0.01	**0.92±0.02e**
100	10	0.70±0.02	0.74±0.04	0.86±0.02	**0.77±0.03b**
	20	0.70±0.01	0.73±0.02	0.83±0.03	**0.75±0.02a**
	30	0.70±0.01	0.77±0.02	0.88±0.01	**0.78±0.01b**
	Mean	**0.70±0.01**	**0.75±0.03**	**0.86±0.02**	**0.77±0.02d**
110	10	0.73±0.01	0.66±0.03	0.83±0.02	**0.74±0.02b**
	20	0.68±0.00	0.62±0.02	0.78±0.01	**0.69±0.01a**
	30	0.64±0.02	0.67±0.02	0.76±0.02	**0.69±0.02b**
	Mean	**0.68±0.01**	**0.65±0.02**	**0.79±0.01**	**0.71±0.02c**
120	10	0.57±0.02	0.61±0.02	0.77±0.02	**0.65±0.02b**
	20	0.53±0.01	0.65±0.01	0.78±0.00	**0.65±0.01a**
	30	0.60±0.07	0.66±0.01	0.77±0.01	**0.68±0.03b**
	Mean	**0.57±0.03**	**0.64±0.01**	**0.77±0.01**	**0.66±0.02b**
130	10	0.53±0.01	0.63±0.02	0.73±0.01	**0.63±0.01b**
	20	0.52±0.00	0.61±0.01	0.73±0.02	**0.62±0.01a**
	30	0.54±0.02	0.67±0.02	0.76±0.02	**0.66±0.02b**
	Mean	**0.53±0.01**	**0.64±0.02**	**0.74±0.02**	**0.64±0.01a**
140	10	0.51±0.00	0.66±0.01	0.75±0.01	**0.64±0.01b**
	20	0.50±0.00	0.66±0.02	0.74±0.04	**0.63±0.02a**
	30	0.50±0.00	0.65±0.02	0.75±0.02	**0.63±0.01b**
	Mean	**0.50±0.00**	**0.66±0.01**	**0.75±0.02**	**0.64±0.01a**
	Pooled mean	**0.65±0.15a**	**0.70±0.09b**	**0.81±0.08c**	**0.72±0.13**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.4.6 Ash content

There was a significant difference at 5% level of probability in sampling height, temperature variation (°C) and time duration, also there were significant effects on interactions among sampling height, temperature variation (°C) and treatment time (minutes) as shown in Table 78.

The average mean value Ash content percentage of the thermal-modified bamboo is presented in the Table 79.

The mean value ranged from 0.70 to 0.50% at base samples, also, the mean ranged from 0.75 to 0.66% at middle while from 0.86 to 0.75% at the top samples with treatment temperature and time; 100, 110,120,130 and 140 °C and 10, 20 and 30 minutes. The highest ash percentage content is recorded at the untreated top samples (0.95%) while the least value (0.55%) is found at the highest temperature and time level 140 °C-30minutes.

The percentage ash content was highest at the untreated top samples; the thermal modification imparted the percentage ash content with a decreasing trend from top to base. *Bambusa vulgaris* ash content is quite high compared with some other species of bamboo, if silica is found in sufficient amounts (0.5% oven-dry1 weight), it can dull machining equipment (CES, 2013). The ash content of wood is made up of inorganic minerals, primarily calcium, potassium, and magnesium. Manganese and silica are two other common minerals. The follow up test further revealed the interaction effect between temperature variation and time (Table 80).

Table 80: Follow up test for interaction between temperature variation and time duration for Ash content

Temperature (°C)	Time (minutes)	Mean
130	20	0.62a
140	20	0.63a
120	20	0.65a
110	20	0.69a
100	20	0.75a
130	10	0.63b
140	30	0.63b
140	10	0.64b
120	10	0.65b
130	30	0.66b
130	30	0.68b
110	30	0.69b
110	10	0.74b
100	10	0.77b
100	30	0.78b
untreated	untreated	0.92e

Mean with the same alphabet are not significantly different from one another

4.5 The Biological Accelerated Test of Untreated and Thermal-Modified *Bambusa Vulgaris*

Table 81: Analysis of Variance (ANOVA) of Percentage weight loss of Brown Rot Fungi of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	73.50	36.75	156.72^{*}	0.00
Temperature variation(°C)	5.00	351.00	70.20	299.37^{*}	0.00
Treatment time(minutes)	2.00	140.96	70.48	300.56^{*}	0.00
Sampling height * Temperature variation(°C)	10.00	8.85	0.89	3.77^{*}	0.00
Sampling height * Treatment time(minutes)	4.00	1.74	0.44	1.86^{ns}	0.12
Temperature variation(°C) * Treatment time(minutes)	10.00	45.51	4.55	19.41^{*}	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	9.59	0.48	2.05^{*}	0.01
Error	216.00	50.65	0.23		
Total	270.00	4424.26			

*=significant at P<0.05

ns=not significant at P>0.05

Table 82: Mean value of Percentage weight loss of Brown Rot Fungi for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	5.60±0.29	6.15±0.20	6.41±0.39	**6.06±0.29d**
100	10	4.19±1.26	4.62±0.88	5.40±0.22	**4.74±0.79c**
	20	3.24±0.45	3.50±0.50	4.57±1.10	**3.77±0.68b**
	30	1.43±0.00	2.45±0.49	3.03±0.55	**2.30±0.35a**
	Mean	**2.95±0.57**	**3.52±0.63**	**4.33±0.62**	**3.60±0.61c**
110	10	4.37±1.29	4.90±1.04	5.57±0.72	**4.95±1.02c**
	20	3.26±0.17	3.60±0.34	3.87±0.50	**3.58±0.34b**
	30	1.83±0.00	2.05±0.45	3.50±0.00	**2.46±0.15a**
	Mean	**3.15±0.49**	**3.52±0.61**	**4.31±0.41**	**3.66±0.50c**
120	10	3.48±0.48	4.58±0.19	5.14±0.36	**4.40±0.34c**
	20	3.64±0.00	4.36±0.53	4.77±0.18	**4.26±0.23b**
	30	1.25±0.01	2.47±0.48	3.07±0.45	**2.27±0.31a**
	Mean	**2.79±0.16**	**3.81±0.40**	**4.33±0.33**	**3.64±0.30c**
130	10	3.44±0.12	3.70±0.00	4.50±0.89	**3.88±0.34c**
	20	1.37±0.35	3.68±0.43	4.08±0.12	**3.04±0.30b**
	30	1.07±0.14	2.10±0.00	3.00±0.00	**2.06±0.05a**
	Mean	**1.96±0.20**	**3.16±0.14**	**3.86±0.34**	**2.99±0.23b**
140	10	3.26±0.18	3.50±0.41	3.67±0.00	**3.48±0.20c**
	20	1.37±0.35	2.01±0.00	2.39±0.63	**1.92±0.32b**
	30	0.98±0.11	2.17±0.52	2.09±0.04	**1.75±0.23a**
	Mean	**1.87±0.21**	**2.56±0.31**	**2.72±0.22**	**2.38±0.25a**
	Pooled mean	**3.05±1.64a**	**3.79±1.17b**	**4.33±1.41c**	**3.72±1.59**

Mean with same superscript in the same column are not significantly different (P<0.05

4.5.1 Percentage weight loss of Brown Rot Fungi

There was a significant different at 5% level of probability in sampling height, temperature variation (°C) and time duration. The result of interaction effect showed that there were significant variations among the variable factors, except between sampling height and treatment time (minutes), (Table 81).

The result of mean value of percentage weight loss of brown rot fungi of untreated and thermal-modified bamboo is presented in Table 82.

The mean value of percentage weight loss of fungi ranged from 3.15 to 1.87% at base for temperature variations; 100, 110, 120,130, and 140 °C with respect to the effect of treatment time (minutes); 10, 20 and 30minutes, the mean values at middle ranged from 3.81 to 2.56% and while at top ranged from 4.33 to 2.72%, The mean value of percentage weight loss increased axially from the base to the top, at maximum temperature and time variation 140 °C-30minutes the percentage weight loss was recorded as 1.87%.

The result of this study revealed that there is a decreasing trend in the percentage weight loss of brown rot fungi test from top to base, with respect to the increases in the adopted temperature variations and treatment time (minutes). Mass loss of control samples was significantly higher than that of the treated samples, this result compared favourably with the report of Bazyar, (2012).He reported that the best results were achieved in the wood samples that were treated with the highest temperature. In relative terms, good durability increment against brown rot fungi was obtained after thermal treatment (Bazyar, 2012).

The follow up test further revealed the interaction effect between temperature variation and time (Table 83).

Table 83: Follow up test for interaction between temperature variation and time duration for percentage brown fungi weight loss

Temperature (°C)	Time (minutes)	Mean
140	30	1.75a
130	30	2.06a
120	30	2.27a
100	30	2.30a
110	30	2.46a
140	20	1.92b
130	20	3.04b
110	20	3.58b
100	20	3.77b
120	20	4.26b
140	10	3.48c
130	10	3.88c
120	10	4.40c
100	10	4.74c
110	10	4.95c
untreated	untreated	6.06d

Mean with the same alphabet are not significantly different from one another

Table 84: Analysis of Variance (ANOVA) of Percentage weight loss from white Rots of untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	81.10	40.55	109.17^{*}	0.00
Temperature variation(°C)	5.00	233.51	46.70	125.74^{*}	0.00
Treatment time(minutes)	2.00	199.31	99.65	268.29^{*}	0.00
Sampling height * Temperature variation(°C)	10.00	7.49	0.75	2.02^{*}	0.03
Sampling height * Treatment time(minutes)	4.00	3.69	0.92	2.48^{*}	0.05
Temperature variation(°C) * Treatment time(minutes)	10.00	45.48	4.55	12.24^{*}	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	8.98	0.45	1.21^{ns}	0.25
Error	216.00	80.23	0.37		
Total	270.00	3364.43			

*=significant at P<0.05

ns=not significant at P>0.05

Table 85: Mean value of Percentage weight loss from white Rots for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	3.92±1.39	5.25±0.65	6.09±0.55	**5.09±0.86c**
100	10	3.87±0.70	4.47±0.08	5.89±0.51	**4.74±0.43c**
	20	2.90±0.10	2.80±0.84	3.37±0.58	**3.02±0.50b**
	30	1.25±0.00	2.06±0.09	2.17±0.24	**1.83±0.11a**
	Mean	**2.67±0.27**	**3.11±0.33**	**3.81±0.44**	**3.20±0.35b**
110	10	3.50±0.14	4.45±0.07	4.89±0.56	**4.28±0.26c**
	20	2.69±0.40	2.96±1.11	3.79±0.44	**3.15±0.65b**
	30	1.28±0.06	1.67±0.00	2.77±0.57	**1.91±0.21a**
	Mean	**2.49±0.20**	**3.03±0.39**	**3.82±0.52**	**3.11±0.37b**
120	10	3.10±0.00	4.13±0.18	4.77±0.72	**4.00±0.30c**
	20	3.06±0.03	2.92±1.15	3.60±0.37	**3.19±0.52b**
	30	1.11±0.00	1.76±0.79	2.21±0.62	**1.69±0.47a**
	Mean	**2.42±0.01**	**2.94±0.71**	**3.52±0.57**	**2.96±0.43b**
130	10	3.06±0.09	3.77±0.52	4.57±0.60	**3.80±0.40c**
	20	1.13±0.30	2.40±0.89	2.73±1.01	**2.09±0.74b**
	30	1.00±0.00	1.12±0.11	1.67±0.00	**1.26±0.04a**
	Mean	**1.73±0.13**	**2.43±0.51**	**2.99±0.54**	**2.38±0.39a**
140	10	2.79±0.69	3.48±0.36	4.47±0.08	**3.58±0.38c**
	20	1.44±0.43	2.05±0.24	2.71±0.56	**2.07±0.41b**
	30	0.92±0.08	1.21±0.27	1.16±0.15	**1.10±0.17a**
	Mean	**1.72±0.40**	**2.25±0.29**	**2.78±0.26**	**2.25±0.32a**
	Pooled mean	**2.49±1.29a**	**3.17±1.47b**	**3.84±1.64c**	**3.17±1.1.57**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.5.2 Percentage weight loss from white Rots

The result of analysis of variance revealed that there were significant differences in sampling height, temperature variation (°C) and treatment time (minutes) at 5% level of probability. There was a significant variation in the interaction effect among all the factors considered except, among sampling height, temperature variation (°C) and treatment time (minutes), (Table 84). The result of the average mean of percentage white rot fungi weight loss is presented in Table 85

The mean value of percentage weight loss white rot fungi ranged from 2.67 to 1.72 % at base for temperature 100,110,120,130, and 140 °C with respect to the effect of treatment time (minutes) 10, 20 and 30minutes, the mean values at middle ranged from 3.11 to 2.25% and while at top ranged from 3.82 to 2.78% The mean value of percentage weight loss increases axially from the base to the top, at maximum temperature 140 °C -30minutes the percentage weight loss was recorded as 1.72%.

There is an increasing pattern in the fungi weight loss effect, which was consistent from the base to the top, also increase in treatment time (minutes)10 to 30minutes caused decrease in the mean values percentage weight loss consistently.

The highest percentage weight loss values (6.09%) of white rot fungi test was recorded at the untreated top samples, the least values were recorded at the heat modified base samples at the highest temperature and time (140 °C-30minutes). There were consistent decreases pattern in the percentage weight loss values of white rot fungi test from the top to the base in respect to temperature and time increases from 100-10minutes to 140 °C-30minutes. The result of this study is in line with the studies of (Kamarudin and Sugiyanto, (2012); Bazyar, (2012), they reported that the higher the temperature, the lower the fungi weight loss during test. It indicates that more starch content was reduced after heating treatment and the starch was reduced by hot oil palm. The averages of sample weight loss were 9.9%, 7.2% and 5.1% in the heating temperature of 100 °C, 150 °C and 200 °C as reported by Kamarudin and Sugiyanto, (2012). This is as a result of different heating temperatures resulted in different weight loss, during biological test. Therefore, it is postulated that with increasing temperature the bamboo substrates vulnerable to fungal attack have been rendered inert or unrecognizable as a food source. The higher temperature of treatment the more starch content in bamboo samples will presumably reduce (Kamarudin and Sugiyanto, 2012). The follow up test further revealed the interaction effect between temperature variation and time (Table 86).

Table 86: Follow up test for interaction between temperature variation and time duration for percentage brown fungi weight loss

Temperature (°C)	Time (minutes)	Mean
140	30	1.75a
130	30	2.06a
120	30	2.27a
100	30	2.30a
110	30	2.46a
140	20	1.92b
130	20	3.04b
110	20	3.58b
100	20	3.77b
120	20	4.26b
140	10	3.48c
130	10	3.88c
120	10	4.40c
100	10	4.74c
110	10	4.95c
untreated	untreated	6.06d

Mean with the same alphabet are not significantly different from one another

4.6 The Seasonal Graveyard Test of Untreated and Thermal-Modified *Bambusa vulgaris*

Table 87: Analysis of Variance (ANOVA) of Six (6) months weight loss from Grave Yard Test for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	205.19	102.59	2.70^{ns}	0.07
Temperature variation(°C)	5.00	5749.44	1149.89	30.23^{*}	0.00
Treatment time(minutes)	2.00	660.71	330.36	8.69^{*}	0.00
Sampling height * Temperature variation(°C)	10.00	2787.66	278.77	7.33^{*}	0.00
Sampling height * Treatment time(minutes)	4.00	99.73	24.93	0.66^{ns}	0.62
Temperature variation(°C) * Treatment time(minutes)	10.00	678.34	67.83	1.78^{ns}	0.07
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	890.67	44.53	1.17^{ns}	0.28
Error	216.00	8215.83	38.04		
Total	270.00	127783.80			

*=significant at P<0.05

ns=not significant at P>0.05

Table 88: Mean value of Six (6) months weight loss from Grave Yard Test for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	20.59±11.98	18.53±10.94	6.75±2.89	**15.29±8.60ab**
100	10	26.49±2.24	33.59±8.94	43.45±3.24	**34.51±4.81b**
	20	22.17±2.04	22.48±1.48	36.59±2.80	**27.08±2.11a**
	30	20.91±6.51	26.02±8.68	31.42±0.97	**26.11±5.39a**
	Mean	**23.19±3.60**	**27.36±6.37**	**37.15±2.34**	**29.23±4.10e**
110	10	20.06±3.34	22.36±5.44	28.64±0.80	**23.69±3.19b**
	20	18.71±3.49	21.36±5.31	25.91±1.38	**21.99±3.39a**
	30	15.61±2.38	16.25±2.84	23.22±0.49	**18.36±1.90a**
	Mean	**18.13±3.07**	**19.99±4.53**	**25.92±0.89**	**21.35±2.83d**
120	10	26.81±16.39	19.33±6.53	21.59±0.42	**22.58±7.78b**
	20	19.80±15.15	17.62±6.12	20.97±0.35	**19.46±7.21a**
	30	16.24±3.53	16.67±3.15	19.97±0.36	**17.63±2.35a**
	Mean	**20.95±11.69**	**17.87±5.27**	**20.84±0.38**	**19.89±5.78cd**
130	10	16.38±2.18	19.78±2.49	18.85±0.49	**18.33±1.72b**
	20	22.10±6.37	17.62±1.26	17.71±0.20	**19.15±2.61a**
	30	18.66±6.00	16.83±0.98	17.19±0.28	**17.56±2.42a**
	Mean	**19.04±4.85**	**18.08±1.58**	**17.92±0.33**	**18.35±2.25bc**
140	10	13.04±2.15	13.38±1.72	15.85±0.26	**14.09±1.37b**
	20	16.01±11.39	18.66±10.55	15.32±0.48	**16.66±7.47a**
	30	12.72±3.13	14.59±3.70	14.31±0.18	**13.87±2.34a**
	Mean	**13.92±5.56**	**15.54±5.32**	**15.16±0.31**	**14.88±3.73a**
	Pooled mean	**19.30±8.59a**	**19.56±7.70ab**	**21.27±9.02c**	**20.05±8.47**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.6.1 Six (6) months weight loss of *Bambusa vulgaris* from Grave Yard Test

The result of analysis of variance indicated that there were significant differences in the temperature variation(°C) and treatment time(minutes) except in sampling height, also there were no significant differences among the interaction effect except between sampling height and temperature variation(°C), as shown in Table 87.

The average mean value of the percentage weight loss for six (6) months seasonal graveyard test is presented in Table 88.

The average mean values of weight loss for 6 months of thermal-modified *Bambusa vulgaris* range at base from 23.19 to 13.92%, from 27.36 to 15.54% for middle and from 37.15 to 15.16% for top, at temperature level treatments; 100, 110, 120, 130 and 140 °C with respect to time 10, 20 and 30 minutes respectively.

The result of this study revealed the increasing percentage mass loss values in the timber grave yard test for six months of *Bambusa vulgaris* thermal-modified. The highest mean values (20.59%) were recorded at the untreated base samples, while the least values (13.92%) were also recorded at thermal-modified base samples at the highest adopted temperature and time in this study (140 °C-30minutes). This result is in accordance with the reports of Kaul, (2014) and Ashaari and Mamat, (2000). Kaul *et al,* (2014) reported on the decay resistance of bamboo modified with plant Extracts and Oil cakes, they observed in the untreated blocks of bamboo weight loss of 65%, they also reiterated that all treated samples with extracts and oil cake resulted in weight loss less than control blocks. More so, Ashaari and Mamat, (2000) reported on their study on the resistance towards white rot fungus and durability of traditional treated two Malaysian bamboo species, namely; *Dendrocalamus asper* and *Bambusa vulgaris*, they reported that at the end of six months, 35-53% mass loss was recorded in the untreated both species samples while 14-20% weight loss was recorded at treated both species samples. This is because termites depend merely on cellulose rather than starch for source of food (Ahmad *et al,* 2000). The follow up test further revealed the interaction effect between temperature variation and time (Table 89).

Table 89: Follow up test for interaction between temperature variation and time duration for Grave Yard Test weight loss for 6months

Temperature (°C)	Time (minutes)	Mean
140	30	13.87a
140	20	16.66a
130	30	17.56a
120	30	17.63a
110	30	18.36a
130	20	19.15a
120	20	19.46a
110	20	21.99a
100	30	26.11a
100	20	27.08a
140	10	14.09b
untreated	untreated	15.29ab
130	10	18.33b
120	10	22.58b
110	10	23.69b
100	10	34.51b

Mean with the same alphabet are not significantly different from one another

Table 90: Analysis of Variance (ANOVA) of Twelve (12) months weight loss percentage from Grave Yard Test for untreated and thermal-modified *Bambusa vulgaris*

Source of variation	Df	Sum of square	Mean of square	F-cal	P-value
Sampling height	2.00	1156.01	578.00	4.79*	0.01
Temperature variation(°C)	5.00	27014.82	5402.96	44.78*	0.00
Treatment time(minutes)	2.00	2758.21	1379.11	11.43*	0.00
Sampling height * Temperature variation(°C)	10.00	8232.01	823.20	6.82*	0.00
Sampling height * Treatment time(minutes)	4.00	312.90	78.23	0.65ns	0.63
Temperature variation(°C) * Treatment time(minutes)	10.00	3644.19	364.42	3.02*	0.00
Sampling height * Temperature variation(°C) * Treatment time(minutes)	20.00	2919.74	145.99	1.21ns	0.25
Error	216.00	26062.42	120.66		
Total	270.00	470528.20			

***=significant at P<0.05**

ns=not significant at P>0.05

Table 91: Mean value of Twelve (12) months weight loss percentage from Grave Yard Test for untreated and thermal-modified *Bambusa vulgaris*

Temperature variation(°C)	Treatment time(minutes)	Sampling Base	Height Middle	Top	Pooled Mean
0	Untreated	37.33±22.12	31.67±13.97	15.65±6.02	**28.21±14.04a**
100	10	60.74±20.11	62.07±16.91	85.60±5.86	**69.47±14.30c**
	20	42.74±3.95	48.34±11.15	71.95±4.82	**54.34±6.64b**
	30	43.61±7.42	52.38±11.67	60.87±2.28	**52.28±7.12a**
	Mean	**49.03±10.49**	**54.26±13.24**	**72.81±4.32**	**58.70±9.35d**
110	10	35.16±9.74	35.44±6.41	55.54±1.63	**42.05±5.93c**
	20	37.00±5.67	45.99±12.21	50.58±1.87	**44.52±6.58b**
	30	27.99±0.81	29.56±2.84	44.61±0.87	**34.05±1.51a**
	Mean	**33.39±5.41**	**37.00±7.15**	**50.24±1.46**	**40.21±4.67c**
120	10	41.58±24.94	37.89±12.37	41.55±1.12	**40.34±12.81c**
	20	49.60±34.01	34.04±11.55	40.16±0.37	**41.27±15.31b**
	30	30.23±7.21	32.35±5.62	38.28±0.58	**33.62±4.47a**
	Mean	**40.47±22.05**	**34.76±9.85**	**40.00±0.69**	**38.41±10.86bc**
130	10	31.17±4.08	35.18±6.17	36.28±0.88	**34.21±3.71c**
	20	36.50±10.95	34.89±3.60	33.94±0.58	**35.11±5.05b**
	30	39.93±14.04	32.57±1.39	32.94±0.42	**35.15±5.28a**
	Mean	**35.87±9.69**	**34.21±3.72**	**34.39±0.63**	**34.82±4.68a**
140	10	26.19±5.37	25.40±3.22	30.55±0.89	**27.38±3.16b**
	20	31.32±21.24	35.67±19.95	29.55±0.23	**32.18±13.81**
	30	21.92±3.96	25.87±4.32	27.35±0.26	**25.05±2.85**
	Mean	**26.48±10.19**	**28.98±9.16**	**29.15±0.46**	**28.20±6.61**
	Pooled mean	**37.09±17.34a**	**36.81±13.65a**	**41.34±17.61c**	**38.41±16.37**

Mean with same superscript in the same column are not significantly different (P<0.05)

4.6.2 Twelve (12) months weight loss percentage of Bambusa vulgaris from Grave Yard Test.

The result of analysis of variance indicated that there were significant differences in all the factors considered, also there were significant differences among interaction effect except between sampling height and treatment time (minutes) and among sampling height , temperature variation(°C) and treatment time(minutes) (Table 90).

The average mean value of the percentage weight loss for 1 year seasonal graveyard test is presented in Table 91.

The average mean values of weight loss for 1 year of thermal-modified *Bambusa vulgaris* range at base from 49.03 to 26.48%, from 54.26 to 28.98% for middle and from 72.81 to 29.15% for top, at temperature level treatments; 100, 110, 120, 130 and 140 °C with respect to time 10, 20 and 30 minutes, respectively.

This result revealed a decreasing pattern of the thermal-modified *Bambusa vulgaris* from top to base, although least percentage weight loss values were recorded at base samples treated at temperature 140 °C-30minutes, according to the result in this study, the treated samples between temperature 100 to 120°C had higher values of percentage mass loss due to termite infestation compared with the control samples, this report is in contrary to the report of Ashaari and Mamat, (2000). The follow up test further revealed the interaction effect between temperature variation and time (Table 92).

Table 92: Follow up test for interaction between temperature variation and time duration for Grave Yard Test weight loss for 12months

Temperature (°C)	Time (minutes)	Mean
140	30	25.05a
Untreated	Untreated	28.21a
140	20	32.18a
120	30	33.62a
110	30	34.05a
100	30	52.28a
130	30	35.15a
140	10	27.38b
130	20	35.11b
120	10	41.27b
110	20	44.52b
100	20	54.34b
120	10	40.34c
110	10	42.05c
100	10	69.47c

Mean with the same alphabet are not significantly different from one another

4.7 Interrelationship Properties of Untreated and Thermal-Modified *Bambusa vulgaris*

Table 93: Regression equations showing relationship between MOE and Vessels/Parenchyma characteristics

	Predictor	Coefficient	R^2	T	P	Standard Error Coefficient
1	(constant)	-17021.2	0.625	-1.714	0.088	9931.599
	MTD	186.156		12.402	0	15.01
	Parenchyma height	-84.507		-2.306	0.022	36.651
	Parenchyma width	373.045		6.777	0	55.045
	Vessel counts	-2615.97		-1.114	0.266	2347.299

Dependent variable: MOE

MOE=-1721.2+186.156MTD-84.507PH+373.045PW-2615.97VC-----------Equation (24)

4.7.1 Relationship between MOE and Vessels/Parenchyma characteristics

Regression model was also developed for predicting MOE of thermal-modified *Bambusa vulgaris*, and the Parenchyma and Vessels characteristics as independent variables, the model had a R^2 value of 62.5%. The R^2 value is good and a bit reliable for predictive purposes, other results of linear regression calculated in Table 93 subjecting the ANOVA, it was revealed that the model had a calculated F value that was statistically significant at $P < 0.05$ (Table 93). The implication of these results is that the model can be used to predict MOE of thermal-modified *Bambusa vulgaris* at varied temperature levels and treatment time (minutes) at 5% probability level.

Table 94: Regression equations showing relationship between MOR and Vessels/Parenchyma characteristics

	Predictor	Coefficient	R^2	T	P	Standard Error Coefficient
1	(constant)	-23.294	0.6	-1.207	0.229	19.301
	MTD	0.324		11.108	0	0.029
	Parenchyma height	-0.019		-0.271	0.786	0.071
	Parenchyma width	0.587		5.491	0	0.107
	Vessel counts	-7.726		-1.694	0.091	4.562

Dependent variable: MOR

MOR=-23.294+0.324MTD-0.019PH+0.587PW-7.726VC-------------------- Equation (25)

4.7.2 Relationship between MOR and Vessels/Parenchyma characteristics

A Regression model for predicting MOR from the Parenchyma and Vessel characteristics as predictors in the model was developed. The model (equation 25) had a R^2 of 60% with other results of the linear regression such as coefficient of predictors, standard error coefficient, T and P values tabulated in Table 94. ANOVA results tabulated in table 94 also showed that the regression model had a statistically significant F calculated value at $P<0.05$ indicating that the model can be used for predictive purpose at this probability level.

Table 95: Regression equations showing relationship between Compressive strength and MOE

	Predictor	Coefficient	R^2	T	P	Standard Error	Coefficient
1	(Constant)	-1.285	0.846	-2.01	0.045	0.64	
	MOE	0.001		38.331	0	0	

Dependent variable: Compressive strength

COMPRESSIVE =-1.285+0.001MOE-- Equation (26)

4.7.3 Relationship between Compressive strength and MOE

In predicting Compressive strength of thermal-modified bamboo from the MOE characteristics as independent variables, it was found that the model, depicted by equation (26) had R^2 of 84.6 % with other result of linear regression for equation (26) in Table 95, The R^2 value is a high and good for predictive purposes while the ANOVA result also showed that the calculated F value for the equation significant at 5% probability level (Table 95).

Table 96: Regression equations showing relationship between Compressive strength and MOR

	Predictor	Coefficient	R^2	T	P	Standard error Coefficient
1	(Constant)	-7.417	0.887	-11.296	0	0.657
	MOR	0.776		45.86	0	0.017

Dependent variable: Compressive Strength

COMPRESSIVE STRENGHT =-7.417+0.776MOE----------------------Equation (27)

4.7.4 Relationship between Compressive strength and MOR

A simple linear regression model for predicting CS from MOR characteristics as predictors in the model was developed; the model (equation 27) had a R^2 of 88.7 %. The R^2 value is good for predictive purposes, other results of the linear regression such as coefficient of predictors, standard error coefficient, T and P values, ANOVA results tabulated in Table 96 also showed that the regression model had a statistically significant calculated F value at $P<0.05$ indicating that the model can be used for predictive purpose at this probability level.

Table 97: Regression equations showing relationship between Compressive strength and Impact bending

	Predictor	Coefficient	R^2	T	P	Standard Coefficient	Error
1	(Constant)	-6.403	0.622	-4.738	0	1.351	
	Impact bending	14.57		21.003	0	0.694	

Dependent variable: Compressive Strength

Compressive -16.403+14.57IB-------------------------Equation (28)

4.7.5 Relationship between Compressive strength and Impact bending

In an attempt to estimate the values of Compressive strength on thermal-modified *Bambusa vulgaris*, the Impact strength value was imputed into a model as the independent variable thereby giving the model depicted by equation 28, the model had coefficient of determination (R^2) value of 62% The R^2 value is fairly strong for predictive purposes and other linear results of linear regression for equation 33 in table (97).

Table 98: Regression equations showing relationship between Sampling height and selected Strength properties

	Predictor	Coefficient	R^2	T	P	Standard Error Coefficient
1	(Constant)	3.888	0.851	58.833	0	0.066
	MOE	0.0000432		6.408	0	0
	MOR	-0.012		-2.88	0.004	0.004
	Shear strength	0.011		0.984	0.326	0.011
	Compressive strength	0.006		1.164	0.245	0.005
	Impact bending	-1.241		-25.372	0	0.049

Dependent variable: Sampling height

Sampling Height =3.888+0.0000432MOE-0.012MOR+0.011SS+0.0006CS-1.241IB---Equation (29)

4.7.6 Relationship between Sampling height and selected Strength properties

Regression equation were also developed for predicting MOE or thermal-modified bamboo, and the parenchyma and vessels characteristics as independent variables, the model had a R^2 value of 85% ,and other results of linear regression calculated in Table 98 subjecting the ANOVA, it was found that the model had a calculated F value that was statistically significant at $P < 0.05$ (Table 98) the implication of these results is that the model can be used to predict MOE of thermal-modified bamboo at varied temperature levels and Treatment time(minutes)at 5% probability level.

Table 99: Regression equations showing relationship between Impact bending and selected chemical composition

Model	Predictor	Coefficient	R2	T	P	Standard error coefficient
1	(constant)	5.384	0.839	6.052	0	0.89
	Cellulose	-0.169		-2.881	0.004	0.059
	Hemicellulose	-0.45		-11.188	0	0.04
	Lignin	0.575		19.748	0	0.029
	Ash	4.407		12.573	0	0.35

Dependent variable: Impact bending

IMPACT BENDING =5.384-0.169CE-0.45HM+0.575L+4.407AS----------Equation (30)

4.7.7 Relationship between Impact bending and selected Chemical compositions

A simple linear regression model for predicting Impact bending from the Chemical characteristics of thermal-modified bamboo as predictors in the model was developed; the model (equation 30) had a R^2 of 83.9 % with other results of the linear regression such as coefficient of predictors, standard error coefficient, T and P values tabulated in Table 99. ANOVA results tabulated in Table 99 also showed that the regression model had a statistically significant calculated F value at $P<0.05$ indicating that the model can be used for predictive purpose at this probability level.

Table 100: Regression equations showing relationship between Compressive strength and selected chemical composition

Model	Predictor	Coefficient	R2	T	P	Standard Error Coefficient
1	(Constant)	33.877	0.719	1.558	0.121	21.75
	Cellulose	0.505		0.352	0.725	1.433
	Hemicellulose	-9.669		-9.842	0	0.982
	Lignin	7.456		10.475	0	0.712
	Ash	115.132		13.437	0	8.568

Dependent Variable: Compressive Strength

COMPRESSIVE =33.877+0.505CE-9.669HM+7.456L--------Equation (31)

4.7.8 Relationship between Compressive strength and selected chemical composition

In predicting Compressive Strength of thermal-modified bamboo from the chemical compositions characteristics as independent variables, it was found that the model, depicted by equation (31) had R^2 of 71.9% with other result of linear regression for equation (31) in Table 100. The R^2 value is good for predictive purposes while the ANOVA result also showed that the calculated F value for the equation significant at 5% probability level.

Table 101: Regression equations showing relationship between EMC and selected chemical composition

Model	Predictor	Coefficient	R2	T	P	Standard Error Coefficient
1	(Constant)	-6.515	0.538	-1.695	0.091	3.843
	Cellulose	-0.22		-0.868	0.386	0.253
	Hemicellulose	0.258		1.485	0.139	0.174
	Lignin	0.371		2.952	0.003	0.126
	Ash	7.875		5.201	0	1.514
Dependent Variable: EQUILIBRUM MOISTURE CONTENT (EMC)						

EMC=-6.515-0.22CE+0.258HM+0.371L+7.875AS------------------------ Equation (32)

4.7.9 Relationship between EMC and selected Chemical compositions

In attempt predicting EMC of thermal-modified *Bambusa vulgaris* from the chemical composition characteristics as independent variables, it was found that the model, depicted by equation (32) had R^2 of 53.8 % with other result of linear regression for equation (32) in Table 101. The R^2 value is averagely moderate for predictive purposes while the ANOVA result also showed that the calculated F value for the equation significant at 5% probability level.

Table 102: Regression equations showing relationship between sampling height and selected chemical composition

Model	Predictor	Coefficient	R2	T	P	Standard Error Coefficient
1	(constant)	-4.611	0.945	-7.754	0	0.595
	Cellulose	0.244		6.232	0	0.039
	Hemicellulose	0.435		16.207	0	0.027
	Lignin	-0.622		-31.961	0	0.019
	Ash	-2.32		-9.905	0	0.234

Dependent Variable: Sampling Height

SAMPLING HEIGHT =-4.611+0.244CE+0.4335HM-0.622L-2.32AS------Equation (33)

4.7.10 Relationship between Sampling height and selected Chemical composition

In estimating the values of Sampling height on thermal-modified *Bambusa vulgaris*, from chemical compositions characteristics were imputed into a model as the independent variable thereby giving the model depicted by equation (33) the model has coefficient of determination (R^2) value of 94.5 %. The R^2 value is high and good for predictive purposes and other linear results of linear regression for equation (33) in Table 102

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the findings of the study, the following conclusions were made:

The use of thermal modification application in *Bambusa vulgaris* at different temperature and time variations has adequately revealed pertinent findings on how visible the preservative measure created changes in the anatomical structures and chemical compositions, improved the dimensional stability, decreased the mechanical properties, reduced significantly the termite and fungi activities and through the Stereology approach quantified the quantum effect of the thermal modification on *Bambusa vulgaris* microstructures. An optimum temperature range was noted to exist between 120^{o}C-30minutes and 140 °C-30minutes, as most of the technical properties exhibited in the tropical wood compared favourably with the thermal-modified bamboo within this temperature ranges.

5.1.1 Anatomical Properties

Fibre length decreased significantly from the base sampling height to the top in untreated samples; 3.11% to 2.10%, respectively. Also, at the highest temperature and time variations adopted, there was a consistent decreasing trend observed from the base to the top. Fibre diameter decreased inconsistently from 100 °C-10minutes to 140 °C-30minutes of thermal modified samples. Fibre cell wall decreased inconsistently from top to the base of the treated samples. Cell lumen of *Bambusa vulgaris* were generally small against the general believe by many authors, heat modification decreased inconsistently the *Bambusa vulgaris* cell lumen the least lumen value (2.46 µm) was observed at temperature and time variations 140 °C-30minutes at middle samples.

Mean tangential dimension of vessel (MTD) decreased significantly from the base to the top, the heat modification reduces the vessels dimensions in respect to an increase in treatment temperature and time, the higher values of vessels dimension were found at untreated middle samples (220.85 µm).

Parenchyma height increased at initial temperature and time variation and latter decreased, there were visible indications of swelling and fusing in the cells of parenchyma cell of *Bambusa vulgaris* in response to heat modification. The highest value among the untreated samples was found at base (102.82 µm), while 96.12 µm was found at middle and the least value was found at top (95.66 µm). Parenchyma width also increased at initial temperature and time variation and latter decreased, there were visible indications of swelling and fusing in the cells of parenchyma cell of *Bambusa vulgaris* in response to heat modification, the highest value of parenchyma cell in the untreated categories were found at middle samples, followed by base and top samples respectively. Axial parenchyma cells are predominantly found in bamboo.

Vessel counts per millimeter square (mm^2) increased significantly from top to base, thermal modification increased the vessel count per millimeter square (mm^2) in an increasing trend from top, middle and base (2.40, 2.17 and 2.25 mm^2, respectively.

5.1.2 Bamboo Stereology

Parenchyma cell along longitudinal section volume fraction increased at initial temperature and latter decreased with an increase in treatment temperature and time. Parenchyma cell along transverse section volume fraction increased at initial temperature and latter decreased with an increase in treatment temperature and time. Vessel volume fraction decreased significantly from top to the base samples when thermal-modified. The untreated values at base, middle and top were; 0.19, 0.28, 0.23, respectively. The untreated samples had the middle samples as the highest value followed by top and then base samples, respectively. While the least value (0.08) was found at base treated at 140 °C/20minutes. Fibre sheath volume fraction decreased consistently from the base height to the top for the thermal-modified samples, while the untreated observed the highest value middle (0.36), followed by base (0.31) and then top (0.28) samples. Vessel feature count decreased significantly in the untreated samples from top to base, while most vessel feature count were recorded at middle, top and base samples respectively at the highest temperature and time treatment. Fibre sheath feature count decreased inconsistently from top to base samples in the thermal-modified samples.

Vessel intercept count varies inconsistently along the sampling height in the untreated samples, it ranged from Base, top and middle respectively. Thermal modification resulted into increases of the vessel intercept count ranged from top to middle and base samples respectively. Fibre sheath intercepts count increased significantly from top to base samples in both thermal-modified and untreated samples. Vessel average perimeter decreased inconsistently along the bamboo culm, from middle to top and to the base samples in the untreated categories. The highest value (377.37mm^2) of Vessel perimeter was recorded at the Base treated at 140 °C/20minutes while the least at middle treated at 110 °C/30minutes Fibre sheath average perimeter decreased inconsistently along the culm. The highest value (1603.30 µm) was recorded at base treated at 140 °C/10minutes while the least value (613.00 µm) was recorded at top treated at 120 °C/30minutes

5.1.3 Microstructure

Photomicrographs comparison of thermal-modified and untreated *Bambusa vulgaris* revealed changes in the anatomical structures of the cells in respect to heat and time treatment variations. SEM (Scanning Electron Microscope) revealed visible changes in the microstructure of thermal-modified *Bambusa vulgaris*, there were shrinkage variations among the parenchyma cells also, the fibre cell walls were observed to be distorted from the temperature and time variations 130 °C/10minute to 140 °C/30minutes.

5.1.4 Physical properties

Colour of thermal-modified *Bambusa vulgaris* changes from light yellow from untreated (Control) to brown at treatment level (120 °C/30minutes) and dark brown at 140 °C in respect to increases in treatment time. Specific gravity (SG) of untreated samples decreased significantly from the base to the top samples, while the thermally modified also observed a decreasing trend from the base to top with respect to an increase in temperature and time variations. Equilibrium Moisture Content (EMC) decreased significantly along the bamboo culm from Base to top samples, while the thermal modification decreased the EMC from middle, top to base samples respectively at treatment temperature and time from 100 °C-30minutes to 140 °C-30minutes,

Radial shrinkage for 24 hours decreased consistently along the bamboo culm from base to top in the untreated samples, while, decreased significantly from top to the base samples in the treated samples. Radial shrinkage for 48 hours decreased consistently along the bamboo culm from base to top in the untreated samples, but, decreased inconsistently from medium to the top and to the base samples in the treated samples respectively. Radial shrinkage for 72 hours of thermal-modified *Bambusa vulgaris* decreased from base to the top of untreated samples, while decreased significantly in the categories of thermal-modified samples from medium to top and to the base samples. The mean values of thickness swelling for 24hours, 48hours and 72hours for thermal-modified were 2.04±1.56, 2.20±1.48**,** 2.22±1.50**,** respectively. The thickness swelling test for 72hours has the highest value and the least value was found in 24hours

Water absorption for 24 hours reduced consistently and significantly along culm from top to the base samples in both modified and untreated samples. Water absorption for 48 hours reduced inconsistently and significantly along culm from middle, top and base samples in the modified samples, while from top, middle and base samples in the untreated samples. Water absorption for 72 hours reduced inconsistently and significantly along culm from middle, top and base samples in the modified samples, while from top, middle and base samples in the untreated samples.

5.1.5 Mechanical properties

The CS┴, MOE, MOR, SS and IB varied from 7.41±0.24, 5461.83±594.86, 18.39±2.01, 1.07±0.26 N/mm^2 and 1.68±0.03 KJ/m^2, respectively in 140°C/30 minutes to 36.14±0.11, 29,703.50±4192.77, 56.29±1.86, 3.88±0.50N/mm^2 and 2.30±0.02 KJ/m^2, respectively for untreated samples. Compressive strength perpendicular to the grain showed a rather large decrease after heat modification.

Modulus of Elasticity (MOE) during the bending test has been noticed after heat modification to be decreased, the largest decrease was noticed at the highest temperature and time variation. Since MOE is often the most critical parameter for a construction, heat modification appears to lower the potential for constructive applications, hence the chances of using *Bambusa vulgaris* in construction is limited.

Modulus of Rupture (MOR) showed a consistent decrease along the culm sampling height from base to top, with respect to increase in treatment temperature and time. Shear Strength showed a rather large decrease after heat modification at the highest temperature and time variation Impact bending strength showed a significant decrease after heat modification from base to top with respect to increase in treatment temperature and time.

5.1.6 Chemical properties

The cellulose (46.46±0.11% and 42.19±0.18%), hemicellulose (35.59±0.10% and 31.80±0.01%), lignin (29.11±0.12% and 26.17±0.13%), ash (0.92±0.02% and 0.63±0.01%) were obtained in control and 140°C/30 minutes thermal-modified samples, respectively. According to this result, thermal modification reduced the chemical compositions of the treated samples.

5.1.7 Accelerated fungi Test

The highest WL was obtained from untreated samples inoculated with *Sclerotium rolfsii* (6.1±0.3%) and *Pleurotus florida* (5.1±0.9%), while the least WL of 1.8±0.2% and 1.1±0.2%, respectively was recorded for samples modified at 140°C/30 minutes. Brown rot fungi (*Sclerotium rolfsii*) weight loss shows considerably less weight reduction from top to the base samples, that indicates less fungal attack, the higher the temperature and time treatment, the better the durability of bamboo. The results demonstrated that the longer the heating time, the more improved the durability of bamboo.

Heat-modifications at more than 130 °C improve wood durability against the *Sclerotium rolfsii*. Longer modification at higher temperature results in stronger resistance against the fungus. White rot fungi weight loss shows considerably less weight reduction from along the bamboo culm from top to base, that indicates less fungal attack. The results of the study showed that steam modification process greatly enhanced the durability of bamboo against biodegradation agents particularly the *Pleurotus florida*.

The WL of untreated samples in TGY was 28.2±14.1%, while the least WL (25.1±2.9%) was observed for 140°C/30 minutes thermal modified samples. According to the result in this study; there was an indication that thermal-modified bamboo does not have enough resistance for ground-contact uses.

Grave Yard Test for 12 months of thermal-modified *Bambusa vulgaris* reduced weight percentage consistently along the bamboo culm from base to top in untreated samples. According to the result in this study; thermal-modified base samples of *Bambusa vulgaris* was most resistant to termite attack and most promising for ground-contact uses.

The IB and EMC accounted for 83.9 and 53.8% variation of chemical characteristics.

5.2 Recommendation

Thermal modification enhances the dimensional stability of bamboo, it is advisable to adopt the temperature ranges above 130 °C to be able to achieve best EMC, increase in time variation also contributed substantially.

It was obvious that further increase in the temperature and time treatment may cause further distortion in the microstructures and decreased the chemical constituents; which were inversely responsible for the decrease in all the selected strength properties tested and fungi and termite resistance of the modified bamboo, conversely.

Also, result indicates that the high-temperature wood drying has the potential to improve fungal resistance when the process maintains timber at an adequate temperature for a sufficient amount of time.

It is not advisable to use thermal modified bamboo for prolong exterior usage as it has poor resistance to termite attack, and should be discouraged in the application in load bearing construction.

5.3 Suggested Study

Further research is noticeably required on the information on bamboo properties, cost-effective technologies and managements.

Research should be focused on application of stress wave and ultrasound Nondestructive method in evaluation of thermally modified bamboo to help reduce the number of bamboo culm in use for research work.

Research should be made into usage of microscopic Image analyser for the stereological application for distinct and accuracy in cell quantification and assess slight shift in the cells as a result of heat modification.

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