BIO-MECHANICAL PROPERTIES OF *KLAINEDOXA GABONENSIS* AND THE STRENGTH PERFORMANCE OF ITS DOVETAIL AND MORTISE-TENON JOINTS IN LEG-AND-RAIL CONSTRUCTION

BY

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DECLARATION

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Wood product demand far outstrips timber supply. Secondary timbers, likely-substitutes for endangered traditional hardwoods, lack information about their engineering applications. Furniture strength depends on their joints, design and timber suitability. Thus, the extent to which furniture producers utilize non-traditional timber species was ascertained by interviewing 300 Timber Firms from Kumasi and Accra using the stratified random sampling technique. Key bio-mechanical properties of *Klainedoxa gabonensis* (Lesser-Utilized-Species [LUS]) and *Entandrophragma cylindricum* (a notable building and furniture material), which was the control as well as the strength of two dovetail and mortise-tenon joint-designs from the two timbers were further investigated based on BS 373, ASTM D 1037-06a (24), EN 252 and the International Association of Wood Anatomists (IAWA). Most manufacturers (85%) hardly use any LUS; 44% of these attributed this to lack of information on their properties and prospective uses and 32% to their non-availability on the markets. *K. gabonensis* moisture content and density (at 12% mc) were greater than those of *E. cylindricum*. The former's Tangential-Radial ratio for swelling (1.31–1.38) and shrinkage (1.58–1.63) are within acceptable thresholds (<1.6 and <2.5 respectively) for structural timbers. Anatomically, *K. gabonensis* is diffuse-porous, has simple perforation plates, sclerotic tyloses, prismatic crystals and thick-walled fibres forming the greatest proportion (42.4±4.5–45.6±4.5%) of all its tissues. Its fibre diameter (20.1±0.2–22.7±0.2 µm) and double wall thickness (8.9±0.3–9.7±0.3 µm) were greater than those of *E. cylindricum* (19.6±0.4–19.7±0.3 µm and 8.6±0.2–9.0±0.2 µm respectively). Vessel lumen diameters for *K. gabonensis* (144.8±2.2–176.9±4 µm) and *E. cylindricum* (115.6±1.4–184.4±2 µm) compare with those reported for tropical diffuse-porous timbers (<200 µm). *K. gabonensis* heartwood and sapwood were found very durable (Visual Durability Rating: 1; mass loss: 4.8±0.3%) and durable (1; 8±0.6%) respectively against termite attacks, *E. cylindricum* heartwood was durable (2; 10±0.7%) and sapwood was moderately

durable (3; 13.1±0.6%). Dovetail joints were strongerh (e.g., *K. gabonensis* heartwood: 913.8±49.2) than mortise-tenon (e.g., *K. gabonensis* heartwood: 745.9±59.7). For both joints, the design with longer, wider and thicker tails and tenons (Type LS) was stronger (e.g., *K. gabonensis* heartwood dovetail: 913.8±49.2 Nm) than those with shorter, narrower and thinner tails and tenons (Type SS) (e.g., *K. gabonensis* heartwood dovetail: 745.9±59.7 Nm). *K. gabonensis* joints were also stronger (e.g., heartwood Type LS dovetail: 913.8±49.2 Nm) than those from *E. cylindricum* (heartwood Type LS dovetail: 759.6±16.8 Nm). To improve on the level of LUS utilization including *K. gabonensis*, wood workers must be supplied with comprehensive information about their properties and economic values. The superior physico-mechanical and biological properties of *K. gabonensis*, its abundance (> 396 m^3km^{-2}) and great amount of biomass (diameter: 120-150 cm; height: 45-50 m) make it a suitable material for the building/construction sector, the wood and other related industries. Its use will contribute to reducing pressure on the primary timbers, ensuring consistent supply of wood and keeping the timber sector always operational. *K. gabonensis* chairs designed with dovetail joints and longer, wider and thicker tails would resist bending forces better and ensure greater strength of furniture than mortise-tenon.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
ASTM	-	American Standard for Testing Materials
BS	-	British Standard
CODW	-	Corrected Oven Dried Weight
CRD	-	Completely Randomized Design

CSIL	-	Center for Industrial Studies
CSIR	-	Council for Scientific and Industrial Research
FAO	-	Food and Agriculture Organization
FAWAG	-	Furniture and Wood Products Association of Ghana
FORIG	-	Forestry Research Institute of Ghana
FPRDI	-	Forest Products Research and Development Institute
FSD	-	Forest Services Division
GDP	-	Gross Domestic Product
IAWA	-	International Association of Wood Anatomists
ITTA	-	International Tropical Timber Agreement
ITTO	-	International Tropical Timber Organization
KNUST	-	Kwame Nkrumah University of Science and Technology
LSD	-	Least Significant Difference
LUS	-	Lesser-Utilized Species
MC	-	Moisture content
MOE	-	Modulus of Elasticity
MOR	-	Modulus of Rupture
PU	-	Polyurethane
PVAc	-	Polyvinyl acetate
SME	-	Small- and Medium-scale Enterprise
T/R	-	Tangential-Radial ratio
USA	-	United States of America
WWAG-WR	-	Wood Workers Association of Ghana-Western Region

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background and problem statement

Growth in human population and an upsurge in developmental activities have led to an increase in global demand for timber (Millennium Ecosystem Assessment, 2005). With an anticipated increase in population by 1 billion people in the next decade, pressure on traditional timber resources is expected to intensify (United Nations, 2011; Krausmann *et al.*, 2013). Meanwhile, timber product manufacturers and end-users are adapted to using very limited range of timber species. This has led to over-exploitation and unsustainable forest production (Adekunle *et al.*, 2013). Leicester (2001) explained that diversification of marketed timber species to include abundant and Lesser Utilized Species (LUS) could resolve the challenge of raw materials shortage in the timber industry. Many tropical countries (e.g., Brazil) have recognized the need for alternative timber resources and are conducting extensive researches into the properties and uses of the ―neglected species‖ (International Tropical Timber Organisation [ITTO], 1997), especially several of the abundant LUS in the tropical forests.

Klainedoxa gabonensis Pierre ex Engl. (Fam.: Irvingiaceae) is endemic to tropical Africa and often grows up to 120-150cm in diameter with a cylindrically straight stem (45-50 m), which indicates its great commercial potential (Harris, 1996; Oteng-Amoako and Obeng 2012). It is classified as LUS with a mean basal area of 10.77 m^2km^{-2} in most forests (Ghana Forestry Commission, 2012). Forest inventory conducted between 1986 and 1991 in Ghana indicated its volume (for diameter classes 30 – 130cm) to be 158, 164 and $\geq$74 m^3km^{-2} $\geq$ in the $\geq$ Moist

Evergreen, Wet Evergreen and Moist Semi-deciduous North West sub-type ecological zones.

However, it is rarely traded on the global timber market and has no information in trade statistics. Its poles are for hut construction and spring traps. Similarly, most consumers are generally unaware of the utilization potential of the LUS, which could serve as substitutes to the over-dependent traditional timbers. In some cases, products made from LUS have faced serious problems of acceptance on international markets (Barany *et al.*, 2003; Eastin *et al.*, 2003; Ogunwusi, 2012a). Eastin *et al.* (2003) and Poku *et al.* (2001) have attributed this to reliable supply of comprehensive information about the properties of LUS, which has restricted their promotion and acceptance into the timber markets. These properties often contribute to predict their uses, marketability, service performance and appropriate processing methods (Cox, 2004). Thus, adequate information about the properties of *K. gabonensis* could contribute to the identification of its prospects on the international market.

According to Cordero and Kanninen (2002), the most essential properties needed to promote any LUS include its physical, mechanical and biological characteristics. Ayarkwa (1998) and Opoku (2007) recommended some tropical LUS including *Cylicodiscus gabonensis* (Taub.) Harms, *Nesogordonia papaverifera* (A. Chev.) R. Capuron (Kotibé) and *Petersianthus macrocarpus* (P. Beauv.) for structural products based on these properties. In Costa Rica and Nicaragua, secondary timber species have been used to manufacture furniture parts exported to Cuba, the Dominican Republic, Puerto Rico and the United States because their properties were well investigated (Vlosky and Aguirre, 2001). Fonti *et al*. (2010) and Scholz *et al*. (2013) mentioned that dense and strong timbers with narrow microfibrillar angle and vessel lumen (e.g., *N. papaverifera* and *Diospyros mespiliformis* Hochst. ex A. DC.) are important for tough engineering structures such as bridge, building, furniture and floor construction. The range of uses of *K. gabonensis* could be well established when adequate information about its physicomechanical and biological properties exist.

A consumers' choice of wood products is affected by several factors including aesthetics, functionality and strength (Tankut, 2007). Smardzewski and Majewski (2013) explained that the strength of joinery products (such as furniture) depends greatly on its joint, which is influenced by the design and type of timber used in construction. Many types of joints are available for wood work. The most popular of these joints for furniture construction is the mortise-tenon (Tankut and Tankut, 2005), which is used for the construction of the leg-and-rail of chairs. However, mortise-tenon joints fail under severe tension that results from bending stresses through activities such as rocking during sitting process (Morris, 2014). Zhang and Eckelman (1993) and Hoadley (2000) noted that dovetail joints would resist tensile forces better than mortise-tenon. It could therefore offer an alternative to mortise-tenon in leg-and-rail construction. However, few researches [such as Su and Wang (2007)] have compared the performance of mortise-tenon and dovetail joints against bending, tensile and compressive forces in chair construction.

The success of every joint would partly depend on the appropriateness of the timber used for its construction; different wood species are suitable for making certain kinds of joints (Erdil *et al*., 2005; Tankut *et al*., 2014). For instance, Jivkov and Marinova (2006) found that end corner miter joints constructed with *Juglans regia* were stronger than those from *Alnus* spp. and *Pinus sabiniana* because of the superior mechanical properties of *J. regia*. Therefore, Ratnasingam *et al*. (2010) and Haviarova *et al*. (2013) recommended that when constructing joinery products, manufacturers should have adequate knowledge on the effect of the type of timber and design used on the overall performance of the joints. However, this information is often non-existent for most of our local LUS recommended for joinery. Thus, in order to promote *K. gabonensis* successfully for construction works involving joinery and furniture, information about the strength performance of its joints in structures is essential. This study therefore investigated the physico-mechanical and biological properties of *K. gabonensis* as an alternative engineering material to the traditional timbers so as to widen the raw material base for the Timber Industry. It also evaluated the extent to which LUS are utilized by furniture manufacturers and compared the strengths of mortise-tenon and dovetail joints constructed from *K. gabonensis*.

1.2 Justification

Wood availability is the single most important consideration for timber industries in the world (Forest Products Research and Development Institute (FPRDI) and International Tropical Timber Organization (ITTO), 1997). However, the industry's survival is threatened because the amount of wood required annually cannot be met due to scarcity of timber (Adekunle *et al.*, 2013). Manufacturers and end-users have held onto the ever diminishing primary species, which has resulted in excessive pressure and over-exploitation of traditional timbers. Much attention is therefore needed to promote LUS that could substitute the declining levels of the traditional species (Ayarkwa, 1998). Timber selection for wooden products manufacture is based on information on its properties, which is often not available for several secondary timber species (Ayarkwa, 1998). Investigations into the properties of *K. gabonensis* would enhance its utilization as an alternative structural material, increase the wood raw material stock and contribute to minimize the pressure on the highly-utilized primary timbers. Erdil *et al*. (2005), Likos *et al*. (2012) and Smardzewski and Majewski (2013) asserted that the strength of furniture largely depends on its joints and the type of timber used for its parts. In most cases, LUS recommended for furniture lack information on the best joint that must be employed to produce furniture with great strength (Addae-Mensah, 1998; Barany *et al*., 2003) and joint selection is normally left to the discretion of manufacturers whose choices may compromise the structural rigidity of the entire work piece (Tankut, 2007). Thus, joints that ensure great strength of furniture and joinery products from *K. gabonensis* ought to be established to guide furniture designers in their choice. It was also important to identify the current challenges associated with utilization of LUS by the furniture industry and to propose ways of solving them in order to ensure consistent supply of timber to the industry.

1.3 Aim

The study assessed the utilization potential of *K. gabonensis* and the strength of its mortise-tenon and dovetail joints in leg-and-rail construction.

1.4 Specific objectives

Specific objectives were to determine the:

(i) Level of utilization of LUS including *K. gabonensis* among furniture manufacturers in Ghana.

(ii) Physical and mechanical properties of the heartwood and sapwood of *K. gabonensis* and *Entandrophragma cylindricum* (a widely-used traditional utility timber, which was the control).

(iii) Biological properties (anatomy and durability) of the heartwood and sapwood of *K. gabonensis* and *E. cylindricum*.

(iv) Strength of mortise-tenon and dovetail joints in leg-and-rail constructed from *K. gabonensis*.

1.5 Research questions

The study was conducted with the following research questions:

a. What is the level of utilization of LUS among furniture producers?

b. What are the physico-mechanical and biological properties of *K. gabonensis*?

c. What is the strength of mortise-tenon and dovetail joints manufactured from *K. gabonensis*?

1.6 Scope of the study

The study determined the anatomy of *K. gabonensis* including its fibre and vessel morphology (i.e, proportion, length, wall thickness, diameter and lumen width) as well as its durability, moisture content (mc), density, shrinkage and swelling characteristics, Moduli of Rupture and Elasticity, Compressive and shear strengths parallel to the grain. The strengths of *K. gabonensis* mortise-tenon and dovetail joints were compared. It further investigated the level of usage of LUS in the operations of furniture manufacturers.

CHAPTER TWO

LITERATURE REVIEW

2.1 THE OVERVIEW OF GLOBAL DEMAND FOR TIMBER RESOURCES

Timber is undoubtedly an important resource in the socio-economic growth of societies. Rapid development of the global economy coupled with growing human population has led to significant increase in the demand of wood for products such as lumber, pulpwood, board and wood-based panels (Chaowana, 2013; World Wildlife Fund, 2015). Lead *et al.* (2005) found that China's demand for logs and wood products increased by more than 50% during the last decade. In 2005 alone, about 20% of the growing stock of forests in Russia was harvested to supply the international timber market (FAO, 2005). According to Agyarko (2001), the Ghanaian wooden furniture manufacturing sector requires about 219,000 m^3 of sawn timber annually in order to remain in operation. This represents about 72% of the total domestic timber requirement for the entire country. The current demand places huge pressure on wood resources (Lead *et al.*, 2005; Union of Concerned Scientists, 2011). Shortages of high-value timber species due to overharvesting have been reported (Ghazoul and Sheil, 2010). FAO (1998) estimated that wood demand would rise to about 2 billion m^3/yr by 2045/50. This will further increase pressure on forests, while limiting production activities of wood industries (Union of Concerned Scientists, 2011).

Longwood (1962) and Brokaw (2012) found that despite the availability of over thousand different wood species in the Caribean forests, commercial production and utilization were limited to less than 20 timber species. World Conservation Monitoring Centre (2012) also observed that only 60 out of 680 tree species that reach timber size in Ghana have been exploited over the past 20 years. Agyeman *et al*. (1999) and World Wildlife Fund (2015) asserted that with the current trend where logging and commercial trade is greatly concentrated on few well-known timbers including *Triplochiton scleroxylon* (Wawa), *Khaya grandifoliola* (Mahogany), *E. cylindricum* (Sapele) and *M. excelsa* (Odum), supply of raw materials for wood products is unsustainable. Bioversity International (2009) and International Wood Products Association (2015) explained that by promoting the neglected timbers, pressure on the few highly exploited timbers could be reduced, while increasing commercial production.

2.2 THE ROLE OF SECONDARY TIMBER SPECIES IN THE SUSTAINABLE SUPPLY OF WOOD

Natural forests have a great number of timber species which are characteristically different from each other. Roelof *et al.* (2013) noted that a scale of preference for the timbers for commercial utilization exists; while some species including *Pericopsis elata*, *K. anthotheca*, *Ocotea porosa* and *Shorea spp*. are in high demand, others such as *K. gabonensis*, *Peronema canescens* and *Canarium schweinfurthii* are rarely traded. In the three major wood-producing regions in the developing world, namely Southeast Asia, South America and Central Africa, about half the total number of timber species that grow to timber size are not utilized or under-utilized (Erfurth, 1976; Lead *et al*., 2005). These timbers are broadly called ―secondary timber species‖ or ―Lesser-Utilized Species‖ and appear in large quantities in the forest. Shupe *et al.* (2005) defined Lesser-Utilized Species (LUS) as timbers that are not being put to best advantage. Barany *et al*. (2003) noted that many LUS have properties (e.g., durability, strength and beauty) that are comparable to the presently traded timbers, which could make them accepted by the local and export market for building, decking, flooring, mouldings, veneer, bridge and furniture construction once their availability and technical qualities are investigated. Grant (2008) found that limited stock and high demand for the more popular species make them very expensive, while the cost of secondary timber species is generally low due to their abundance. For instance, while

Loxopterygium sagotii, a popular species for furniture and building construction in Guyana was sold for about $250/Bm, *Hymenolobium flavum*, a LUS with similar properties and utilization potential as *L. sagotii* was sold for $180/Bm (Forest Products Development and Marketing Council, 2014). International Wood Products Association (2015) observed that several LUS from many parts of the world are making phenomenal sales on the U.S. market. Lim *et al*. (2004) mentioned that increased use of LUS promotes sustainable forest management by ensuring maximum utilization of forest resources, while alleviating the pressure on the currently over-exploited timbers. International Wood Products Association (2015) also mentioned that utilization of LUS would reduce the vulnerability to extinction of timber species that currently have high market demand. Subsequently, biodiversity would be conserved and the forests ability to satisfy future demands for timber materials would be maintained. Ofori *et al.* (2009) explained that the several advantages of LUS have encouraged the government of Ghana to actively advocate for their use as a sustainable forest management strategy. However, they are neglected by end users due to poor understanding of their characteristics (Barany *et al*., 2003). Union of Concerned Scientists (2011) asserted that adequate efforts aimed at promoting LUS are needed to halt increasing scarcity and rise in prices of current commercial timbers.

2.2.1 Factors influencing acceptance of secondary timber species by end users

In many countries, efforts aimed at increasing the utilization of LUS as alternatives to the commonly traded timbers have increased (Chaowana, 2013). However, Dadzie *et al.* (2014) noted that many factors influence their acceptance by end users. According to Schulte and Schöne (1996), several non-traditional timbers lack information about their properties and uses, are sparsely distributed in the forest, and have relatively small diameters and high percentage of non-durable sapwood, which affect the willingness of wood product manufacturers to exploit them.

Guyana Forestry Commission (2013) mentioned that the lack of information about the properties of most of Guyana's LUS deterred the timber industry from successfully accepting and utilizing them. Boampong *et al*. (2015) observed that knowledge about the durability, aesthetics, quality and processability of timber influenced its selection for furniture and joinery production. Chaowana (2013) also mentioned that acceptance of alternative timber materials depended on its cost, availability, physical and mechanical properties and compatibility with existing processing technologies. However, such information is often non-existent for most secondary timber species. Therefore, Bonney (1998) explained that in order to increase acceptance of LUS on the local and foreign markets, an effective marketing strategy that focuses on making available information about their characteristics and uses should be adopted.

2.2.2 *Klainedoxa gabonensis* as a promising alternative timber material

K. gabonensis Pierre ex Engl. (Fam.: Irvingiaceae) is a tropical LUS which commonly occurs in the humid evergreen and semi-deciduous forests in Angola, Cameroon, Democratic Republic of Congo, Ghana, Senegal, Sudan, Tanzania, Uganda and Zambia (Oteng-Amoako and Obeng, 2012). It has an open evergreen crown, which makes it one of the largest trees in tropical rainforests (Harris, 1996). Its bole could be branchless for up to 25 m from the ground (OtengAmoako and Obeng, 2012). The wood has a fine texture, straight or interlocked grain and thin light brown sapwood, which is susceptible to insect damage. Its heartwood has reddish to golden brown colouration with zigzag markings (CIRAD Forestry Department, 2008). Its density (940 – 1150 kgm^{-3}), shrinkage, nail-holding ability and sawing characteristics are some of the few properties investigated by Oteng-Amoako and Obeng (2012). The authors found that the wood was dense, difficult to dry and liable to checking and distortions after drying. Preliminary studies on its anatomy showed that the wood is diffuse porous and has thick-walled non-septate fibres (Harris, 1996; Oteng-Amoako and Obeng, 2012).

Ogunwande *et al*. (2008) explained that in most countries, it is left standing to provide shelter when forest is clear-felled for agricultural purposes. It is locally exploited for medicine, firewood, spring traps and hut construction (Neuwinger, 2000; Wansi *et al*., 2010). In Sierra Leone, the buttresses are sometimes used to construct doors. However, the wood is seldom exploited and lacks information in Trade Statistics. Harris (1996) asserted that its prospects on the international market could be enhanced when further researches are conducted on its properties, processing and end-uses.

2.3 PROPERTIES OF WOOD INFLUENCING THEIR PROSPECTIVE USES

In spite of the versatility of wood, Likos *et al*. (2012) and Tankut (2007) explained that timbers with specific properties are required for specific applications. For example, Discovery Communications (2013) observed that since 1900 furniture has been manufactured from *J. nigra*, *Quercus spp.*, *E. cylindricum*, *Acer saccharum* and *M. excelsa* due to their beauty, strength, durability and workability. Several LUS including *Koordersiodendron pinnatum*, *Diospyros pyrrhocarpa*, *Artocarpus blancoi* and *Ziziphus talanai* were recommended for various structural works because they had fair to good finishing properties as well as great bending (65.9 – 84.0 Nmm^{-2}), compression parallel to the grain (19.5 – 36.1 Nmm^{-2}) and Shear (8.31 – 11.0 Nmm^{-2}) strengths (Forest Products Research and Development Institute (FPRDI) and International Tropical Timber Organization (ITTO), 1997). Studies on specific properties of wood are therefore important for ascertaining timbers' utilization potential (Tankut, 2007; Discovery Communications, 2013). Cordero and Kanninen (2002), Rowell and Winandy (2005) and Strong (2013) observed that the biological, physical and mechanical properties of wood mostly influence its selection for certain applications. Therefore, in order to predict the full range of uses of *K. gabonensis*, its physical, mechanical and biological properties were investigated.

2.3.1 Biological properties influencing the uses of wood

2.3.1.1 Anatomical properties

Major cells that make up tropical hardwoods are vessels, fibres and parenchyma. These cells may be hollow, elongated or spindle-shaped (McGraw-Hill Concise Encyclopedia of Bioscience, 2002). Vessels are comparatively large cells with large cavities and open ends that conduct sap up a plant. Fibres rather have small cavities, relatively thick cell walls and are the main elements that give strength to wood (Izekor and Fuwape, 2011). Barnett and Jeronimidis (2003), and Ocloo and Laing (2003) explained that the strength, density, dimensional stability and many other properties, which determine the uses of wood basically depend on fibre, vessel and parenchyma characteristics such as wall thickness, diameter, length, lumen width and proportion. Rowell and Winandy (2005) observed that wood density increases as the proportion of cells with thick walls increases. They further explained that most high density woods possess more thickwalled fibres in relation to vessels and parenchyma and subsequently have great bending, compressive and shear strengths. They also tend to be dimensionally stable, shrinking and swelling less. These timbers are good for flooring, furniture, building and bridge construction (Rowell and Winandy, 2005). On the contrary, Raven *et al.* (1999) and Quartey (2009) observed that woods such as *Ochroma pyramidale* and *Albizia ferruginea* which have thin-walled vessels and fibres have very low density (i.e., about 40-340 kg/m^3) and poor strength. Consequently, such timbers are recommended for light construction (Wiedenhoeft and Miller, 2005). Quartey (2009) further noted that *Blighia sapida* was very brittle due to the large proportion of short fibres and was only suitable for applications where strength was not of prime importance. Walter *et al*.

(2009) recommended *Picea mariana* based on its long fibres for manufacturing paper that produced highest quality newsprint. Lei *et al*. (1997) mentioned that in furniture construction, it is important to select wood with narrow vessels in order to minimize excessive moisture absorption, which results in swelling and shrinkage of furniture products. Wood deposits also have great influence on the uses of timber. Adeniyi *et al*. (2013) observed that *Xylia dolabriformis* was largely used for flooring due to the large amount of gum within its fibres that were resistant to wear. Boulton *et al*. (2013) also noted that white oak was suitable for cooperage because its vessels were plugged by tyloses. Thus, anatomical characteristics of wood are good indices that guide wood end-use.

2.3.1.1 Durability

Wood product deterioration is a challenge to consumers. Meanwhile, wood, as a natural polymer, is prone to bio-degradation by bacteria, fungi and insects (Khatib, 2009). Termites, carpenter bees, ants and powder-post beetles are the major insect pests to wooden structures (Abood, 2008). These organisms decompose the cellulose in wood for biochemical energy (Sonowal and Gogoi, 2010). Usually the durability of wood is widely correlated with the amount of cellulolytic materials it loses from attacks by bio-degraders (Arango *et al*. 2006; Ashaduzzaman *et al*. 2011; Asamoah *et al.* 2011). When less biomass is removed, wood marginally loses weight and becomes more resistant to bio-degradation (Ashaduzzaman *et al*. 2011). In order to ensure increased service-life of manufactured products, while minimizing maintenance costs and protecting the environment from the harmful effect of preservative-chemicals against biodeterioration (Venmalar and Nagaveni 2005), naturally-durable timbers are highly recommended (Connell 1991; Scottish Wood Ltd., 2000). Koch *et al.* (2013) and Ibach (2013) explained that wood durability is its resistance to bio-deterioration, and different wood species have different natural abilities to resist insect and fungal decay; timber utilization must be based on the level of resistance to bio-deteriorators. Ali (2011) recommended tropical timbers such as *Acacia nigrescens* Oliv., *P. angolensis* (Baker) Meeuwen and *Pseudolachnostylis maprounaefolia* Pax for building and furniture-making based on their properties including durability. According to Australian Durability Standard (AS 5604, 2005), Podocarpus *totara* var. totara, *Manoao colensi* (Hook.) Molloy and *Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little are employed in full weather-exposed applications (Hazard Class H1 - H4) because they are very durable. In order to successfully determine the uses of *K. gabonensis*, the durability of its sapwood and heartwood was determined in this study using visual assessment, which evaluates the durability of timber from signs of attack on stakes exposed to insects and decay organisms in the field (Eaton and Hale 1993; Australian Standard 2005), and mass loss techniques (Ashaduzzaman *et al*. 2011).

2.3.2 Mechanical and physical properties influencing the uses of wood

2.3.2.1 Mechanical properties

Mechanical properties of wood are its ability to resist forces that tend to deform it (Atar *et al*., 2009; Smardzewski, 2015). They determine how much load wood can bear without fracture or undue distortion (Rowell and Winandy, 2005; Callister and Rethwisch, 2012). Wooden structures are subjected to varying forces during their life span, predominantly compression, bending and shear (Cai and Wang, 1993; Ali, 2011; Forest Products Development and Marketing Council of Guyana Inc., 2015). These forces affect wood in different ways. For instance, while compressive forces tend to shorten wood fibers (Desch and Dinwoodie, 1996; Abdolzadeh *et al*., 2015), shear stress causes one section of a piece of wood to slide along the other section in a direction often longitudinal to the grain (Ritter *et al*., 1998; Yuksel *et al*., 2014). Shear stress normally results when one side of a piece of wood is subjected to tension forces and the other compression (Korkut and Guller, 2008; Abdolzadeh *et al*., 2015).

Engineers choose wood for flooring, building, bridge and furniture construction based on how much stress the timber material will be able to withstand without failure. Ratanawilai *et al*. (2006), Tankut (2007) and Lima *et al.* (2014) mentioned that in predicting the uses of wood, its mechanical properties such as Modulus of Rupture (MOR), Modulus of Elasticity (MOE), compressive and shear strengths parallel to the grain need to be ascertained. Asafu-Adjaye (2012) noted that based on mechanical properties such as MOE (5253.0 – 25871.8 N/mm^2), MOR (48.5 – 217.1 N/mm^2), Compression parallel to the grain (27.6 – 99.8 N/mm^2) and shear parallel to the grain (5.47 – 19.75 N/mm^2), the dermal zones of *Borassus aethiopum* could be similarly used as *P. elata, Pepdiniastrum africanum, T. grandis* and *E. cylindricum* for veneer, flooring and furniture construction. Forest Products Laboratory (1999) and Lemmens (2008) also observed that *T. grandis* and *K. ivorensis* were good for truss and furniture construction because they have great compressive strengths (57.98 Nmm^2 and 37 – 48 Nmm^2 respectively) and can resist stress that tends to crush wood fibres in columns, props, posts and spokes. According to Green (2007), *Carya ovata* is suitable for flooring, cabinetry and furniture because its great MOR (138.6 Nmm^{-2}) and MOE (15590 Nmm^{-2}) make it stiff, harder to flex and return to its original shape without breaking when stress is removed. Studies on mechanical properties such as MOR, MOE, compressive and shear strengths parallel to the grain of timber would thus help to assign timber to their right uses (Hodgkinson, 2000; Ntalos and Grigoriou, 2002; Lima *et al.* 2014).

2.3.2.2 Physical properties

Physical properties are the quantitative characteristics of wood and its behavior to external influences other than applied forces (Winandy, 1994). The physical properties of great concern to the timber industry include density, moisture content (mc) and swelling and shrinkage characteristics (Johnson *et al.*, 2006; Ali, 2011).

2.3.2.2.1 Density

Wood density is defined by the amount of cell wall material, moisture and proportion of void space created by fibre and vessel cavities (Kollman and Côté, 1986; Canadian Wood Council, 1991; Desch and Dinwoodie, 1996; Antwi-Boasiako and Pitman, 2009). It influences other wood properties such as strength, dimensional stability, durability and treatability (Gryc and Horácek 2007) and subsequently identifies timber for a particular uses. Haygreen and Bowyer (1996), Zhang (1997), Persson (1997), Miller (1999), Dickson (2000) and Hernandez (2007) observed that wood strength greatly depended on its density; lower density species were suitable for nonload bearing applications like internal trim and ceiling construction due to their low strengths. Ali (2011) recommended medium (400 kg/m^3) to high (1100 kg/m^3) density woods for furniture production. Humar *et al.* (2008) and Antwi-Boasiako and Pitman (2009) also found that higher density species were more durable than their lower density counterparts. They explained that high density timbers were important materials for fencing, mine props, railway sleepers, floor bearers and joists.

2.3.2.2.2 Swelling and shrinkage characteristics

Antwi-Boasiako and Boadu (2013) explained that wood is hygroscopic and undergoes dimensional changes when its moisture varies below or above the Fibre Saturation Point (FSP). These changes can lead to reduction in wood strength, tightening and fracture of joints, splits, and change of cross-sectional shapes of wooden products (Kollman and Côté, 1986; Winandy, 1994). Since movement of wood in service cannot be entirely prevented, it is important to select wood that shrinks or swell less for structures. The age-long use of traditional species such as *K. ivorensis* (with a density of 420–570 kg/m^3), *T. grandis* (with a density of 440–820 kg/m^3) and *Quercus spp* (with a density of

750 kg/m^3) for furniture, window and door frames and decking stem from their properties including dimensional stability (Richter and Dallwitz, 2009; Lemmens, 2008).

Therefore, knowledge on the mc, density as well as swelling and shrinkage characteristics of timbers would enhance their utilization.

2.4 WOODEN FURNITURE PRODUCTION

Furniture construction is one of the oldest jobs in the manufacturing sub-sector of many countries (Yang *et al*., 2012). Until the industrial revolution where materials such as aluminium, steel, plastic and glass were used, furniture was conventionally made of wood (Asomani, 2009) The introduction of automation, standardization in design and construction techniques and the use of composite materials have brought some advancement to the furniture industry (International Tropical Timber Organization, 2015). Global trade in wooden furniture witnessed a rapid growth from US$42 billion in 1997 to US$97 billion in 2007 (Xiao *et al*., 2009) and US$128 billion in 2013 (International Tropical Timber Organization, 2015) with prospects for further growth. Joyce and Spielman (2000) and Tankut and Tankut (2009) noted that successful construction of wooden furniture depends on several factors including the choice of timber species and fasteners. Cordero and Kanninen (2002), Rowell and Winandy (2005) and Tankut (2007) asserted that not all wood species are suitable for furniture making and the biological, physical and mechanical properties of timber should be taken into account before their selection. Eckelman (2003), Likos *et al*. (2012) and Strong (2013) also explained that fasteners influence the overall strength of furniture and should be chosen based on the kind of product and the level of strength required.

2.4.1 Fasteners available for furniture and joinery production

Atar *et al*. (2009) explained that furniture making requires bringing together pieces of wood with the help of fasteners. McDonald (2013) noted that fasteners strengthen furniture and also help attach hardware to furniture parts. Fasteners employed for wood work include nails, bolts, dowels, hinges, screws, joints and adhesives (Kureli and Altinok, 2011). Yuksel *et al*. (2014) observed that nails and screws were the most common types for attaching wood members in light-frame structures, while bolts were used for heavy members such as the beam to the posts. Glued joints are also recommended for the construction of quality chairs and tables (Asomani, 2009). In most furniture firms in Ghana, glued joints are the most common fasteners used for wooden furniture construction because they are economical and impact great strength (Asomani, 2009). McDonald (2013) explained that since the overall integrity of wooden furniture depends on how its components are held together, a careful analysis of the strengths of these fasteners is required prior to their selection.

2.4.1.1 Joints

Jesberger (2007) and Koch *et al*. (2013) noted that joints are needed to put wood pieces together in furniture frame construction. They play a major role in the structural behavior of joinery products (Tankut, 2007; Tankut and Tankut, 2011). Several kinds are available for wood work including dowel, dado, rabbet, lap, tongue and groove, mitre, butt, dovetail and mortise-tenon (Jesberger, 2007). According to Corbett (2003), Baylor (2009) and Zwerger (2012) each type of joint is appropriate for specific uses and should be employed depending on the kind of product, its desired strength and ease of construction. For instance, dowels are recommended for joining chair rail to post, frames and boards at right angles to each other. Dado is also used in making book shelves to hold them in position (Smardzewski and Majewski, 2013). Rabbet commonly joins the top and bottom ends of furniture. Zwerger (2012) found that tongue and groove (T&G) joints were suitable for putting together wood edge to edge in flooring and paneling. Dovetail and mortise-tenon are also frequently used in joinery work (Eckelman, 2003; Hoadley, 2000). While dovetail is often used to attach the sides to fronts of drawers and boxes, mortise-tenon is employed for chair, beds, tables and door frame construction (Corbett, 2003; Baylor, 2009; Tankut and Tankut, 2011). Erdil (2005) mentioned that choosing the wrong kind of joint for furniture making could make construction difficult, affect the integrity of the design and cause early failure of the wooden product.

2.4.1.1.1 Mortise-tenon joint

Mortise-tenon is one of the oldest joints used to connect the rails and stiles of frames, panel doors and chairs, and aprons to the legs of tables (Tankut, 2007). They are mostly used where reliability and strength are highly demanded. Tankut and Tankut (2011) found that mortise-tenon have several advantages including great strength, neatness, and large surface for adhesive application. The tenon is produced by creating a tongue at the end of a piece of wood whereas the mortise is formed by cutting an equal size hole in another piece (Fig. 2.1). The tenon is cut to fit the mortise hole exactly by its length, width and thickness. Likos *et al*. (2012) noted that its width should be more than a third of the thickness of the wood from which it is made and its thickness one third of the thickness of the wood. The length of the tenon usually extends halfway or three-quarters into the stile (Eckelman *et* al., 2001). Liu and Eckelman (1998) mentioned that the joint can be pinned or glued to firmly lock it in place. It could also be constructed without application of glue.

There are several kinds of this joint. The through mortise-tenon joint results when the mortise passes completely through the stile. A wedge may be slotted diagonally or straight across the width at the exposed end of the inserted tenon to make the joint stronger (Likos *et al*., 2012). The blind mortise-tenon joints have the mortise passing only partly through the stile. The tenon is therefore not visible after joint assemblage. It is currently the most used type of mortise-tenon joints (Liu and Eckelman, 1998). Other types include the haunched, wedged, pegged, loose tenon type, groove and stub tenon, those with mitered shoulders and stuck moulding (Rachel, 2012). For these joints, their rectangular shaped kinds are commonly used although round, square and diamond shaped types are available (Likos *et al*., 2012). Rectangular mortise-tenon joints are commonly employed to join the back leg and the side rail of a chair frame whereas the round or square tenon is best suited for stretchers (Eckelman *et* al., 2001; Tankut, 2007). Tankut and Tankut (2005) observed rectangular mortise-tenon joints to be about 15% stronger than their round counterparts.

Maguire (1990) and Davis (2005) observed some problems with the use of mortise-tenon in joinery and furniture construction. They explained that since mortise-tenon involves cross-grain joinery, it faces the risk of failure due to seasonal wood movement. MacDonald (2013) mentioned that in order to minimize wood movement, the tenon must be wedged or extended halfway into the stile. Judd *et al.* (2012) also explained that orienting the tenon radially with respect to the mortise grain improves stability of the wood members. Morris (2014) further observed that the mortise-tenon joint has poor mechanical restraint to direct withdrawal of the tenon from the hole. Thus, although this joint has great resistance to shearing forces and racking, it easily fails under bending and tensional forces. Meanwhile, wooden products such as chairs and tables are often subjected to great amount of tensional forces through activities such as rocking (Eckelman and Haviarova, 2006).

The use of pinned-, keyed through-, spline- and wedged-tenon has minimally improved mortisetenon resistance to tension (Landis, 1998; Tankut, 2007; Tankut and Tankut, 2011; Likos *et al*., 2012). These modifications have not entirely overcome breakdown of mortise-tenon under bending and tensional forces. Chan (2002) asserted that some of the modifications reduce the aesthetic characteristics of products, while increasing their cost of production. Smardzewski (2015) recommended further research that compares the resistance to shear, compression and tension forces of mortise-tenon and other joints. This will help identify other joints that have the potential to overcome the challenges associated with mortise-tenon (Landis, 1998).

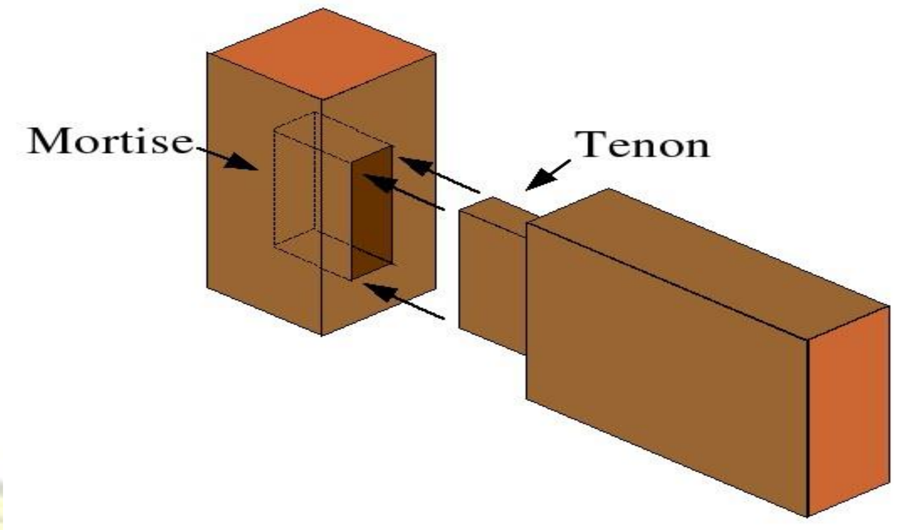

Plate 2.1: Mortise-tenon joint showing the mortise and tenon

(Source: https://commons.wikimedia.org/wiki/File:Mortise_tenon.png)

2.4.1.1.2 Dovetail joint

Dovetail is a strong, aesthetically pleasing side-grain to side-grain joint used for constructing blanket chests and small box drawers (Lau, 1991). It consists of tails and pins that interlock to give a wedging effect, which can resist great amount of bending and tensile forces (Fig. 2.2). Halstead (1999) explained that dovetails could overcome wood movement associated with mortise-tenon and also provide resistance against tensile stress. Dovetail has large gluing area and can hold together even without adhesive (Lau, 1991). Due to its resistance against pulling forces, Asomani (2009) mentioned that dovetail is frequently used to join drawer sides to the front. However, it is seldom used for chair construction.

Several types of dovetail joints exist: through, half-blind, secret mitred and sliding. Through dovetail is the most basic type created by joining the ends of the pieces which are exposed on both sides of the joint. It is used to join the corners of boxes, frames and cabinets. The half-blind is often used to join drawer fronts to drawer sides and it hides the joint from the front end of the wood frame. Only one side of the joint is seen. The secret mitred joint conceals the joint internally, while the sliding dovetail allows the tail to slide into the socket.

Fairham (2007) mentioned that dovetail construction requires high precision and accuracy. As a result, many wood workers regard it as a very difficult joint and is seldom used for chair construction. However, Herren (2014) asserted that with quality hand or power tools, dovetail joints are easier to manufacture. Eiki (2012) found that dovetail strength depends on the number and angle of tails, shear strength parallel to the grain of the wood from which it was made and the strength of the adhesive bond between the side-grain faces. Ozkaya *et al.* (2010) noted that the slope of the tail should not be too wide or narrow to maintain the wedge-locking advantage.

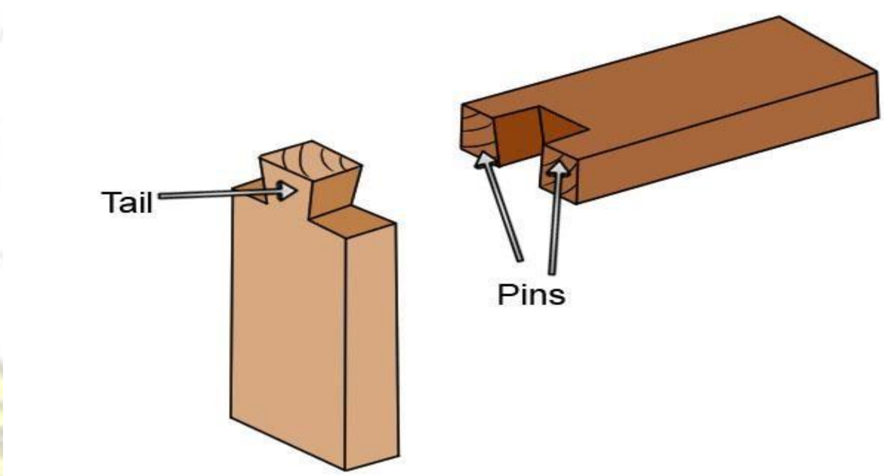

Plate 2.2: Dovetail joint showing the various parts

(Source: http://www.wonkeedonkeetools.co.uk/wood-chisles/how-to-cut-a-dovetail-joint-with-a-wood-chisel/)

2.4.1.1.3 Factors affecting the strength of furniture joints

Tankut (2007) and Haviarova *et al*. (2013) observed that the wood strength properties and moisture content affect its joint strength. Erdil *et al*. (2005) explained that greater joint strength is often associated with greater wood shear strength. Haviarova *et al*. (2013) found that joints constructed with *Fagus orientalis* had greater strength than those with *P. sylvestris* because *F. orientalis* had greater shear strength (9.72 Nmm^2) (Bektaş *et al*., 2002) than *P. sylvestris (*8.82 Nmm^2) (Ulker *et al*., 2012*)*. Similarly, Kamperidou *et al*. (2011) observed that joints constructed with *Populus Balsamifera* (shear strength = 5.446 Nmm^2) had lower strength than those from *F. sylvatica* (shear strength = 14.84 Nmm^2). Ratnasingam *et al.* (2010) also found that the bending moment capacity of rectangular mortise-tenon joints made from *Elaeis guineensis* (shear strength = 7 Nmm^2) was only half of those for joints from *Hevea brasiliensis* (shear strength = 11 Nmm^2), *Pallaquim sp*. (shear strength = 12 Nmm^2), *Shorea sp*. (shear strength = 11.5 Nmm^2) and *Sindora sp*. (shear strength = 13 Nmm^2).

According to Rowell and Winandy (2005) and Antwi-Boasiako and Boadu (2013), fluctuations in wood moisture content cause internal stresses in glue lines and subsequently decreases joint strength. Tankut (2007) noted that when wood was conditioned at a relative humidity (RH) of 85%, joint strength reduced by 15%. Dupont (1963) found 7-9% wood mc appropriate for strong joints. Therefore, timbers with great strength properties and low mc may be more appropriate for the construction of wooden products with strong joints.

Yang and Li (1986) further mentioned that joint design and type of adhesive also affect joint strength. In their study on mortise-tenon joints using two adhesives, Haviarova *et al*. (2013) observed that joints constructed with Polyvinyl acetate (PVAc) were stronger than those produced using Polyurethane (PU). Altun *et al*. (2010) had higher bending moment capacity under diagonal compression for joints glued with PVAc compared to cyanoacrelate. Erdil *et al.* (2005) noted that PVAc was better than UF and resorcinol phenol adhesives in an experiment to determine the effect of wood species, adhesives, rail width, tenon depth and length, on bending strength and flexibility of some wood joints. They concluded that different adhesives would influence joint strength differently. Kamenicky (1975), Yang and Li (1986), Erdil *et al*. (2005) and Likos *et al*. (2012) found that joints designed with longer tenons had greater stiffness than those with shorter tenons. Wilczyński and Warmbier (2003) also observed that increasing tenon thickness from 6 to 12mm led to a 10% increase in joint strength. According to Tankut and Tankut (2005), rectangular end mortise-tenon was stronger than round end mortise-tenon. They recommended round end mortise-tenon for constructing the front leg-side rail joint in a chair frame where stresses were more uniformly distributed. Mihailescu (2001) and Haviarova *et al.* (2013) mentioned that manufacturers must carefully take into account the influence of joint design and adhesives on the strength of furniture joints during their construction.

2.4.1.2 Adhesives

Mahu̓t (1995) and the U.S. Department of Agriculture (2011) defined adhesives as materials used for sticking, or adhering, one surface to another. Yuksel *et al*. (2014) explained that manufacturers often prefer making joints without adhesives because it reduces shipping costs and enables furniture to be exported in the knock-down condition for assemblage on site. However, adhesives add great strength and rigidity to furniture when they are used (Haviarova *et al.*, 2013).

There are two groups of adhesives that could be used for joinery: natural and synthetic (Conner, 1996; Atar *et al*., 2009). The natural adhesives are made from hides, bones, milk and other parts of animals and plants such as cassava and soybean. This group of adhesives is hardly used in recent times because they stain wood, have poor resistance to moisture and heat and could best be applied when hot. Synthetic adhesives are of two basic types: thermosetting and thermoplastic. PVAc, polyvinyl alcohol (PVA), polyacrylates, polyester acrylics, acrylic solvent cement, cyanoacrylates (superglue) and silicone resins are examples of the thermoplastic type. Thermoplastic adhesives harden on cooling but soften and flow upon heating (Vick, 1999). They are easy to apply, durable against bio-deteriorating organisms, odorless and nonflammable. They develop very good bond between wood pieces within 15 min of application under room temperature (Atar *et al*., 2009). However, it is very expensive and not resistant to heat. Tout (2000) and Atar *et al*. (2009) recommended PVAc for indoor furniture. They cautioned against its usage in permanently stressed joints. Thermosetting adhesives require longer time for curing under room temperature (Mahu̓t, 1995). However, they do not soften on reheating once cured. They are resistant to moisture and other chemicals and have better gap-filling ability and good adhesion to wood (Tout, 2000; Frihart, 2005). Resorcinol, phenol-resorcinol, epoxy, phenol- and Urea-formaldehyde are examples of thermosetting glue. Asomani (2009) noted that most thermosetting adhesives contain formaldehyde and catalyst that controls the speed for curing.

Wengert (1998) explained that adhesives should be chosen based on their costs, moisture resistance, heat sensitivity, flexibility and ease of application. In Ghana, most furniture production companies employ Fevicol SH synthetic adhesive, which is thermosetting, due to their availability, great bonding strength, impact and fire resistance, quick setting time and nonstaining property (Asomani, 2009).

2.5 Summary

The review of literature has discussed current problems with the supply of timber resources. It has explained the potential role secondary timber species could play in ensuring sustainable supply of wood and the need for research into the properties and uses of several of these neglected but abundant timbers in the forests. Little evidence was identified through literature about commercial utilization of *K. gabonensis* Pierre ex Engl., an abundant tropical LUS. In order to draw meaningful conclusions on the appropriateness of *K. gabonensis* for wooden products, empirical research needs to be conducted on its physical, mechanical and biological characteristics.

In recommending *K. gabonensis* for furniture construction, joints that ensure great strength of its products needs to be identified, as joint strength is a function of wood species. The review has indicated that mortise-tenon, the popular joint used in furniture work is fraught with problems including breakdown under bending and tensile forces. Although, there are speculations on the ability of dovetail joints to overcome these forces, research that compares the performance of dovetail and mortise-tenon joint under bending and tensile stress is non-existent. Therefore, in order to choose the appropriate joint for furniture construction, empirical research is needed on the level of strength produced by different joints constructed from *K. gabonensis*.

CHAPTER THREE

LEVEL OF UTILIZATION OF SECONDARY TIMBER SPECIES AMONG FURNITURE PRODUCERS

3.1 Introduction

Production activities of the wooden furniture industries continuously get hindered by the decline in the supply of raw materials (Shih, 2012). Purnomo *et al*. (2011) and Zhou *et al.* (2015) explained that increasing scarcity of preferred (especially the traditional/primary) timber species limits the output and growth of the timber firms. For instance, supply of *Hevea brasiliensis* (rubberwood), a major timber for furniture production in Malaysia, decreased from 489,378 m^3 in 2001 to 91,605 m^3 in 2008 due to overexploitation (Puasa *et al.*, 2010). Consequently, Sarawak, a leading furniture producer contributed less than 0.5% of Malaysia's furniture export (Shih, 2012). Hashim (1998) reported that sustainability of Thailand's furniture industry continues to face serious risk because deforestation has reduced the country's forest cover from 53% to 28% of the total land area. A further reduction to 24% was anticipated by 2010. Currently, wooden furniture is giving way to the metal type in Taiwan, one of the world's largest furniture producing countries, due primarily to wood shortage (Hashim, 1998). The impacts of timber shortage on furniture industries in these countries are not different from those experienced in other parts of the world. Nutassey *et al*. (2014) noted that many companies in Accra and Kumasi have folded up because the traditional timbers for furniture are not available, while the few are very expensive to acquire.

Adupong (2011) reported that about 78% of furniture on the national market are imported from

Asia, Italy and South Africa partly due to a reduction in the processing capacities of the local industries from timber shortage. Importation increased by about 400% between 2005 and 2011 (Nutassey *et al*., 2014). This has led to a decline in the contribution of the industry to the national economy. For instance, Attah (2014) reported that the nation's timber industry's contribution to Gross Domestic Product (GDP) dropped from 4.1% in 2006 to 3.7% in 2010. The decline was attributed to poor performance of the industry on the export market due to operational challenges such as reduced supply of timber. Timber importation is one attempt at solving the challenge of inadequate raw material supply. In 2012, 66% of wood used for furniture production by Vietnam was imported from the USA (Cel consulting, 2010). Hansen *et al.* (2013) mentioned that logging ban placed by the Chinese Government on natural forests due to shortage of domestic timber supply has resulted in a surge in the amount of timber imported into the country, which is estimated at 70% of China's total timber consumption. Similarly, Ghana imports timber from neighboring countries including Cameroon to augment the local supply (Tarlue, 2014). However, continuous importation of wood increases the cost of operation and furniture products, which subsequently slows the growth of the local industries (Ogunwusi, 2012). Hansen *et al.* (2013) observed that China's continuous dependence on imported timber is a source of industry insecurity. Donovan and Nicholls (2003) and Smith *et al.* (2005) mentioned that the introduction of Lesser Utilized timber Species (LUS) with known properties on the market is one of the best strategies that would widen the raw material base and ensure continuous supply of timber resources for furniture production. In the USA, previously underutilized species such as *Alnus rubra* Bong. are making substantial contributions to the growth of the furniture sub-sector (Green *et al.*, 1995). Manufacturers in Malaysia have accepted alternatives such as *Dipterocarpus confertus* v. Sloot, *Pseudolachnostylis maprounaefolia* Pax, *Shorea* spp. and *Koompassia malaccensis* Maingay ex Benth., which have similar properties as rubberwood (Puasa *et al.*, 2010). In Ghana, several LUS (e.g., *K. gabonensis* Pierre ex Engl., *Celtis* spp., *Borassus* *aethiopum* Mart., *Strombosia glaucescens* Engl., *Pycnanthus angolensis* (Welw.) Warb., *Canarium schweinfurthii* Engl. and *Azadirachta indica* Adr. Juss.) that have the potential to substitute the scarce traditional timbers for furniture production have been investigated (AddaeMensah and Ayarkwa, 1998; Appiah-Kubi *et al*., 2011; Asafu-Adjaye *et al*., 2013). However, there is still high uncertainty about the survival of the industry due largely to persistent wood shortage (Brod, 2009; Ozarska, 2009; Muhtaman 2009). It is therefore unclear the extent to which manufacturers utilize LUS as alternatives to the dwindling primary timbers. This work sought to ascertain among manufacturers the level of utilization of LUS (including *K. gabonensis*) for furniture production and to identify the current challenges associated with their utilization by the furniture industry and their solution so as to ensure reliable timber supply.

3.2 Materials and methods

3.2.1 Study Area

The study was conducted in selected 300 (out of 550) active furniture manufacturing companies randomly sampled and interviewed in Accra and Kumasi between October 2014 and February 2015 since most of these firms which produce furniture and joinery products are concentrated in the two cities (Owusu, 2012). Kumasi lies in the moist semi-deciduous forest zone (60° 35' - 60° 40' N, 001° 30' - 001° 35' W), is Ghana’s largest wood product manufacturing District (Center for International Forestry Research, 1996; Effah *et al*., 2013) and dominated by small to medium-scale firms which produces every kind of furniture. Accra is located on latitude 5°33'N and longitude 0°15'W (GhanaDistricts.com, 2006) and hosts many of the large-scale furniture companies in Ghana (Nutassey *et al*., 2014). These firms largely depend on timber markets in Kumasi and other forested areas for raw materials (Owusu, 2012).

3.2.2 Sampling technique

Data were collected from the Furniture and Wood Products Association of Ghana (FAWAG) Secretariat at Kumasi about the active Furniture Production Firms in the country. These have been stratified into Small-, Medium- and Large-scale companies based on staff strength, capacity of logs processed as well as the machinery and technology employed. Large companies included those with more than 80 workers and a processing capacity of over 20,000 m^3 of wood per annum while medium-size had 60 - 80 workers with a processing capacity of 5,000 – 20,000 m^3 of wood per annum. Small-scale furniture firms had 10 - 60 workers and processed about 5,000m^3 of wood or less per annum. The number of companies (n) sampled from each stratum was determined by Slovin's formula (Tejada and Punzalan, 2012):

$$n = \frac{N}{1 + Ne^2}$$

Where: N = Total number of companies in each stratum; e = margin of error (0.05).

3.2.3 Data collection and analysis

Data were collected from respondents through questionnaires (Appendix H) and personal observation. Furniture producers provided information on the types of products they manufacture, their choice of timber species and the use of LUS in their operations. Statistical Package for Social Scientists (SPSS) and Microsoft Excel were used to analyze the data and presented in Figures and Tables.

3.2.4 Validity and Reliability of the questionnaire

Zikmund (2003) and Faux (2010) mentioned that pre-testing in survey research is essential for determining the validity and reliability of the questionnaire. Thus, the questionnaire was pretested before it was finally administered to respondents. Informal and individually-based expert review was the first method used in evaluating the validity of the questions in respect of the objectives for this survey. Based on the responses obtained, the questionnaire was re-designed and subsequently administered to two groups: the target population (furniture manufacturers from all the strata) and a second group known to have little knowledge on the subject matter

(Second year Natural Resources Management students from KNUST) (Parmenter and Wardle, 2000). According to Baker (1994), 10-20% of the sample size for the actual study should be considered for a pre-test. Thus, 15% of the sample size for the survey were randomly selected from each group for the pre-test. The furniture manufacturers completed the questionnaires at two different periods; two weeks apart (Parmenter and Wardle, 1999). They were not privy to the second scheduled test until it was due. After the first test, the correctness of responses and the number of questions answered/unanswered by the groups were compared to determine the validity or the extent to which the survey instrument measures exactly what it is intended for.

The test-retest method was also employed to evaluate the reliability of the questionnaire (McIntire SA, Miller, 1999; Hogan, 2007). In this method, manufacturers' responses from the first and second tests were correlated. High Pearson's correlation coefficient (r) indicated a high degree of reliability of the questionnaire.

3.3 Results

3.3.1 Size of firm

Table 3.1 shows that majority of the firms in both Accra and Kumasi were small-scale (70%) while the least were large-scale (5%). More small-scale firms (56%) were observed in Kumasi than Accra (14%), while large scale-firms were greater in Accra (3%) than Kumasi (2%).

Table 3.1: Respondents sampled from the various categories of firms in Accra and Kumasi

Location of firm	Category of firm (%)			Total
	Small	Medium	Large	
Accra	14	12	3	28
Kumasi	56	13	2	72
Total	**70**	**25**	**5**	**100**

3.3.2 Furniture products manufactured by firms

Most of the firms (33%) manufactured office chair, tables as well as bedroom furniture (Table 3.2). Living room, dining furniture, bedroom furniture and others (e.g. garden benches and kitchen stools) were produced by about 1% of the firms. About 40% of the companies indicated that their choice of products depended only on market availability, 27% mentioned profitability and market availability, while 1% cited profitability and other reasons such as vocation (Table 3.3).

Table 3.2: Furniture products manufactured by the firms in Accra and Kumasi

Furniture products	Respondents/Firms (%)
Office chairs and tables; bedroom furniture	33
Office chairs and tables; living room and dining furniture	27
Office chairs and tables; living room, dining, bedroom furniture	22
Office chairs and tables; living room, dining furniture; others (e.g. garden benches and kitchen stools)	3
Office chairs and tables; others (e.g. garden benches and kitchen stools)	3
Office chairs and tables; living room, dining, bedroom furniture; others (e.g. garden benches and kitchen stools)	2

Living room, dining and bedroom furniture	1
Living room, dining, bedroom furniture; others (e.g. garden benches and kitchen stools)	1
Office chairs and tables	4
Total	**100**

Table 3.3: Reasons for choice of furniture products manufactured by the firms

Reasons	**Respondents/Firms (%)**
Market availability	40
Profitability; market availability	28
Market availability; ease of manufacturing	11
Profitability; market availability; others (e.g. vocation)	5
Profitability	5
Profitability; ease of manufacturing	5
Market availability; others (e.g. vocation)	4
Profitability; market availability; ease of manufacturing	1
Profitability; others (e.g. vocation)	1
Total	**100**

3.3.3 Choice of markets for sale of furniture products

Fig. 3.1 shows that 93% of the manufacturing companies sold their products on the local market and 7% on the international market. About 92% of those who sold their products on the domestic market explained that their choice was due to their inabilities to meet international demand (Fig.

3.2).

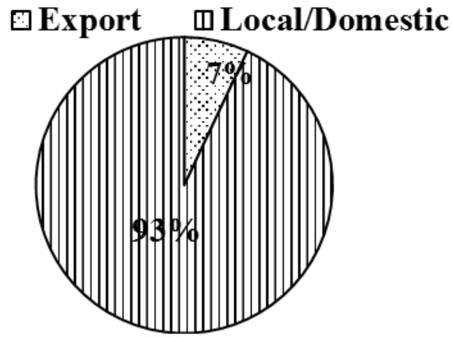

Fig. 3.1: Choice of market for sale of furniture products by the manufacturing firms

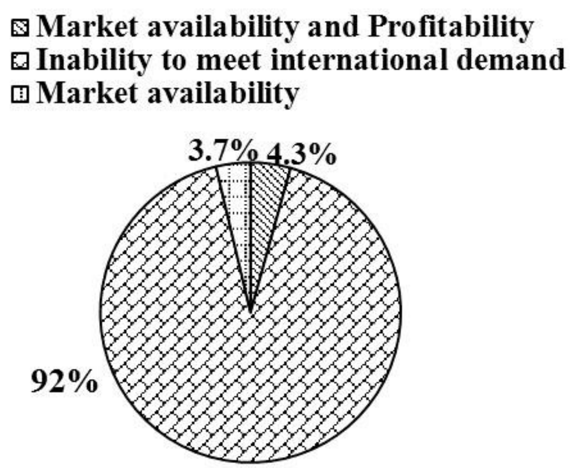

Fig. 3.2: Reasons for manufacturers' choice of market for furniture products

3.3.4 Timber materials used for furniture production

3.3.4.1 Choice of wood species

Timber species such as mixed red wood (e.g., *Cedrella odorata*, *Entandrophragma* spp., *Khaya* spp., *Afzelia africana*), *Aningeria robusta* (asanfena), *Guarea cedrata* (guarea) and *T. grandis* (teak) were used for furniture production by majority of the manufacturers (32%) (Table 3.4); 22% of these firms indicated that their choice of wood species was based on the timbers' strength, 20% attributed it to strength and durability and 14% due to strength and aesthetics (Table 3.5).

Table 3.4: Timber species used by firms for furniture production

Timber species	Respondents/Firms (%)
Mixed red wood; *A. robusta*; *G. cedrata*; *T. grandis*	32
G. cedrata; *T. grandis*	11
Mixed red wood; *A. robusta*; *M. excelsa*; *G. cedrata*; *T. grandis*	9
Piptadeniastrum africanum; *G. cedrata*; *T. grandis*	5
Mixed red wood; *A. robusta*; *M. excelsa*	5
Mixed red wood; *A. robusta*; *D. ogea*; *G. cedrata*; *T. grandis*	4
Mixed red wood; *A. robusta*; *Mansonia altissima*; *G. cedrata*; *T. grandis*	3
A. robusta; *G. cedrata*; *T. grandis*	2
Mixed red wood; *A. robusta*	2
M. excelsa; *P. africanum*; *G. cedrata*; *T. grandis*	2
M. altissima; *D. ogea*; *G. cedrata*; *T. grandis*	2
Mixed red wood; *A. robusta*; *M. excelsa*; *M. altissima*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *Celtis* spp.; *P. africanum*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *Celtis* spp.; *G. cedrata*; *T. grandis*	1
A. robusta; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *Celtis* spp.; *P. africanum*	1
Mixed red wood; *A. robusta*; *D. ogea*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. altissima*; *D. ogea*	1
A. robusta; *P. africanum*; *G. cedrata*; *T. grandis*	1

A. robusta; *M. excelsa*; *D. ogea*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. altissima*; *D. ogea*; *G. cedrata*; *T. grandis*	1
Celtis spp.; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*; *P. africanum*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *P. africanum,*	1
A. robusta; *M. excelsa*; *G. cedrata*; *T. grandis*	1
M. excels; *M. altissima*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*	1
Mixed red wood; *A. robusta*; *D. ogea*; *P. africanum*	1
Mixed red wood; *M. excelsa*; *Celtis* spp.; *G. cedrata*; *T. grandis*	1
Total	**100**

Table 3.5: Reasons for choice of timber used for furniture manufacturing

Reasons	Respondents/Firms (%)
Strength	22
Strength; durability	20
Strength; aesthetics	14
Durability	8
Strength; aesthetics; consumers' choice	6

Strength; consumers' choice	6
Strength; durability; aesthetics	6
Consumers' choice	3
Durability; consumers' choice	3
Strength; durability; consumers' choice	2
Strength; durability; others (good carving properties)	1
Durability; consumers' choice; others (good carving properties)	1
Strength; consumers' choice; others(good carving properties)	1
Durability; others (good carving properties)	1
Strength; durability; consumers' choice; others (good carving properties)	1
Strength; aesthetics; others (good carving properties)	1
Strength; others (good carving properties)	2
Strength; durability; aesthetics; consumers' choice	1
Durability; aesthetics; other (good carving properties)	1
Total	**100**

3.3.4.2 Utilization of LUS for furniture manufacturing

Only 15% of the manufacturers use LUS (e.g., *Celtis* spp., *Magnifera indica* and *A. indica*) for furniture production (Fig. 3.3). The others (i.e., 85%) rely on only the primary timbers. Specifically, none of the respondents use *K. gabonensis* in their operations. For those who do not use any LUS for production, 32% attributed this to market unavailability, while 44% indicated lack of information about the properties and uses of LUS as challenges that hinder their utilization.

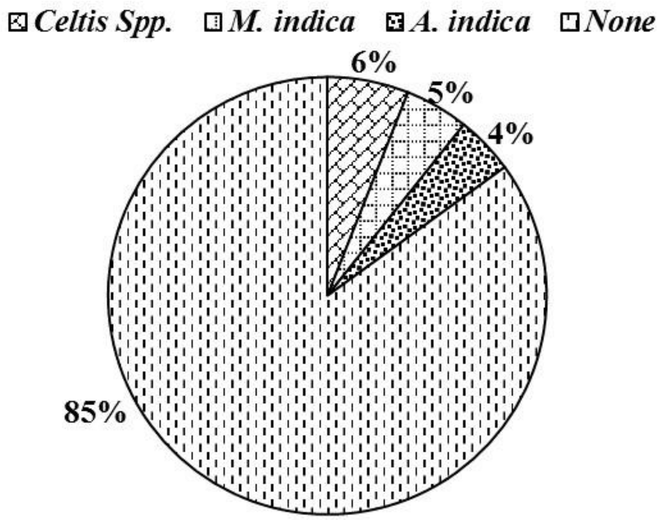

Fig. 3.3: LUS used for furniture production by the manufacturing firms

Table 3.6: Reasons for low level of utilization of LUS among furniture manufacturers

Reasons	Respondents/Firms (%)
LUS unknown; lack of technical data on the properties and uses of LUS	44
Unavailability of LUS on the market	32
LUS unknown; unavailability of LUS on the market	5
LUS unknown	5
Lack of technical data on the properties and uses of LUS	4
LUS unknown; unavailability of LUS on the market; lack of technical data on the properties and uses of LUS	1
None of the options	1
Total	**100**

3.3.4.3 Sources of timber materials

Timber markets; contractors served as the major suppliers of wood for most manufacturers (26%), followed by timber markets (23%), timber markets; sawmills (21%), timber contractors (18%), sawmills (8%) and then sawmills; timber contractors (4%) (Table 3.7).

Table 3.7: Sources of timber raw materials for furniture manufacturers

Sources of raw materials	Respondents/Firms (%)
Timber markets; timber contractors	26
Timber markets	23
Timber markets; sawmills	21
Timber contractors	18
Sawmills	8
Sawmills; timber contractors	4
Total	**100**

3.3.5 Challenges faced by firms in furniture manufacturing

For the major challenges faced by the companies, 31% mentioned non-availability of preferred wood, while 19% stated non-availability of preferred wood; competition from imported furniture (Table 3.8).

Table 3.8: Challenges faced by firms in furniture manufacturing

Challenges facing firms	Respondents/Firms (%)
Non-availability of preferred wood	31
Non-availability of preferred wood; frequent power outage	31

Competition from imported furniture	4
Competition from imported furniture; frequent power outage	3
Non-availability of preferred wood; competition from imported furniture; frequent power outage	2
Frequent power outage	2
Total	**100**
Non-availability of preferred wood; competition from imported furniture	19
Non-availability of preferred wood; high cost of operation	8

3.4 Discussion

3.4.1 Size of firm

The Ghanaian wooden furniture industry is steadily declining in performance, productivity and profits due to lack of raw materials, skilled labour, competition brought about by trade liberalization and high operational costs (Ametsistsi *et al.*, 2009). These challenges are more pronounced among the large scale companies (Mukhopadyay and Pendse, 1984). According to Söderbom *et al.* (2006), many Ghanaian large-scale firms have shut down due to increasing costs of operations. A few of those remaining have reduced their production capacities drastically due to raw material shortage. It was therefore not surprising to find more small- (70%) and mediumscale (25%) furniture firms than the large type (5%). Small- and Medium-scale Enterprises (SMEs) are recognized as catalysts for sustainable development of many countries (Odeh, 2005; Ogbo and Nwachukwu, 2012). They provide about 50% of all jobs in Nigeria (Ojeka, 2011) and make up about 70% of all industrial establishments and 90% of all businesses in Ghana. According to Oppong *et al.* (2014), Ghanaian SMEs employ 60% of the labour force, contribute about 22% to the GDP and support the development of indigenous entrepreneurship. Ranabijoy (1993) observed that a major bottleneck to the survival of small-, medium- and large-scale industries in the forestry sub-sector is the limited supply of timber materials. Policies aimed at boosting innovation and increasing the availability of raw materials would promote the competitiveness and growth of these firms (Nootebom, 1994). Zziwa *et al*. (2006) explained that in order to increase the raw material base for furniture product manufacturing, an increase in the use of LUS to supplement the supply of primary timbers need be encouraged. This, according to Ssseremba *et al*. (2011), would preserve firms, keep the sector operational and prevent job losses.

3.4.2 Furniture products manufactured by firms

The study revealed that most of the manufacturers (33%) engaged in the production of office chairs, tables as well as bedroom furniture. Centre for Industrial Studies (2015) observed a faster growth in the office furniture trade on the European market. Ponder (2013) explained that the emergence of new businesses and expansion of existing ones have led to the growth in sales of office chairs and tables. Ha (2007) and Kazemifar and Khodadadeh (2013) also noted that every individual spends about a third of their lives in bed for relaxation and privacy. As a result, most families rank bedroom furniture as the most important product to be purchased for the home. Consequently, Drayse (2008) and Kingsway Furniture Co. Ltd. (2009) observed that office and bedroom furniture were the main commodities traded on the global furniture market. Flow control magazine (2015) noted that the household and office furniture sectors accounted for about two-thirds of the total revenue for the furniture sector in USA over the last decade. The high availability of market for office chairs, tables and bedroom furniture could explain the frequency of their production among manufacturers. The high rate of production also implies that large amount of wood would be needed by the office and bedroom furniture manufacturers.

3.4.3 Choice of markets for sale of furniture products

Most of the firms (93%) sold their products on the domestic market; 92% of them attributed this to inability to meet international demand. According to Oppong *et al.* (2014), inadequate financial resources, lack of export marketing strategies and inability to meet international demands/standards are responsible for the reliance of the furniture industry on the local market for sale of products. Ward and Gilbert (2001) explained that firms choose to sell their products on the local market because export marketing requires more time, greater financial resources and greater ability to withstand far wider and more intense competition. As a result, about 73% of middle-market firms in North America currently sell their products on the domestic market (Economist Intelligence Unit, 2012). However, Julian (2014) observed that the international market helps local industries to grow fast, improve their innovation, credibility and competitiveness. Biggs (2013) mentioned that due to the relatively small size of domestic markets, firms looking to expand their businesses must take advantage of the export markets. Thus, the growth of the Ghanaian furniture sector could be enhanced when more firms are supported to produce furniture in quantities that meet international demand. However, this will partly be dependent on continuous supply of raw materials (Adebara *et al.*, 2014). With decreasing quantities of popular timbers for furniture, producers could rely on secondary timber species to augment supply and promote the competitiveness of the sector.

3.4.4 Timber materials used for furniture production

3.4.4.1 Choice of wood species

Timber is the single most important raw material in the furniture industry (Boampong *et al*., 2015). Adebara *et al.* (2014) noted that certain products require specific timber species.

Therefore, Ayarkwa (1998) asserted that timber users in Ghana are very selective in their choice of wood, such that furniture products are usually made from a small number of preferred timbers. It was observed from this study that mixed red wood (e.g., *Cedrella odorata*, *E.* spp., *Khaya* spp., *A. africana*), *A. robusta, G. cedrata* and *T. grandis* were the timber species used by majority of the manufacturers (32%) due to their strength, durability and aesthetics. In a study to determine the factors influencing the choice of timber for furniture and joinery production in Ghana, Dadzie *et al.* (2014) and Boampong *et al*. (2015) similarly found that among a list of 22 wood species, only few including mixed red wood, *G. cedrata* and *T. grandis* were mostly patronized by furniture manufacturers. Trevallion and Strazzari (2003), Zziwa *et al.* (2006), Louppe (2008), Binggeli (2008), Derkyi *et al.* (2009), Govorčin *et al*. (2010) and Chernyh *et al.* (2013) confirmed that factors such as strength, cost, durability, beauty and availability influenced the choice of timber for furniture. This accounts for the high patronage of mixed red wood, *A. robusta*, *G. cedrata* and *T. grandis* among manufacturers. Consumers preferred to spend more money to purchase products made from strong and durable timbers that would reduce maintenance and replacement cost (Boampong *et al*., 2015). Tropical timber species with great strength and good aesthetic properties such as *K. anthoteca*, *P. elata*, *Simarouba versicolor* and *E. cylindricum* are therefore common on the Italian furniture market (Centre for the Promotion of Imports from Developing Countries, 2015). Thus, in seeking alternatives for the over-dependent primary timbers, secondary timber species that are strong, durable and aesthetically good could gain acceptance by furniture manufacturers. For instance, *K. gabonensis* is a naturally durable and strong timber with attractive grain pattern; it is abundant in most tropical forests and has prospects for furniture-making (Oteng-Amoako and Obeng, 2012). Based on its characteristics, it could contribute to satisfying the raw material needs of the furniture industry.

3.4.4.2 Utilization of LUS for furniture manufacturing

Acquah and Whyte (1998) explained that the volume of high-valued commercial timbers that remains in the forests for furniture production faces stiff competition from all the other woodrelated sectors. Oteng-Amoako *et al.* (2008) found that LUS could serve as substitutes to and reduce the pressure on these commercial timbers. Boampong *et al*. (2015) noted that several secondary timber species whose properties make them suitable for furniture are in large quantities in the tropical forests. However, this study showed that only 15% of manufacturers use LUS such as *Celtis* spp., *M. indica* and *A. indica* for furniture production. Sseremba (2005) found *M. indica* among several other secondary timbers used for furniture-making in Uganda. It was further observed that none of the respondents had ever used *K. gabonensis* in their operations. Manufacturers indicated unavailability of secondary timbers on the market and lack of information regarding their properties and uses as some of the hindrances to their utilization. Smith (2000) found that utilization of timber by wood product manufacturers depends on accessibility on the market and availability of comprehensive technical data on its properties. Similarly, Ayarkwa (1998) and Effah and Osei (2014) mentioned that dissemination of research results among wood workers about new timber species that could serve the same purpose as their already utilized counterparts would enhance their utilization. Sseremba *et al.* (2011) found that accessibility of data regarding the characteristics and uses of LUS such as *M. indica* and *Artocarpus heterophyllus* improved their acceptance and utilization by Ugandan furniture manufacturers. It could be understood from the results that the level of utilization of LUS, the likely alternatives for furniture-making, is low among manufacturers because information on their characteristics and uses are not readily available. Therefore to increase the utilization of secondary timber species for wood products, adequate information about their abundance, properties and uses must be made available to manufacturers (Graham, 2012).

3.4.4.3 Sources of timber materials for furniture production

Raw materials supplied to furniture manufacturers are obtained through a network of buyers who purchase timber from both private and public forest landowners (Cubbage *et al*., 1996). About 26% of the respondents sourced wood from timber markets and contractors (loggers). Nketiah and Wieman (2004) and Marfo (2010) explained that wood procured from these two sources are comparatively cheaper than those sold by sawmills. Therefore, many furniture manufacturing firms prefer to buy lumber from the former. Since firms do not use secondary timber species due to market unavailability, it could be stated that timber contractors and operators do not supply LUS to furniture manufacturers. Boyes and Melvin (2015) mentioned that the level of supply of raw materials for any production process depends on demand for those materials by producers. In Northern India, although many secondary timber species that could be used for housing construction existed in great numbers in the forests, timber providers did not risk bringing them on the market due to their low demand among users (Tai and Sidel, 2012). Therefore, the failure by timber contractors and operators to supply LUS on the market may be due to low demand for the species. Venn and Whittaker (2003) also mentioned that most timber sellers are unaware of the properties and the prospective uses of a lot of the LUS in the forests as well as profits that might be obtained from their sales. This leads to total neglect of the non-traditional timbers in the timber trade. Providers of timber for furniture production do not make available LUS to manufacturers due likely to a lack of understanding of their quality and profitability (Quinlan, 2011). Thus, in encouraging the use of secondary timbers for furniture and other wooden products, information on the characteristics, uses and profitability of LUS should also be made available to wood suppliers.

3.4.5 Challenges faced by furniture manufacturers

According to Center for Industrial Studies (CSIL) (2010), about US$376 billion was obtained on the global market from the production of furniture in 2010. Ngui *et al*. (2011) explained that furniture has greater monetary value than other wood-based products such that furniture manufacturing is an ideal option for countries that seek to earn more from the timber-processing industry. Nonetheless, furniture industries face serious challenges that have led to the collapse of many (Nutassey *et al*., 2014). Nutassey *et al*. (2014) explained that the number of industries in Ghana's tertiary wood sub-sector declined by over 60% between 1990 and 1999. Norini *et al.* (2009) estimated that only 26% of the total furniture firms in Sarawak State in Malaysia remained active as of 2009 due to myriad of problems such as decline in quantities of raw materials and rising costs of operations.

Respondents mentioned that non-availability of preferred wood and competitions from imported furniture were among the challenges confronting the furniture industry. Similarly, Adupong (2011) observed in a survey commissioned by Wood Workers Association of Ghana-Western Region (WWAG-WR) that decreasing quantities of primary timbers hindered the activities of furniture-making firms. Respondents from that survey explained that the volumes of timbers had declined drastically over the years. The few amounts remaining were difficult and expensive to acquire partly because sawmills that had large forest concessions were export-oriented and did not provide for the local market. Local manufacturers were therefore unable to meet customers' increasing demand for furniture and have resorted to their importation to supplement local production (Tettey *et al*., 2003; Budu-Smith, 2005). This situation has led to stunted growth of the local industry, while rendering many manufacturers jobless (Dinh *et al*., 2013). The challenges associated with the drastic decline in timber supply could be reduced by encouraging the use of secondary timber species to widen the raw material base for the sector (Budu-Smith, 2005). However, the present study has shown that manufacturers hardly use LUS primarily due to market unavailability and lack of technical information about them. Thus, to increase the use of secondary timber resources by the wood industry, wood suppliers, product manufacturers and end users must be fed with reliable and sufficiently detailed information about the characteristics and uses of the large amount of neglected timber species in the forests. This will help meet the raw material requirement of the industry, while reducing pressure on the current commercial timber species.

3.5 Summary

This chapter investigated the level of utilization of LUS including *K. gabonensis* among furniture producers. Continuous decline and non-availability of preferred traditional timbers and competition from imported furniture were the main challenges confronting the furniture industry. Data obtained indicated that information on the properties of many LUS with prospects for furniture-making (such as *K. gabonensis*), that are available in great quantities in many tropical forests, are hardly available to local producers, which affects their popularity among timber suppliers and manufacturers. To improve on the level of utilization of secondary timbers, wood workers must be supplied with comprehensive information about their properties and economic values. This will contribute to reducing pressure on the primary timbers, ensuring consistent supply of timber and keeping the sector operational.

CHAPTER FOUR

PHYSICAL AND MECHANICAL PROPERTIES OF *K. GABONENSIS*

4.1 Introduction

Wood has a long history of use due to its beauty, strength, durability and workability (Tankut, 2007). However, many tropical timbers with varying properties remain neglected by end-users because their properties are unknown (Simeone, 2011). As the traditional ―favourites‖ for wooden products become increasingly rare, Lesser-Utilized Species (LUS) abound, which could be the probable substitutes. Forest Products Research and Development Institute (FPRDI) and International Tropical Timber Organization (ITTO) (1997) recommended the use of some LUS (e.g. *Koordersiodendron pinnatum*, *Diospyros pyrrhocarpa*, *Artocarpus blancoi* and *Ziziphus talanai*) in the Philippines for building construction and furniture production based on their physical (e.g., density) and strength (e.g., Moduli of Rupture and Elasticity) properties. Currently, *Hevea brasiliensis* (rubberwood), a former LUS, forms over 80% of wood used for furniture production in Malaysia (Boon-Kwee and Thiruchelvam, 2012). Other LUS could also provide alternative raw materials for the Timber Industry.

For instance, *K. gabonensis* occurs widely in several East and West African countries (OtengAmoako and Obeng, 2012). Oteng-Amoako and Obeng (2012) reported 940 – 1150 kgm^{-3} as its density; it has a beautiful grain pattern, saws well, dresses to a smooth finish and glues well. However, it is seldom utilized locally or internationally. Meanwhile, Simeone (2011) recommended that no timber species is useless if its strength properties are known. However, like several other LUS, it lacks comprehensive technical data on its properties and working performance, which affects its acceptance by wood product manufacturers and consumers (Smith, 2000). Cordero and Kanninen (2002) and Strong (2013) mentioned that the physical and strength properties are predominantly important when choosing wood for structural works. Wood strength is largely influenced by its physical properties (Gryc and Horácek, 2007). Those of great concern are moisture content (mc), density, swelling and shrinkage (Johnson *et al.*, 2006; Ali, 2011). Dickson (2000) and Hernandez (2007) mentioned that lower density woods, due to their thin cell walls, have lower strength properties than the heavy types. Persson (1997) and Zhang (1997) also found Modulus of Rupture (MOR) of wood to be linearly related to its density. Thus, Ali (2011) stressed that medium-density woods (i.e., about 400 kg/m^3) to highdensity types (i.e., about 1100 kg/m^3) are preferred for most manufacturing products including furniture.

Wood hygroscopicity also renders it liable to dimensional changes such that when its moisture fluctuates around the fiber saturation point (FSP), it results in unequal degrees of either shrinkage or swelling in its three directions: longitudinal, tangential and radial surfaces (Rowell *et al*., 2009; Antwi-Boasiako and Boadu, 2013). These changes often lead to reduction in timber strength, tightening and fracture of joints, splitting and change of cross-sectional shapes of wood structures (Winandy, 1994). Desch and Dinwoodie (1996) and Ali (2011) therefore suggested that dimensionally-stable timber should be employed in works that utilize wood externally. This explains the age-long use of medium to high density dimensionally-stable traditional timbers of great strength such as *E. cylindricum*, *K. ivorensis*, *T. grandis* and *Quercus spp.*, for building construction, flooring and furniture-making.

Different applications require specific mechanical properties from different wood types (Zwerger, 2012). In constructing wooden structures, timber is expected to possess great strength against bending, compression and shear stresses (Tankut, 2007). A designer's knowledge of all these properties predicts its suitability or compliance with established standards for manufactured products (Tankut, 2007). This chapter presents the physical and mechanical properties of *K.*

gabonensis as one of the substitutes to the over-utilized traditional timbers. Its properties were compared to those of *E. cylindricum*, a widely-used traditional timber for building, roofing and furniture construction.

4.2 Materials and methods

4.2.1 Study area and sampling of wood materials

Three trees (70-90cm diameter) each of *K. gabonensis* (Plate 4.1) and *E. cylindricum* (control) of 40–45 years (obtained from the Forest Services Division) were randomly harvested (at 1.3m above the ground) from the Bobiri Forest Reserve in the Ashanti Region of Ghana [Latitudes 6^o 39'S and 6^o 44'N; Longitudes 1^o 15'E and 1^o 23'W] (Fig. 4.1) (Addae-Wireko, 2008). Bolts (1m long) were taken from the butt (in order to avoid juvenile wood), quarter sawn into boards (to prevent the samples from cupping during drying) (Plate 4.1) and further sawn into the desired dimensions for the various tests at the Wood workshop of the Faculty of Renewable Natural Resources. Forty-eight defect-free (based on visual assessment) heartwood and sapwood samples each were randomly taken from the sections for determining the physico-mechanical properties.

Plate 4.1: ***K. gabonensis*** **log (a), bolt (b) and quarter sawn samples (c)**

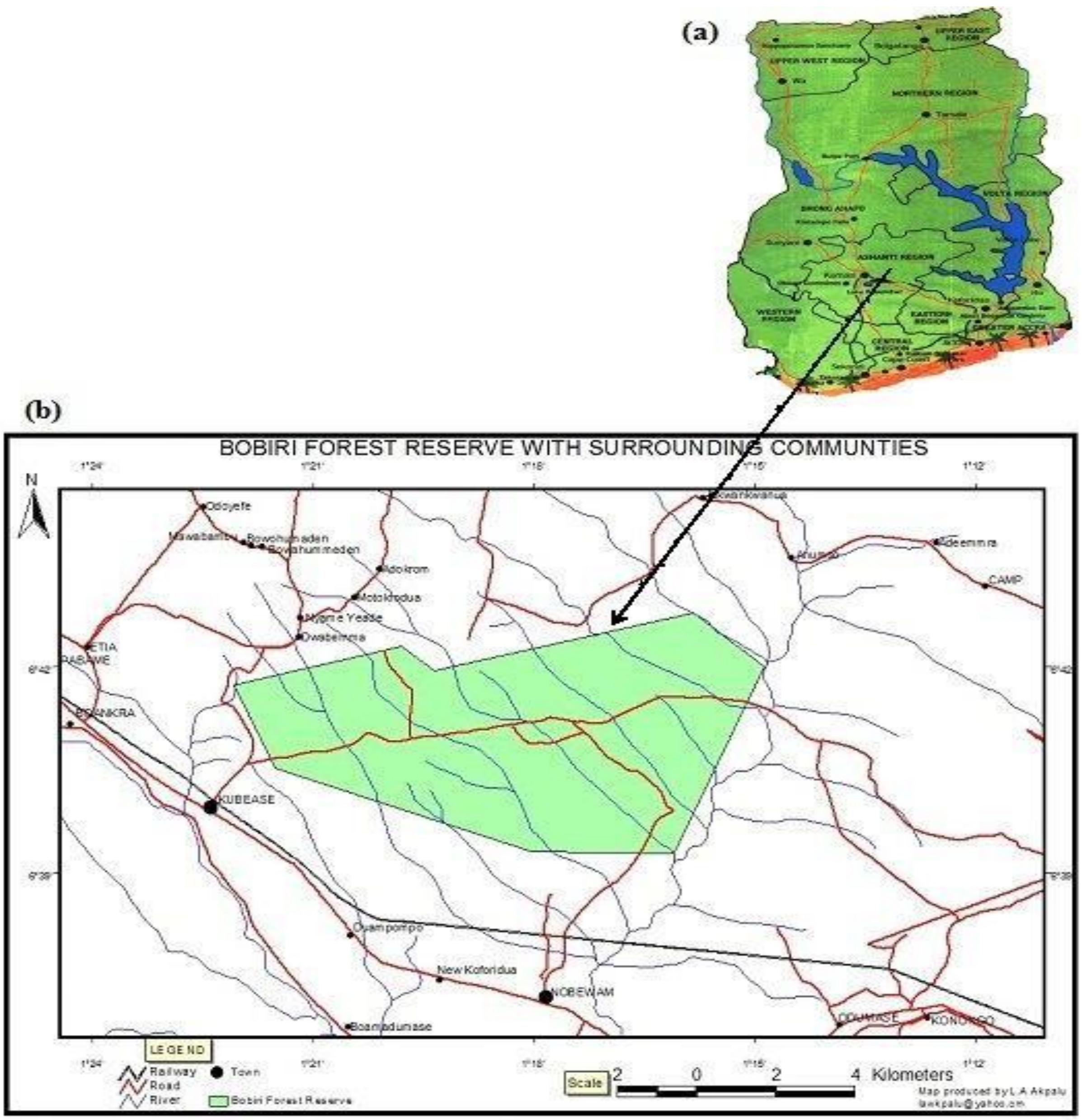

Fig. 4.1: Map of Ghana (a) showing the position of Bobiri Forest Reserve (b).

4.2.2 Determination of physical properties

4.2.2.1 Moisture content

Wood samples (2 x 2 x 2 cm) were kept in polythene bags to prevent moisture loss after initial weighing and drying at 103 ± 2 °C to a constant or final weight of each sample. The moisture content (mc) of each sample was calculated using Equation 4.1 (BS 373, 1957]:

$$Moisture\ Content\ (\%) = \frac{Initial\ weight - Final\ weight}{Final\ weight} \times 100 \qquad Equation\ 4.1$$

4.2.2.2 Density at 12% mc

Wood samples (2 x 2 x 2 cm) were soaked in distilled water for 14 days until full saturation and their volumes determined using the water displacement method. After oven-drying, basic density was calculated from Equation 4.2 (BS 373, 1957) and converted to specific gravity at 12% mc using Equation 4.3; density at 12% mc was then determined from Equation 4.4 (Forest Products Laboratory, 2010):

$$\text{Basic density} = \frac{Mo}{Vf}\ (g/cm^3) \qquad \textit{Equation 4.2}$$

Where: *Mo* = oven-dried mass; *Vf* = green volume

$$G_{12} = G_b / [1 - 0.265 G_b (1 - 12)/M_{fs}] \qquad \textit{Equation 4.3}$$

Where: G_{12} = Specific gravity at 12% mc; G_b = basic density; M_{fs} = Moisture content at FSP (i.e., 30%)

$$Density = \rho w \times G_{12} \left(1 + \frac{12}{100}\right) \times 1000\ (kg/m^3) \qquad \textit{Equation 4.4}$$

Where: G_{12} = Specific gravity at 12% mc; ρw = density of water (0.9976 g/cm^3)

4.2.2.3 Dimensional stability

4.2.2.3.1 Swelling

Using the water-soak method (ASTM D 1037-06a (24), 2006), directional and volumetric swellings of wood samples (152 x 76 x 5 mm), air-dried to 12% mc, were determined from Equations 4.5 and 4.6 respectively (Mantanis *et al*., 1994; ASTM D 1037-06a (24), 2006; Antwi-

Boasiako and Boadu, 2013):

$$Swelling\ (\%) = \frac{Wda - Wdb}{Wdb} \times 100$$ *Equation 4.5*

Where: Wda = Wood dimension after immersion (i.e., wet dimension); Wdb = Wood dimension before immersion (i.e., dry dimension).

$$Volumetric\ Swelling\ (\%) = \frac{Sl \times St \times Sr - Dl \times Dt \times Dr}{Dl \times Dt \times Dr} \times 100$$ *Equation 4.6*

Where: Sl, St and Sr = respective Longitudinal, Tangential and Radial dimensions of stakes in swollen condition; Dl, Dt and Dr = respective Longitudinal, tangential and radial dimensions of stakes in dry condition.

4.2.2.3.2 Shrinkage

Green samples (2 x 2 x 10 cm) were weighed, arranged on wire racks and allowed to air-dry to approximately 12% mc at 25 °C and 65% RH. Directional and volumetric shrinkages were determined from Equations 4.7 and 4.8 respectively (BS 373, 1957; Mantanis *et al*., 1994; Dilik *et al*., 2007):

$$Shrinkage\ (\%)\ \frac{Wda - Wdb}{Wda} \times 100$$ *Equation 4.7*

Where: Wda = Dimension of wood in wet condition; Wdb = Wood dimension after air-drying.

$$Volumetric\ Shrinkage\ (\%) = \frac{Sl \times St \times Sr - Dl \times Dt \times Dr}{Sl \times St \times Sr} \times 100$$ *Equation 4.8*

Where: Sl, St and Sr = respective Longitudinal, Tangential and Radial dimensions of wood in wet condition; Dl, Dt and Dr = respective Longitudinal, Tangential and Radial dimensions of wood after airdrying.

4.2.3 Determination of mechanical properties

Strength properties of wood were determined using Instron-4482 machine (at a loading speed of

3mm/sec) for shear parallel to the grain using sample dimension of 5 x 5 x 5 cm, compression parallel to the grain (2 x 2 x 6 cm) and Moduli of Rupture and Elasticity (2 x 2 x 30 cm). Strength values obtained were standardized to 12% mc using Equation 4.9 (BS 373, 1957):

$$\tau_{12} = \tau_{\acute{\omega}} \quad \{1+\alpha\,(w - 12)\} \qquad \textit{Equation 4.9}$$

τ_{12} = Standardized strength property at 12% mc; $\tau_{\acute{\omega}}$ = calculated strength property; w = mc of test sample; α = a constant (0.04)

4.2.4 Experimental design and data analysis

Data obtained from the measurements of all the properties of the wood samples were presented in Split-plot in Completely Randomized Design (CRD). The replicates were organized into 3 groups of 16 replicates each for analysis. Data were subjected to Analysis of Variance (ANOVA) and Fisher's Least Significant Difference (LSD) Test at 95% Confidence level.

4.3 Results

4.3.1 Physical properties of *K. gabonensis* and *E. cylindricum*

4.3.1.1 Moisture Content

K. gabonensis sapwood recorded the greatest mc (44.2±0.6%) followed by its heartwood (42.1±1.1%) and then *E. cylindricum* sapwood (35±0.5%) and its heartwood (34.8±1.2%) (Table 4.1). Significant difference ($p<0.05$) existed between mc for *K. gabonensis* heartwood and sapwood (Table 4.1; Appendix D).

4.3.1.2 Density

K. gabonensis was more dense than *E. cylindricum* (Table 4.1). Densities for the heartwood of *K. gabonensis* (958±19 kgm^{-3}) and *E. cylindricum* (536±19 kgm^{-3}) were greater than those of their sapwood (932±31 kgm^{-3} and 490±13 kgm^{-3} respectively). No significant difference ($p<0.05$) existed between density for the heartwood and sapwood of *K. gabonensis* (Appendix D).

4.3.1.3 Dimensional Stability of *K. gabonensis* and *E. cylindricum*

4.3.1.3.1 Swelling

Swelling was greatest at the tangential direction for both *K. gabonensis* (5.8±0.2%–5.8±0.4%) and *E. cylindricum* (7.7±0.1%–8.0±0.3%) but least at the longitudinal directions (0.2±0.1%–0.4 ±0.1%, and 0.3±0.1%–0.4±0.1% respectively). Swelling was generally greater for *E. cylindricum* than *K. gabonensis* (Fig. 4.2). Tangential-Radial ratio (T/R) was 1.43 and 1.39 for *E. cylindricum* sapwood and heartwood respectively; 1.38 and 1.31 were respectively also recorded for *K. gabonensis*. Volumetric swelling for *K. gabonensis* sapwood was greater (14.5±0.9%) than its heartwood (10.6±0.3%). Similarly, that for *E. cylindricum* sapwood was greater (14.6±0.8%) than its heartwood (14.2±0.4%) (Fig. 4.2).

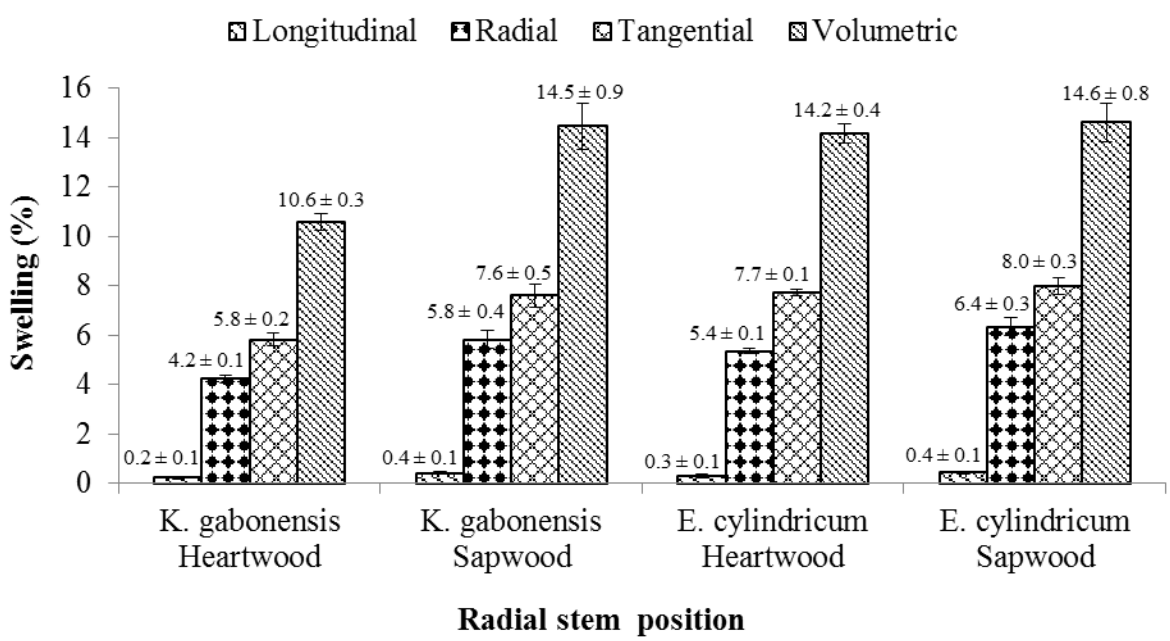

Fig. 4.2: Directional and volumetric swellings across the stems of *K. gabonensis* and *E. cylindricum* (Bar = Standard Error)

4.3.1.3.2 Shrinkage

Shrinkage was greatest at the tangential direction of *K. gabonensis* (3.1±0.3%–3.3±0.3%) and *E. cylindricum* (4.0±0.3%–4.1±0.2%) and least at the longitudinal direction (0.3±0%–0.4±0% and 0% respectively) (Fig. 4.3). Tangential and radial shrinkages were greater for *E. cylindricum* than *K. gabonensis* (Fig. 4.3). T/R was 2.22 and 2.06 for *E. cylindricum* heartwood and sapwood respectively; 1.63 for *K. gabonensis* heartwood and 1.58 for its sapwood. Volumetric shrinkage for *K. gabonensis* sapwood was greater (5.7±0.5%) than its heartwood (5.1±0.3%). Likewise, that for *E. cylindricum* sapwood was greater (6.7±0.5%) than its heartwood (6.1±0.4%) (Fig. 4.3).

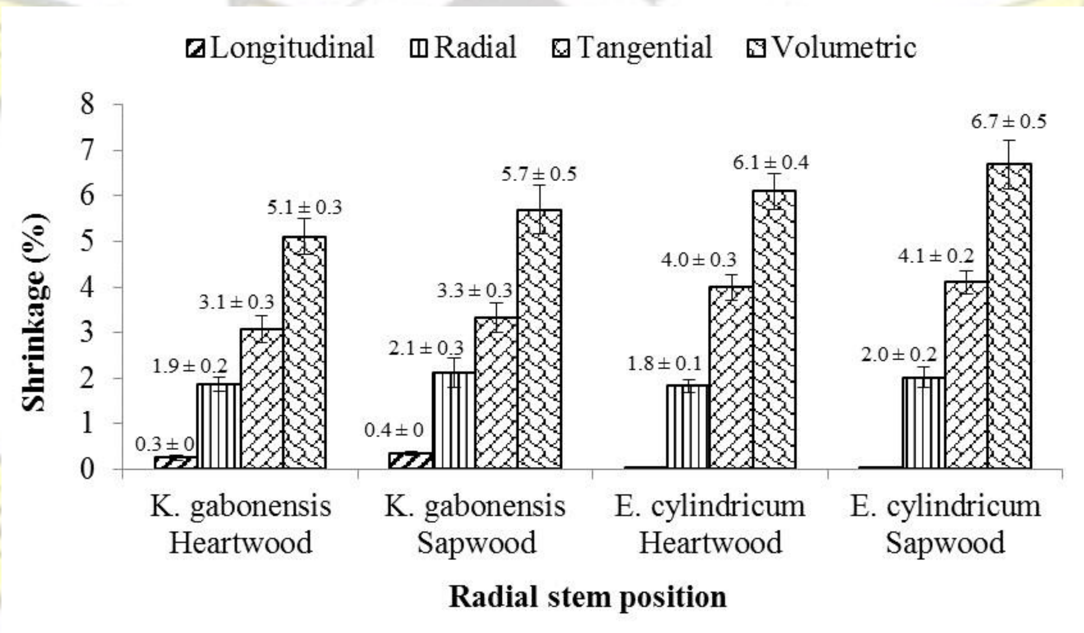

Fig. 4.3: Directional and volumetric shrinkages across the stems of *K. gabonensis* and *E. cylindricum* at 12% mc (Bar = Standard Error)

4.3.2 Mechanical properties of *K. gabonensis* and *E. cylindricum*

4.3.2.1 Shear strength parallel to the grain

K. gabonensis shear strength was greater for the heartwood (33.5±1 Nmm^{-2}) than its sapwood (32.2±0.4 Nmm^{-2}); the difference was significant ($p<0.05$) (Table 4.1; Appendix D). *E. cylindricum* heartwood was also greater (15.6±1 Nmm^{-2}) than its sapwood (15.5±1 Nmm^{-2}) (Table 4.1). *K. gabonensis* was stronger than *E. cylindricum* for both heartwood and sapwood.

4.3.2.2 Compressive strength parallel to the grain

The compressive strength of *K. gabonensis* heartwood was greater (90.6±1 Nmm^{-2}) than its sapwood (80.7±1.4 Nmm^{-2}); the difference was significant ($p<0.05$) (Table 4.1; Appendix D). It was similarly greater for *E. cylindricum* heartwood (63.6±1.2 Nmm^{-2}) than its sapwood (56.4±4.5 Nmm^{-2}). *K. gabonensis* also recorded greater compressive strength than *E. cylindricum*.

4.3.2.3 MOR and MOE

MOR was greater for *K. gabonensis* heartwood (214±4 Nmm^{-2}) than its corresponding sapwood (204±4 Nmm^{-2}); the difference was significant ($p<0.05$) (Table 4.1; Appendix D). *E. cylindricum* heartwood was also greater (121.3±10.6 Nmm^{-2}) than its sapwood (99.4±4.7 Nmm^{-2}). *K. gabonensis* MOE was greater for the heartwood (29493±822 Nmm^{-2}) than its sapwood (28932±664 Nmm^{-2}); the difference was not significant ($p<0.05$) (Table 4.1). It was also greater for *E. cylindricum* heartwood (10051±258 Nmm^{-2}) than its sapwood (9987.4±207 Nmm^{-2}).

Generally, *K. gabonensis* had greater MOR and MOE than *E. cylindricum*.

Table 4.1: Physical and strength properties across the stems of *K. gabonensis* and *E. cylindricum*

Timber	Stem position	Physical property mc		Strength p (Nmm^{-2})			
			Density (kgm^{-3})	MOE	MOR	Compression	Shear
K. gabonensis	Heartwood	42.1±1.1^{a}	958±19^{a}	29493±822^{a}	214.2±4^{a}	90.6±1^{a}	33.5±0.7^{a}
	Sapwood	44.2±0.6^{b}	932±31^{a}	28932±664^{a}	204±4^{b}	80.7±1.4^{b}	32.2±0.4^{b}
E. cylindricum	Heartwood	34.76±1.2^{c}	536±19^{b}	10051±258^{b}	121.3±10.6^{c}	63.6±1.2^{c}	15.6±0.6^{c}
	Sapwood	35.03±0.5^{c}	490±13^{c}	9987.4±207^{b}	99.4±4.7^{d}	56.4±4.5^{c}	15.5±0.9^{c}

Means in the same column with similar superscripts are not significantly different ($p<0.05$).

4.4 Discussion

Engineering applications of many timbers are restricted due to inadequate information about their properties (Barany *et al.*, 2003). Ozarska (2009) explained that the growth of the timber industry is unsustainable with over-dependence on only well-known traditional timbers. According to Borota (1991), many developed products from radiata pine, Douglas fir and several tropical LUS (e.g., *K. ivorensis* and *M. excelsa*) established good European markets because their properties were well investigated. *K. gabonensis* is rarely used due to lack of information about its physical and strength properties (Cordero and Kanninen, 2002). To ascertain its suitability as a useful raw material or an alternative to several of the traditional wood species for the timber industry, its properties were worth-investigating. According to Joyce and Spielman (2000), the sapwood of most timbers with desirable physical and strength properties could be used where durability is not of great importance. Thus, physico-mechanical properties of both the sapwood and heartwood of *K. gabonensis* were studied.

4.4.1 Physical properties of *K. gabonensis* and *E. cylindricum*

4.4.1.1 Moisture Content

Moisture occurs in wood chiefly as bound water by the free hydroxyl groups of the main structural compounds (i.e., cellulose, lignin and hemicelluloses) within the cell walls through electro-static forces, and free water in the cell lumens and cavities (Rowell, 2005). Sherwood (1994) and Vick (1999) explained that moisture influences dimensional stability and growth of bio-degraders, which destroy woods structural rigidity in service. According to Anderson (2002), wood is dense with much water, which affects its processing and transportation cost. Thus, the great mc recorded for *K. gabonensis* (i.e., 42.1±1.1–44.2±0.6%) would create processing and transportation challenges, especially when it is freshly harvested. Wood moisture also affects glueability and strength of joints, depth of adhesive penetration and curing time (Kumaran, 1999; Rowell, 2005). Tankut (2007) found joint strength to reduce by 15% when the wood was conditioned at 85% relative humidity (RH) but there was an increase of 6% when conditioned at 35% RH. The great amount of moisture for *K. gabonensis* could affect its finishes and cause surface staining as well as leaching of extractives from wooden products made from wood particularly at green state (Pakarinen, 1999). In buildings, this could lead to a reduction in the mechanical stiffness of walls as the moisture begins to leave wood (Winandy, 1994). Sapwoods for both timbers contained more moisture than their heartwoods since the active cells in sapwood make them regularly involved in mechanical transport of water (Bekhta and Niemz, 2009; Rijsdijk and Laming, 2010). To avoid the challenges associated with much moisture in wood (e.g. bio-deterioration and movement in service), *K. gabonensis* would need thorough drying before utilizing it for any wooden structure.

4.4.1.2 Density at 12% mc

The performance of wooden products is largely a function of their density, which influences their strength (Niklas, 1997; Ocloo and Laing, 2003), dimensional stability and durability (Desch and

Dinwoodie, 1996; Gryc and Horácek, 2007). However, timbers with density above 1200 kgm^{-3} might be expensive for the manufacturing of products because of the costs involved in transportation and processing (Zobel and Jett, 1995; Shelly, 2001; Pinto *et al*., 2004). Additionally, such woods are not dimensionally-stable; this could lead to distortion of the parts of their products with mc changes (Sherwood, 1994; Izekor *et al.*, 2010). Although the density of *K. gabonensis* (932±31–958±19 kgm^{-3}) is greater than that of *E. cylindricum* (490±13–536±19 kgm^{-3}), the former timber could overcome the problems associated with very dense timbers because of its recorded density. *K. gabonensis* recorded a lower density than was earlier reported by Oteng-Amoako and Obeng (2012) (940–1150 kgm^{-3}). However, it compares well with those of *Dalbergia retusa* (880–980 kgm^{-3}), *Chrysophyllum pomiferum* (950 kgm^{-3}) and *Intsia bijuga* (780–930 kgm^{-3}), which are all popular timbers often used for building construction, flooring, roofing and furniture manufacturing (Shelly, 2001; Gunduz *et al*., 2009; Izekor *et al*., 2010; Ali, 2011; Asamoah *et al*., 2012, Forest Products Development and Marketing Council of Guyana Inc., 2015). *K. gabonensis* could therefore be equally employed for similar and other structural applications.

4.4.1.3 Dimensional Stability

Wood is hygroscopic and easily exchanges moisture with its surroundings (Winandy, 1994). It therefore shrinks and swells when it loses or gains moisture respectively. These lead to warping, checking or splitting that compromise the performance of wood (Bajwa *et al*., 2011). For wooden products, the movement can only be minimized by selecting timber species that has the ability to maintain stable dimensions under extreme temperature and moisture conditions. Carli and Passarelli (2012) reported that most of the challenges of utilizing timber for engineering purposes involve the understanding of wood-moisture relationship and the influence on its properties. The swelling and shrinkage characteristics of *K. gabonensis* were investigated to predict the dimensional stability of its products, especially in service.

4.4.1.3.1 Swelling

Swelling is mostly responsible for warping and other forms of distortions of wooden products (Winandy, 1994; Hagstrom, 2010). It also leaves wooden structures unsightly and weakens timber joints (Eckelman, 1998). Zhu *et al.* (2014) mentioned that the collective effect of swelling in the tangential (T) and radial (R) directions of wood has the greatest influence on its dimensional stability. To overcome these challenges, Minford (1991) recommended a T/R ratio of <1.6 for timbers used for building, roofing, flooring and furniture construction. The T/R ratio for *K. gabonensis* [1.31 (heartwood) and 1.38 (sapwood)] compares well with this recommendation and fits it for constructional purposes. Swelling was least in the longitudinal direction of *K. gabonensis* since microfibrils align more along the axis of cell walls to restrict moisture uptake (Murata and Masuda, 2006; Mecklenburg, 2007; Derome *et al.*, 2011; AntwiBoasiako and Boadu, 2013). Volumetric swelling for *K. gabonensis* was also less (10.6±0.3%– 14.5±0.9%) than that for *E. cylindricum* (14.2±0.4–14.6±0.8%). Thus, like *E. cylindricum*, *K. gabonensis* is a suitable raw material, which is dimensionally-stable and could resist great mc changes in harsh conditions.

4.4.1.3.2 Shrinkage

Wood shrinks as bound water escapes from the hemicellulose and cellulose chains in the cell wall thereby getting the chains closer together (Shmulsky and Jones, 2011; Engelund *et al.*, 2013). Understanding the degree of shrinkage for timbers (e.g. *K. gabonensis*) is essential for determining its stability in structures (Hernandez, 2007). It could contribute to define adequate clearance or allowance to be made on the initial dimensions of green wood before utilization or drying (Shmulsky and Jones, 2011). Since the in-service mc for timber products is usually within 8-14%

mc (Vick, 1999), volumetric shrinkage of *K. gabonensis* from the green condition to 12% mc was estimated to be less (5.1±0.3%-5.7±0.5%) than that of *E. cylindricum* (6.1±0.4%– 6.7±0.5%). Haygreen and Bowyer (1996) asserted that dense woods shrink more than their lighter counterparts. Our current results agree with the observation made by Shmulsky and Jones (2011) that black walnut (density = 550 kgm^{-3}) had a lower volumetric shrinkage (12.8%) than that of low-density Eastern Cottonwood (13.9%), which has a density of 400 kgm^{-3}. Shrinkage in the tangential (3.1±0.3%–3.3±0.3%) and radial surfaces (1.9±0.2%–2.1±0.3%) was also less than the values (9.9–13.2% and 6.6–9.8% respectively) reported by Oteng-Amoako and Obeng (2012). These meet the acceptable values of <5% (for tangential surface) and <3% (for radial direction) for most industrial uses (Davis, 1962; Hernandez, 2007). Upton and Attah (2003) noted that T/R greater than 2.5 is not appropriate for wooden structures. Accordingly, the low T/R (1.58 – 1.63) for *K. gabonensis* would assist it to overcome the numerous problems associated with high T/R of a number of wood species such as *Delbergia melanoxylon* (1.7),

Acer saccharum (2.1) and *D. latifolia* (2.2) (Meier, 2014).

4.4.2 Mechanical properties

Ntalos and Grigoriou (2002) explained that the mechanical properties of wood assist engineers in product design, material selection and efficient usage of timber. Ratanawilai *et al*. (2006) and Tankut (2007) found shear and compressive strengths parallel to the grain and Moduli of Rupture and Elasticity very important for structural purposes and that the overall strength of any timber products depended on the mechanical properties for their wooden members. Therefore, to utilize *K. gabonensis* very effectively, its strength properties should be properly examined.

4.4.2.1 Shear strength parallel to the grain

The shear characteristics of wood are important when the structural rigidity of the bond between its two surfaces is considered (Harris and Pond, 2012). Kémeuzé (2008) and Oteng-Amoako and Obeng (2012) reported shear strength parallel to the grain for *E. cylindricum* and *K. gabonensis* to be 7–18 and 14.5–18.5 Nmm^{-2} respectively. On the contrary, 15.5±1–15.6±1 Nmm^{-2} and 32.2±0.4–33.5±1 Nmm^{-2} were respectively recorded for the current investigation. Wahab *et al*. (2012) and Massayuki (2014) noted that differences in wood density could be responsible for shear strength variation. Thus, *K. gabonensis* (932±31–958±19 kgm^{-3}) would have greater shear strength than *E. cylindricum* (490 ± 13–536 ± 19 kgm^{-3}). According to Shmulsky and Jones (2011), Lima *et al.* (2014) and Massayuki *et al.* (2014), such timbers with great shear strength would be suitable for trusses, columns and beams in bridges and buildings, as well as for the legs and rails of furniture. They further explained that when wood is loaded in bending, the cells attempt to slip past each other and behave like many independent cells. Thus, wood for structural construction must possess great shear strength to resist forces that tend to split its fibres especially along its neutral plane where induced stress changes from compression to tension (Lima *et al.*, 2014; Massayuki *et al.*, 2014). *K. gabonensis* could resist shearing from loads in wooden products due to its great shear strength. It could be similarly employed by the Timber Industry like *E. cylindricum*, *Lophira alata* (shear strength = 14–20 Nmm^{-2}) (Doumenge and Séné, 2012) and *M. excelsa* (shear strength = 5.4 –14.1 Nmm^{-2}) (Ofori, 2007).

4.4.2.2 Compressive strength parallel to the grain

Compression parallel to the grain is a measure of wood resistance to crushing when load is applied at its ends (Meier, 2014). The compressive strength for *K. gabonensis* was greater for both its heartwood and sapwood (90.6±1 Nmm^{-2} and 80.7±1.4 Nmm^{-2} respectively) than that for *E.*

cylindricum (63.6±1.2 Nmm^{-2} and 56.4±4.5 Nmm^{-2} respectively). It was also greater than those for several other timbers such as *P. elata* (63–71 Nmm^{-2}) and *Pterocarpus angolensis* (50– 57 Nmm^{-2}), which are greatly used for bridge and building construction, deck posts, chair and table legs where great compressive strength is required (Unger *et al.*, 2001). Thus, *K. gabonensis* could likewise be suitable for structures where great strength is required. Gunduz *et al.* (2009) observed that variation in density could affect compressive strength parallel to the grain. The authors noted a reduction in compressive strength of *Carpinus betulus* when its density was lowered after heat treatment. Gindl and Teischinger (2002) observed that density accounted for 84% of the differences in the axial compressive strength of Norway spruce, while Unsal and Ayrilmis (2005) made similar observation from *Eucalyptus camaldulensis*. The great compression strength for *K. gabonensis* could be partly attributed to its greater density. Meier (2014) asserted that high density timbers (including *Q. alba* and *Sequoia sempervirens*) are used in structural applications as a result of their great compression strengths (i.e., 51.3 Nmm^{-2} and 39.2 Nmm^{-2} respectively). Compared with *Q. alba, S. sempervirens and E. cylindricum, K. gabonensis* could be appropriately utilized as an alternative raw material for the construction industry.

4.4.2.3 MOR and MOE

Rivers and Umney (2007) reported that MOR (bending or flexural strength) and MOE determine the rigidity of the members of any wooden products. While MOR expresses the greatest load a piece of wood can carry and describes its overall strength before breaking, MOE is a measure of wood stiffness or elastic resistance to deformation (Ozcifci *et al*., 2011; Meier, 2014). For instance, a structure made with wood of great MOR and MOE supports and returns to its original shape when load is removed (Postell, 2012). Green (2007) asserted that *C. ovata* (i.e., hickory, with

MOR and MOE of 138.6 Nmm^{-2} and 15590 Nmm^{-2} respectively) has been extensively used for flooring, cabinetry and furniture because it is stiff, harder to flex and returns to its original shape without breaking when stress is removed. The MOR and MOE of *K. gabonensis* [i.e., 204±4.0–214±4.0 Nmm^{-2}, and 28900±660–29500±820 Nmm^{-2} respectively] compare favourably with those from Oteng-Amoako and Obeng (2012) (167–250 Nmm^{-2} and 15970–21280 Nmm^{-2}) but they are greater than those of some well-known timbers such as *E. cylindricum* (i.e., 66–184 Nmm^{-2} and 8900–13,800 Nmm^{-2} respectively), *C. ovata* (i.e., 138.6 Nmm^{-2} and 15590 Nmm^{-2} respectively) and *Q. alba* (98.6 Nmm^{-2} and 12500 Nmm^{-2} respectively) (Kémeuzé, 2008; Meier, 2014). Haviarova *et al*. (2001) observed that the use of wood with great MOR and MOE for heavy construction ensures its longer resistance against heavy static and dynamic loads. Thus, MOR and MOE of *K. gabonensis* have proven its suitability for both non-building and building structures that demand great strength.

4.5 Summary

The physical and mechanical properties of *Klainedoxa gabonensis*, a Lesser-Utilized-Species and *Entandrophragma cylindricum* were compared in this chapter. *K. gabonensis* contained more moisture with greater density at 12% mc than *E. cylindricum*. Its Tangential-Radial ratio for swelling and shrinkage were 1.31–1.38 and 1.58–1.63, respectively, which are within acceptable thresholds for engineering/structural timbers. The mechanical properties of *K. gabonensis* were shear parallel to grain: 32.2±0.4–33.5±1 Nmm^{-2}; compressive parallel to grain: 80.7±1.4–90.6±1 Nmm^{-2}; MOR: 204±4.0–214±4.0 Nmm^{-2} and MOE: 28932±664–29493±822 Nmm^{-2}. These were superior to those of *E. cylindricum*: 15.5±0.9–15.6±0.6 Nmm^{-2}; 56.4±4.5–63.6±1.2 Nmm^{-2}; 99.4±4.7–121.3±10.6 Nmm^{-2} and 9987.4±207–10051±258 Nmm^{-2}, respectively. These superior properties of *K. gabonensis* compare well with those of several traditional timbers for construction and furniture production. Its utilization would contribute to minimize pressure on the primary timbers in the forests and widen the raw material base for wooden products.

CHAPTER FIVE

BIOLOGICAL PROPERTIES OF *K. GABONENSIS*

5.1 Introduction

Adeniyi *et al*. (2012) mentioned that successful prediction of the utilization potential and processing of timber relies partly on the study of its biological properties (anatomy and durability) since wood is a complex tissue whose structure comprises vessels, tracheids, fibres and parenchyma. The number, size, arrangement and distribution of these cells as well as their chemical composition and deposits influence wood properties and its end-uses (Carlquist, 2001; Adeniyi *et al*., 2012).

Sudo (2007) attributed the differences in wood properties such as density and strength to variations in anatomical properties. Thus, Dinwoodie (2002) observed that thick fibre-walled timbers (e.g., *Acer saccharum* Marsh. and *Robinia seudoacacia* L.) have great densities and strength. These are used for heavy construction (e.g., building, railway sleepers, furniture, joinery and roofing). Thick walled fibres resist more stress (Choong *et al*., 2000). However, those with thin-walled fibres (e.g., *Ochroma pyramidale* (Cav. ex Lam.) Urb. and *Ceiba pentandra* (L.) Gaertn.) are light and weak in strength, which therefore make them only suitable for light construction (e.g., lightweight furniture, boxes, crates and particle boards). Uetimane *et al.* (2009) explained that the anatomical properties of *Sterculia appendiculata* K. Schum. (a tropical timber) make it less dense and only suitably utilized for purposes where great strength and durability are not of prime importance. The timber is diffuse-porous, has very few ($<5/mm^2$) but wider vessels (195- 527 μm); it lacks extractives and has larger percentage of its volume occupied by thin-walled axial and ray parenchyma cells. Timbers with narrow vessels (e.g., *N. papaverifera* (A. Chev.) Capuron and *Diospyros mespiliformis* Hochst ex A. DC.) are most often fine-textured, dimensionally-stable, durable and very stiff, and are important for strong engineering structures and aesthetic construction (Fonti *et al*., 2010; Scholz, 2013). However, their small-sized lumen restricts adhesive penetration which could be disadvantageous in joinery and furniture manufacturing (Choong *et al*., 2000). Deposits in wood cells have also considerable impacts on the glueability, sawing, strength and dimensional stability of the timber (Kurjatko *et al*., 2006). Adeniyi *et al*. (2013) explained that *Xylia dolabriformis* Benth. is used extensively for flooring because its fibres are plugged with gum deposits that make it resistant to wear. Adeniyi *et al*. (2012) noted that the Forestry Research Institute of Nigeria found *Celtis mildbraedii* Engl. and *Bosqueia angolensis Ficalho* unsuitable for making matches because the cells contained deposits that produced an undesirable thick-smelling smoke when burnt. According to Kaiser (2003), wood with calcerous deposits is liable to checking and requires cautious handling during processing. These deposits also blunt tool surfaces and interfere with glueing of laminates and wood finishing (Adeniyi *et al*., 2013).

Arowosoge and Tee (2010) found that the ability of timber to resist bio-deterioration is an important determinant of consumers' choice for wooden products. Resistance of wood to biodegradation can be a natural attribute or induced by treatment with chemicals (Florian 1995; Beckwith 1998; Chang *et al.* 2000; Nascimento *et al*. 2013). Ohmura (2000), Schultz and Nicholas (2000), Antwi-Boasiako and Pitman (2009) and Oliveira *et al*. (2010) found several factors including cell wall thickness, density, extractives and lignin content to be responsible for the natural durability of timber. In wood product manufacturing, naturally-durable timbers (such as *Quercus* spp., *E. cylindricum* (Sprague) Sprague, *M. excelsa* (Welw.) C.C. Berg, *Cedrus libani* A. Rich, *Robinia pseudoacacia* L. and *T. grandis* L.f.) are greatly preferred to non-durable ones that are chemically-treated (Humar *et al*. 2008; Asamoah *et al*. 2011) since chemicalpreservatives could be costly, harmful to life as well as the environment and render wood unable to receive finishes (Florian

1995; International Agency for Research on Cancer 1995; Nakayama *et al*. 2000). In Uganda, durable but Lesser utilized species (e.g. *Podocarpous latifolius* R.Br. ex Mirb., *Funtumia elastica* (P. Preuss) Stapf. and *Trichilia dregeana* E. Mey. Ex Harv. & Sond.) are progressively used to substitute the traditional timbers (e.g., *Milicia* spp. and *Khaya* spp.) in the furniture industry (Zziwa *et al*. 2006). For building and furniture-making, Ali (2011) recommended the under-exploited tropical timbers such as *Acacia nigrescens* Oliv., *Pericopsis angolensis* (Baker) Meeuwen and *Pseudolachnostylis maprounaefolia* Pax based on their relative abundance, expected biomass per tree and other properties including durability. Opoku (2007) noted that effective substitution could be properly achieved when adequate information on the properties of the LUS including anatomy and durability are available. However, these properties of *K. gabonensis* are poorly understood.

This chapter reports on the durability and anatomy (tissue proportion, and fibre and vessel morphology) of *K. gabonensis* as a potential substitute to the declining primary timbers from the tropical forests. This would increase its prospects of utilization, which would contribute to the widening of the raw material base for the Timber Industry.

5.2 Materials and methods

5.2.1 Sampling of wood material

Wood samples for anatomical studies were obtained from defect-free heartwood (within 8–15 cm from the pith) and sapwood (within 40–50 cm from the pith) positions of bolts (1m long) obtained from processing *K. gabonensis* and *E. cylindricum* (control) logs. Forty eight heartwood and sapwood samples each were also randomly taken from the bolts and their field performance (durability) tested against termites.

5.2.2 Determination of anatomical characteristics

5.2.2.1 Study of the anatomical features of *K. gabonensis*

K. gabonensis wood blocks (about 2 cm^3) were softened by boiling to remove excess air and immersed in distilled water (Chowdhury *et al*., 2012; Wan-Mohd-Nazri *et al.*, 2012). Transverse, radial and tangential sections (20-30μm thick) were sliced with a microtome knife, stained with Safranin red on a slide and sequentially washed in ethanol with increasing concentrations of 50, 95 and 100% until any excess stains were removed (Wan-Mohd-Nazri *et al.*, 2012). They were mounted in Canada balsam and oven-dried. The sections were examined under Fisher Scientific Micromaster Infinity Optics microscope [magnification = 10x (eye piece), 4x (objective lens)] at the Anatomy Department of Forestry Research Institute of the Council for Scientific and Industrial Research (CSIR), Ghana. Images were captured randomly at 5 different locations on each slide with Image J software at a scale of 200 microns. Guidelines approved by the International Association of Wood Anatomists (IAWA) (1989) were employed in describing the anatomical features of the timbers.

5.2.2.1.1 Determination of tissue proportions

A 25-point scale grid with an area of 90000μm^2 per point was laid on each image (resolution = 2048 x 1536 pixels) using the image J software. The number of points covering the tissues (fibres, vessels, ray and axial parenchyma) was counted and expressed as a percentage of the total points (i.e., 25). This represented the proportion (%) of each tissue in the wood (IAWA, 1989).

5.2.2.2 Determination of fibre and vessel morphological characteristics through maceration

Match-stick sized samples (heartwood and sapwood) (about 10mm long) were put in a heat resistant test tube and equal parts of 99.8% glacial acetic acid and 30% hydrogen peroxide (1:1) added to cover them and incubated at 65ºC for maceration (IAWA, 1989, Wan-Mohd-Nazri *et al.*, 2012). The macerates were thoroughly washed with distilled water, while small sample was put in glycerol on a standard slide (i.e., 7.5 x 2.5 cm), teased with a pin (IAWA, 1989) and covered with slips for viewing under Fisher Scientific Micromaster Infinity Optics microscope using 10x for eye piece and objective lens and measuring scale of 200µm. Photomicrographs of straight and unbroken fibres were captured under magnification and measuring scales of 40x and 50µm respectively. The processes were repeated to obtain micrographs of fibres and vessels whose diameter, lumen width or diameter and double wall thickness could easily be measured with the Image J software. A total of 300 fibres and vessels each were measured for each timber.

5.2.3 Determination of durability

Forty eight *E. cylindricum* and *K. gabonensis* stakes (500 x 50 x 25 mm) (BS EN 252, 2014) were conditioned at 20°C and 65% RH until equilibrium moisture content was reached (Forest Products Laboratory 1999). *Ceiba pentandra* (L.) Gaertn. served as the control. Each stake was weighed. The moisture content (mc) of 10 other stakes from *C. pentandra* and each stem position of *K. gabonensis* and *E. cylindricum* was measured at 103 ± 2 °C to determine their corrected oven-dry weights (Antwi-Boasiako and Pitman, 2009) (Equation 5.1):

$$Corrected\ Oven\ Dry\ Weight\ (CODW) = \frac{100 \times Fresh\ weight\ of\ sample}{100 + Moisture\ content\ of\ sample} \quad \textit{Equation 5.1}$$

The replicates from each timber were randomly inserted into the soil to cover one third of their lengths at the test site (50 x 60 m^2) of the Demonstration Farm of the Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology (Kumasi-Ghana) (Plate 5.1). The stakes were 50 cm apart. The site lies within the Semi-deciduous vegetation zone [6° 40'N and 1° 33'W] with moderate temperature (25 °C), high RH of 83% and dominated by

Ochrosol soil (Kumasi Metropolitan Assembly 2006). The site contains many termite mounds (Plate 5.1) with high decay hazard index. Common insects at the test field include subterranean termites, *Anobium spp.*, *Ancistrotermes* spp. and *Nasutitermes latifrons* (Usher, 1975). The stakes were exposed to termites for 24 months.

5.2.3.1 Visual durability ratings

The stakes were inspected every month and also after field exposure for termite and other damages. Stakes were graded as: 0 = No sign of attack, 1 = Slight attack, 2 = Moderate attack, 3 = Severe attack, 4 = Failure (BS EN 252, 2014).

5.2.3.2 Mass loss (%)

All debris were cautiously brushed off from the stakes, which were oven-dried at 103 ± 2 °C and their final weights determined. The mass loss (%) for each stake was calculated (BS EN 252, 2014) (Equation 5.2):

$$Mass\ loss\ (\%) = \frac{CODW - Final\ Weight}{CODW} \times 100 \qquad \textit{Equation 5.2}$$

Mass loss (%) was related to natural durability ratings: 0 – 5% = very durable, 6 – 10% = durable, 11 – 40% = moderately durable, 41 – 100% = non-durable (BS EN 252, 2014).

Plate 5.1: Stakes inserted vertically at the test site (a); a termitarium located 2m from the test site (b).

5.2.4 Experimental Design and Data Analysis

The data on tissue proportion, fibre and vessel morphological characteristics (length, diameter, wall thickness, lumen width) and durability were subjected to ANOVA and Fisher's Least Significant Difference (LSD) Test (at 95% confidence level) to compare their means.

5.3 Results

5.3.1 Anatomical Characteristics

5.3.1.1 Anatomical description of *K. gabonensis* sapwood and heartwood

K. gabonensis growth ring boundaries indistinct or absent. Wood diffuse-porous. Vessels in tangential bands, cluster with simple perforation plates and sclerotic tyloses (Plate 5.2). Fibres have simple to minutely bordered pits, nonseptate and very thick-walled. Axial parenchyma winged-aliform, confluent, in narrow bands or lines up to three cells wide with over 8 cells per parenchyma strand (Plates 5.2 and 5.3). Ray width 1-3 cells, larger and commonly 4- to 10seriate, procumbent with 1-row of upright and/or square marginal cells (Plates 5.3 and 5.4).

Prismatic crystals in chambered axial parenchyma cells common (Plate 5.3).

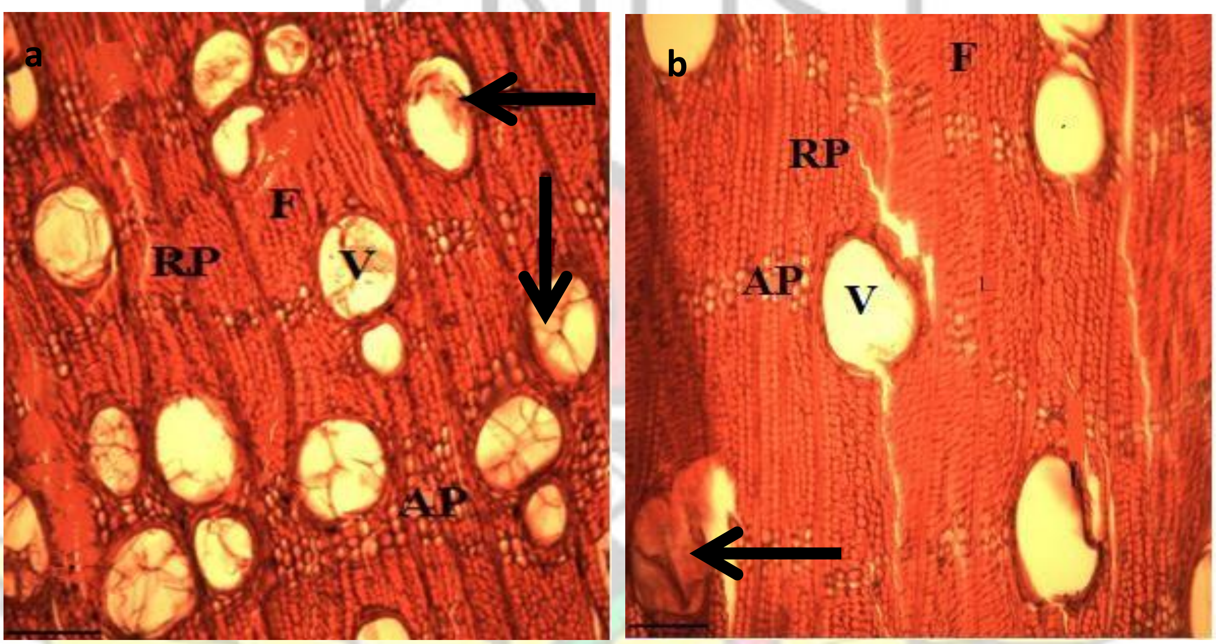

Plate 5.2: Transverse section of *K. gabonensis* heartwood (a), sapwood (b) with vessels (V), fibres (F), ray parenchyma (RP), aliform axial parenchyma (AP) and tyloses (arrowed). Scale bar = 200µm

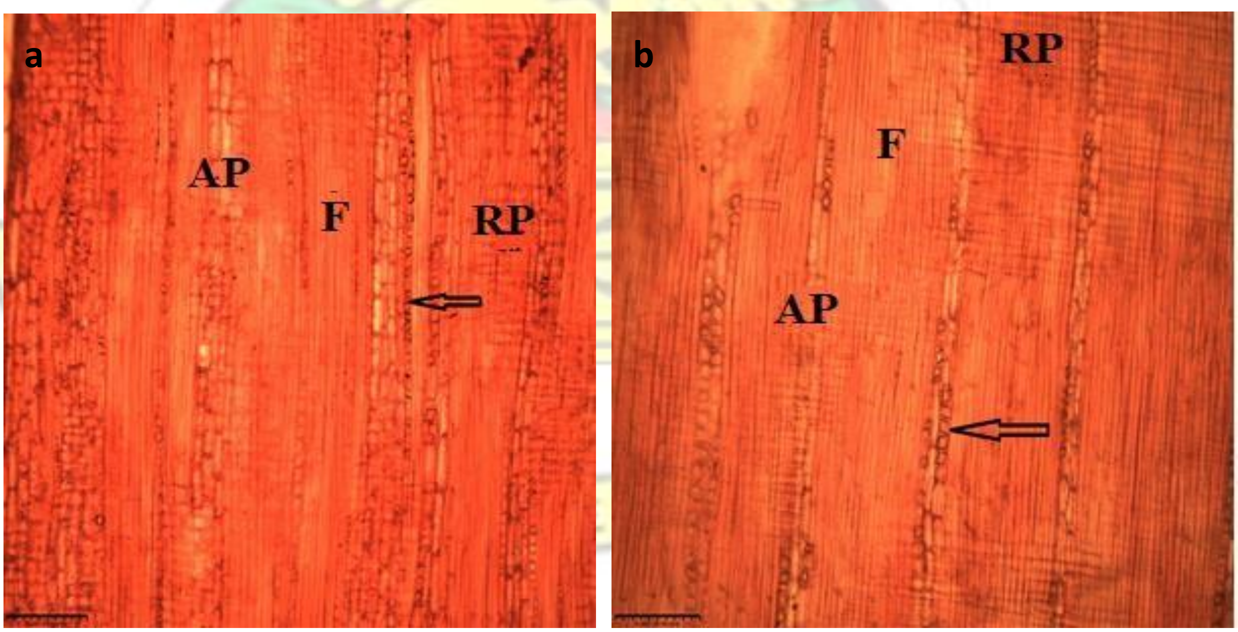

Plate 5.3: Radial section of *K. gabonensis* heartwood (a), sapwood (b) with fibres (F), procumbent ray parenchyma (RP), aliform axial parenchyma (AP) and prismatic crystals (arrowed) in chambered axial parenchyma. Scale bar = 200µm

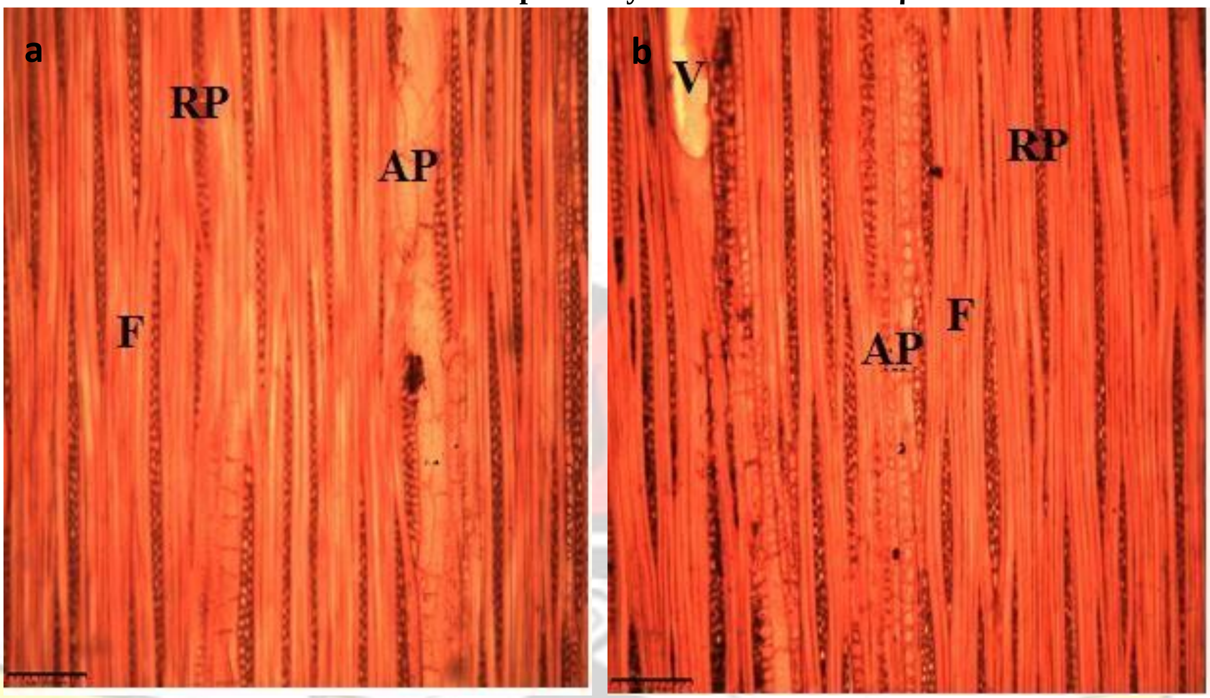

Plate 5.4: Tangential section of *K. gabonensis* heartwood (a), sapwood (b) with 4- to 10-seriate procumbent ray parenchyma (RP), aliform axial parenchyma (AP) and fibres (F). Scale bar = 200µm

5.3.1.2 Fibre and vessel morphology

5.3.1.2.1 Fibre characteristics

Fibre dimensions observed for *K. gabonensis* sapwood and heartwood were respectively: 20.1±0.2 µm and 22.7±0.2 µm (diameter), 1860±20 µm and 1890±10 µm (length), 11.5±0.2 µm and 13.7±0.2 µm (lumen width) and, 8.9±0.3 µm and 9.7±0.3 µm (double wall thickness). Those for *E. cylindricum* sapwood and heartwood were respectively: 19.6±0.4 µm and 19.7±0.3 µm (diameter), 1590±10 µm and 1540±10 µm (length), 10±0.2 µm and 10.7±0.2 µm (lumen width) and, 8.6±0.2 µm and 9.0±0.2 µm (double wall thickness). Fibre dimensions were greater for *K. gabonensis* than *E. cylindricum* and for the heartwood than sapwood for both species except the length and lumen width for the stem positions of *E. cylindricum* (Figs. 5.1 and 5.2). Significant differences ($p<0.05$) existed between the heartwood and sapwood of *K. gabonensis* for fibre diameter and lumen width (Fig. 5.1; Appendix E).

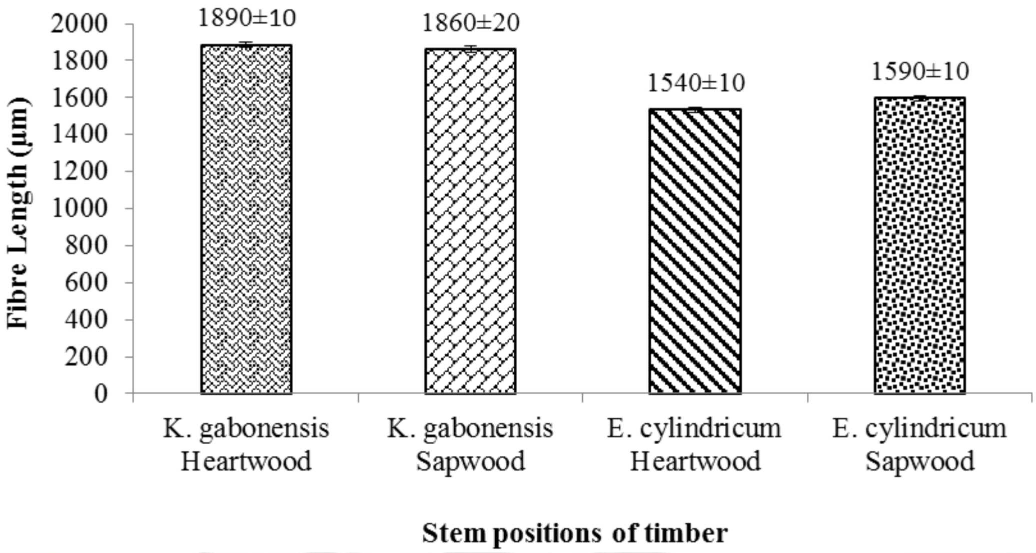

Fig. 5.1: Fibre length across the stems of *K. gabonensis* and *E. cylindricum* (Bars=Standard Errors)

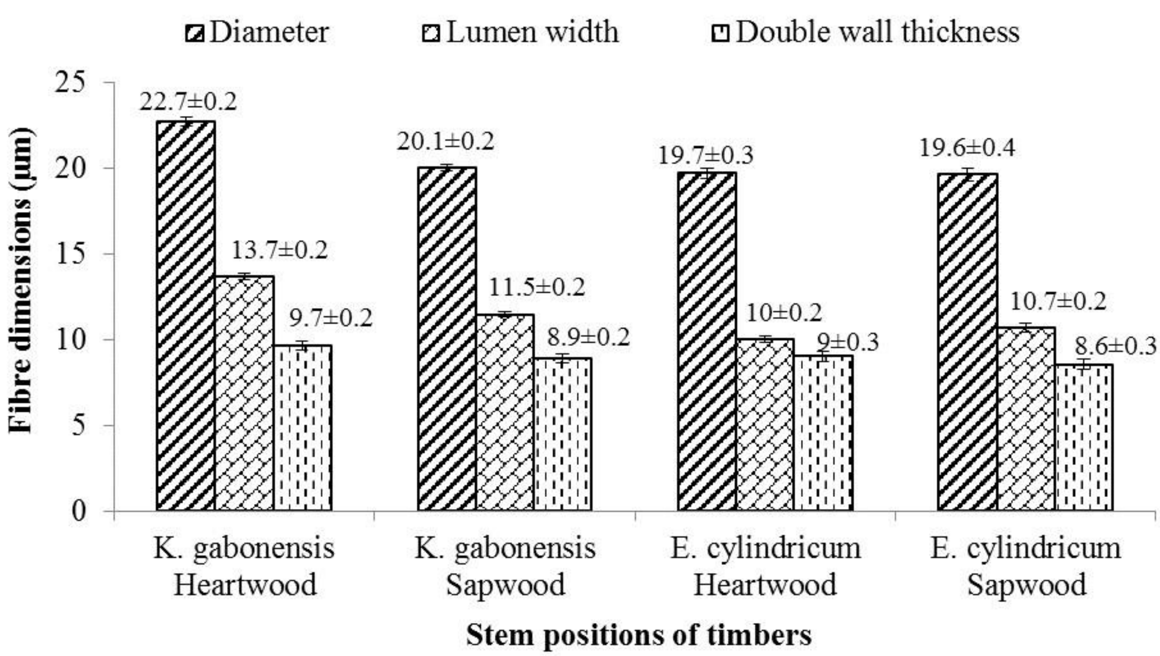

Fig. 5.2: Fibre dimensions across the stems of *K. gabonensis* and *E. cylindricum* (Bars=Standard Errors)

5.3.1.2.2 Vessel lumen diameter

Vessel lumen diameter ranked for the two timbers as: *E. cylindricum* sapwood (184.4±2 μm) > *K. gabonensis* sapwood (176.9±4 μm) > *K. gabonensis* heartwood (144.8±2.2 μm) > *E. cylindricum* heartwood (115.6±1.4 μm) (Fig. 5.3).

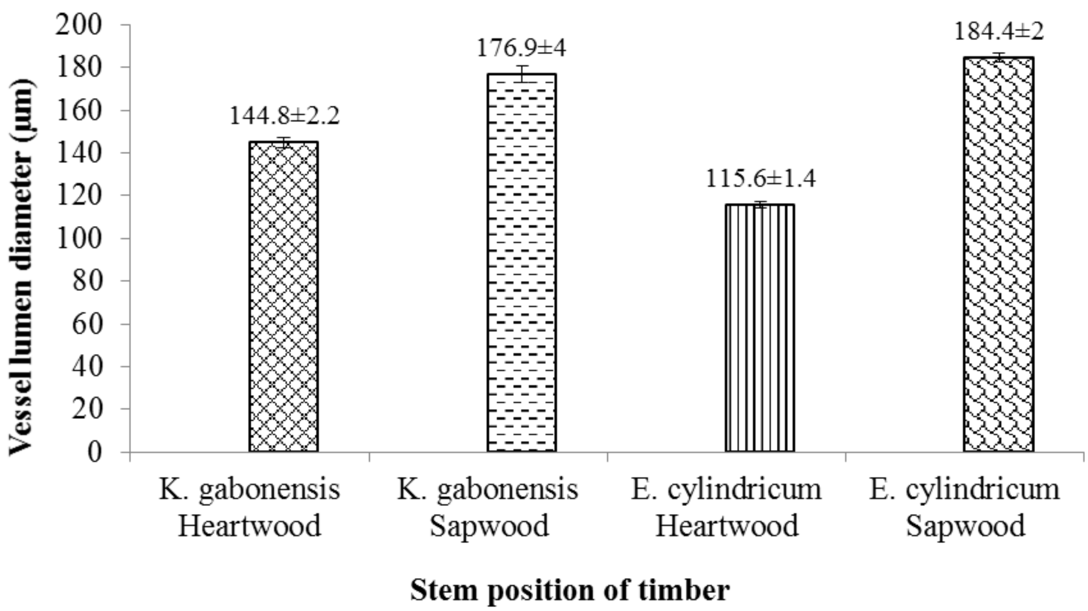

Fig. 5.3: Vessel lumen diameter across the stems of *K. gabonensis* and *E. cylindricum* (Bars = Standard Errors)

5.3.1.3 Tissue proportions

Tissue proportions recorded for *K. gabonensis* generally ranked as: fibres (42.4±4.5% - 45.6±4.5%) > ray parenchyma (20.8±2.2% - 26.4±2.1%) > axial parenchyma (15.2±2.3% - 18.4±1%) > vessels (12.8±1.5% - 15.1±2.7%). A similar trend was observed for *E. cylindricum*: fibres (35.2±1.5% - 52±4.7%) > ray parenchyma (19.2±2% - 24±3%) > axial parenchyma (15.2±2.3% - 24±3.4%) > vessels (13.6±2.4% - 16±2.2%) (Fig. 5.4). For *K. gabonensis*, more fibres and vessels were obtained in the heartwood (45.6±4.5% and 15.1±2.7% respectively) than its sapwood (42.4±4.5%

and 12.8±1.5% respectively). However, its rays and axial parenchyma were greater in the sapwood (26.4±2.1% and 18.4±1% respectively) than in the heartwood (20.8±2.2% and 15.2±2.3% respectively). Similar observations were made for *E. cylindricum* except for vessels which were greater in its sapwood (16±2.2%) than for the heartwood (13.6±2.4%). Significant differences ($p<0.05$) existed between the heartwood and sapwood of *K. gabonensis* for proportions of their ray parenchyma and vessels, and also fibres and axial parenchyma for *E. cylindricum* (Fig. 5.4; Appendix F). Generally, fibres and ray parenchyma were greater in *K. gabonensis* (42.4±4.5% - 45.6±4.5% and 20.8±2.2% - 26.4±2.1% respectively) than *E. cylindricum* (35.2±1.5% - 45.2±4.7% and 19.2±2% - 24±3% respectively), while vessels and axial parenchyma were greater in *E. cylindricum* (13.6±2.4% - 16±2.2% and 15.2±2.3% - 24±3.4% respectively) than *K. gabonensis* (12.8±1.5% - 15.1±2.7% and 15.2±2.3% - 18.4±1% respectively).

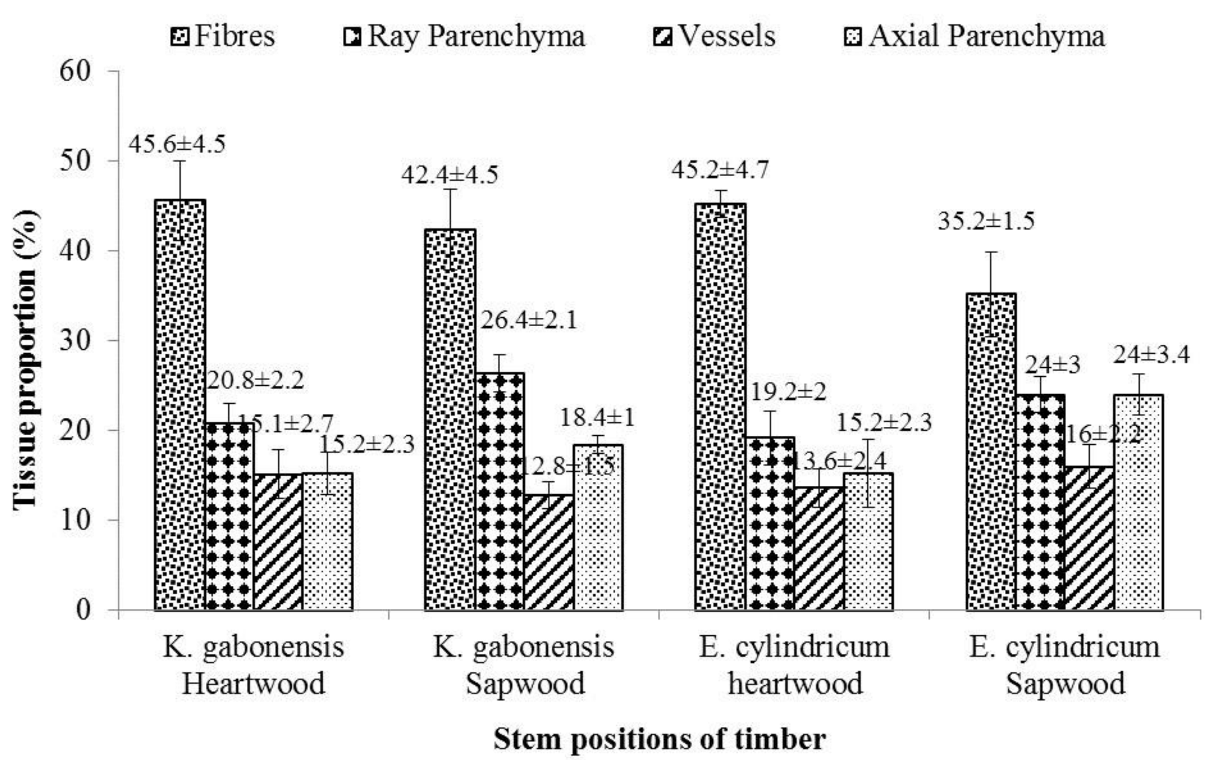

Fig. 5.4: Tissue proportion across the stems of *K. gabonensis* and *E. cylindricum* (Bars = Standard Errors)

5.3.2 Durability

5.3.2.1 Visual durability rating

The heartwood and sapwood of *K. gabonensis* were slightly deteriorated with visual durability rating of 1 (Table 5.1; Plate 5.5). *E. cylindricum* heartwood suffered moderate attack (rating = 2), while its sapwood was severely attacked (rating = 3) (Plate 5.5) and *C. pentandra* was heavily degraded (rating = 4). The differences between the ratings for the timber species were significant (p<0.05) (Table 5.1).

Table 5.1: Visual durability ratings for *K. gabonensis*, *E. cylindricum* and *C. pentandra* (Control)

Wood species	Stem position	Visual durability rating*	Interpretation
K. gabonensis	Heartwood	1^{a}	Slight attack
	Sapwood	1_{a}	Slight attack
E. cylindricum	Heartwood	2^{b}	Moderate attack
	Sapwood	3_{c}	Severe attack
C. pentandra	Sapwood	4_{d}	Failure

*Ratings with the same letters are not significantly different (p<0.05).

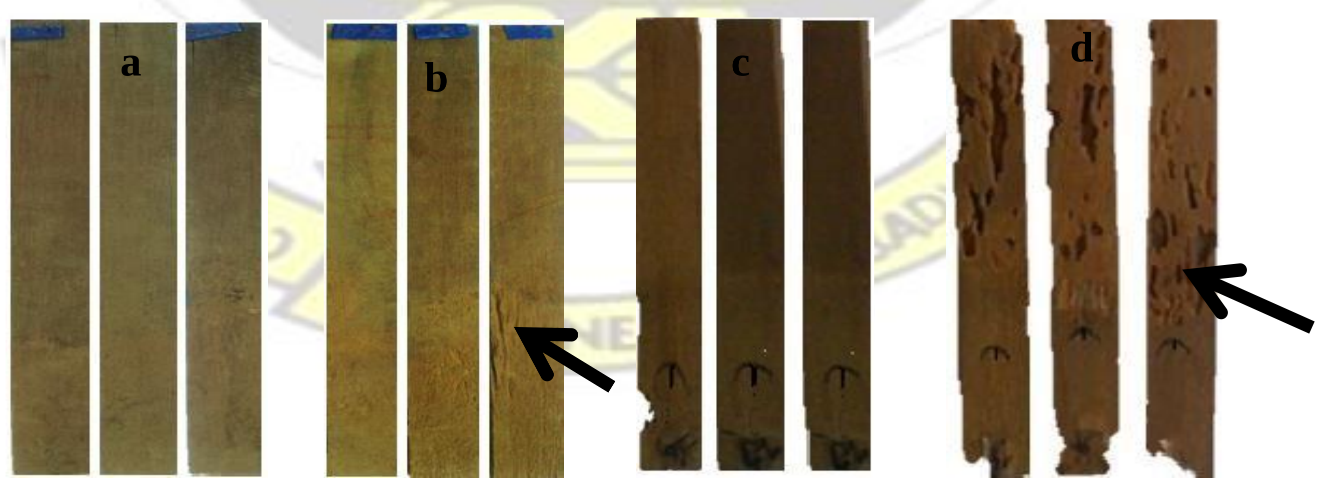

Plate 5.5: ***K. gabonensis*** **heartwood (a), sapwood (b),** ***E. cylindricum*** **heartwood (c) and sapwood (d) after field exposure (Arrow = Termite attack). NB: C. pentandra stakes were completely destroyed.**

5.3.2.2 Mass loss (%)

Mean mass losses for the respective stem positions of the timbers were in this order: *C. pentandra* (100%; i.e., non-durable) > *E. cylindricum* sapwood (13.1±0.6%; moderately durable) > *E. cylindricum* heartwood (10±0.7%; durable) > *K. gabonensis* sapwood (8.2±0.6%; durable) > *K. gabonensis* heartwood (4.8±0.3%; very durable). The differences between them were significant ($p < 0.05$) (Fig. 5.5; Tables 5.2 and 5.3).

Table 5.2: ANOVA for mass loss for *K. gabonensis*, *E. cylindricum* and *C. pentandra*

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	**11**	**33206.6**	**3018.9**	**6491**	**<.0001**
Replicates	2	0.1	0.1	0.2	0.97
Species	2	33169.4	16584.7	12656.5	<.0001#
Stem position	1	21.2	21.2	45.7	0.0005*
Replicates*Species	4	5.2	1.3	2.8	0.1
Species*stem position	2	10.7	5.3	11.5	0.0089
Error	**6**	**2.8**	**0.5 Corrected**		
Total	**17**	**33209.4**			

R-Square	Coeff Var	Root MSE	Mass loss Mean
0.999916	**1.732540**	**0.681961**	**39.36192**

#Significant: p(<.0001)<0.05; *Significant: p(0.0005)<0.05.

Table 5.3: LSD for mass loss for *K. gabonensis*, *E. cylindricum* and *C. pentandra*

Wood species	Stem position	Least Significant mean	Interpretation
K. gabonensis	Heartwood	4.8^{a}	Very durable
	Sapwood	8.2b	Durable

E. cylindricum	Heartwood	10[c]	Durable
	Sapwood	13.1[d]	Moderately durable
C. pentandra	Sapwood	100[e]	Non-durable

Means with the same superscripts are not significantly different ($p<0.05$).

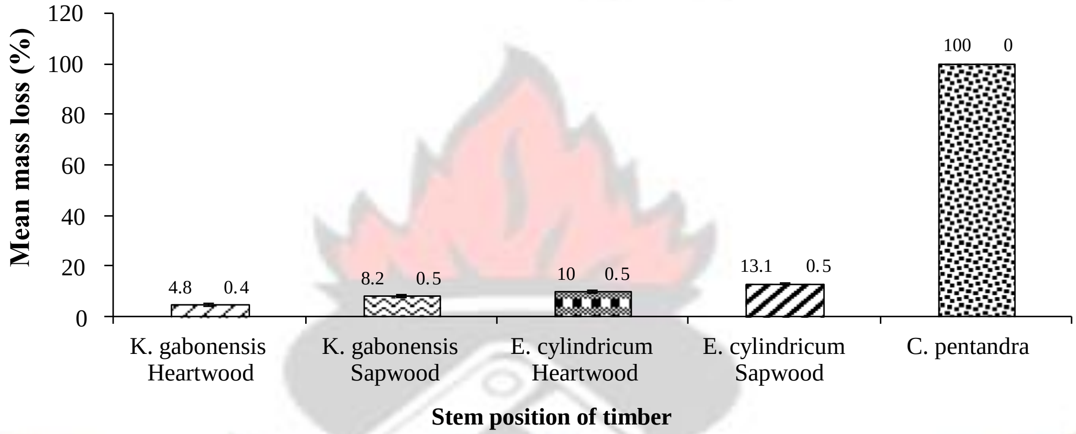

Fig. 5.5: Durability (mass loss) across the stems of *K. gabonensis*, *E. cylindricum* and *C. pentandra* (Bars=Standard Errors)

5.4 Discussion

5.4.1 Anatomical characteristics

Wood is a natural product of tree growth with a complex formation process that involves differentiation of cambial initials into several xylem tissues (Moutinho *et al*., 2012). Variation in the arrangement, dimension and proportions of these tissues are fundamental to the properties of wood, processing and uses (Wheeler and Manchester, 2007). Since the mid-1960's, several researches have been carried out on the anatomy of tropical timbers that are lesser-utilized to the extent that the results have greatly influenced their processing and utilization (Sudo, 2007). LUS such as *Arpinus betulus* L., *Fagus orientalis* (Lipsky), *Parrotia persica* (DC.) C. A. Mey., *Diospyrus lotus* L., *Alnus glutinosa* (L.) Gaertn., *Acer insigne* var. velutinum (Boiss.), *A. leatum* C. A. Mey. and *Fraxinus excelsior* L. gained popularity in the global wood industry for structural construction as well as pulp and paper production following successful experiments that established their properties including anatomy (Kiaei and Samariha, 2011). Essien *et al.* (2012) determined the tissue proportions and fibre morphology of two tropical LUS (*Ficus sur* Forssk. and *Cola gigantean* A. Chew.). Based on their mean fibre length (1.5 - 2.0mm), lumen diameter (14.8 - 23.9µm) and double wall thickness (9.9 - 7.5µm), they concluded that *F. sur* and *C. gigantean* were suitable for pulp and paper production. Adeniyi *et al*. (2013) also observed that *Xylia dolabriformis* Benth. was an excellent raw material for flooring because the fibres were plugged by gum which made the wood resistant to wear. Oyagade (1994) studied the anatomy of *Gmelina arborea* Roxb. and found it unsuitable for wood-cement board manufacture due to the presence of tyloses. *Holoptelea grandis* (Hutch.) Mildbr. was found easy to saw due to the absence of rhomboidal crystals which are capable of blunting saws (Alex and Regis, 2005). Thus, an understanding of the anatomy of LUS is required for efficient processing of timber and development of wood-based products.

5.4.1.1 Anatomical description of *K. gabonensis* wood

K. gabonensis is diffuse-porous with no growth ring boundaries. It has thick-walled fibres, simple pits, prismatic crystals and sclerotic tyloses common in axial parenchyma cells and vessels respectively. Anatomical description of wood belonging to its family (i.e., *Irvingiacaea*) is scanty except the attempt by Oteng-Amoako and Obeng (2012) about *K. gabonensis* as diffuse-porous. Coulson (2011) explained that most diffuse-porous tropical timbers often have indistinct or no growth ring boundaries. The even-sized pores are scattered throughout the wood since timber growth does not occur in discrete annual or seasonal pattern. This provides timber with straight grains and uniform texture (Sperry *et al.*, 1994). *K. gabonensis* is straight-grained and uniformly-textured. Sperry *et al.* (1994) and Hoadley (2000) noted that straight grains and uniform texture improve the workability of timbers. For instance, *Dalbergia melanoxylon* Guill. & Perr. was the most preferred timber among wood carvers in Kenya because it performed better during planing, polishing and varnishing due to its uniform wood texture and straight grains (Muga *et al.*, 1998). Based on its grain direction and wood texture, *K. gabonensis* would have good working characteristics. Its thick-walled fibres would give it superior mechanical properties and make it suitable for heavy construction, railway sleepers, mine props, flooring, paneling and furniture production (Lumbile and Oagile, 2008; Uetimane *et al*., 2009). Simple pits of the fibres would also ensure efficient adhesive penetration, which would increase the bond strength in composite product manufactured from *K. gabonensis* (Pizzi and Mittal, 2011).

The sclerotic tyloses and prismatic crystals in *K. gabonensis* would affect its sawing, turning and boring characteristics as well as reduce the bondability of its members with adhesive in joinery and laminated product manufacturing (Oluyege, 2007). According to Oluyege (2007) and Quartey (2009), crystals stain and reduce the aesthetic value of unspecified timber species and affect its pulping characteristics, permeability to preservatives, fire retardants and finishes. Collardet (1976) also found that crystals and resins in some Malaysian timbers (e.g., *Hopea odorata* Roxb., *Dryobalanops camphora* Colebr. and *Dryobalanops oblongifolia* Dyer) clogged up saw teeth and abrasive papers. However, for easy machining of *K. gabonensis* to produce high quality timber surface, improve finishing and adhesive bonding, tungsten-carbide or polycrystaline diamond tipped tools and extensive sanding would be required (Killmann and Fink, 1996). Pressure methods would be necessary for chemical impregnation. Taylor *et al.* (2002) and Antwi-Boasiako (2004) observed that tyloses and crystals could increase wood durability by restricting pathogen movement and making browsing difficult. Tyloses in *Ulmus Americana* L. make it resistant to the Dutch Elm disease (Dickson, 2000). Scholz *et al*. (2007) mentioned that phenolic extractives and other organic deposits are reasons for the great natural durability of *Brosimum guianense* (Aubl.) Huber ex Ducke., a diffuse porous tropical timber

(Richter and Dallwitz, 2009). Therefore, it is worthy to note that although tyloses and crystals in *K. gabonensis* would pose challenges to its processing, in addition to the thick-walled fibres, they would contribute to improving its durability for engineering construction.

5.4.1.2 Fibre and vessel morphology

5.4.1.2.1 Fibre characteristics

Fibres are produced from cambial fusiform initials; these determine characteristics such as fibre length, thickness and diameter (Izekor and Fuwape, 2011). According to Ziemińska *et al.* (2013), these characteristics give an indication of end-use of timbers. Muga *et al.* (1992) and AntwiBoasiako and Ayimasu (2012) found that fibre length is a major indicator of the quality of wood for pulping. Long fibres optimize strength and formation of paper; these fibres have the capacity to create bigger and stronger network than their shorter counterparts. Fibre length observed for

K. gabonensis (1860±20 - 1890±10 µm) compares with those of *Irvingia malayana* Oliv. ex Benn (>1600 µm) and other timbers, which are usually used for pulp and paper production.

These include *Grevillea robusta* A. Cunn. (1890 µm), *Buclandia poplunea* R. Br. ex Griff. (1840 µm) and *C. pentandra* (L.) Gaertn. (1830 µm) (Muga *et al.*, 1992). Thus, based on fibre length, *K. gabonensis* would be suitable for pulping. However, the presence of crystals and tyloses would obstruct the flow of pulping liquor and consequently make pulping very difficult and costly (Kollmann and *Côté*, 2012). Other fibre morphological characteristics such as diameter, cell-wall thickness and lumen width greatly affect wood density, durability, sorption characteristics and strength (Wimmer, 1995, Ziemin´ska *et al.*, 2013). Fibre diameter and wall thickness were greater for *K. gabonensis* [20.1±0.2 µm (sapwood) - 22.7±0.2 µm (heartwood) and 8.9±0.3 µm (sapwood) - 9.7±0.3 µm (heartwood) respectively] than *E. cylindricum*

[19.6±0.4 µm (sapwood) - 19.7±0.3 µm (heartwood) and 8.6±0.2 µm (sapwood) - 9.0±0.2 µm (heartwood) respectively]. Izekor and Fuwape (2011) explained that such a variation could be due to the intrinsic physiological and genetic differences between the timbers. Wood with thinner and wider fibres (including *Populus deltoids* Marsh., *Tilia Americana* L., *C. pentandra* (L.) Gaertn. and *Ochroma pyramidale* (Cav. ex Lam.) Urban) has low density and strength; it also ruptures more easily when load is applied (Bosman *et al.,* 1994; Jacobsen *et al.* 2007; MartínezCabrera *et al.,* 2009). They are mostly used for light frame construction (Wiedenhoeft and Miller, 2005). Those with thick-walled fibres (e.g. *E. cylindricum, A. saccharum* Marsh.*, A. nigrum* Michx. f., *Robinia pseudoacacia* L., *Tabebuia serratifolia* (Vahl) G. Nicholson. and *Manilkara bidentata* (A.de Candolle) Chevalier) have great strength and are normally recommended for structural works such as building, furniture production and bridge construction (Wiedenhoeft and Miller, 2005; Martínez-Cabrera *et al.,* 2009). The greater diameter and wall thickness for *K. gabonensis* would likely make the timber heavier and tougher than *E. cylindricum* (Ziemińska *et al.*, 2013). Thus, it would be similarly suitable for structural applications. Fibre dimensions were also greater for the heartwoods of the two timbers than their sapwoods. These variations are consistent with the differences in fibre morphology from the pith towards the bark of *C. equisetifolia* J.R. & G. Forst. by Chowdhury *et al.* (2012). The heartwoods of the two timbers would be more dense and stronger than their sapwoods due to the great wall thickness and diameter of the heartwoods. However, the thick walls and narrow pit openings between fibres of *K. gabonensis* could restrict adhesive penetration and create poor bonding and weak joinery and composite products (Malanit *et al.*, 2009). However, pressure treatments for chemical and adhesive applications would overcome these challenges.

5.4.1.2.2 Vessel lumen diameter

Tangential diameters of the vessel lumina for *K. gabonensis* (144.8±2.2 - 176.9±4 µm) were far less than that (≥ 200 µm) obtained by Oteng-Amoako and Obeng (2012). Those recorded for *E. cylindricum* (115.6±1.4 - 184.4±2 µm) also compare well with those (100 – 200 µm) reported by Kémeuzé (2008). Hemsley and Poole (2004) explained that most diffuse-porous tropical timbers have narrow vessels (<200 µm). Thus, the values recorded for *K. gabonensis* and *E. cylindricum* are consistent with this finding for diffuse-porous woods. The size of vessel lumina influences the water conduction efficiency of timber (Zimmermann, 1982; Antwi-Boasiako, 2004; AntwiBoasiako and Atta-Obeng, 2009). Quartey (2009) concluded that *Albizia ferruginea* (Guill. & Perr.) Benth. had great capacity for water uptake due to its great vessel lumen diameter (310 µm). Savidge (2003) explained that wider vessels reduce wood density and make timber unsuitable for production of paper and solid-wood products. However, their narrower counterparts improve resistance to embolism where gases fill the conduits and leads to cavitation. Thus, the narrow vessels of *K. gabonensis* could improve its density, reduce excessive moisture absorption and vessel cavitation (Hacke *et al.*, 2001; 2006). However, its permeability to chemicals could be challenging (Poorter *et al*., 2010). Opoku (2007) recommended pressure methods of chemical application for timbers with narrow pores due to difficulty in penetration. Wider pores were also obtained for the sapwoods than heartwoods of the timbers.

Gimenez and Lopez (2000) and Rao *et al*. (2003) explained that vessel diameter in most timber species increases from the pith to the bark. Saravanan *et al*. (2013) observed an increase in vessel lumen diameter from the pith to the periphery of *Melia dubia* Cav., a diffuse porous tropical tree and concluded that water absorption and conduction increase with vessel lumen diameter. Thus, the sapwoods of *K. gabonensis* as well as *E. cylindricum* could contain more water and would be more permeable to chemicals than their heartwoods. Greater potential for moisture absorption would create processing challenges and affect glueability and strength of joints (Kumaran, 1999; Rowell, 2005).

5.4.1.3 Tissue proportions

Rahman *et al*. (2005) and Walker (2006) reported that ray parenchyma often forms about 15 - 30% of hardwood tissues. In consistence, the proportion of ray parenchyma cells obtained for *E. cylindricum* and *K. gabonensis* ranged between 19.2±2% (heartwood) – 24±3% (sapwood) and 20.8±2.2% (heartwood) – 26.4±2.1% (sapwood) respectively. Boyce *et al*. (1970), Beery *et al*. (1983), Mattheck and Kubler (1997) and Rahman *et al*. (2005) noted that ray proportion was positively correlated with the density and compression strength of most hardwoods. *K. gabonensis* has greater ray proportion [20.8±2.2% (heartwood); 26.4±2.1% (sapwood)] than *E. cylindricum* [20.8±2.2% (heartwood); 26.4±2.1% (sapwood)]; the former would have greater density and radial compression strength, which are important for timbers for construction. Generally parenchyma was greater in the sapwood than heartwood of the two timbers. AntwiBoasiako (2004), Adeniyi *et al.* (2012) explained that large amount of carbohydrate could lead to early growth of anaerobic bacteria, which produce compounds that make wood highly degradable and unworkable. Thus, products from the sapwoods of *K. gabonensis* and *E. cylindricum* could have limited service-life through bio-deterioration by the activities of wooddestroying organisms.

For both stem positions of the two timbers, fibres formed the greatest of wood tissues, while the least were vessels. However, *K. gabonensis* has more of these tissues than *E. cylindricum*. Walker (2006) explained that fibres make up a high proportion of the volume of most hardwoods. Chowdhury *et al*. (2012) observed in a study on the variation in anatomical properties of *C. equisetifolia* that, fibres formed the greatest proportion of tissues (54%) followed by rays (19%), vessels (14%) and then axial parenchyma (13%). Similar trend was found in the wood of 24 Australian angiosperms by Ziemińska *et al.* (2013). Woodcock *et al*. (2000), Huda *et al.* (2012), Ogunwusi (2012b) and Ziemińska *et al.* (2013) noted that timbers with great amount of fibres and fewer quantities of vessels and parenchyma were more dense with greater mechanical properties than those with few fibres and great amount of vessels and parenchyma. According to Uetimane *et al.* (2009), MOR of the sapwood of *Pseudolachnostylis maprounaefolia* Pax was greatly associated with fibre proportion but negatively correlated with proportion of parenchyma tissue and that greater proportion of vessels generally affects wood density and strength. Sreevani and Rao (2014) also explained that the least amount of vessels and parenchyma cells compared to fibres improve timber durability and shrinkage characteristics. Thus, based on the proportion of fibres, vessels and parenchyma tissues, *K. gabonensis* would be expected to be more dense, stronger and durable than *E. cylindricum* and could likely substitute *E. cylindricum* for structural works, which need timbers of greater strength and longer service-life.

Cox (2004) and Uetimane *et al*. (2009) explained that an understanding of the anatomy of wood is required for efficient processing and development of wood-based products. So far, the anatomy of *K. gabonensis*, including tissue proportion and the morphology of its fibres and vessels, has found it suitable for furniture production and heavy engineering construction. However, due to its thick-walled fibres and the presence of tyloses and crystals, power tools are recommended for its processing. In laminated product manufacturing, pressure method would be the best for the application of adhesives and finishes. It is anticipated the information would assist wood product manufacturers towards the processing and utilization of *K. gabonensis*.

Incorporation of *K. gabonensis* into the timber sector's stream of raw materials would increase the wood supply base and help meet growing demand for timber products.

5.4.2 Durability

Although wood is a desirable material for building and furniture production (Pakarinen, 1999), as a natural polymer, it is prone to bio-degradation by bacteria, fungi and insects (Khatib, 2009). Termites, carpenter bees, ants and powder-post beetles are the major insect pests to wooden structures (Abood, 2008). These organisms decompose the cellulose in wood for biochemical energy (Sonowal and Gogoi, 2010). To ensure increased service-life of manufactured products, while protecting the environment from the harmful effect of preservative-chemicals against biodeterioration (Venmalar and Nagaveni, 2005), naturally-durable timbers are highly recommended (Connell, 1991). Although *K. gabonensis* has desirable characteristics for several structural applications including flooring and furniture production (Oteng-Amoako and Obeng, 2012), dearth of knowledge on its durability could hinder its utilization.

According to Peralta *et al.* (2003), Antwi-Boasiako (2004) and Ravenshorst *et al.* (2013) , the use of the field test is mostly preferred to the laboratory type since the former allows the collective effects of many biotic and abiotic factors of deterioration to be evaluated. However, Miltiz *et al.* (1996), Antwi-Boasiako and Baidoo (2010), Schultz and Nicholas (2000) and Sonowal and Gogoi (2010) explained that duration for field test could be shortened to produce useful results for reliable prediction of the durability of LUS. Thus, the wood stakes for the current investigation were exposed to bio-degraders through an accelerated field performance test.

5.4.2.1 Visual durability rating

This rating assesses the durability of timber from signs of attack on stakes, which have been exposed to insects and decay organisms in the field (Eaton and Hale, 1993; Australian Durability

Standard (AS 5604), 2005). Råberg *et al.* (2005) and Edlund *et al.* (2006) explained that the rating could be subjective as a measurement tool for durability. However, it could be an effective and easy-to-use method if meticulously employed (Kasal and Anthony, 2004). This method was employed to examine the extent of deterioration of the timbers to support the mass loss. *K. gabonensis* heartwood and sapwood were slightly attacked and had a visual durability rating of 1. The heartwood for *E. cylindricum* suffered moderate attack (2), while *C. pentandra* failed completely (4). Wagner *et al.* (2009) and Ncube *et al*. (2012) mentioned that visual durability rating could be verified by the Gulfport scale (0=no damage, 1=nibbles to surface etching, 2=light damage with penetration, 3=moderate damage, 4=heavy damage, and 5=block failure), which is a tool used to explain the extent of termite resistance. The current ratings for *K. gabonensis*, *E. cylindricum* and *C. pentandra* are in agreement with measurement by the Gulfport wood damage scale. Thus, *K. gabonensis* would be rated as more durable [and categorized into durability Class 1 under the European durability Standard, EN 252 (BS EN 252 2014)] than the popularly utilized traditional timber (*E. cylindricum*) for several wooden structures. Thus, it could be used in applications where they come into contact with the ground (i.e., European Hazard Class 4). According to the Australian Durability Standard (AS 5604, 2005), *K. gabonensis* could be placed in the same Durability Class (i.e., 1) as *Podocarpus totara* var. totara, *Manoao colensoi* (Hook.) Molloy and *Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little, which are employed in full weather-exposed applications (Hazard Class H1 - H4). Information on the properties of *K. gabonensis* is scanty except its density (940 – 1150 kgm^{-3}) and cell wall thickness (i.e., thick fibre walls), which are some of the few characteristics reported by Oteng-Amoako and Obeng (2012). Eaton and Hale (1993), Antwi-Boasiako and Atta-Obeng (2009) and Cookson and McCarthy (2013) explained that density and cell wall thickness could improve the resistance of timber to bio-deterioration, as they make browsing difficult. *E. cylindricum* is lighter with a density of 560 – 750

kgm^{-3} (Kémeuzé 2008) than *K. gabonensis*. *C. pentandra* is the lightest with density of 380 – 450 kgm^{-3} (Duvall, 2011). They all have thin-tomedium walled-fibres according to the two authors. Based on these characteristics, they explain why *K. gabonensis* is more durable than *E. cylindricum* and *C. pentandra*.

5.4.2.2 Mass loss

Usually natural durability of wood is widely correlated with the amount of cellulolytic materials it loses from attacks by bio-degraders (Arango *et al*., 2006; Ashaduzzaman *et al*., 2011; Asamoah *et al*., 2011). When less biomass is removed, wood marginally loses weight and becomes more resistant to bio-degradation (Ashaduzzaman *et al*., 2011). *C. pentandra* (the control) lost the greatest mass (i.e., 100%) and would be ranked non-durable. *K. gabonensis* heartwood lost the least (4.8±0.3%) and would be rated very durable. According to Duvall (2011), Walia *et al*. (2009) and Antwi-Boasiako and Boadu (2013), *C. pentandra* contains high amount of carbohydrates and less extractives, which make it easily attacked by micro-organisms for food. Festus and Nwala (2012) confirmed that most timber species of the family *Irvingiaceae* (including *Irvingia glaucescens*, *I. excelsa* and *K. trillessii*) are durable. Based on its rating, *K. gabonensis* could be classified into Use-Class 3 (i.e., suitable for exterior and above ground structures) and 4 (i.e., for exterior and in-ground applications) under EN 335 (Thompson, 1991;

Czichos, 2011). Thus, its utilization would be comparable to those of *Nauclea diderrichii* (De Wild. & T.Durand) Merr., *Chlorocardium rodiei* (R.Schomb.) R.R.W. and *Lophira alata* Banks ex P.Gaertn., which are traditional timber species for bridge construction, decking and flooring (Meaden *et al*., 2011). Eaton and Hale (1993), Peralta *et al*. (2003), Antwi-Boasiako and AttaObeng (2009) and Cookson and McCarthy (2013) mentioned that density and cell wall thickness have good correlation with the durability of timber. Humar *et al.* (2008) observed that

Quercus sp. (a very dense and popular furniture-making material) was very resistant to bio-deterioration.

The thick-wall materials of such timbers retard bio-degraders from penetrating and thereby degrading the wood substance (Schultz *et al.*, 2000). Pitman *et al*. (1999) also observed that durability is improved with the presence of tyloses, which makes wood impermeable to microorganisms by blocking the passage ways such as cell lumina and pits. Thus, the durability rating for *K. gabonensis* could be partly attributed to its thick-walled fibres, great density and the presence of tyloses, which were reported by Oteng-Amoako and Obeng (2012).

Manufacturers and consumers consider durability as a key factor in selecting timber for particular end-uses (Arowosoge and Tee, 2010). Lionetto and Frigione (2009) explained that the use of durable timbers prevent frequent breakdown and reduce replacement cost of wooden products, which contribute to the promotion of forest/timber conservation. Rahman and Chattopadhyay (2003) asserted that about AU$1500-2500 was incurred per pole as replacement cost for more than 5.3 million wooden poles used to supply power in the Queensland region of Australia due to bio-deterioration. Teles and Valle (2001) also estimated that about ₣300-400 million could be spent yearly to repair or replace wood destroyed through bio-degradation in France. Thus, naturally-durable timbers (e.g. *Larix decidua* var. polonica, *M. excelsa*, *Intsia palembanica* Miq. and *E. cylindricum*) are used effectively as stakes and posts for outdoor structures in contact with the ground (e.g. buildings) and for windows and doors, roofing, flooring and furniture construction (Eaton and Hale, 1993; Grace and Tome, 2005; Kémeuzé, 2008). The current durability status for *K. gabonensis* suggests its products could overcome the problems associated with frequent breakdown and replacement of wooden products due to bio-
deterioration.

5.5 Summary

Chapter 5 studied the anatomy (i.e., tissue proportion and arrangement, and fibre and vessel morphology) and durability of *K. gabonensis*. *K. gabonensis* is diffuse-porous, has sclerotic tyloses, prismatic crystals and thick-walled fibres, which formed the greatest proportion (42.4±4.5–45.6±4.5%) of all its tissues, while its vessels had the least (12.8±1.5–15.1±2.7%). Its fibre diameter (20.1±0.2–22.7±0.2 µm) and double wall thickness (8.9±0.3–9.7±0.3 µm) were greater than those of *E. cylindricum* (19.6±0.4–19.7±0.3 µm and 8.6±0.2–9.0±0.2 µm respectively). Vessel lumen diameters for *K. gabonensis* (144.8±2.2–176.9±4 µm) and *E. cylindricum* (115.6±1.4–184.4±2 µm) compare with those reported for tropical diffuse-porous timbers (<200 µm). *K. gabonensis* has very high termite resistivity. Based on its anatomy, *K. gabonensis* would be expected to be denser and stronger than *E. cylindricum*. Coupled with its termite resistivity, it could be similarly employed for furniture manufacturing, building construction and where great strength and durability are required. However, its thick walled fibres, tyloses and crystals would affect machining, and adhesive and finish application in wood composite manufacturing; power tools and extensive sanding could enhance processing, improve adhesive penetration and application of surface finishes.

CHAPTER SIX

THE BENDING STRENGTH OF MORTISE-TENON AND DOVETAIL JOINTS IN LEG-AND-RAIL CONSTRUCTED FROM *K. GABONENSIS* PIERRE EX ENGL.

6.1 Introduction

Wooden furniture (made by joining several pieces of wood together with a fastener) is found in almost every home and office; it is preferred to their plastic and metal counterparts because of the ecological and aesthetic properties of wood (Abdolzadeh *et al*., 2015). Its rigidity largely depends on the strength of its joints and members (Eckelman, 2003), as furniture mostly fails at the joints under static and cyclic loads (Eckelman, 1978; Zhang and Eckelman, 2003; Örs and Altınok, 1995; Ratnasingam *et al*., 1997). Its failure has economic implications. Consequently, furniture joints are designed to ensure great strength and reliability in service (Ratnasingam *et al*., 2010). Manufacturers' choice of joint usually depends on intended use of the product and the level of strength required (Zhang and Eckelman, 2003). According to Smardzewski (2015), joints that greatly resist bending, compression and tensile forces are the most preferred for working chairs, as these forces predominantly act on chair members. Tankut and Tankut (2005) and Eckelman *et al*. (2006) observed that mortise-tenon is the most used joint for manufacturing working chairs due to their strength against twisting and the ease of assembly. This joint, however, breaks down with time when chairs are subjected to bending stresses during the sitting process (Morris, 2014). Eckelman and Haviarova (2006) explained that when people sit, they exert undue pressure on chairs through activities (such as rocking and swinging) that cause the failure of glued joints.

Zhang and Eckelman (1993) and Hoadley (2000) noted that dovetail joints have great resistance to tension from bending forces and could offer an alternative to mortise-tenon. Its great resistance to tensile forces and beauty has led to its success for drawer construction and cabinetry. However, it is seldom used for the construction of leg-and-rail of chairs because most manufacturers are not familiar with the extent to which its strength exceeds that of mortise-tenon in such applications (Landis, 1998; Van de Kuilen *et al*., 2014). Smardzewski (2015) proposed that in order to select other joints that would overcome the problems associated with chairs constructed with mortise-tenon, extensive researches that compared their strengths were needed. However, most of the previous researches have failed to compare mortise-tenon and dovetail joints in chair construction.

The strength of any type of joint is influenced by the design of its parts and the wood species (Halstead, 1999; Kureli and Altinok, 2011). Tankut and Tankut (2011) observed that rectangularend mortise-tenon joint with wider and longer tenons were stronger than round end mortisetenon with narrow and shorter tenons. Erdil *et al*. (2005) found that a close tolerance maintained between the tenon and mortise resulted in strong joint. Love (1950) and Chan (2002) explained that dovetail joint derives its strength from careful design of the tail and socket that enhances their wedging effect. Albin *et al.* (1987), Erdil *et al*. (2005), Haviarova *et al*. (2013) and Abdolzadeh *et al.* (2015) also noted that, based on the desired level of joint strength, different wood species might be suitable for constructing certain kinds of joints. Jivkov and Marinova (2006) found that end corner miter joints made from *J. regia* L. had greater strength than those from *Alnus* spp. (L.) Gaertn. and *P. sabiniana* Douglas ex D.Don because of the superior mechanical properties of *J. regia*. When the appropriate wood species and joints are not chosen, furniture construction could become difficult, the integrity of joints would be undermined and the furniture piece could fail earlier than expected (Haviarova *et al*., 2013). According to Smardzewski and Majewski (2013), the decision to use a particular timber species and a corresponding joint design for furniture production must be based on experimental results of the performance of the wood-joint design combination. Therefore, to promote successfully any timber for furniture construction, information on the appropriate joint design that would give great strength was required (Ratnasingam *et al*., 2010).

Most Lesser-Utilized-Species (LUS) with the potential for joinery-making lack information about the joint design that must be employed to produce strong furniture (Sseremba, 2011). Although the physico-mechanical properties of *K. gabonensis* would likely make it an excellent timber for joinery products (Oteng-Amoako and Obeng, 2012), the best joint design for the production of strong furniture need be ascertained. The current study assessed the strengths of two designs of dovetail and the traditional mortise-tenon joints in the leg-and-rail of working chairs constructed from *K. gabonensis* and *E. cylindricum*. It sought to provide fundamental information on the most suitable joint that would improve the strength characteristics of working chairs to furniture designers and manufacturers. A stress analysis of the joints was also done to determine their efficiency against bending, deflection and shear stresses.

6.2 Materials and methods

6.2.1 Choice of joint designs and fastener

The designs for the joints (Figs. 6.1–6.4) and fastener were chosen based on the responses of 300 furniture manufacturing firms (randomly selected from Accra and Kumasi) to a questionnaire that sought for the types of joints, their designs as well as the fasteners used to construct working chairs (Appendix A). Most of the firms, which produce furniture and joinery products in the West African sub-region, are concentrated in these cities (Owusu, 2012).

6.2.2 Construction of joints

6.2.2.1 Mortise-tenon joint

Air-dried (12% mc) defect-free and straight-grained sapwood and heartwood of *K. gabonensis* and *E. cylindricum* (control) were planned to the dimensions of leg and rail (Table 6.1; Figs. 6.1 and 6.2) of a standard working chair (Sitting height: 39 – 42cm; Sitting depth: 38 – 42cm; Backrest width: 40 – 42.04cm). The positions of mortise-tenon on the respective leg and rail were marked. The rail was put in a vice and a tenon saw was used to cut along the marked lines that created the tenon (Haviarova *et al*., 2013). Securing the leg to a bench with a clamp, the mortise depth was cut with an auger bit, cleaned and squared with a chisel. The mortise-tenon pieces were pre-assembled to ensure the correct fitting before applying the glue. They were disassembled, while Fevicol SH synthetic adhesive was uniformly applied to all the faces of the tenon and to the sides and bottom of the mortise to ensure complete coverage. The joints were finally clamped together (Plate 6.1) at room temperature (25 °C) for 8 h to allow the glue to set; any excess adhesive was removed (Tankut, 2007). Squareness was checked and corrected. Ten replicates each were made for the Small-Sized (Type SS) and Large-Sized (Type LS) joints (Figs. 6.1 and 6.2 respectively) for all the wood species.

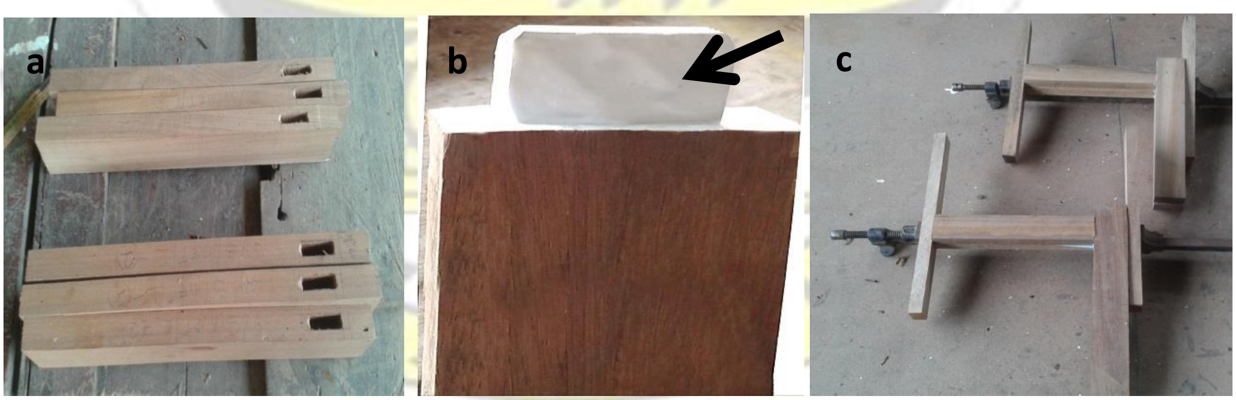

Plate 6.1: Leg (a), rail (b) with glue on the face of the tenon (arrowed); Leg and rail clamped together to produce a mortise-tenon joint (c).

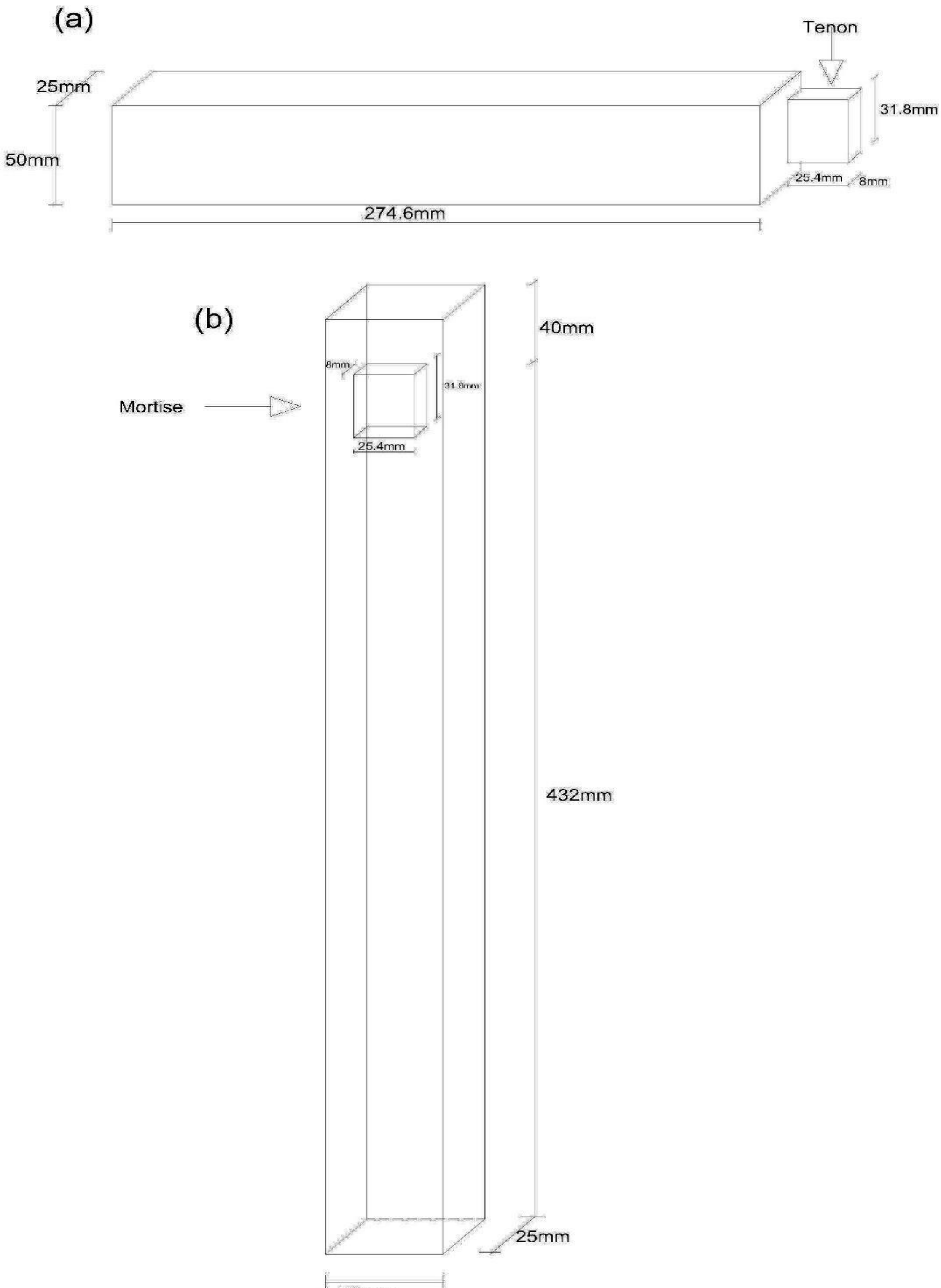

Fig. 6.1: Schematic illustration of the rail (a) and leg (b) of Type SS mortise-tenon joint showing the final dimensions of the mortise and tenon (Scale = 1:2.5).

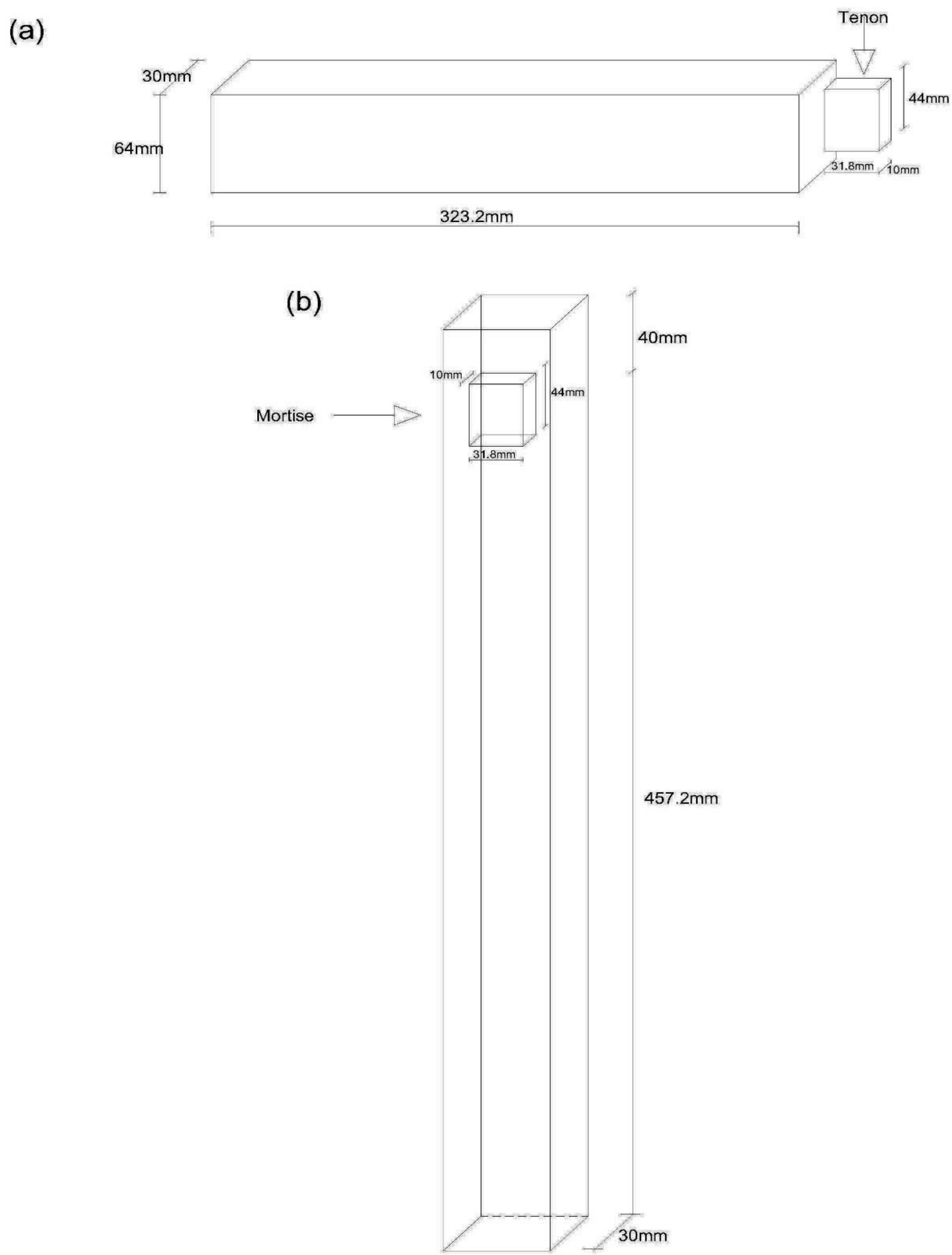

Fig. 6.2: Schematic illustration of the rail (a) and leg (b) of Type LS mortise-tenon joint showing the final dimensions of the mortise and tenon (Scale = 1:2.5).

Table 6.1: Cutting list for the construction of rail and leg pieces for mortise-tenon and dovetail joints

Joint design	Wood species	Joint part	No. of samples	al Dimens (mm)			Dimensions after plan		
				Length	Width	Thickness	Length	Width	Thickness
Type	*K.*	Rail	20	320	60	35	300	50	25
SS	*gabonensis*	Leg	20	492	60	35	472	50	25
	E.	Rail	20	320	60	35	300	50	25
	cylindricum	Leg	20	492	60	35	472	50	25
	K.	Rail	20	375	74	40	355	64	30
Type LS	*gabonensis*	Leg	20	517.2	61	40	497.2	51	30
	E.	Rail	20	375	74	40	355	64	30
	cylindricum	Leg	20	517.2	61	40	497.2	51	30

6.2.2.2 Dovetail halving joint

With a bevel gauge and pencil, the tails (Figs. 6.3 and 6.4) of the dovetail joint were marked around the faces and sides of the rail piece (rail dimensions in Table 6.1) and cut with a tenon saw at a slope of 1 in 8 (Zhang and Eckelman, 1993). Once the tails were created, a chisel was used to clean up its surfaces. The leg board was secured in a vice to a bench. Using the tails as template, lines which created sockets that interlocked with the tails were marked on the faces of the board. The sockets were cut out using dovetail saw and chisel to ensure a perfect fit of the tail (Eckelman, 1978; Erdil *et al*., 2005). The tail and socket were bonded together with Fevicol SH synthetic glue and clamped securely at 25 °C for 8 h for the glue to set (Plate 6.2) (Tankut, 2007). Excess adhesive was removed, while squareness was checked and corrected. Ten replicates were made for each of Type SS and Type LS joints for each timber.

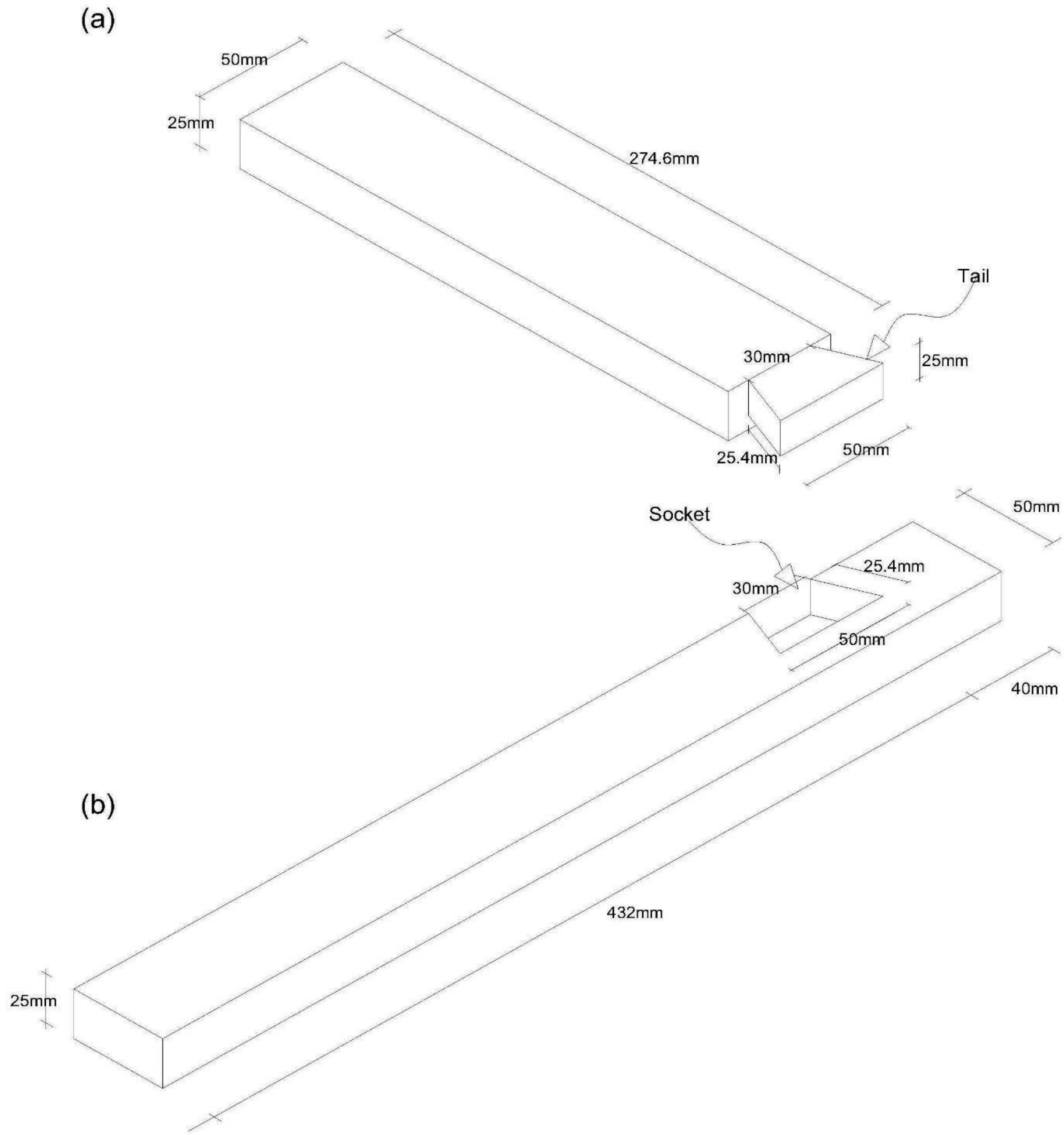

Fig. 6.3: Schematic illustration of the rail (a) and leg (b) of Type SS dovetail joint showing the final dimensions of the tail and socket (Scale = 1:2.5).

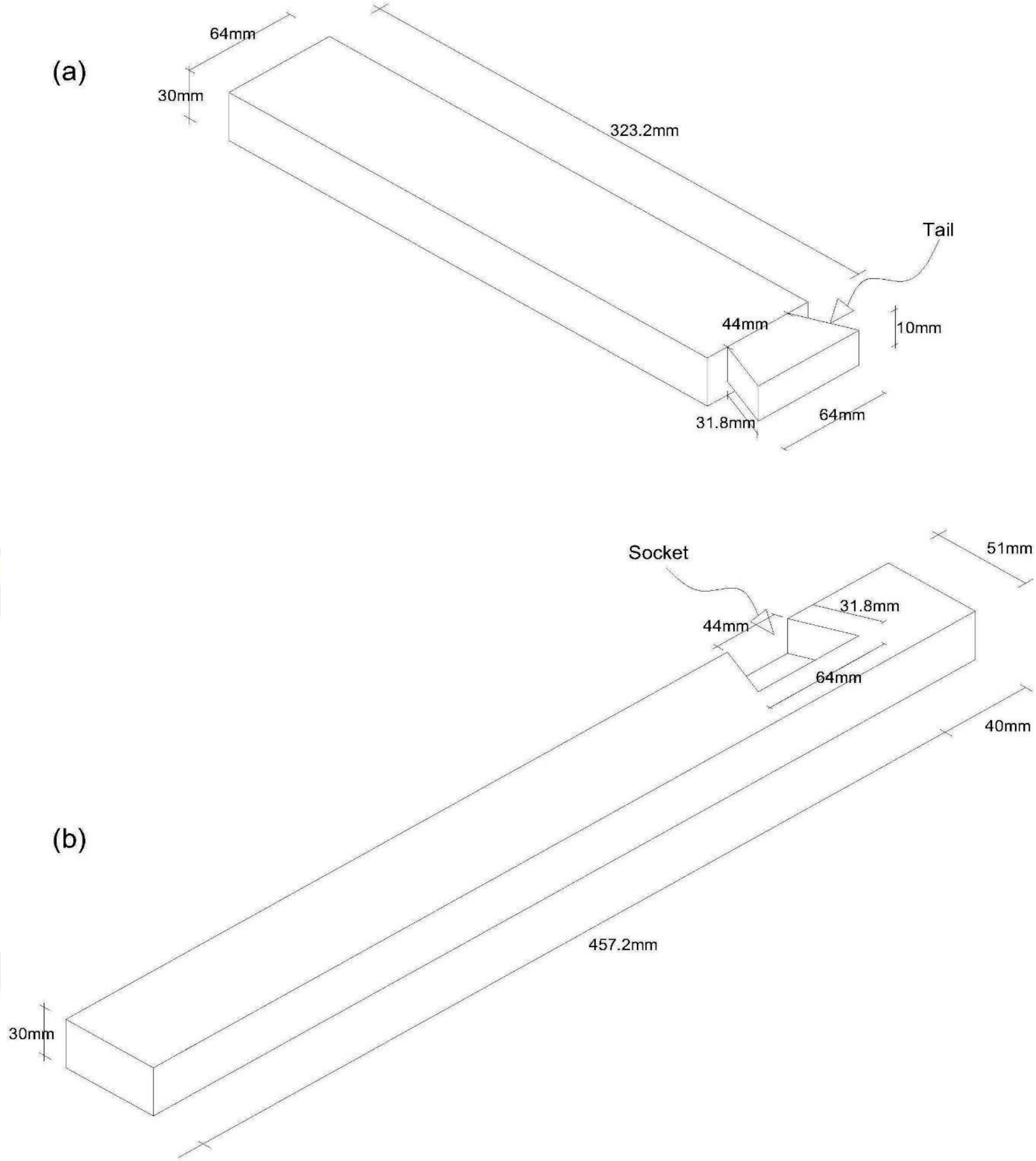

Fig. 6.4: Schematic illustration of the rail (a) and leg (b) of Type LS dovetail joint showing the final dimensions of the tail and socket (Scale = 1:2.5).

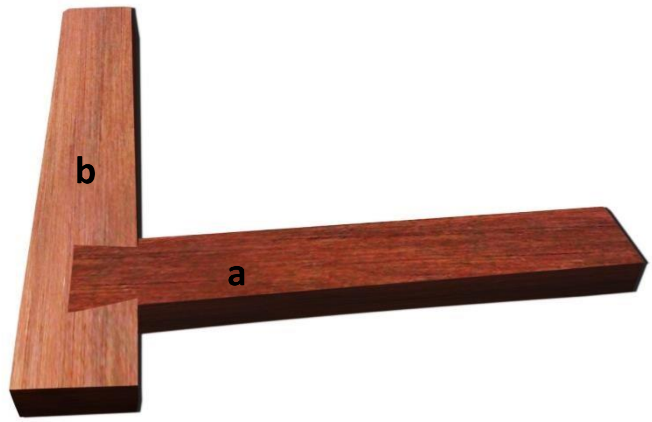

Plate 6.2: Rail (a) and Leg (b) boards fitted to form a dovetail joint.

6.2.3 Strength of joints determination

Strength test was carried out in a Riehle Universal Testing Machine at the Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. The leg member of the joint was clamped to a testing jig using a cast aluminum alloy angle plate, while load was applied by a cross head to the rail board (Plate 6.3) at a rate of 3 mm/sec. The maximum load (F) that caused rupture at the face of the joint (Plate 6.4) was recorded. The applied load created compound stresses including tension in the fibres at the upper part of the rail, shear at the neutral plane and compression in the fibres at its bottom. The bending deflection of the rail was proportional to the applied load. According to the Cantilever Beam Theory, the reaction of the wood fibres at the joint produced a moment that corresponds to the ultimate strength of the joint. Bending moment capacity (ultimate strength) of the joint (f (Nm)) was calculated using the formular by Tankut and Tankut (2005) and Tankut (2007) (Equation 6.1):

$$f = F \times L$$ *Equation 6.1*

Where: L = distance between the point of application of the load and the face of the joint.

Plate 6.3: A universal testing machine for determination of the joint strength a – Machine cross head that applies the load; b - Horizontal member (rail board) of joint; c - Vertical member (leg board) of joint; d - Cast aluminum alloy angle plate that supports the leg board

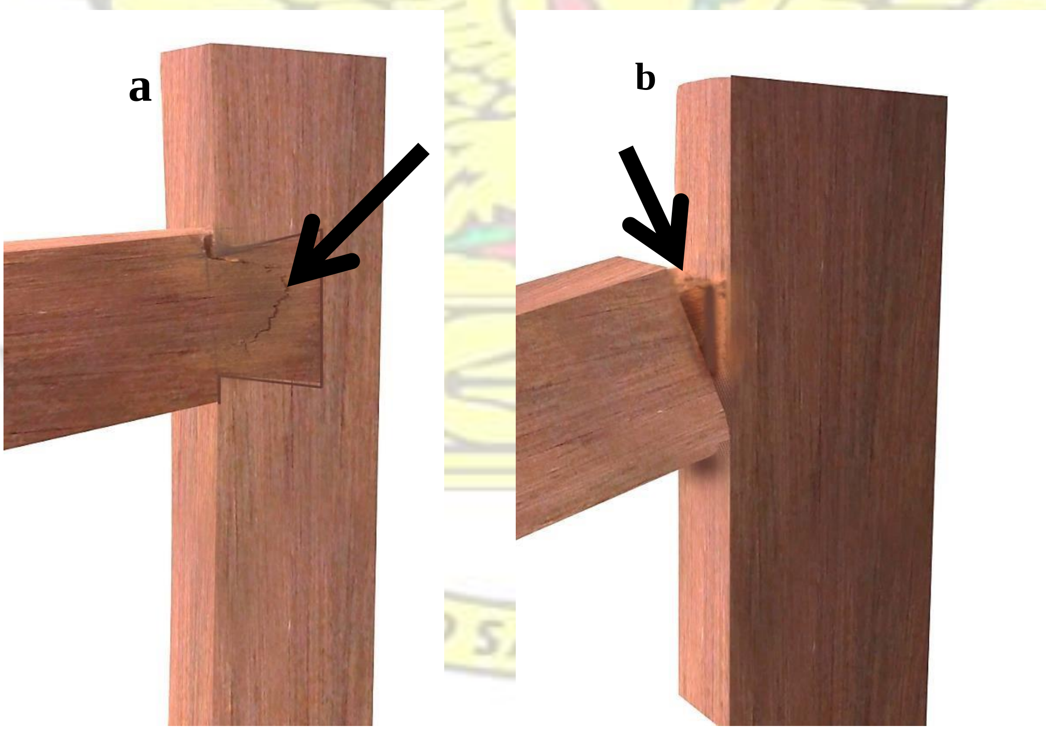

Plate 6.4: Failure (arrowed) of dovetail (a) and mortise-tenon (b) joints.

6.2.4 Data Analysis

The data on the strength of joints were subjected to ANOVA and Fisher's Least Significant Difference (LSD) test to compare their means at 95% confidence level.

6.2.5 Stress analysis of the design for the flexural member of Types SS and LS mortisetenon and dovetail joints

The two timbers were classified into the appropriate strength classes (*K. gabonensis*= D70; *E. cylindricum* = D30) according to their density and bending strength ranges (BS EN 338, 2003). Based on these, the standardized Minimum Modulus of Elasticity (E_{min}), bending ($\delta_{m,g,II}$) and shear stress parallel to the grain were obtained from Timber Grade stress Tables (BS 5268-2). The bending stress parallel to the grain ($\delta_{m,g,II}$) was adjusted to obtain the permissible bending stress ($\delta_{m,adm,II}$) for the rail member of the joint (Arya, 2009) as follows:

$$\delta_{m,adm,II} = \delta_{m,g,II} \times K_5 \times K_7 \times K_3 \quad \textit{Equation 6.2}$$

Where: K_5 = Notch factor = 0.636; K_7 = Depth factor = 1.17; K_3 = Duration factor = 1.

The permissible bending stress ($\delta_{m,adm,II}$) and the design moment (M) of the rail were used to calculate its required section modulus (Z) (mm^3) about the x-x axis (Arya, 2009; Draycott, 2012):

$$Z \geq \frac{M}{\delta_{m,adm,II}} \quad \textit{Equation 6.3}$$

$$M = \frac{WL}{8} \quad \textit{Equation 6.4}$$

Where: W = Minimum load that caused failure of the joint; L = Span of the horizontal member.

Based on the calculated Section Modulus (Z), the Moment of Inertia (I) (mm^4) about the x-x axis and the dimensions [breadth (mm), depth (mm) and area (mm^2)] required for the rail member to resist the design moment (M) without failure were obtained from BS 5268-2. The dimensions were compared with those used for constructing the mortise-tenon and dovetail joints and any discrepancies noted. The accuracy of the new dimensions obtained from BS 5268-2 was verified by comparing the anticipated total deflection (shear and bending) of the rail (with the new dimensions) with the permissible deflection for flexural members (Arya, 2009; Draycott, 2012):

$$Permissible\ deflection\ (mm) \geq Total\ deflection\ (mm) \qquad \textit{Equation 6.5}$$

=

$$0.003 \times span \geq \frac{WL^3}{3EI} + \frac{96WL}{5EA}$$

Where: W = Minimum load that caused failure of the joint; L = Span of the horizontal member; E = Minimum Modulus of Elasticity for the strength class of the timber species; I = Moment of Inertia corresponding to the new dimensions; A = Area of the section corresponding to the new dimensions.

According to Draycott (2012), when permissible deflection is greater than total deflection, the new dimensions for the joint member would be adequate for bending and deflection when used in cases where such design moments are expected. The new sections were also checked for their resistance to shearing forces (Equation 6.6) (Arya, 2009):

$$Permissible\ shear\ stress\ (Nmm^{-2}) \geq Maximum\ shear\ stress\ at\ neutral\ axis\ (Nmm^{-2})$$

=

$$Shear\ stress\ parallel\ to\ the\ grain \times K_5 \times K_3 \geq \frac{3 \times F_v}{2A}$$

Where: K_5 = Notch factor = 0.636; K_3 = Duration factor = 1; A = Area of the section corresponding to the new dimensions; $F_v = \frac{Load\ that\ caused\ failure\ of\ joint\ member}{2}$ Draycott (2012) explained that when permissible shear stress is greater than maximum shear at the neutral axis, the new dimensions for the joint member would adequately withstand shearing stress when subjected to the design moments.

6.3 Results

6.3.1 Strength of mortise-tenon and dovetail joints

Dovetail joints were stronger (e.g. *E. cylindricum* sapwood: 595.7±32.1; *K. gabonensis* heartwood: 913.8±49.2 Nm) than the mortise-tenon joints (*E. cylindricum* sapwood: 556.6±38.9; *K. gabonensis* heartwood: 842.9±39.5 Nm) (Fig 6.5). For both dovetail and mortise-tenon joints, Type LS was stronger (e.g., *E. cylindricum* sapwood mortise-tenon: 674.5±47.1; *K. gabonensis* heartwood dovetail: 913.8±49.2 Nm) than Type SS (e.g., *E. cylindricum* sapwood mortise-tenon: 556.6±38.9; *K. gabonensis* heartwood dovetail: 745.9±59.7 Nm). For wood species, joints manufactured from *K. gabonensis* also had greater strength (e.g., Type SS Mortise-tenon: 578.05±35.3; Type LS dovetail: 913.8±49.2 Nm) than those from *E. cylindricum* (e.g., Type SS Mortise-tenon: 556.6±38.9; Type LS dovetail: 759±7.5 Nm); their heartwoods produced joints with greater strength (e.g., *E. cylindricum* Type SS mortise-tenon: 612±52.6; *K. gabonensis* Type LS dovetail: 913±49.2 Nm) than those from their sapwoods (e.g., *E. cylindricum* Type SS mortise-tenon: 556.6±38.9; *K. gabonensis* Type LS dovetail: 775.5±44.6 Nm). Mostly, Type LS dovetail constructed from *K. gabonensis* heartwood had the strongest joint (913.8±49.2 Nm), while Type SS mortise-tenon made from *E. cylindricum* sapwood was the weakest (556.6±38.9 Nm). Significant differences ($p<0.05$) were recorded between Type SS dovetail and Type SS mortise-tenon produced from *K. gabonensis* sapwood, and also between Type LS dovetail and Type LS mortise-tenon manufactured from *E. cylindricum* (Tables 6.2 and 6.3; Fig. 6.5).

Table 6.2: ANOVA for the strength of Mortise-tenon and Dovetail joints made from *K. gabonensis* and *E. cylindricum*

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	**87**	**2447513.2**	**28132.2**	**1.6**	**0.02** [i]
Replicates	9	138085.9	15342.9	0.9	0.5
Species	1	282828.3	282828.3	30.3	0.0004[ii]
Stem position	1	169032.5	169032.5	11.1	0.0016[iii]
Joint Type	3	844528.8	281509.6	16.1	<.0001[iv]
Replicates*Stem Position	9	84082.1	9342.5	0.5	0.8
Replicates*Stem Position*Joint Type	54	825273.6	15282.8	0.9	0.7
Species*stem position	1	24181.8	24181.8	1.4	0.2
Species*Joint Type	3	44767.6	14922.5	0.9	0.5
Stem Position*Joint Type	3	10679.9	3559.9	0.2	0.9
Species*Stem Position*Joint Type	3	24052.5	8017.5	0.5	0.7
Error	**72**	**1255988.5**	**17444.3**		
Corrected Total	**159**	**3703501.7**			

R-square	Coeff Var	Root MSE	Bending Moment Mean
0.7	18.9	132.1	699.6

[i]Significant: p(0.02)<0.05; [ii]Significant: p(0.0004)<0.05; [iii]Significant: p(0.0016)<0.05; [iv]Significant: p(<.0001)<0.05.

Table 6.3: LSD for the strength of Mortise-tenon and Dovetail joints made from *K. gabonensis* and *E. cylindricum*

Timber species	Stem position	Joint Type	Least Significant mean*
K. gabonensis	Heartwood	Mortise-tenon SS	643.4_{ag}
		Mortise-tenon LS	842.875^{b}
		Dovetail SS	745.85^{cf}
		Dovetail LS	913.75^{d}
	Sapwood	Mortise-tenon SS	578.05^{e}
		Mortise-tenon LS	725.95^{cf}
		Dovetail SS	708^{ch}
		Dovetail LS	775.5^{f}
E. cylindricum	Heartwood	Mortise-tenon SS	612^{ae}
		Mortise-tenon LS	697.45^{cg}
		Dovetail SS	642.175^{ag}
		Dovetail LS	759.55^{cf}

Sapwood		
	Mortise-tenon SS	556.6^{e}
	Mortise-tenon LS	674.05^{gh}
	Dovetail SS	595.7^{e}
	Dovetail LS	723.15^{cf}

*Least Significant Means with similar superscripts are not significantly different ($p<0.05$).

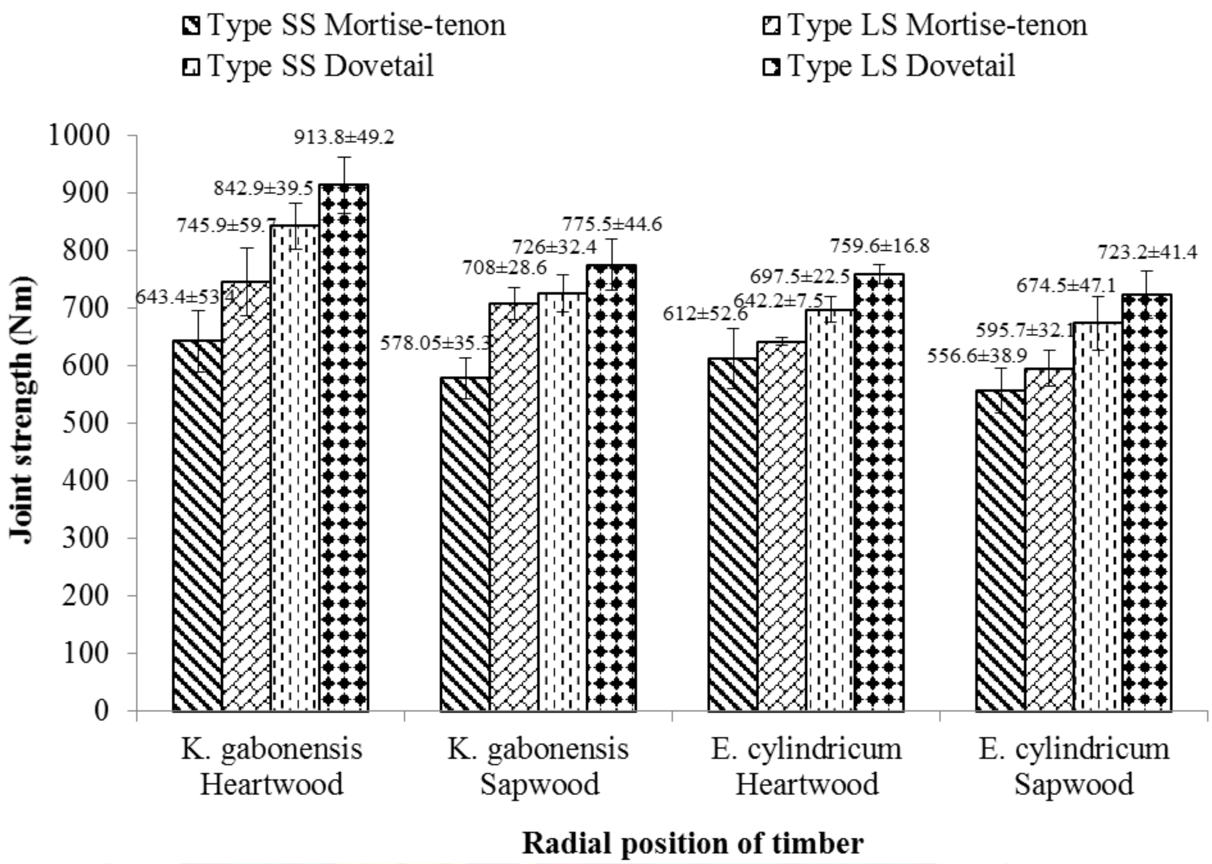

Fig. 6.5: Strength of mortise-tenon and dovetail joints made from *K. gabonensis* and *E. cylindricum*.

6.3.2 Stress analysis of the design for the flexural member of Types SS and LS mortisetenon and dovetail joints

The design used for the construction of joints were all inefficient with respect to their moments in resisting bending, deflection and shear stresses since the breadth and depth of the flexural member were either less or greater than the required dimensions (Table 6.4). To be able to sustain the respective moments without failure in shear, bending and deflection, Type SS (50 x 25 mm) and Type LS (64 x 30 mm) mortise-tenon and dovetail joints for *K. gabonensis* must have its breadth and depth re-designed to 25 mm and 75 mm respectively (Tables 6.4 and 6.5).

Table 6.4: Stress analysis of the rail for mortise-tenon and dovetail joints

Timber species	**Joint Type**	**Design moment (KNm)**	**Required section modulus (mm^3)**	**Total deflection of rail (mm)**	**Permissible deflection of rail (mm)**	**Section adequate for bending and deflection of rail**
K. gabonensis	Type SS mortise-tenon	0.064	≥ 3724.85	0.0061	0.9	25 x 75 mm
	Type LS mortise-tenon	0.084	≥ 4926.30	0.0149	1.07	25 x 75 mm
	Type SS Dovetail	0.075	≥ 4382.18	0.0118	0.9	25 x 75 mm
	Type LS Dovetail	0.084	≥ 4926.30	0.0149	1.07	25 x 75 mm
E. *Cylindricum*	Type SS mortise-tenon	0.049	≥ 7279.29	0.0063	0.9	25 x 75 mm
	Type LS mortise-tenon	0.532	≥ 79512.3	0.0017	1.07	25 x 75 mm
	Type SS Dovetail	0.075	≥ 11198.9	0.0354	0.9	25 x 75 mm
	Type LS Dovetail	0.710	≥ 106016.4	0.0548	1.07	25 x 75 mm

Table 6.5: Shear stress analysis of the new dimensions for the rail for mortise-tenon and dovetail joints

		Applied Shear	**Permissible Shear**
K. gabonensis	Type SS mortise-tenon	0.4	1.7
	Type LS mortise-tenon	0.5 0.5	1.7
	Type SS Dovetail	0.5	1.7
	Type LS Dovetail		1.7
E. *Cylindricum*	Type SS mortise-tenon	0.3	0.9
	Type LS mortise-tenon	0.2 0.4	0.9
	Type SS Dovetail	0.4	0.9
	Type LS Dovetail		0.9

Timber Species	Joint Type	stress (Nmm^{-2})	stress (Nmm^{-2})

The new rail dimensions (25 x 75 mm) are efficient in shear since permissible shear stress ≥ applied shear stress

6.4 Discussion

dos Santos *et al.* (2015) indicated that about 80% of structural failures in timber structures could often be related to weak joints. Joint strength determines the load-bearing capacity of furniture frames (Smardzewski, 2015). According to Moavenzadeh (1990), Strong (2011) and Aicher *et al.* (2013), careful design of joints is the most important phase in any furniture design process, as it ensures their better resistance to forces imposed on them in service. Joints fail by sliding apart when wood fibers are stretched, compressed or they reach their allowable bending stress (Chan, 2002). The current load applied to the rail created compression in the fibres on the side to which the load was applied and tension in the fibres on the opposite side (Nandanwar *et al*., 2013). In order to ensure great resistance of the working chair to bending and tensile stresses that could lead to early failure, joints with great strength are preferred (Smardzewski, 2015). Meanwhile, Zhang and Eckelman (1993) and Hoadley (2000) explained that dovetail joints made with specific timbers could improve the strength of mortise-tenon in working chairs. Thus, a comparative study on the strength of dovetail and mortise-tenon joints made from *K. gabonensis* was necessary.

6.4.1 Strength of mortise-tenon and dovetail joints

6.4.1.1 Kind of joints

Smardzewski and Majewski (2013) noted that the ultimate strength of furniture was mostly affected by the kind of joint selected for the work piece. Su and Wang (2007) observed in an experiment to compare the withdrawal strengths of dovetail, mortise-tenon and dowel joints that dovetail had greater strength (4915 N) than mortise-tenon (3400 N) and dowel (1654 N) joints. Asomani (2009) also determined the performance of dovetail halving joint in leg-and-rail construction and found that working chairs constructed with dovetail joints were 70% stronger than those with mortise-tenon joint. Similarly, the dovetail joints were stronger (e.g. *E. cylindricum* sapwood: 595.7±32.1; *K. gabonensis* heartwood: 913.8±49.2 Nm) than their mortise-tenon counterparts (*E. cylindricum* sapwood: 556.6±38.9; *K. gabonensis* heartwood: 842.9±39.5 Nm) under the current investigation. Lau (1991) noted that failure mode of joints depends largely on the geometry of the connection, which could give an indication of their strength. For instance, while the tenon for Types LS and SS made from *K. gabonensis* and *E. cylindricum* simply withdrew from the mortise at failure of the mortise-tenon joints, the tail in the dovetail joint under investigation gradually sheared off leaving several wedge-shaped sections behind in the sockets. This indicates the strong resistance of the dovetail to the bending stress as was observed by Lau (1991). Edwards (2012) explained that dovetail represents quality and artisanship in furniture and timber building construction, as it offers an admirable grain-tograin surface connection that overcomes warping. The pins and tails interlock to create a strong natural mechanical bond with good ability to resist bending and tensional forces better than mortise-tenon (Halstead, 1999; Strong, 2011; Derikvand and Ebrahimi, 2014). These characteristics explain why greater strength was obtained for dovetail than mortise-tenon joint. Alexander (1994) and Tankut and Tankut (2005) noted that the use of dovetail for joining legs, slats and stretchers to rails of chairs has not gained much prominence among manufacturers compared to mortise-tenon. This is because dovetail joints are difficult to construct and require higher level of care and practice (Fairham, 2007). Furthermore, wood workers are uncertain about the extent to which its strength surpasses that of mortise-tenon in chair construction (Van de Kuilen *et al*., 2014; Herren, 2014). However, dovetail joints produced from *K. gabonensis* and *E. cylindricum* could offer resistance to stress acting on a working chair better than mortisetenon.

6.4.1.2 Joint size

Likos *et al*. (2012) mentioned that the dimensions selected for construction of joint parts affect joint strength. Erdil *et al.* (2005) and Haviarova *et al*. (2013) found that increasing tenon width and length increased the strength of mortise-tenon joints. Kasal *et al.* (2013) obtained greater strength (393 Nm) for joints made with 60mm wide and 45mm long tenon than those made with 30mm wide and 20mm long tenon (125 Nm). Erdil *et al.* (2005) observed an increase in joint strength when tenon length and width were also increased from 12.7 to 50.8 mm and 12.7 to 76.2 mm respectively. Likewise, dovetail and mortise-tenon joints with longer, wider and thicker tails and tenons (Type LS) was stronger (e.g., *E. cylindricum* sapwood mortise-tenon: 674.5±47.1; *K. gabonensis* heartwood dovetail: 913.8±49.2 Nm) than those with shorter, narrower and thinner tails and tenons (Type SS) (e.g., *E. cylindricum* sapwood mortise-tenon: 556.6±38.9; *K. gabonensis* heartwood dovetail: 745.9±59.7 Nm). Wider tails and tenons have more surface area for glue application and bonding and could offer greater strength than their narrow counterparts (Fine Woodworking, 2004). Hajdarević and Martinović (2014) also noted that longer and thicker tenons are not easily pushed out of the mortise when stressed, making their joints stronger than those made with shorter and thinner tenons. Thus, Type LS could withstand great amount of stress than Type SS. Furniture designers would likely get stronger *K. gabonensis* and *E. cylindricum* working chairs when their mortise-tenon and dovetail joints are designed with longer, wider and thicker tails and tenons.

6.4.1.3 Type of timber and joint strength

Mortise-tenon and dovetail joints manufactured from *K. gabonensis* were stronger (e.g., Type SS Mortise-tenon: 578.05±35.3; Type LS dovetail: 913.8±49.2 Nm) than those from *E. cylindricum* (e.g., Type SS Mortise-tenon: 556.6±38.9; Type LS dovetail: 759±7.5 Nm). Jivkov and Marinova (2006) explained that the type of timber used for joint construction has significant influence on the strength of the joint. The strength properties of the timber could be the major factor underlying the failure of wood members and joints (dos Santos *et al*., 2015). Hoadley (2000) found that the strength of dovetail joints linearly correlated with the shear strength parallel to the grain of the wood used for construction of the tails. Jivkov and Marinova (2006) stated that the greater mechanical properties of *J. regia* var. *sinensis* C. DC. Were responsible for its stronger joints than those of *P. sylvestris* L. and *A. rubra* Bong. Haviarova *et al*. (2013) similarly observed greater strength for joints made from *F. orientalis* Lipsky than *P. sylvestris* L. and asserted that the difference in the joint strength was due to variations in the shear strengths of the two timbers (*F. orientalis* = 9.72 Nmm^{-2}; *P. sylvestris* = 8.82 Nmm^{-2}). Tankut *et al*. (2014) also concluded that the modulus of elasticity (MOE) and shear strength of *P. sylvestris* (12000 and 8.82 Nmm^{-2} respectively), *Fraxinus excelsior* L. (11900 and 16 Nmm^{-2} respectively) and *M. 115xcels* (Welw.) C.C. Berg (9134 and 12 Nmm^{-2} respectively) were responsible for the differences in their joint strengths. Kémeuzé (2008) and Oteng-Amoako and Obeng (2012) reported shear strength for *E. cylindricum* and *K. gabonensis* to be 7–18 and 14.5–18.5 Nmm^{-2} respectively, while their respective MOEs were 8900 – 13,800 Nmm^{-2} and 15970 – 21280 Nmm^{2}. The superior MOE and shear strength of *K. gabonensis* than those of *E. cylindricum* could account for the former's greater strength of joints than those from the latter.

Generally, dovetail joints designed with longer, wider and thicker tails (Type LS) and constructed from the heartwood of *K. gabonensis* had the greatest joint strength (913.8±49.2 Nm), while mortise-tenon joint with shorter, narrower and thinner tenons (Type SS) made from the sapwood of *E. cylindricum* was the weakest (556.6±16.8 Nm). This could be due to the great shear strength and MOE of *K. gabonensis* heartwood coupled with the better resistance of dovetail, and longer, wider and thicker tails to bending forces than mortise-tenon and shorter, narrower and thinner tails. Based on its great resistance to stress, dovetail could overcome early failure of mortise-tenon joints in furniture frames. The strength of working chairs could be improved when joints are designed with longer, thicker and wider tails and tenons in leg-and-rail construction. In joinery, timbers that produce strong furniture are desired (Eckelman *et al.*, 2001). *K. gabonensis* (a LUS) produced stronger joints than *E. cylindricum,* (popularly used for joinery) and could likely serve as raw material for the joinery and furniture industry. This will widen the wood resource base for the sector and reduce overexploitation of the few well-known timbers.

6.4.2 Stress analysis of the design for the flexural member of Types SS and LS mortisetenon and dovetail joints

The rail/flexural member of working chairs is subjected to loads applied transverse to its long dimension, which causes it to bend; the wood fibres at its bottom are stretched, while those at the top are compressed (Arya, 2009). This creates tensile and compressive stresses simultaneously on the transverse plane, which leads to deflection of the wood member from its normal geometry. Siddiqi (2014) explained that the deflection that occurs causes serious damage to the upper part of the rail member, surface finishes and the overall stability of the structure. Anderson and Anderson (2005) noted that deflection is a function of the applied load, material stiffness and the design/dimensions of the rails. Thus, the choice of an appropriate design for joint construction is very important. Patel (2014) mentioned that stress analysis must be performed on all designs to ensure that they meet the standard specifications that would resist bending and deflection in service. According to Draycott (2012), although bending stresses are of greatest concern for beams/flexural members in bending, shear stresses exist when transverse loads are applied, which needs to be considered in stress analysis.

Stress analysis of engineering structures is prominent in the manufacturing, building and construction sectors. It determines the performance of structural products against applied loads (Danawade *et al*., 2012). Siddiqi (2014) mentioned that such an analysis produces more reliable and efficient structural designs, while minimizing errors, cost of production and product failure. Smardzewski and Papuga (2004) further added that stress analysis ensures that a piece of furniture is characterized by strong elements and joints, which meet all the aesthetic requirements. Furniture designers could establish accurate relationships between structural configuration, loading and the expected strength of their construction.

The designs used for the construction of the joints [Type SS (50 x 25 mm); Type LS (64 x 30 mm)] were not adequate against bending, deflection and shear stresses with respect to their applied moments (0.049-0.710 KNm), since the required section modulus indicated different dimensions other than those that were used for the construction. This implies that the current dimensions (50 x 25 mm and 64 x 30 mm) used for constructing the rails of working chairs by furniture manufacturers cannot sustain loads that create moments ranging from 0.049 KNm to 0.710 KNm and would need to be re-designed under such loads. The appropriate rail dimensions (breadth and width) that could withstand failure were observed to be 25 x 75 mm respectively.

Patel (2014) and Hajdarević and Busuladžić (2015) noted that aesthetic, ergonomic and safety were the major factors considered in furniture design. Safety of a furniture piece depended on its strength. Smardzewski and Papuga (2004) explained that chairs are expected to be sturdy enough to withstand substantial weight. However, this could be achieved by paying key attention to the design of its joints. When the wrong dimensions of joint members are used, the chair would easily breakdown (Smardzewski and Papuga, 2004) as seen from the results. Therefore, although the test for joint strength indicated that dovetail and longer, wider and thicker tails would give more strength to furniture than mortise-tenon, the dimensions of the rail member used for the joint construction could lead to early failure of the chairs, especially when a moment of 0.0490.710 KNm is applied. A 25 x 75 mm rail designed with dovetail and thicker, wider and longer tails would likely produce stronger joints than those made from a 64 x 30 mm rail. This work has provided the need for furniture designers to conduct extensive stress analysis of designs intended for furniture manufacturing so as to ensure ergonomically and aesthetically acceptable and strong products. This will also reduce the cost of production by avoiding wastage of wood materials associated with over-sizing of joint members.

6.5 Summary

The bending strengths of two joint designs (dovetail and mortise-tenon) for leg-and-rail construction from *K. gabonensis* and *E. cylindricum* were studied in Chapter 6. Dovetail joints were stronger than those of mortise-tenon. For both joints, the design with longer, wider and thicker tails and tenons [Large-sized (Type LS)] was stronger than its counterpart [Small-sized (Type SS)]. Joints manufactured from *K. gabonensis* were also stronger than those from *E. cylindricum*. Thus, *K. gabonensis* could be an appropriate material for joinery/furniture production. This would broaden the raw material base for the furniture sector. However, its working chairs designed with Type LS dovetail joints would resist bending forces better and ensure stronger furniture than mortise-tenon.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 Challenges with utilization of LUS among furniture manufacturers

Although several secondary timber species that could substitute the scarce traditional timbers for many uses including furniture production abound in many forests, the timber industry continuously faces persistent timber shortages (Zziwa *et al*., 2006; Sseremba *et al*., 2011). The level of utilization of these LUS as alternatives by manufacturers and consumers is unclear and needed to be ascertained. Furniture manufacturers mainly use mixed red wood (e.g., *C. odorata*, *Entandrophragma*. spp., *Khaya* spp., *A. africana*), *A. robusta*, *G. cedrata* and *T. grandis* due to their strength, durability and aesthetics. This finding was in agreement with Dadzie *et al.* (2014) and Boampong *et al*. (2015) who found that among a list of 22 wood species, only few, including mixed red wood, *G. cedrata* and *T. grandis*, were mostly patronized by furniture manufacturers. Since the choice of timber for furniture-making depended on factors such as strength, durability and aesthetics (Zziwa *et al.*, 2006), the many LUS with these characteristics could be suitable materials for the furniture industry. However, it was observed in the current work that only 15% of manufacturers use LUS such as *Celtis* spp., *M. indica* and *A. indica* for furniture production, while none had ever used *K. gabonensis* in their operations. Market unavailability and lack of information regarding the properties and uses of secondary timber species were some of the hindrances to their utilization by producers, thus, confirming the assertion by Smith (2000), Barany *et al.* (2003), Ozarska (2009), Sseremba *et al.* (2011) and Effah and Osei (2014) that utilization of timber depends on accessibility on the market and availability of technical data on its properties.

Therefore, the level of utilization of non-traditional timbers could be improved by supplying the timber industry with information about their charcteristics and application. This will widen the raw material stock and reduce pressure on the primary timber species (Graham, 2012).

According to Borota (1991), many developed products from *P. radiata, Pseudotsuga menziesii and* several tropical LUS (e.g., *K. ivorensis* and *M. excelsa*) established themselves in good European markets because their properties were well investigated. *K. gabonensis* is rarely used due to lack of information about its physical, mechanical and biological properties (Cordero and Kanninen, 2002). To ascertain its suitability as a useful raw material for the timber industry, its properties were worth-investigating.

7.2 Moisture content

K. gabonensis had great mc (42.1±1.1–44.2±0.6%), which could affect its processing and transportation, especially when freshly felled (Anderson, 2002). If not properly dried, glueability and application of surface finishes would also be difficult. According to Winandy (1994), more moisture could lead to a reduction in the strength of manufactured joints and mechanical stiffness of walls as it leaves wood. To avoid these challenges, *K. gabonensis* needs thorough drying before utilizing it as any wooden structure.

7.3 Density

Pinto *et al*. (2004) and Izekor *et al.* (2010) asserted that timbers with density above 1200 kgm^{-3} are less preferred for construction and furniture production due to their poor dimensional stability and the costs involved in transportation and processing. The density of *K. gabonensis* (932±31–958±19 kgm^{-3}) was greater than that of *E. cylindricum* (490±13–536±19 kgm^{-3}). However, *K. gabonensis* could overcome the problems associated with very dense timbers because of its recorded density, which compares with those of popular timbers (*Dalbergia retusa*: 880-980 kgm^{-3}; *Chrysophyllum pomiferum*: 950 kgm^{-3}; *Intsia bijuga*: 780-980 kgm^{-3}) often used for building construction, flooring and furniture manufacturing (Forest Products Development and Marketing Council of Guyana Inc. 2015).

7.4 Dimensional stability

Zhu *et al.* (2014) noted that swelling and shrinkage in the tangential (T) and radial (R) directions of wood have the greatest influence on its dimensional stability. Minford (1991) and Upton and Attah (2003) recommended a T/R ratio of <1.6 (swelling) and <2.5 (shrinkage) for timbers used for wooden structures. The T/R ratio for *K. gabonensis* [swelling: 1.31 (heartwood) and 1.38 (sapwood); shrinkage: 1.58 (heartwood) and 1.63 (sapwood)] compares well with this recommendation and fits it for structural purposes.

7.5 Mechanical properties

The mechanical properties of wood assist manufacturers in product design, material selection and efficient usage of timber (Ntalos and Grigoriou, 2002). *K. gabonensis* shear and compressive strengths (32.2±0.4–33.5±1 Nmm^{-2} and 80.7±1.4–90.6±1 Nmm^{-2} respectively), MOR (204±4.0–214±4.0 Nmm^{-2}) and MOE (28900±660 – 29500±820 Nmm^{-2}) were greater than those of several timbers used for engineering purposes including *E. cylindricum* (i.e., 15.5±1– 15.6±1 Nmm^{-2}, 56.4±4.5– 63.6±1.2 Nmm^{-2}, 66–184 Nmm^{-2} and 8900–13,800 Nmm^{-2} respectively), *L. alata* (shear strength = 14–20 Nmm^{-2}) reported by Doumenge and Séné (2012), *Q. alba* (compressive strength = 51.3 Nmm^{-2}) and *C. ovata* (MOR: 138.6 Nmm^{-2}; MOE: 15590 Nmm^{-2}) by Meier (2014). Based on its strength properties, *K. gabonensis* could resist heavy static and dynamic loads in both non-building and building structures (Haviarova *et al.*, 2001;

Meier, 2014).

7.6 Durability

Venmalar and Nagaveni (2005) noted that naturally-durable timbers are highly recommended for the wood industry for increased service-life of manufactured products. *K. gabonensis* heartwood and sapwood were slightly attacked and had a visual durability rating of 1. The heartwood for *E. cylindricum* suffered moderate attack (2), while *C. pentandra* failed completely (4). *C. pentandra* recorded 100% mass loss (failure), *E. cylindricum* sapwood lost 13.1±0.6% (Moderately durable), its heartwood and *K. gabonensis* sapwood lost 10±0.7% and 8±0.6% respectively (Durable), while *K. gabonensis* heartwood lost 4.8±0.3% (Very durable). *K. gabonensis* would be categorized into Durability Class 1 (BS EN 252 2014) and Use-Classes 3 and 4 (EN 335). It would be suitable for exterior and above ground structures as well as exterior and in-ground applications (Thompson 1991; Czichos 2011).

7.7 Joint strength

According to dos Santos *et al.* (2015), most of the failure in timber structures could be attributed to weak joints resulting from its poor configuration and the wrong choice of timber. The traditional mortise-tenon joint used for constructing the leg-and-rail of chairs easily fails under bending and tensile forces (Aicher *et al.*, 2013). Although dovetail joint could overcome this challenge, its success depends on the design/dimension of its parts and the kind of timber employed (Smardzewski and Majewski, 2013). The strengths of two designs of dovetail and mortise-tenon produced from *K. gabonensis* were assessed to assist manufacturers with information on the best joint design that could give great strength to manufactured products. Dovetail joints were stronger (e.g. *E. cylindricum* sapwood: 595.7±32.1; *K. gabonensis* heartwood: 913.8±49.2 Nm) than mortise-tenon joints (*E. cylindricum* sapwood: 556.6±38.9; *K. gabonensis* heartwood: 842.9±39.5 Nm). Edwards (2012) explained that the pins and tails of dovetail joints interlock to create a strong natural mechanical bond with good ability to resist bending and tensional forces better than mortise-tenon (Halstead, 1999; Strong, 2011; Derikvand and Ebrahimi, 2014). Thus, dovetail joints could resist stress acting on a working chair better than mortise and tenon (Herren, 2014). Dovetail and mortise-tenon joints with longer, wider and thicker tails and tenons (Type LS) were stronger (e.g., *E. cylindricum* sapwood mortise-tenon: 674.5±47.1; *K. gabonensis* heartwood dovetail: 913.8±49.2 Nm) than those with shorter, narrower and thinner tails and tenons (Type SS) (e.g., *E. cylindricum* sapwood mortisetenon: 556.6±38.9; *K. gabonensis* heartwood dovetail: 745.9±59.7 Nm) because the wider and longer tails and tenons provided the joints with larger surface area for glue application and bonding, while preventing the rails from being pushed out easily under stress (Haviarova *et al*., 2013; Kasal *et al.*, 2013). Joinery product manufacturers would likely get stronger furniture when joints are designed with longer, wider and thicker tails and tenons. Mortise-tenon and dovetail joints manufactured from *K. gabonensis* had greater strengths (e.g., Type SS Mortisetenon: 578.05±35.3; Type LS dovetail: 913.8±49.2 Nm) than those from *E. cylindricum* (e.g.,

Type SS Mortise-tenon: 556.6±38.9; Type LS dovetail: 759±7.5 Nm). According to Hoadley (2000) and the U.S. Department of Agriculture (2011), timber with great density and mechanical properties have great capacity against heavy loads and provide joints with greater strength. Tankut *et al*. (2013) further explained that the modulus of elasticity (MOE) and shear strength of timber significantly influenced the strength of its manufactured joints. Stronger dovetail (e.g., Type LS: 913.8±49.2 Nm) and mortise-tenon (Type LS: 842.9±39.5 Nm) joints obtained for *K. gabonensis* than those for *E. cylindricum* (Type LS: 759.6±16.8 Nm and 697.5±22.5 Nm respectively) could be attributed to the mechanical properties of the timbers. U.S. Department of Agriculture (2011) mentioned that a major setback of joints constructed with dense wood is that, due to their thicker cell walls and narrow lumen, adhesive penetration is often poor, which limits the interlocking of glue to a few cells. This could, however, be improved by pressure application of the adhesive to ensure its firm contact with the wood surface (U.S. Department of Agriculture, 2011).

Stress analysis performed on the rail member of the joint indicated that its dimensions (50 x 25 mm and 64 x 30 mm) cannot efficiently withstand bending, deflection and shear stresses arising from the applied moments (0.049-0.710 KNm). This would lead to early failure of manufactured chairs. Appropriately, the rail dimension (breadth and width) needed to resist failure from such moments was observed to be 25 x 75 mm respectively. Thus, a 25 x 75 mm rail designed with dovetail and thicker, wider and longer tails would likely produce stronger joints than those made from a 64 x 30 mm rail. Furniture manufacturers would need to conduct extensive stress analysis of designs intended for furniture manufacturing so as to ensure ergonomically and aesthetically acceptable and strong products.

7.8 The relationship between the physico-mechanical and biological properties of *K. gabonensis*

Eaton and Hale (1993) mentioned that the interaction of all the properties of wood influences its behaviour in service. Uetimane and Ali (2011) and Santini *et al.* (2012) explained that the physico-mechanical and durability properties of wood were mainly influenced by its anatomy. Chowdhury *et al*. (2012) and Walker *et al*. (2013) noted that denser, stronger and durable timbers often have larger proportion of thick-walled fibres and vessels, tyloses and crystals, while low density timbers are characterized by thin-walled fibres and vessels, and greater proportion of parenchyma, which limits their uses for wooden products manufacturing. Similarly, the larger proportion of thicker walled fibres and ray parenchyma, narrower vessels, tyloses, crystals and lower proportion of axial parenchyma of *K. gabonensis* could be responsible for the timber's greater density (932±31–

958±19 kgm^{-3}), mechanical properties (shear strength = 32.2±0.4– 33.5±1 Nmm^{-2}; compressive strength = 80.7±1.4–90.6±1 Nmm^{-2}; MOR = 204±4.0–214±4.0 Nmm^{-2}; MOE = 28900±660–29500±820 Nmm^{-2}) and durability (mass loss = 4.8±0.3–8.2±0.6%) than those of *E. cylindricum* [density = 490±13–536±19 kgm^{-3}; shear strength = 15.5±1–15.6±1 Nmm^{-2}; compressive strength = 56.4±4.5–63.6±1.2 Nmm^{-2}; MOR = 99.4±4.7–121.3±10.6 Nmm^{2}; MOE = 9987.4±207–10051±258 Nmm^{-2}; mass loss = 10±0.7–13.1±0.6%]. Uetimane and Ali (2011) and Cookson and McCarthy (2013) noted that thick-walled fibres and vessels generally have large sectional areas to support great amount of loads, while retarding bio-degraders from penetrating wood. Moreover, wood vessels encrusted with tyloses were dense, impenetrable to micro-organisms and therefore possessed great resistance to stress and bio-deterioration. de Lima *et al.* (2014) found a linear relationship between the proportion of the rays and shear strength of wood. They explained that rays act as reinforcing elements that lock the growth layers of wood and prevent slippage under shear stress. The rays in *K. gabonensis* could have offered the timber great resistance against shear stress. Thus, the presence of tyloses and proportion of thick-walled fibres and vessels contributed to the greater density, strength and durability of *K. gabonensis* than *E. cylindricum*.

The anatomical studies of *K. gabonensis* and *E. cylindricum* again showed that vessel lumen diameter for *K. gabonensis* was greater (144.8.±2.2–176.9 ±4 µm) than *E. cylindricum* (115.6.±1.4–184.4±2 µm). Moya *et al.* (2012) observed that vessel lumen diameter greatly affected wood moisture content. Wider vessels conduct more water than their narrower counterparts. Therefore, much more moisture was recorded from *K. gabonensis* (42.1±1.1– 44.2±0.6%) than *E. cylindricum* (34.8±1.2–35±0.5%) due to the former's wider vessels. Thus, thorough drying would be needed to remove moisture from *K. gabonensis* before its utilization. K. *gabonensis* Glass and Zelinka (2010) and de Lima *et al.* (2014) found a linear relationship between shrinkage and the density of timbers; denser timbers shrink more than less dense wood. However, *K. gabonensis* with its greater density (932±31–958±19 kgm^{-3}) than that of *E. cylindricum* (490±13–536±19 kgm^{-3}) shrank the least (5.1 ± 0.3–5.7 ± 0.5%). Okon (2014) explained that increasing fibre dimensions could lower wood shrinkage. For instance, Boyd (1977) explained that thick-walled fibres have high visco-elastic strain recovery abilities, which minimize dimensional changes due to shrinkage. The thick-walled fibres of *K. gabonensis* could have therefore lowered its volumetric shrinkage.

7.9 Prospects of *K. gabonensis*

Haviarova *et al*. (2001), Massayuki *et al.* (2014) and Meier (2014) observed that wood used in structural applications should be dimensionally-stable and possess superior mechanical properties that can withstand great stress. In addition, Eaton and Hale (1993) and Grace and Tome (2005) explained that they should withstand bio-deterioration when extensively exposed to the ground and water. The physico-mechanical and biological characteristics of *K. gabonensis* have proven it to be a suitable engineering material for structural applications. Its abundance in the forests of many African countries [mean basal area and volume (for diameter classes 30 – 130cm) in the Ghanaian forests are 10.77 m^2km^{-2} and $\geq$396m^3km^{-2} respectively] (Ghana Forestry Commission 2012), straight and cylindrical bole, which could be branchless for up to 25m from the ground and great quantities of biomass (diameter: 120-150 cm; height = 45-50 m tall) would ensure its sustainable supply for the construction/building industry and other wood related sectors, while reducing pressure on the highly-exploited timbers.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATION

8.1 Conclusion

- Furniture manufacturers select timber for furniture-making based on their strength, durability and aesthetics due to reduced future maintenance and replacement cost of their products. Thus, with decreasing quantities of the conventional timbers, many of the secondary timbers with comparable strength, beauty and durability (e.g., *K. gabonensis*) could substitute the traditional timbers to ensure regular wood supply.
- However, most manufacturers rely on only the well-known timbers (e.g. mixed red wood, *G. cedrata* and teak) and hardly use the secondary timber species due to market unavailability and lack of information about their characteristics and uses. This has led to pressure on the demand for and exploitation of few primary timbers.
- Thus, the furniture industry's ability to meet future demand for wood products is unsustainable, which requires adequate efforts for the promotion and utilization of the secondary timbers (or LUS). *K. gabonensis* is an abundant timber material with great amount of biomass and commercial potential; its utilization would ensure sustainable supply of wood for product manufacturing.
- Compared with commonly used timbers such as *E. cylindricum*, *Q. alba* and *C. ovata* for construction of rigid frame, beam-column, strut and truss, both *K. gabonensis* heartwood and sapwood have been established to be dense with corresponding superior mechanical properties.
- It had great mc which could pose challenges to processing and transportation, especially when it is freshly harvested. However, swelling and shrinkage were least for sapwood

and heartwood in all their directions, which resulted in their good T/R ratios and dimensional stabilities.

- *K. gabonensis* is diffuse-porous with sclerotic tyloses, prismatic crystals and more thickwalled fibres than vessels and parenchyma. It also had greater fibre dimensions, ray parenchyma and fibre proportions than *E. cylindricum* (control). These would make *K. gabonensis* more dense, strong and durable against bio-deterioration than the control.
- The presence of tyloses and crystals in *K. gabonensis* would create challenges for liquid movement, chemical preservation and processing. Tungsten-carbide tools and extensive sanding would facilitate machining and chemical treatment.
- *K. gabonensis* heartwood and sapwood were slightly deteriorated and lost the least mass making them very durable compared to *E. cylindricum* and *C. pentandra* (control).
- Dovetail joints were stronger than their mortise-tenon counterparts and could provide working chairs with great strength. Joints with longer, wider and thicker tails and tenons (Type LS) were stronger than those with shorter, narrower and thinner tails and tenons (Type SS); Type LS would be more appropriate for furniture leg-and-rail construction.
- A 25 x 75 mm rail would be adequate in bending, deflection and shear than the current dimensions (50 x 25 mm and 64 x 30 mm) used by furniture manufacturers under moments ranging from 0.049 to 0.710 KNm.
- *K. gabonensis* joints had greater strength than those from *E. cylindricum* (traditional material for joinery) and could be a suitable material like *E. cylindricum* (traditional material for furniture) for joinery due to the great strength characteristics of its joint.

8.2 Recommendation

- To increase the level of utilization of the secondary timber species to ensure consistent wood supply for the furniture industry, adequate information about their abundance, properties and uses must be made available to wood workers.
- As the dwindling supply of preferred naturally-durable timbers requires the promotion of LUS with excellent properties as their substitutes, *K. gabonensis* could be a good alternative to widen the raw material base for the Timber Industry.
- *K. gabonensis* could be similarly used as *E. cylindricum*, *I. palembanica* and *Quercus sp*. for roofing, flooring, bridge, building and furniture construction, mine props and other wood-related sectors where great strength is required.
- *K. gabonensis* would need thorough drying before utilizing it for any wooden structure in order to minimize the challenges associated with high wood moisture.
- Due to the presence of tyloses and crystals in *K. gabonensis*, tungsten-carbide or polycrystaline diamond tipped tools would facilitate machining. Extensive sanding would also improve timber surface quality for application of finishes and bonding with adhesives.
- Working chairs designed with dovetail joints and longer, wider and thicker tails would likely resist bending forces better and ensure greater strength of furniture than mortisetenon.
- *K. gabonensis* could be a suitable material like *E. cylindricum* (traditional material for furniture) for joinery due to the great strength characteristics of its joint.
- To ensure great strength of furniture products, wood species and joint design used in the construction must be carefully selected as the joint design and timber type affected the strength performance of joints.

8.3 Contribution to knowledge

- Reliable information on the bio-mechanical properties and uses of *K. gabonensis* have been provided, which will enhance its utilization to expand the raw material stock and contribute to solving the wood demand and supply imbalances.
- To offset frequent furniture breakdown, designers have been provided with information regarding joint strengths from different designs and timbers to guide selection.
- This work has added to the global debate on promotion of LUS as one of the best and sustainable strategies for the reduction of over-dependence on the endangered traditional timbers.

8.4 Limitations of the study

- The timbers were obtained from only the moist semi-deciduous ecological zone.
- Samples for the various tests were taken from the butt portion of trees.
- The chemical properties of *K. gabonensis* were not investigated.
- The effect of adhesive on the joints produced was not determined since only one type of adhesive was used.

8.5 Suggestions for further work

- Further studies should be conducted on the chemical properties of *K. gabonensis*, which will enhance its utilization and processing.
- The properties of *K. gabonensis* from other ecological zones should be investigated.

REFERENCES

1. Abdolzadeh, H., Ebrahimi, Gh., Layeghi, M. and Ghassemieh, M. (2015) Analytical and experimental studies on stress capacity with modified wood members under combined stresses. *Maderas. Ciencia y tecnología*, Vol. 17(2), 263 – 276.
2. Abood, F. 2008. Degradation of wood by insects and the effects on furniture production. Malays For, 71, (1), 95-106.
3. Acquah, E. T. and Whyte, C. (1998) The potential for Ghana's wood/wood products in the U.S market. Office of Sustainable Development, USAID Africa Bureau. pp. 8 - 133.
4. Addae-Mensah, A. G. and Ayarkwa, J. (1998) Some Machining Qualities Of Selected Lesser-Used Timber Species Of Ghana. *Ghana J. of Forestry*, Vol. 6, 8-14.
5. Addae-Wireko, L. (2008) Mapping distribution of butterflies in Central Bobiri Forest and investigation of logging and stage of regeneration on butterfly species richness and diversity Reserve. MSc Thesis. International Institute for Geo-information Science and Earth Observation (The Netherland) and Kwame Nkrumah University of Science and Technology (Ghana).
6. Adebara, S. A., Hassan, H., Shittu, M. B. and Anifowose, M. A. (2014) Quality and Utilization of Timber Species for Building Construction in Minna, Nigeria. *The International Journal of Engineering and Science*, 3 (5): 46-50.
7. Adekunle, V. A. J., Olagoke, A. O. and Ogundare, L. F. (2013) Timber Exploitation Rate in Tropical Rainforest Ecosystem of Southwest Nigeria and its implications on Sustainable Forest Management. *Applied Ecology and Environmental Research*, Vol. 11(1): 123-136.
8. Adeniyi, I. M, Areghan, S. E., Alao, O. J., Salaudeen, G. T. and Falemara, B. C. (2012) Deposits in Wood Micro-Structures of Some Wood Species. *Mediterranean Journal of Social Sciences*, Vol. 3(15), 203-208.
9. Adeniyi, I. M., Adebagbo, C. A., Oladapo, F. M. and Ayetan, G. (2013) Utilization of Some Selected Wood Species in Relation to their Anatomical Features. *Global Journal of Science Frontier Research - Agriculture and Veterinary*, Vol. 13(9), 21-27.
10. Adupong, R. (2011) Strategies for the Protection and Promotion of Local Manufactured Furniture in Ghana. Report on research commissioned by Wood Workers Association of Ghana-Western Region (Wwag-Wr) For the Busac Project. 31 pp.
11. Agyarko, T. (2001) Forestry Outlook Study for Africa (FOSA) – Ghana. 2nd Draft Report, Ministry of Lands and Forestry. 49 pp.
12. Agyeman,V. K., Appiah, S. K., Siisi-Wilson, E., Ortsin, G. and Pattie, D. (1999) Timber harvesting in Ghana: a review of ecological impacts and potentials for increased harvesting of timber resources. *Ghana Journal of Forestry*, Vol. 7, 1-14
13. Aicher, S., Reinhardt, H. W. and Garrecht, H. (2013) Materials and Joints in Timber Structures: Recent Developments of Technology. Springer Science & Business Media, 855 pp.
14. Albin, R., Muller, M., Scholze, H. (1987) Investigations on the strength of corner joints in case-type furniture. *Holz als Roh- und Werkstoff*, Vol. 45(5), 171–8.
15. Alex, C. W. and Regis, B. M. (2005) Structure and function of wood. In: Handbook of Wood Chemistry and Wood Composites. R. M. Rowell (ed.) CRC Press, 487 pages.
16. Alexander, J. D. (1994) Making a chair from a tree: an introduction to working green wood. Fine woodworking.com (accessed on 20/08/15).

17. Ali, A. C., Uetimane Jr., E., Råberg, U. and Terziev, N. (2011) Comparative natural durability of five wood species from Mozambique. Int. Biodeterior. Biodegradation, 65, (6), 768-776

18. Ali, C. A. (2011) Physical-Mechanical Properties and Natural Durability of Lesser Used Wood Species from Mozambique. Thesis (PhD). Swedish University of Agricultural Sciences. 60 pp.

19. Altun, S., Burdurlu, E and Kilic, M. (2010) Effect of adhesive types on the bending moment capacity of miter frame corner joints. *BioResources*, Vol. **5**(3), 1473–1483.

20. Ametsistsi, G. K. D., Kyereh, B., Duah-Gyamfi, A. and Agyeman, V. K. (2009) Quality control and Standardization of Ghanaian Wood Products. Identify local market requirements for timber and wood Products and priority areas for standards and grading rules development. ITTO Project PD 318/04 Rev. 2. (I) (Activity 2.2).

21. Anderson, L. O. (2002) Wood-Frame House Construction. New York: The Minerva Group Inc. 236 pp.

22. Anderson, T. L. and Anderson, T. L. (2005) Fracture Mechanics: Fundamentals and Applications, Third Edition. CRC Press. 640pp.

23. Antwi-Boasiako, C. (2004). Assessment of Anatomy, Durability and Treatability of Two Tropical Lesser-Utilized Species and Two Related Species from Ghana. PhD Thesis. The University of Reading. UK. 319pp.

24. Antwi-Boasiako, C. and Atta-Obeng, E. (2009) Vessel-Fibre Ratio, Specific Gravity and Durability Of Four Ghanaian Hardwoods. *J Sci and Technol*, 29, (3), 8-23.

25. Antwi-Boasiako, C. and Ayimasu, A. (2012) Inter-family variation in fibre dimensions of six tropical hardwoods in relation to pulp and paper production. *Pro Ligno*, Vol. 8(2), 19-36. **26.** Antwi-Boasiako, C. and Baidoo, A. H. (2010) Accelerated Field Durability Assessment of Two Non-durable Timbers (Ceiba pentandra (L) Gaertn. And Celtis Milbraedii Engl.) Impregnated with Natural and Inorganic Preservatives. *J Sci and Technol*, 30, (1), 18-29

27. Antwi-Boasiako, C. and Boadu, B. K. (2013) Swelling characteristics of conventional and organic preservative-treated porous tropical utility hardwood [*Ceiba pentandra* (l.) gaertn.], *Special Topics & Reviews in Porous Media - An International Journal*, 4(2), 137-145.

28. Antwi-Boasiako, C. and Pitman, A. J. (2009) Influence of density on the durabilities of three Ghanaian timbers. *Journal of Science and Technology,* Vol. 29(2), 34-45.

29. Anwar, U. M. K., Paridah, M. T., Hamdan, H., Latif, A. M. and Zaidon, A. (2005) Adhesion and bonding of plybamboo manufactured from *Gigantochloa scortechinii*. *American Journal Applied Science*, 5:52-58.

30. Appiah-Kubi, E., Adom-Asamoah, M., Frimpong-Mensah, K. and Tekpetey, S. L. (2011) Capacity of sawmills and carpentry workshops for processing Lesser Used Species (LUS) in Ghana. *Ghana J. Forestry*, Vol. 27(3), 63-70.

31. Arango, R. A., Green, F., Hintz, K., Lebow, P. K, and Miller, R. B. (2006) Natural durability of tropical and native wood against termite damage by Reticulitermes flavis (Kollar). *Int. Biodeterior. Biodegradation*, 57, 146-150.

32. Arowosoge, O. G. E. and Tee, N. T. (2010) Evaluation of Consumers' Choice of Wooden Dining Furniture in Southwestern Nigeria: A Market Strategy for Furniture Manufacturers and Marketers. *Afri J Biotechnol*, 9, (21), 3109-3115

33. Arya, C. (2009) Design of Structural Elements: Concrete, Steelwork, Masonry and Timber Designs to British Standards and Eurocodes, Third Edition. CRC Press, 504 pp.

34. Asafu-Adjaye, O. (2012) Characterization of the physico mechanical properties of the different zones of Borassus aethiopum (Mmaa Kube). MPhil Thesis. Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. 229 pp.

35. Asafu-Adjaye, O. A., Frimpong-Mensah, K. and Darkwa, N. A. (2013) Assessment of the effects of density on the mechanical properties variations of *Borassus aethiopum*. *Arch. Appl. Sci. Res.*, 5 (6):6-19.

36. Asamoah, A., Atta-Boateng, A. and Sarfowaa, A. (2012) *Intsia bijuga* (Colebr.) *In*: R. H. M .J. Lemmens, D. Louppe, & A. A. Oteng-Amoako (eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Available from: http://www.prota4u.org/search.asp (accessed on 17/02/15).

37. Asamoah, A., Atta-Boateng, A., Frimpong-Mensah, K. and Antwi-Boasiako, C. (2011) Efficacy of extractives from parts of Ghanaian Pawpaw, Avocado and Neem on the durability of Alstonia. Afri J Environ Sci and Technol, 5, (2), 131-135.

38. Ashaduzzaman, M., Das, A. K., and Shams, M. I. (2011) Natural Decay Resistance of Acacia auriculiformis Cunn. ex. Benth and Dalbergia sissoo Roxb. *Bangladesh J. Sci. Ind. Res*., 46, 225230.

39. Asomani, J. (2009) The performance of dovetail halving joint in Leg-and rail construction using *Chrysophyllum albidum*. Case study: the working chair. M.Phil Thesis, Kwame Nkrumah University of Science and Technology, Kumasi. 71pp.

40. ASTM D 1037 – 06a (24) (2006) Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. Linear Expansion with change in Moisture Content. American Standard for Testing Materials, 2006.

41. Atar, M., Ozcifci, A., Altinok, M and Celikel, U. (2009) Determination of diagonal compression and tension performances for case furniture corner joints constructed with wood biscuits. *Materials and Design*, Vol. 30, 665–670.

42. Attah, N. A. (2014) The contribution of forests to the economy of Ghana. http://www.fornis.net/system/files/users/Contribution_of_forests.pdf (accessed on 1/10/15).

43. Australian Durability Standard (2005) Timber—Natural durability ratings. AS 5604. Standards Australia. 26pp.

44. Ayarkwa, J. (1998) New marketable Ghanaian timber Species for furniture and construction. *Wood News*, pp. 13-18.

45. Bajwa, S. G., Bajwa, D. S., Holt, G. D., Coffelt, T. and Nakayama, F. (2011) Properties of thermoplastic composites with cotton and guayule biomass residues as fiber fillers. *Industrial Crops and Products*, 33, 747–755.

46. Baker, T. L. (1994) Doing Social Research (2nd edn.). New York: McGraw-Hill Inc. 525 pp.

47. Barany, M., Hammett, A. L. and Araman, P. A. (2003) Lesser used species of Bolivia and their relevance to sustainable forest management. *Forest Products Journal*. Vol. 53(7/8), 28-33.

48. Barboutis, O. and Vassiliou, V. (2008) Bondability of Chestnut wood with PVAC adhesives for furniture production. In: *Proceeding from International Conference of Nábytok 2008*.

49. Barnett, J. R. and Jeronimidis, G. (2003) Wood Quality and its Biological Basis. Blackwell Publishing Ltd. Oxford. 240 pp.

50. Baylor, C. (2009) Wood Joinery Types, Various Methods for Connecting Wood. http://woodworking.about.com/od/joinery/tp/JoineryHub.htm (accessed 12/07/13).

51. Beckwith, J. (1998) Durability of Wood. University of Georgia School of Forest Resources.www.warnell.forestry.uga.edu (accessed 30/10/09).

52. Beery, W. H, Ifju, G., and Mclain, T. E. (1983) Quantitative wood anatomy-relating anatomy to transverse tensile strength. *Wood Fiber Sci*., Vol. 15(4), 395–407.

53. Bekhta, P. and Niemz, P. (2009) Effect of relative humidity on some physical and mechanical properties of different types of fibreboard. *European Journal of Wood Products*, 67(3), 339-342.

54. Bektaş, İ., Güler, C. nd Baştürk, M. A. (2002) Principal Mechanical Properties of Eastern Beech Wood (Fagus orientalis Lipsky) Naturally Grown in Andırın Northeastern Mediterranean Region of Turkey. *Turk. J. Agric. For.*,Vol. 26, 147-154.

55. Biggs, R. P. (2013) 10 reasons to go international. http://choosewashingtonstate.com/wpcontent/uploads/2013/06/10_Reasons_to_go_International.pdf (accessed on 10/05/2015).

56. Binggeli, C. (2008) Materials for Interior Environments. John Wiley & Sons. 339 pages.

57. Bioversity International (2009) Forest genetic resources conservation and management: status in seven South and Southeast Asian countries. 151 pp.

58. Boampong, E., Effah, B., Antwi, K., J. N. Asamoah and A. B. Asante (2015) Factors influencing the choice of timber for furniture and joinery production in Ghana. *European Journal of Engineering and Technology*, Vol. 3(5), 48-59.

59. Bonney, E. K. (1998) The impact of the promotion of six lesser-used species on Ghana's timber trade and industry. MSc thesis, Kwame Nkrumah University of Science and Technology, Kumasi.

60. Boon-Kwee, Ng and Thiruchelvam, K. (2012) The dynamics of innovation in Malaysia's wooden furniture industry: Innovation actors and linkages. *Forest Policy and Economics*, 14, 107–118.

61. Borota, J. (1991) Tropical forests, some African and Asian case studies of composition and structure. *Development in agriculture and management*, Vol. 22, 1-274.

62. Bosman, M. T. M., Kort, I. de, Genderen, M. K. van and Baas, P. (1994) Radial variation in wood properties of naturally and plantation grown light red meranti (*Shorea*, Dipterocarpaceae). *IAWA Journal*, Vol. 15(2), 111-120.

63. Boulton, R. B., Singleton, V. L., Bisson, L. F. and Kunkee, R. E. (2013) Principles and Practices of Winemaking. Springer Science & Business Media, 604 pp.

64. Boyd, J. D. (1977) Relationship between fibre morphology and shrinkage of wood. *Wood Science and Technology*, Vol 11(1), 3-22.

65. Boyes, W. and Melvin, M. (2015) Microeconomics. Cengage Learning, 528 pp.

66. Boyce, S. G., Kaeiser, M., and Bey, C. F. (1970) Variation of some wood features in five walnut trees. *For. Sci*., Vol. 16(1), 95–100.

67. British Standard Institution (1957) BS 373: Methods of testing small clear specimens of timber.

68. Brod, A. (2009). The Survival of the Furniture Industry? NHFA's Home Furnishings Retailer. Nov. /Dec. 2009, 37. *https://libres.uncg.edu/ir/uncg/f/A_Brod_TheSurvival_2009.pdf* (accessed on 10/11/15).

69. Brokaw, N. (2012) A Caribbean Forest Tapestry: The Multidimensional Nature of Disturbance and Response. OUP USA, 460 pp.

70. BS 5268-2 (2002) Structural use of timber. Code of practice for permissible stress design, materials and workmanship.

71. BS EN 252 (2014) Field Test Method for Determining the Relative Protective Effectiveness of a Wood Preservative in Ground Contact. European Committee for Standardisation. 28pp.

72. BS EN 338 (2009) Structural timber. Strength classes. 14pp.

73. Budu-Smith, J. (2005) The Need for Polytechnics to Assert and Create a Niche for Themselves among Tertiary Institutions in Human Resource Development. *Journal of Polytechnics in Ghana*, Vol. 1(1), 14-22.

74. Cai, L. and Wang, F. (1993) Influence of the stiffness of corner joint on case furniture deflection. *Holz als Roh- und Wekstoff*; Vol. 51, 406–8.

75. Callister, W. D. and Rethwisch, G. D. (2012) Fundamentals of Materials Science and Engineering: An Integrated Approach. John Wiley & Sons. 910 pp.

76. Canadian Wood Council (1991) Wood Reference Handbook: A guide to the Architectural Use of Wood in Building Construction, Ottawa, Ontario Canada. 561pp.

77. Carli, L. and Passarelli, R. (2012) Dimensional Changes in Wood. Available from: http://woodchanges.com/ (accessed on 11/09/14).

78. Carlquist, S. (2009) Xylem heterochrony: an unappreciated key to angiosperm origin and diversifications. *Bot. J. Linn. Soc.* 161(1), 26–65.

79. Castro, G. and Paganini, F. (1997) Parameters affecting end finger joint performance in Poplar wood. In: *Proceedings of International Conference of IUFRO S 5.02 Timber Engineering*, 10pp.

80. Cel consulting (2010) Raw material shortage in furniture export sector. http://www.celconsulting.com/en/category/market-news/Raw-material shortage-in-furniture%20export-sector) (accessed on 10/07/15).

81. Center for Industrial Studies (CSIL) (2010) World Furniture Outlook 2010/2011. http://www.newsabahtimes.com.my/nstweb/fullstory/36916/ (accessed on 23/07/2015).

82. Center for International Forestry Research (1996) Current Issues in Non-Timber Forest Products Research. *In* Pérez R. M. and Arnold, J. E. M. (eds.). Indonesia: CIFOR. 275 pp.

83. Centre for the Promotion of Imports from Developing Countries (2015) CBI Product Factsheet: Tropical timber furniture components in Italy. http://www.cbi.eu/sites/default/files/study/productfactsheet-tropical-timber-furniture components-italy-2014.pdf (accessed on 14/08/15).

84. Chan, Y. (2002) Classic joint with power tools. Lark Books. 174 pp.

85. Chang, S. T., Wang, J-H., Wu, C. L., Chen, P. F. and Kuo, Y. H. (2000) Comparison of the Antifungal Activity of Cadinane Skeletal Sesquiterpenoid from Taiwania (Tawania Crypromerioides Hayara) heartwood. Holzfor, 54, (3), 241-245.

86. Chaowana P. (2013) Bamboo: An Alternative Raw Material for Wood and Wood-Based Composites. *Journal of Materials Science Research*, Vol. 2(2), 90-102.

87. Chernyh, M., Kargashina, E. and Štollmann, V. (2013) Assessing the impact of aesthetic properties characteristics on wood decorativeness. *ACTA FACULTATIS XYLOLOGIAE ZVOLEN*, Vol. 55(1), 21−26.

88. Choong, E. T., Roliadi, H. and Chin, Y. H. (2000) Wood properties of the Dipterocarpaceae. www.forestry.sarawak.gov.my/forweb.com (accessed on 11/06/15).

89. Chowdhury, Md Q., Ishiguri, F., Hiraiwa, T., Matsumoto, K., Takashima, Y., Iizuka, K., Yokota, S. and Yoshizawa, N. (2012) Variation in anatomical properties and correlations with wood density and compressive strength in *Casuarina equisetifolia* growing in Bangladesh. *Australian Forestry*, Vol. 75(2), 95–99.

90. CIRAD Forestry Department, (2008) Eveuss. [Internet] Tropix 6.0. http://tropix.cirad.fr/africa/eveuss.pdf. (accessed on 12/12/2012).

91. Collardet, J. (1976) Processing hard-to-process and lesser used species. Unasylva, Vol. 28(112-3), 93-105.

92. Connell, M. 1991. Industrial Wood Preservatives - The History, Development, Use, Advantages and Future Trends In R. Thompson (ed.), The chemistry of wood preservation. The Royal Society of Chemistry, Cambridge,16-33.

93. Conner, A. H. (1996) Urea Formaldehyde Adhesive Resins. Forest Products Laboratory, USDA Forest Service, Madison, Wisconsin, USA, 1-8.

94. Cookson, L. J. and McCarthy, J. K. (2013) Influence of Tree Age and Density on the Above ground Natural Durability of Eucalypt species at Innisfail. *Aust For*, Vol. 76(3-4), 113- 120.

95. Corbett, S. (2003) The practical woodworker. Hermes House. 256 pp.

96. Cordero, L. D. P. and Kanninen, M. (2002) Wood density and aboveground biomass of *Bombacopsis quinata* plantations in Costa Rica. *Forest Ecology and Management*, 165, 1–9.

97. Coulson, J. (2011) Wood in Construction: How to Avoid Costly Mistakes. John Wiley & Sons. 208 pp.

98. Cox, M. (2004) Domestic And Export Marketing Prospects For Small-Scale Growers In North Queensland. *Proceedings of the Conference on marketing of farm-grown timber in tropical North Queensland at the University of Queensland*, Brisbane, Australia on 18 June 2003, 149-155.

99. Cubbage, F. W., New, B. D. and Moulton, R. J. (1996) ―Evaluations of technical assistance programs for nonindustrial private forest landowners.‖ in *Proceedings: Symposium on Nonindustrial Private Forests: Learning from the Past, Prospects for the Future*. Minnesota Extension Service. St. Paul, MN: University of Minnesota, 367–376.

100. Czichos, H., Saito, T. and Smith, E. L. (2011) Springer Handbook of Meteorology and Testing. Springer, 1500 pp.

101. Dadzie, P. K., Amoah, M. and Tekpetey, S. L. (2014) Preliminary assessment of wealth creation in wood products' business in Ghana: The perspective of lumber and furniture production and implications for entrepreneurship. *International Journal of Business and Economics Research*, Vol. 3(6), 243-249.

102. Danawade, B. A., Malagi, R. R. and Mulla, A. I. (2012) Study of Effect of Tolerance on Flexural Strength of Wood Reinforced Steel Tube. *International Journal of Engineering and Innovative Technology* (IJEIT), Volume 2, Issue 1, 156-163.

103. Davis, E. M. (1962) Machining and Related Characteristics of United States Hardwoods. Technical Bulletin No. 1267.

104. Davis, R. (2005) Design & Technology. Letts and Lonsdale. 160 pp.

105. de Lima, I. L., Longui, E. L., Freitas, M. L. M., A. C. S. Z., Zanata, M., Florsheim, S. M. B., Bortoletto Jr., G. (2014) Physical-Mechanical and Anatomical Characterization in 26-Year-Old Eucalyptus resinifera Wood. *Floresta e Ambiente*, Vol. 21(1), 91-98.

106. Derikvand, M. and Ebrahimi, G. (2014) Strength performance of mortise and loose-tenon furniture joints under uniaxial bending moment. *Journal of Forestry Research*, Vol. 25(2), 483486.

107. Derkyi, N. S. A., Bailleres, H., Chaix, G., Thevenon, M. F., Oteng-Amoako, A. A and Adu Bredu, S. (2009) Colour variation in teak (*Tectona grandis*) wood from plantations across the ecological zones of Ghana. *Ghana J. Forestry*, Vol. 25, 40-48.

108. Derome. D., Griffa, M., Koebel, M., Carmeliet, J. (2011) Hysteretic swelling of wood at cellular scale probed by phase-contrast X-ray tomography. *Journal of Structural Biology*, 173, 180–190

109. Desch, H. E and Dinwoodie, J. M. (1996) Timber: Structure, properties, conversion, and use. 7th ed.
New York: Food Products Press, 320 pp.

110. DFID Human Development Resource Centre 2012. Helpdesk Report: Desk Construction Materials and their Longevity. http://www.heart-resources.org/wp-content/uploads/2012/05/DeskConstruction-Materials-Febraury-2012.pdf?577b65 (accessed on 18/11/14).

111. Dickson, W. C. (2000) Integrative plant Anatomy. Academic press. 533 pp.

112. Dilik, T., Dündar, T.,Kurtoğlu, A. and Hiziroglu, S. (2007) Effect of adhesive types on some of the properties of laminated window profiles. *Journal of Materials Processing Technology*, 189(1–3), 320–324.

113. Dinh, H. T., Rawski, T. G., Zafar, A., Wang, L. and Mavroeidi, E. (2013) Tales from the Development Frontier: How China and Other Countries Harness Light Manufacturing to Create Jobs and Prosperity. World Bank Publications, 552 pp.

114. Dinwoodie, J. M. (2002) Timber: Its Nature and Behaviour, Second Edition. CRC Press, 272 pp.

115. Discovery Communications (2013) A Guide to Furniture Woods, http://tlc.howstuffworks.com/home/guide-to-furniture-woods-ga.htm (accessed on 9/03/14).

116. Donovan, G. and Nicholls, D. L. (2003) Consumer preferences and willingness to pay for character marked cabinets from Alaska birch. *Forest Prod. J*., Vol. 53(11/12), 27–32.

117. dos Santos, C. L., Morais, J. J. L. and de Jesus A. M. P. (2015) Mechanical behaviour of wood T joints. Experimental and numerical investigation. *Frattura ed Integrità Strutturale*, Vol. 31, 23-37.

118. Doumenge, C. & Séné, V.O. (2012) *Lophira alata* Banks ex C.F.Gaertn. *In*: R. H. M. J. Lemmens, D. Louppe & A. A. Oteng-Amoako (eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Available from: <http://www.prota4u.org/search.asp> (accessed on 4/03/15).

119. Draycott, T. (2012) Structural Elements Design Manual. Routledge, 244pp.

120. Drayse, M. H. (2008) Globalization and Regional Change in the U.S. Furniture Industry. Growth and Change, Vol. 39(2), 252–282.

121. Dupont, W. (1963) Rationalization of glued joints in the woodworking industry. *Modeern Holzverarbeitung*, Vol. 30, 176-180.

122. Duvall, C. S. (2011) Ceiba pentandra (L.) Gaertn. [Internet] Record from Protabase. Brink, M. & Achigan-Dako, E.G. (Editors). PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. www.database.prota.org/search.htm (Accessed 27/01/2015).

123. Eastin, I., Addae Mensah, A. G and Appiah, S. K. (2003) ―The Marketing of Lesser Used Timber Species‖, *Proceeding of the XX IUFRO Conference*, University of Helsinki, Department of Forest Economics, Helsinki, Finland. Publication No 4, 23-31.
124. Eaton, R. A. and Hale, M. D. C. 1993. Wood Decay, Pest and Production. Chapman and Hall. London. U.K., Madison, No. 217. 28pp.
125. Eckelman, C. A. (1978) Strength Design of Furniture. Tim Tech. Inc.. 231 pp.
126. Eckelman, C. A. (1998) The Shrinking and Swelling of Wood and Its Effect on Furniture. Purdue University Cooperative Extension Service, 26 pp.
127. Eckelman, C. A. (2003) Textbook of product engineering and strength design of furniture. West Lafayette (IN): Purdue University Press.
128. Eckelman, C. A., Erdil, Y., Haviarova, E. (2006). Effect of shoulders on bending moment capacity of round mortise and tenon joints. *Forest Prod J*, Vol. 56, 82–86.
129. Eckelman, C. and Haviarova, E. (2006) Performance tests of school chairs constructed with round mortise and tenon joints. *Forest Prod. J*. Vol. 56(3), 51-57.
130. Eckelman, C., Haviarova, E., Zhu, H. and Gibson, H. (2001) Considerations in the design and development of school furniture based on local resources. *Forest Prod. J.* Vol. 51(6), 56-63.
131. Edlund, M. L., Evans, F., Henriksen, K. and Nilsson, T. (2006) Testing Durability of Treated Wood according to EN 252: Interpretation of Data from Nordic Test fields. Stockholm: The International Research Group on Wood Protection (The International Research Group on Wood Protection. Document IRG/WP 06-20341).
132. Edwards, C. (2012) Through, lapped or blind: the dovetail joint in furniture history. *In*: Proceedings of the 10th International Symposium for wood and furniture conservation: Reproduction and Reconstruction in Furniture Conservation, Amsterdam, The Netherlands, November 2010.
133. Effah, B. and Osei, J. K. (2014) Development of Kiln-Drying Schedules for two lesser-known timber species in Ghana. *Journal of Science and Technology*, Vol. 6(1), 67-76.
134. Effah, B., Antwi, K., Adu, G. and Boampong, E. (2013). The Safety Culture of Artisans at the Sokoban Wood Village Enclave, Ghana. *American International Journal of Contemporary Research*, 3(12): 121-128.
135. Eiki, M. (2012) *Mechanical Design for 3D Printing - Dovetail Joints.* http://eikimartinson.com/engineering/3dparts/#dovetail. *(accessed on 27/10/15).*
136. Engelund, E. T., Thygesen , L. G., Svensson, S. and Hill, C. A. S. (2013) A critical discussion of the physics of wood–water interactions. *Wood Science and Technology*, 47, 141–161.
137. Erdil, Y. Z., Kasal, A., Eckelman, C. A. (2005) Bending moment capacity of rectangular mortise and tenon furniture joints. *Forest Prod. J.*, Vol. 55(12), 209-213.
138. Erfurth, T. (1976) Product development and the choice and effective application of promotional measures to advance the wider use of products from the tropical moist forest. FAO, Rome. http://www.fao.org/docrep/l2015e/l2015e04.htm (accessed on 10/09/15).
139. Essien, C., Ofori, J., Sekyere, D., Owusu, W. F. and Tekpetey, L. S. (2012) Assessing the suitability of *Ficus sur* and *Cola gigantea* as raw material for pulp and paper production in Ghana. *Annals of Biological Research*, 3(10), 4650-4656.
140. Fairham, W. (2007) Woodwork Joints; How they are Set Out, How Made and Where Used. Evans Brothers, Limited. 215 pp.

141. FAO (1998) Global fibre supply model, FAO, Rome, Italy. ftp://ftp.fao.org/docrep/fao/006/X0105E/X0105E.pdf (accessed on 13/08/15).
142. FAO (2005) Global Forest Resources Assessment 2005. www.fao.org/forestry/fra2005 (accessed on 10/02/15).
143. Faux J. (2010) Pre-Testing Survey Instruments. *Global Review of Accounting and Finance*, Vol. 1(1), pp. 100 – 111.
144. Festus, C. and Nwala, L. (2012) Extraction and Procession of Agbono cotyledon for Long Shelf-life. Acad Res Int. J, 2, (1), 139-145.
145. Fine Woodworking (2004) Designing Furniture. Taunton Press. 154 pp.
146. Florian, C. (1995) Wood Preservation student workbook. Ohio Pesticide Applicator Training. The Ohio State University Extension Bulletin 821-13. 40pp.
147. Flow Control Magazine (2015) 6 U.S. Manufacturing Subsectors With Highest Gains & Losses Over Last 10 Years. http://www.flowcontrolnetwork.com/6-u-s-manufacturing-subsectors-with-highestgains-losses-over-last-10-years/ (accessed on 5/10/2015).
148. Fonti, P.,VonArx, G., García-González, I., Eilmann, B., Sass-Klaassen, U. and Gärtner, H. (2010) Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. *New Phytol.* Vol. 185(1), 42–53.
149. Forest Products Development and Marketing Council (2014) The economic advantage of using the lesser used species of timber. http://www.stabroeknews.com/2014/business/02/21/economicadvantage-using-lesser-used-species-timber/ (accessed on 03/04/15).
150. Forest Products Development and Marketing Council of Guyana Inc. (2015) Limonaballi. http://www.fpdmcguy.org/SpeciesPages/speciespage.aspx?spid=Limonaballi (accessed on 17/02/15).
151. Forest Products Laboratory (1999) Wood handbook: Wood as an Engineering Material. General Technical Report FPL–GTR–113, US Department of Agriculture, Forest Service, Madison, USA.
152. Forest Products Laboratory (2010) Wood handbook—Wood as an engineering material. Madison, Forest Products Society: General Technical Report FPL-GTR-190. 508 pp.
153. Forest Products Research and Development Institute (FPRDI) and International Tropical Timber Organization (ITTO) (1997) Manual on the properties and uses of lesser-used species of philippine timbers. FPRDI-ITTO Project PD 47/88 Rev. 3(1). 98pp.
154. Frihart, C. R. (2005) Interaction of copper wood preservatives and adhesives. *In*: Adhesion Fundamentals: From Molecules to Mechanisms and Modelling. Proc. of 26th Annual Meeting of Adhesion Soc., Blacksburg, VA, USA, 244-245.
155. Fuwape, J. A. and Fabiyi, J. S. (2003) Correlation between fibre length characteristics and mechanical properties of *Tectona grandis* wood. *Journal of Tropical Forest Products*, 9(1&2):45-53.
156. Ghana Forestry Commission (2012) Guidebook of Some Lesser Used Timbers of Ghana. 38 pp.
157. GhanaDistricts.com (2006) Greater Accra: Climate & Vegetation. http://www.ghanadistricts.com/districts/?r=1&_=5&rlv=climate (accessed on 01/08/15).
158. Ghazoul, J. and Sheil, D. (2010) Tropical rain forest ecology, diversity, and conservation. Oxford, UK: Oxford University Press. 536 pp.

159. Gimenez, A. M. and Lopez, C. R. (2000) Anatomical features determining wood variability in *Schinopsis quebrachocolorado* (schlecht) barkl et. Meyer, (Ancardiaceae). Invest. Agraria Sistemas Recursos Forestales, 9(2):219-235.
160. Gindl, W. and Teischinger, A. (2002) Axial compression strength of Norway spruce related to structural variability and lignin content. *Composites Part A: Applied Science and Manufacturing*, 33(12), 1623–1628.
161. Glass S, Zelinka SL. (2010) Moisture Relations and Physical Properties of Wood. In: Ross R, editor. Wood Handbook. Wood handbook: wood as an engineering material: chapter 4. Centennial ed. General technical report FPL; GTR-190. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 4.1-4.19.
162. Grace, J. K. and Tome, C. H. M. (2005) Resistance of the Indonesian Woods Bangkirai (Shorea laevis) and Merbau (Instia palembanica) to Formosan Subterrenean Termite attack. Sociobiol, 45, (2), 503-509.
163. Grant, J. (2008) Promoting responsible forest trade of lesser known timber species. WWF US. 6 pp.
164. Green, D., Vonsegen, W. and Willits, S. (1995) Western hardwoods value-added research and demonstration program. USDA For. Serv. Gen. Tech. Rep. FPL-GTR-85. 43 pp.
165. Green, H. (2007) Wood: Craft, Culture, History. New York: Penguin. 464 pp.
166. Gryc, V. and Horácek, P. (2007) Variability in density of spruce (*Picea abies*[L.] Karst.) wood with the presence of reaction wood. *Journal of Forest Science*, 53(3), 129-137.
167. Gunduz, G., Korkut, S., Aydemir, D. and Bekar, I. (2009) The density, compression strength and surface hardness of heat treated hornbeam (*Carpinus betulus* L.) wood. *Maderas. Ciencia y tecnología*, 11(1), 61-70.
168. Guyana Forestry Commission (2013) Factors affecting competitiveness of tropical timber in Guyana. Strengthening market information systems to enhance trade and market intelligence in the forest sector of Guyana TMT-PD 006/11 Rev.3 (M).
169. Ha, T. (2007) Greeniology: How to Live Well, be Green and Make a Difference. Melbourne Univ. Publishing, 324 pp.
170. Hacke, U. G, Sperry, J. S., Pockman, W. T., Davis, S. D. and McCulloh, K. A. (2001) Trends in wood density and structure are linked to prevention of xylem implosion by negative pressure. *Oecologia*, Vol. 126, 457–461.
171. Hacke, U. G., Sperry, J. S., Wheeler, J. K. and Castro, L. (2006) Scaling of angiosperm xylem structure with safety and efficiency. *Tree Physiology*, Vol. 26, 689–701.
172. Hagstrom, C. (2010) Understanding Moisture Content and Wood Movement. Available from: http://www.thisiscarpentry.com/2010/09/03/moisture-content-wood-movement/ (accessed on 9/09/14).
173. Hajdarević, S. and Busuladžić, I. (2015) Stiffness Analysis of Wood Chair Frame. *Procedia Engineering*, Vol. 100, 746–755.
174. Hajdarević, S. and Martinović, S. (2014) Effect of Tenon Length on Flexibility of Mortise and Tenon Joint. *Procedia Engineering*, Vol. 69, 678 – 685.
175. Halstead, G. R. (1999) A brief History of Medieval European Joinery (www.medievalwoodworking.com/articles/joinery.html) (accessed on 19/10/15).

176. Hansen, E., Panwar, R. and Vlosky, R. (2013) The Global Forest Sector: Changes, Practices, and Prospects. CRC Press, 478 pp.

177. Harris, D. J. (1996) A Revision of the Irvingiaceae in Africa. *Bulletin du Jardin botanique national de Belgique / Bulletin van de National Plantentuin van België*. Vol. 65(1/2), 143-196.

178. Harris, T. and Pond, B., 2012. The Importance of Shear Testing in Process Design, Quality Control. Available from: http://www.qualitymag.com/articles/90413-the-importance-of-shear-testing-inprocess-design--quality-control (accessed on 9/09/14).

179. Hashim, N. (1998) An Investigation of Factors Leading to Establishing Downstream Timber Processing in Malaysia, Ph.D. Thesis, Virginia Polytechnic Institute and State University, U.S.A.

180. Haviarova, E., Eckelman, C. and Erdil, Y. (2001) Design and testing of environmentally friendly wood school chairs for developing countries. *Forest Products Journal*, 51(3), 58-64.

181. Haviarova, E., Kasal, A., Efe. H., Eckelman, C. A. and Erdil Y. Z. (2013) Effect of Adhesive type and tenon size on bending moment capacity and rigidity of T-Shaped furniture joints constructed of Turkish Beech and Scots Pine. *Wood and Fiber Science*, Vol. 45(3), 1-7.

182. Haygreen, J. G. and Bowyer, J. L. (1996) Forest Products and Wood Science, 3rd ed. Iowa State: University Press.

183. Hemsley, A. R. and Poole, I. (2004) The Evolution of Plant Physiology. Academic Press. 512 pp.

184. Hernandez, E. R. (2007) Influence of accessory substances, wood density and interlocked grain on the compressive properties of hardwoods. *Wood Science and Technology*, 41, 249–265.

185. Herren, R. (2014) Agricultural Mechanics: Fundamentals & Applications. Cengage Learning. 960 pp.

186. Hoadley, R. B. (2000) Understanding Wood: A Craftsman's Guide to Wood Technology. Taunton Press. 280 pp.

187. Hodgkinson, J. M. (2000) Mechanical Testing of Advanced Fibre Composites. Woodhead Publishing, Ltd., 132–133.

188. Huda, A. A, Koubaa, A. Cloutier, A. Hernandez, R.E and *Périnet*, P. (2012), Anatomical Properties of Selected Hybrid Poplar Clones Grown in Souther Quebec. *Bioresources* 7(3), 3779-3799.

189. Humar, M., Fabčič, B., Zupančič, M., Pohleven, F. and Oven, P. (2008) Influence of Xylem Growth Ring Width and Wood Density on Durability of Oak Heartwood. Int. Biodeterior. Biodegradation 62, 368-371.

190. Ibach, R. E. (2013) Chapter 5: Biological Properties of Wood. In: Handbook of Wood Chemistry and Wood Composites, 2nd edition. CRC press. 99-126.

191. International Agency for Research on Cancer (1995). Wood Dust and Formaldehyde. IARC Monogr Eval Carcinog Risks Hum, 62, 413 pp.

192. International Association of Wood Anatomists (IAWA) (1989) List of microscopic features for hardwood identification. IAWA Bulletin. No.10, 219-232.

193. International Tropical Timber Organisation (1997) The Database of Tropical Industrial Lesser-used Wood Species. ITTO Project PD 58/97 Rev. 1 (1), Reference Guide to Tropical Timber Species. Nagoya University Museum, Nagoya, Japan.

194. International Tropical Timber Organization (2015) Global furniture trade rises up to US$128 billion. http://www.ihb.de/wood/news/CSIL_worldwide_furniture_trade_analysis_40820.html (accessed on 13/11/15)

195. International Wood Products Association (2015) Lesser Known Species. http://www.iwpawood.org/?page=81 (accessed on 03/04/15).
196. Izekor, D. N, Fuwape, J. A and Oluyege, A. O. (2010) Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood. *Archives of Applied Science Research*, 2(6), 113-120.
197. Izekor, D. N. and Fuwape, J. A. (2011) Variations in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. *Archives of Applied Science Research*, Vol. 3(1): 83-90.
198. Jacobsen, A. L., Pratt , R. B., Davis, S. D. and Ewers, F. W. (2007) Cavitation resistance and seasonal hydraulics differ among three arid Californian plant communities. *Plant, Cell and Environment*, Vol. 30, 1599–1609.
199. Jesberger, L. A. (2007) Woodworking Terms and Joints. http://www.prowoodworkingtips.com/ (accessed on 15/10/15).
200. Jivkov, V. and Marinova, A. (2006) Ultimate bending strength and stiffness under compression test of end corner miter joints constructed of solid wood. International conference of Nábytok, ZvolenSlovakia, June 2006.
201. Johnson, G. C., Tornton, J. D., Trajstman, A. C. and Cookson, L. J., 2006. Comparative in -ground natural durability of white and black cypress pines (*Callitris glaucophylla* and *C. endlicheri*). *Australian Forestry*, 69(4), 243-247.
202. Joyce, E. and Spielman, P. (2000) Encyclopedia of Furniture Making. Sterling Publishing (NY). 519 pp.
203. Judd, J., Fonseca, F., Walker, C. and Thorley, P. (2012) Tensile strength of varied-angle mortise and tenon connections in timber frames. *Journal of Structural Engineering*, Vol. 137(5), 636-644.
204. Julian, C. C. (2014) Research Handbook on Export Marketing. Edward Elgar Publishing, 456 pp.
205. Kaiser, J. (2003) Calcerous deposits in Indian Rosewood. Available at www.thefreelibrary.co.East+India (accessed on 10/11/15).
206. Kamenicky, J. (1975) The rigidity of mortise joints in furniture constructions. *Drevarsky Vyskum*, Vol. 20(4), 197-214.
207. Kamperidou, V., Barboutis, I. AND Vassiliou, V. (2011) Correlation between bending and tension strength of corner and middle joints constructed with beech and poplar wood. *Annals of Warsaw University of Life Sciences – SGGW. Forestry and Wood Technology*, No 73, 44-50.
208. Kasal, A., Haviarova, E., Efe, H., Eckelman, C. A. and Erdil, Y. Z. (2013) Effects of adhesive type, and tenon size on bending moment capacity and rigidity of T-shaped furniture joints constructed of Turkish Beech and Scots pine. *Wood and Fiber Science*, Vol. 45(3), 1-7.
209. Kasal, B. and Anthony, W. R. (2004) Advances in in situ Evaluation of Timber Structures. *Prog. Struct. Eng Mater*, Vol. 6, 94–103.
210. Kazemifar, M. H. and Khodadadeh, Y. (2013) Factors Influencing Furniture Sales in High-Income Segments of Societ". *Key Engineering Materials*, Vol. 572, 143-146.
211. Kémeuzé, V. A. (2008) *Entandrophragma cylindricum* (Sprague). *In*: D. Louppe, A. A. OtengAmoako & M. Brink (eds). PROTA (Plant Resources of Tropical Africa/ Ressources végétales de l'Afrique tropicale). Wageningen, Netherlands. Available from: www.prota4u.org/search.asp (accessed on 16/03/2013).

212. Khatib, J. (2009) Sustainability of Construction Materials. Elsevier. USA, Maryland Heights. 900 pp.
213. Kiaei, M. and Samariha, A. (2011) Fiber dimensions, physical and mechanical properties of five important hardwood plants. *Indian Journal of Science and Technology*. Vol. 4(11), 1460-1463.
214. Killmann, W. and Fink, D. (1996) Coconut Palm Stem Processing: Technical Handbook. http://www.fao.org/docrep/009/ag335e/AG335E00.htm. (accessed on 10/08/15). 204 pp.
215. Kingsway Furniture Co. Ltd. (2009) The office furniture market demand has gradually become the main force of the market. http://www.public-seating.com/news/103.htm (accessed on 28/08/15).
216. Koch, H., Eisenbut, L. and Seim, W. (2013) Multi-mode failure of form-fitting timber connections – Experimental and numerical studies on the tapered tenon joint. *Engineering Structures*, Vol. 48, 727–738.
217. Kollmann, F. F. P. and Côté W. A. Jr. (1986) Principles of Wood Science and Technology: I Solid Wood. Springer Science & Business Media, 592 pp.
218. Korkut, S. and Guller, B., 2008. Physical and mechanical properties of European Hophornbeam (*Ostrya carpinifolia* Scop.) wood. *Bioresource Technology*, 99, 4780–4785.
219. Krausmann, F., Erb, K., Gingrich, S., Haberl, H., Bondeau, A., Gaube, V., Lauk, C., Plutzar, C. and Searchinger, D. T. (2013) Global human appropriation of net primary production doubled in the 20th century. *PNAS*, Vol. 110(25), 10324–10329.
220. Kumaran, M. K. (1999) Moisture diffusivity of building materials from water absorption measurements. *Journal of Thermal Envelope and Building Science*, Vol. 22, 349-355.
221. Kumasi Metropolitan Assembly 2006. About this metropolis. http://www.kma.ghanadistricts.gov.gh (accessed 30/1/14).
222. Kureli, I. and Altinok, M. (2011) Determination of mechanical performances of the portable fasteners used on case furniture joints. *African Journal of Agricultural Research*, Vol. 6(21), 48934901.
223. Kurjatko, S., Kúdela, J. and Lagaňa, R. (2006) Wood Structure and Properties '06. Arbora Publishers, 522 pp.
224. Landis, S. (1998) The Workbench Book. Taunton Press. 247 pp.
225. Lau, J. (1991) Solder Joint Reliability: Theory and Application, Van Nostrand Reinhold, NY. 632 pp.
226. Lead, C., Sampson, R. N., Bystriakova, N. and Barber, C. V. (2005) Timber, Fuel, and Fiber. Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group. Vol. 1, 243 pp.
227. Lei, H., Gartner, B. L. and Milota, M. R. (1997) Effect of growth rate on the anatomy, specific gravity, and bending properties of wood from 7-year-old red alder (*Alnus rubra*). *Canadian Journal of Forest Research*, Vol. 27(1), 80-85.
228. Leicester, R.H. (2001) Engineered Durability For Timber Construction. Progress In *Structural Engineering & Materials*. Vol. 3 (3):216–227.
229. Lemmens, R. H. M. J. (2008) *Khaya ivorensis* A.Chev. [Internet] Record from PROTA4U. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. <http://www.prota4u.org/search.asp>. (accessed on 28/07/15).

230. Likos, E., Haviarova, E., Eckelman, C. A., Erdil, Y. Z. and Ozcifci, A. (2012) Effect of Tenon Geometry, Grain Orientation, and Shoulder on Bending Moment Capacity and Rotational Characteristics of Mortise and Tenon Joints. *Wood and Fiber Science*, Vol. 44(4), 1-8.
231. Lim, S. C., Gan, K. S. and Choo, K. T. (2004) Identification and utilisation of lesser-known commercial timbers in Peninsular Malaysia 1: Ara, Bangkal, Bebusok and Bekoi. *Timber Technology* Bulletin. Timber Technology Centre (TTC), No. 29. ISSN: 139-258.
232. Lima, I. L., Longui, E. L., Freitas, M. L. M., Zanatto, A. C. S., Zanata, M. (2014) Physicalmechanical and anatomical characterization in 26-year-old *Eucalyptus resinifera* wood. *Floresta e Ambiente*, 21(1), 91-98.
233. Lionetto, F. and Frigione, M. (2009) Mechanical and Natural Durability Properties of Wood Treated with a Novel Organic Preservative/Consolidant Product. Mater Design, 30, (8), 3303–3307.
234. Liu, W. and Eckelman, C. A. (1998) Effect of Number of Fasteners on the strength of corner joints for cases. *Forest Prod. J.*, Vol. 48(1), 93-95.
235. Longwood, F. R. (1962) Present and Potential Commercial Timbers of The Caribbean. Agriculture Handbook No. 207. http://edicionesdigitales.info/biblioteca/caribbeanpotentialtimbers.pdf, 167pp. . (accessed on 17/11/14)
236. Louppe, D. (2008) Plant Resources of Tropical Africa: Timbers. D. Louppe; A. A. Oteng-Amoako (ed). General ed.: R. H. M. J. Lemmens. PROTA, 704 pp.
237. Love, M. E. (1950) How to make dovetail joints. *In* Githens P. (ed.) Popular Science, Vol. 156(5). 290 pp.
238. Lumbile, A. U. and Oagile, O. (2008) Pericopsis angolensis (Baker) Meeuwen. [Internet] Record from PROTA4U. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. <http://www.prota4u.org/search.asp>. Accessed 26 August 2015.
239. MacDonald, N. (2013) Woodworking. Cengage Learning. 896 pp.
240. Maguire, B. W. (1990) Cabinetmaking: From Design to Finish. Craftsman Book Company. 416 pp.
241. Mahuˈt, J. (1995) Decorative Veneer and Plywood Production. Technical University in Zvolen, Slovak Republic, Russia, pp. 155-172.
242. Malanit, P., Barbu, M. C. and Fruhwald, A. (2009) The gluability and bonding quality of an Asian bamboo *Dendrocalamus asper* for the production of composite lumber. *J. Trop.Forest Sci.*, Vol. 21(4), 361-368.
243. Mantanis, G. I., Young, R. A., and Rowell, R. M. (1994) Swelling of wood Part 1. Swelling in water. *Wood Science and Technology*, 28, 119-134.
244. Marfo, E. (2010) Chainsaw Milling in Ghana: Context, Drivers and Impacts. Tropenbos International, Wageningen, the Netherlands. xii + 64 pp.
245. Martínez-Cabrera, H. I., Jones, C. S., Espino, S., Schenk, H. J. (2009) Wood anatomy and wood density in shrubs: responses to varying aridity along transcontinental transects. *Am. J. Bot.*, Vol. 96, 1388–1398.
246. Massayuki, M., Matoski, A., Magajewski, C. and Machado, J. (2014) Shear strength parallel of the wood fiber stress by punching – proposed test. *Revista ingeniería de construcción*, 29(1), 46-60.

247. Mattheck, C., and Kubler, H. (1997) Wood - the internal optimization of trees. SpringerVerlag, Berlin, Germany. pp. 90–108.
248. McGraw-Hill Concise Encyclopedia of Bioscience. (2002) wood anatomy. The McGraw-Hill Companies, Inc, http://encyclopedia2.thefreedictionary.com/Wood+anatomy. (accessed on 17/03/15)
249. Meaden, M., Williams, J. and Simm, J. (2011) Alternative Hardwood Timbers for use in Marine and Fresh Water Construction. Environment Agency. 30pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291212/scho0411b tpp -e-e.pdf (accessed on 23/02/15).
250. Mecklenburg, M. F. (2007) Determining the acceptable ranges of relative humidity and temperature in museums and galleries, Part 1, Structural response to relative humidity. 1-57. Available from: http://si-pddr.si.edu/dspace/handle/100887055 (accessed 5/11/14).
251. Meier, E. (2014) The Wood Database. Availabile from: http://www.wood-database.com/woodarticles/crushing-strength/ (accessed on 7/10/14).
252. Mihailescu, T. (2001) An investigation of the performance of mortise and tenon joints using the finite element method. *J. of the Institute of Wood Sci*. Vol. 15(5/89).
253. Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC. 245 pp.
254. Miller, R. B. (1999) Structure of wood. In Wood handbook : wood as an engineering material. Madison, WI : USDA Forest Service, Forest Products Laboratory, 1999. General technical report FPL ; GTR-113, 2.1-2.4.
255. Miltiz, H., Michon, S. G. L., Polman, J. E. and Stevens, M. (1996) Comparison between Different Accelerated Test Methods for the Determination of the Natural Durability of Wood. IRG/WP 9620099.
256. Minford, J. D. (1991) Treatise on Adhesion and Adhesives. Vol. 7, Florida: CRC Press. 528 pp.
257. Moavenzadeh, F. (1990) Concise Encyclopedia of Building and Construction Materials. MIT Press. 682 pp.
258. Morris, S. (2014) How Strong is a Dowel Joint? https://www.canadianwoodworking.com/getmore/how-strong-dowel-joint (accessed on 27/09/15).
259. Moutinho, V. H. P., Lima, J. T., Águiar, J. O. R. de. and Nogueira, M. G. de. O. (2012) Scientific determination and wood anatomical features of species know in Brazilian Amazonia as matá-matá (Eschweilera spp.). *Rev. Cienc. Agrar*. Vol. 55(2), 134-141.
260. Moya, R., Tenorio, C. and Meyer, Í. (2012) Influence of wood anatomy on moisture content, shrinkage and during defects in *Vochysia guatemalensis* Donn Sm. *Scientia Forestalis*, Vol. 40(94), 249-258.
261. Muga, M. O., Githiomi, J. K. AND Chikamai, B. N. (1998) Anatomical and related properties of wood carving species in Kenya. A Study Undertaken for the WWF/UNESCO/KEW People and Plants Initiative. 110 pp.
262. Muga, M. O., Kalinganire, A. and Owino, F. (1992) Variation in wood density and fibre length among *Grevillea robusta* (A. CUNN EX R.BR.) families grown in western Kenya. Kenyan

Forestry Research Institute Online repository. http://10.10.20.22:8080//handle/123456789/398 (accessed on 10/08/15).

263. Muhtaman, D. R. (2009) Survey on Jepara export and furniture marketing. Research report. Annex 5, FVC Annual Report. CIFOR, Bogor, Indonesia.

264. Mukhopadyay, A. K. and Pendse, S. (1984) Profit Sharing in small business: An analysis of risk and incentive. Journal of Small Business and Entrepreneurship, Vol. 1(3), 60 pp.

265. Murata, K., and Masuda, M. (2006) Microscopic observation of transverse swelling of latewood tracheid: effect of macroscopic/mesoscopic structure. *Journal of Wood Science and Technology*, 52, 283–289.

266. Nakayama, F. S., Poo, C., Bajwa, D. S., Youngquist, J. A., Muehl, J. H., and Krzysik, A. M. (2000) Preliminary Investigation on the Natural Durability of Guayule (Parthenium argentatum)-Based Wood Products, The International Research Group on Wood Preservation, IRG/WP. 00-40154. USA.

267. Nandanwar, A., Naidu, M. V. and Pandey, C. N. (2013) Development of test methods for wooden furniture joints. *Wood Material Science & Engineering*, Vol. 8(3), 188-197.

268. Nascimento, M. S., Santana, A. L. B. D., Maranhão, C. A., Oliveira, L. S. and Bieber L. (2013) Phenolic Extractives and Natural Resistance of Wood to Biodegradation. In Chamy R. (Ed.) Life of Science. ISBN: 978-953-51-1154-2, DOI: 10.5772/56358. Available from: http://www.intechopen.com/books/biodegradation-life-of-science/phenolic-extractives-and-naturalresistance-of-wood.

269. Ncube, E., Chungu, D., Kamdem, P. D. and Musawa, K. (2012) Use of a Short Span Field Test to Evaluate Termite Resistance of Eucalyptus Grandis and Bobgunnia Madagascariensis in a Tropical Environment. BioResources, 7, (3), 4098-4108.

270. Neuwinger, H. D. (2000) African traditional medicine: a dictionary of plant use and applications. Medpharm Scientific, Stuttgart, Germany. 589 pp.

271. Ngui, K. S., Agrawal, A. and Voon, J. P. (2011) Challenges Impeding Competitiveness of the Wooden Furniture Manufacturing Industry: the Case of Furniture Industry in Sarawak, Malaysia. *Australian Journal of Basic and Applied Sciences*, Vol. 5(9), 1135-1145.

272. Niklas, J. K. (1997) Mechanical Properties of Black Locust (*Robinia pseudoacacia*) Wood: Correlations among Elastic and Rupture Moduli, Proportional Limit, and Tissue Density and Specific Gravity. *Annals of Botany*, 79, 479-485.

273. Niklas, K. J. and Spatz, H. C. (2010) Worldwide correlations of mechanical properties and green wood density. *American Journal of Botany*, 97(10):1587-94.

274. Nketiah, K. S. and Wieman, A. (2004) Chainsaw lumber production: a necessary evil? Workshop Proceedings, Tropenbos International-Ghana (2), 79 pp.

275. Nootebom, B. (1994) Innovation and diffusion in small firms. *Small Business Economics*, Vol. 6, pp. 327-347.

276. Norini, H., Rohana, A. R., Ahmad, F. P. and Mohd Parid, M. (2009) Wooden Furniture Industry Productivity, Cost of Production For Certain Selected Products, Primary Input Content and Policies For Sustainability, Forest Research Institute Malaysia and International Tropical Timber Organization, Malaysia. PD 192/03 Rev.3 (M), Technical Report No. 2.

277. Ntalos, G. A. and Grigoriou, A. H. (2002) Characterization and utilization of vine pruning as a wood substitute for particleboard production. *Industrial Crops and Products*, 16(1), 59-68.

278. Nutassey, K. N., Agyei-Boakye, I. and Quayson, E. (2014) Key Factors that Contribute to the Performance of Furniture Companies in Ghana. *Industrial Engineering Letters*. Vol.4(9), 4 pp.

279. Ocloo, J. K. and Laing, E. (2003) Correlation of Relative Density and Strength Properties with Anatomical properties of the wood of Ghana Celtis species. *Discovery and Innovation*, 15(3/4), 186-
197.

280. Odeh, O. (2005) ―The Impact of Federal Government Reform Programme on the Development of the SMEs Sector‖. A paper presented at the National Seminar on ―Facilitating Easy Accessibility to the SMEEIS Funds by SME operators. Lagos, 10 – 11, October.

281. Ofori, D. A. (2007). *Milicia excelsa* (Welw.) C.C.Berg. *In*: D. Louppe, A. A. Oteng-Amoako & M. Brink (eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Available from: <http://www.prota4u.org/search.asp> (accessed on 4/03/15).

282. Ofori, J., Brentuo, B., Mensah, M., Mohammed, A. I. and Boamah-Tawiah, R. (2009) Properties of 10 Ghanaian high density lesser-used-species of importance to bridge construction–part 1: green moisture content, basic density and shrinkage characteristics. *Ghana J. Forestry*, Vol. 25, 67 -77.

283. Ogbo, A. and Nwachukwu, A. C. (2012) The Role of Entrepreneurship in Economic Development: The Nigerian Perspective. *European Journal of Business and Management*, Vol 4(8), pp. 95 – 105.

284. Ogunwande, I. A., Essien, E. E., Ogunbinu, A. O., Adebayo, M., Karioti, A., Saroglou, V. and Skaltsa, H. (2008) Essential oil constituents of *Klainedoxa gabonensis* Pierre ex Engl. (Irvingiaceae), *Brachystegia nigerica* Hoyle et A. Jones (Caesalpinioideae) and *Acalypha segetalis* (Muell.) Arg.
(Euphorbiaceae). *Journal of Essential Oil Research*, 20(3), 211–215.

285. Ogunwusi, A. (2012a) Characterization of Wood Cellular Structures of Five Lesser Used Wood Species Growing in Nigeria. *Journal of Natural Sciences Research*, Vol. 2(7), 128-134.

286. Ogunwusi, A. A. (2012b) The Forest Products Industry in Nigeria. *African Research Review*. Vol. 6(4), Serial No. 27, 191-205.

287. Ohmura, W., Doi, S., Aoyama, M. and Ohara, S. (2000) Antifeedant Activity of Flavonoids and Related Compounds against the Subterranean Termite Coptotermes formosanus Shiraki. *J Wood Sci*, 46, (2), 149-153.

288. Ojeka, S. A. (2011) Tax Policy and the Growth of SMEs: Implications for the Nigerian Economy. *Research Journal of Finance and Accounting*. Vol. 2(2), 16-26.

289. Okon K. E. (2014) Relationships between fibre dimensional characteristics and shrinkage behavior in a 25 year old Gmelina arborea in Oluwa forest reserve, South West Nigeria. *Archives of Applied Science Research*, Vol. 6 (5), 50-57.

290. Oliveira, L. S., Santana, A. L. B. D., Maranhão, C. A., Miranda, R. C. M., Galvão de Lima, V. L. A., Silva, S. I., Nascimento, M. S., and Bieber, L. (2010) Natural Resistance of Five Woods to Phanerochaete chrysosporium degradation. Int. Biodeterior. Biodegradation, 64, (8), 711-715.

291. Oluyege, A. O. (2007) Wood: a versatile material for national development. *An Inaugural Lecture delivered at the Federal University of Technology*, Akure, on the 26th of June 2007, 4-23.

292. Opoku, F. Y. (2007) A Study of the Suitability of Selected Lesser Utilized Ghanaian Hardwoods for Outdoor Furniture. MPhil thesis. Brunel University. 160 pp.

293. Oppong, M., Owiredu, A. and Churchill, R. Q. (2014) Micro and small scale enterprises development in Ghana. *European Journal of Accounting Auditing and Finance Research*, Vol. 2(6), 84-97.

294. Örs, Y and Altınok, M. (1999) Modelling for optimisation frame and crosscut on chair design. *Turk. J. Agric. For*., Vol. 23(2), 473-547.

295. Oteng-Amoako, A. A. and Obeng, E. A. (2012) *Klainedoxa gabonensis* (Pierre) *In*: R. H. M. J. Lemmens, D. Louppe, & A. A. Oteng-Amoako (eds). PROTA (Plant Resources of Tropical Africa/ Ressources végétales de l'Afrique tropicale). Wageningen, Netherlands. Available from: www.prota4u.org/search.asp (Accessed 16 April 2013).

296. Oteng-Amoako, A., Odoom, F. K., Birikorang, G., Ghartey, K. P., Boateng Poku, O. K., Bitar, G., Cardoso, R., Kwofie, J. H. S. and Opoku, F. Y. (2008) Voluntary Partnership Agreement; Timber Industry Restructuring Group Final Report. 48 pp.

297. Owusu, J. H. (2012) Africa, Tropical Timber, Turfs, and Trade: Geographic Perspectives on Ghana's Timber Industry and Development. Lexington Books, 280 pp.

298. Oyagade, A. O. (1994) Compatibility of some tropical hardwood species with portland cement. *Journal of Tropical Forest Science* 6(4), 387-396.

299. Ozarska, B. (2009) Engineering properties of young plantation-grown Australian hardwoods for furniture production. *Forest Products Journal*, Vol. 59(No7/8), 27-30.

300. Ozcifci, A., Ayar, S., Baysal, E. and Toker. H. (2011) The effects of some impregnation parameters on modulus of rupture and modulus of elasticity of wood. *Wood Research*, 56(2), 277-284.

301. Ozkaya, K., Burdurlu, E., Ilce, A. C. and Ciritcioglu, H. H. (2010) Diagonal tensile strength of an oriented strand-board (OSB) frame with dovetail corner joint. *BioResources*,Vol. 5(4), 2690-2701.

302. Pakarinen, T. (1999) Success Factors of Wood as a Furniture Material. *For Prod J*, 49, 79-85.

303. Patel, N. (2014) Structural Stress Analysis – How Is It Important? http://www.hitechengineeringservices.com/news/structural-stress-analysis-important/
(accessed on 9/12/2015).

304. Peralta, R. C. G.; Menezes, E. B. Carvalho, A. G. Menezes, E. L. A. (2003) Feeding Preferences of Subterranean Termites for Forest Species Associated or Not to Wood Decaying Fungi. *Floresta e Ambiente*, 10, (2), 58-63.

305. Persson, K. (1997) Modelling of wood mechanical properties by a micromechanical approach. Thesis (PhD). University of Lund.

306. Pinto, I., Pereira, H. and Usenius, A. (2004) Heartwood and sapwood development within maritime pine (*Pinus pinaster Ait*) Stems. *Trees*, 18(3), 284-294.

307. Pitman, A. J., Gongora, A. and Smith, G. (1999) The Decay Resistance of Four Belizean Timbers to Fungi and the Marine Borer Liminoria tripunctata. In Proceedings of the fourth International Conference on the Development of Wood Science, 149-156, Missenden Abbey, UK, 14-16 July 1999, Wood Technology and Forestry.

308. Pizzi, A. and Mittal, K. L. (2011) Wood Adhesives. CRC Press, 452 pp.

309. Poku, K., Wu, Q. and Vlosky, R. (2001) Wood properties and their variations within the tree stem of Lesser-Used Species of tropical Hardwood from Ghana. *Wood and Fibre Science*, 33(2), 284-291.

310. Ponder, N. (2013) Consumer Attitudes and Buying Behavior for Home Furniture. Report prepared for the Furniture Outreach Program at Franklin Furniture Institute. 43 pp.

311. Poorter, L., McDonald, I., Alarco´n, A., Fichtler, E., Licona, J., Pen˜a-Claros, M., Sterck, F., Villegas, Z. and Sass-Klaassen, U. (2010) The importance of wood traits and hydraulic conductance for the performance and life history strategies of 42 rainforest tree species. *New Phytologist*, Vol. 185, 481–492.

312. Postell, J. (2012) Furniture Design. New York: John Wiley & Sons. 416 pp.

313. Puasa, F., Rahman, R. A., Ahmad, I., Fui, L. H. and Roda, J. (2010) Rubberwood timber decreasing, wither the wooden furniture industry? *EAS Strategic Options*, Vol. 2010(05), 1-2.

314. Purnomo, H., Abdullah, L. and Irawati, R. H. (2011) Systems dynamics approach to balancing wood supply and demand for sustaining furniture industry. Paper presented in 19th International Congress on Modelling and Simulation, 12-16th December 2011 at Perth, W. A. Australia, 338-344.

315. Quartey, A. G. (2009) Relationships between some anatomical, physical and durability properties of the wood of some lesser utilised Ghanaian hardwoods. PhD thesis, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. 166 pp.

316. Quinlan, P. (2011) Existing Uses and Market Development Opportunities for Naturally Regenerating Totara Timber. SFF Project (L10/145) Report For the Northland Totara Working Group. 98 pp. http://www.landcare.org.nz/files/file/343/ntwg-report-june-2011.pdf (accessed on 6/10/2015).

317. Råberg, U., Edlund, M., Terziev, N. and Land, C. J. (2005). Testing and Evaluation of Natural Durability of Wood in Above Ground Conditions in Europe – An Overview. *J. Wood Sci*, 51, (5), 429-440.

318. Rachel, R. (2012) House-building in Ancient Niya. *IDP News* Vol. 39. http://idp.bl.uk/archives/news39/idpnews_39.a4d (accessed on 26/10/2012).

319. Rahman, A. and Chattopadhyay, G. N. (2003) Estimation of Parameters for Distribution of Timber Pole Failure due to In-ground Decay; Proceedings of the 5th Operations Research Conference on Operation Research in the 21st Century, the Australian Society of Operations Research, Sunshine coast, Australia, 9-10 May, 2003.

320. Rahman, M. Md. Fujiwara, S. and Kanagawa, Y. (2005) Variations in Volume and Dimensions of Rays and their Effect on Wood Properties of Teak. *Wood And Fiber Science*, 37(3), 497 – 504.

321. Ranabijoy, D. R. S. (1993) Small Scale Industries in India: A Case Study from Assam. Mittal Publications, 240 pp.

322. Rao R. V., Sujata M., Hemavathi, T. R. (2003) Radial variation in anatomical properties of plantation grown *Tecomella undulata*. *J. Trop. Forest Prod.*, 9(1-2):68-76.

323. Ratanawilai, T., Chumthong, T. and Kirdkong, S. (2006) An investigation on the mechanical properties of trunks of palm oil trees for the furniture industry. *Journal of Oil Palm Research* (Special Issue - April 2006), 114-121.

324. Ratnasingam, J., Ioras, F. and McNulty, T. (2010) Fatigue Strength of Mortise and Tenon Furniture Joints Made from Oil Palm Lumber and Some Malaysian Timbers. *Journal of Applied Sciences*, Vol. 10, 2869-2874.

325. Ratnasingam, J., Perkins, M. and Reid, H. (1997) Fatigue: Its relevance to furniture. *Holz Roh Werkstoff*, Vol. 55, 297-300.

326. Raven, P., Evert, R. and Eichhorn, S. (1999) Biology of Plants (6th ed.). W. H. Freeman, New York. 875 pp.
327. Ravenshorst, G. J. P., Gard, W. F. and van de Kuilen, J. W. G (2013) The Importance of Characterisation and Sampling of Tropical Wood Species with regard to strength and durability classification. *HERON* Vol. 58 (2013) No. 2/3, 193-220.
328. Richter, H. G., and Dallwitz, M. J. (2009) Commercial timbers: descriptions, illustrations, identification, and information retrieval. In English, French, German, Portuguese, and Spanish. Version: 25th June 2009. http://delta-intkey.com'. (accessed on 6/06/15).
329. Rijsdijk, J. F. and Laming, P. B. (2010) Physical and Related Properties of 145 Timbers: Information for Practice. Netherlands: Springer. 380 pp.
330. Ritter, M. A., Faller, R. K., Bunnell, S., Lee, P. D. H. and Rosson, B. T. (1998) Plans for crashtested bridge railings for longitudinal wood decks on low-volume roads. Gen. Tech. Rep. FPL– GTR–107. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 12 pp.
331. Rivers, S. and Umney, N. (2007). Conservation of Furniture. UK: Routledge. 840 pp.
332. Roelof, A. A. Oldeman, T. J. P. and Alkema, K. (2013) Tropical Hardwood Utilization: Practice and Prospects. Springer Science & Business Media. 584 pp.
333. Rowell, M. R., Ibach, E. R., McSweeny, J. and Nilsson, T., 2009. Understanding decay resistance, dimensional stability and strength changes in heat-treated and acetylated wood. *Wood Material Science & Engineering*, Vol. 4(1-2), 14-22.
334. Rowell, R. M. (2005) Handbook of wood chemistry and wood composites. Florida: CRC Press. 487 pp.
335. Rowell, R. M. and Winandy, J. E. (2005) Handbook of wood chemistry and wood composites. CRC Press, Washington, DC. 47 pp.
336. Santini, N. S., Schmitz, N. and Lovelock, C. E. (2012) Variation in wood density and anatomy in a widespread mangrove species. *Trees*, Vol. 26(5), 1555-1563.
337. Saravanan, V., Parthiban, K. T., Sekar, I., Kumar, P. and Vennila, S. (2013) Radial variations in anatomical properties of *Melia dubia* cav. at five different ages. *Scientific Research and Essays* Vol. 8(45), 2208-2217.
338. Savidge, R. A. (2003) Tree growth and wood quality. *In*: Barnett, J. R. and Jeronimidis, G. (eds) Wood Quality and its Biological Basis. Blackwell Publishing, Oxford, 1-29.
339. Scholz, A., Klepsch, M., Karimi, Z. and Jansen, S. (2013) How to quantify conduits in wood? *Front. Plant Sci*. Vol. 4(56), 1-11.
340. Scholz, G., Liebner, F., Koch, G., Bues, C., Günther, B. and Bäucker, E. (2007) Chemical, anatomical and technological properties of Snakewood [*Brosimum guianense* (Aubl.) Huber]. *Wood Science and Technology*, Vol. 41(8), 673-686.
341. Schulte, A., Schöne, D. H. (1996) Dipterocarp Forest Ecosystems: Towards Sustainable Management. World Scientific. 666 pp.
342. Schultz, T. P, Thomas, N. and Nicholas, D. D. (2000) Synergistic Wood Preservatives: Terrestrial Microcosms (TMCs) and Exposure Efficacy Studies of the Synergistic Copper: Pyrithione Mixture. Wood Fiber Sci, 32(3), 346-353.
343. Schultz, T. P. and Nicholas, D. D. (2000) Naturally Durable Heartwood: Evidence for a Proposed Dual Defensive Function of the Extractives. Phytochemistry, 54(1), 47-52.

344. Scottish Wood Ltd. (2000) All about Hardwoods. http://www.scottishwood.co.uk/hardwoods.htm (accessed on 19/05/13)

345. Sedighi-Gilani, M., Vontobel, P., Lehmann, E., Carmeliet, J. and Derome, D. (2014) Liquid uptake in Scots pine sapwood and hardwood visualized and quantified by neutron radiography. *Materials and Structures*, 47(6), 1083-1096

346. Shelly, J. R. (2001) Wood: Materials for Furniture. *In*: Encyclopedia of Materials: Science and Technology, Elsevier Science Ltd, 9658–9663.

347. Sherwood, G. E. (1994) Moisture-Related Properties and the Effect of Moisture on Wood and Wood Products. *In*: Treschsel, R. H. (ed). Moisture Control in Buildings. ASTM International, 72-83.

348. Shih, C. A. (2012) Shortage of raw materials hinders furniture industry http://www.theborneopost.com/2012/07/06/shortage-of-raw-materials-hinders-furnitureindustry/#ixzz3hqB3XAMt (accessed on 6/07/15).

349. Shmulsky, R. and Jones, D. P. (2011) Forest Products and Wood Science. 6th ed. New York: John Wiley & Sons. 496 pp.

350. Shupe, T. F., Aguilar, F. X., Vlosky, R. P., Belisle, M. and A. Chavez (2005) Wood properties of selected lesser-used Honduran wood species. *Journal of Tropical Forest Science*. Vol. 17(3), 438446.

351. Siddiqi, Z. A. (2014) Mechanics of materials: 1st Edition. Help Civil Engineering Publisher. 300pp.

352. Simeone, R., *2011*. Tropical treasury: Lesser Known Species. Available from: www.nepcon.pl/newsroom/tropical-treasury-known-species (accessed on 20/10/14).

353. Smardzewski, J. (2015) Furniture Design. Springer. 649 pp.

354. Smardzewski, J. and Majewski, A. (2013) Strength and Durability of Furniture Drawers and Doors. *Materials and Design*, Vol. 10(51), 61-66.

355. Smardzewski J. and Papuga T. (2004) Stress distribution in angle joints of skeleton furniture, *EJPAU* 7(1), Available Online: http://www.ejpau.media.pl/volume7/issue1/wood/art-05.html (accessed on 9/12/15).

356. Smith, P. M. (2000) Utilization of lesser-used species as alternative raw materials for forest-based industries. International Tropical Timber Organization. 95 pp.

357. Smith, R. L., Mcdaniel, P. W. and Fell, D. (2005) Opportunities for the utilization of alternative species in secondary wood manufacturing. *Forest Prod. J.*, Vol. 55(4), 71– 77.

358. Söderbom, M., Teal, F., and Harding, A. (2006) The Determinants of Survival among African Manufacturing Firms. *Economic Development and Cultural Change*, Vol. 54(3), 533–555.

359. Sonowal, J. and Gogoi, P. K. (2010) Dimensional Stability, Thermal Degradation and Termite Resistant Studies of Chemically Treated Wood. *Int Journal of Chemistry*, 2(2), 218-225.

360. Sperry, S. J., Nichols, L. K., Sullivan, E. M. J. and Eastlack, E. S. (1994) Xylem Embolism in ringporous, diffuse-porous and coniferous trees of Northern Utah and Interior Alaska. *Ecology*, 75(6): 1736–1752.

361. Sreevani P. and Rao R. V. (2014) Variation in Basic Density and Tissue Proportions of Eucalyptus Tereticornis SM. Clones. *International Research Journal of Biological Sciences*. Vol. 3(1), 64-66.

362. Sseremba, O. E., Kaboggoza, J. R. S., Ziraba, N. Y., Mugabi, P, Banana, A. Y., Zziwa, A, Kambugu, R. K., Kizito, S., Syofuna, A., Ndawula, J. (2011) Timber management practices and timber species used by small scale furniture workshops in Uganda. *Maderas. Ciencia y tecnología*, Vol. 13 (3), 347-358.

363. Strong, J. (2011) Woodworking For Dummies. John Wiley & Sons. 384 pp.

364. Strong, J. (2013) Types of wood for woodworking. Available from: http://www.dummies.com/howto/content/types-of-wood-for-woodworking.html (accessed on 15/09/14).

365. Su, W.C. and Wang, Y. (2007) Withdrawal Properties of Single Dovetail Joints. *Taiwan J For Sci*, Vol. 22(3), 321-8.

366. Sudo, S. (2007) Wood Anatomy in Japan since its early beginnings. IAWA Journal, Vol. 28(3), 259 – 284.

367. Tai, H. H. and Sidel, M. (2012) State, Society and the Market in Contemporary Vietnam: Property, Power and Values. Routledge, 249 pp.

368. Tankut, A. N. and Tankut N. (2009) Investigations the effects of fastener, glue and composite material types on the strength of corner joints in case-type furniture construction. *Materials and Design*, Vol. 30, 4175-4182.

369. Tankut, A. N. and Tankut, N. (2005) The Effects of Joint Forms (Shape) and Dimensions on the Strengths of Mortise and Tenon Joints. *Turkish J Agric Forestry*, Vol. 29(6), 493–8.

370. Tankut, A. N. and Tankut, N. (2011) Section modulus of corner joints in furniture frames as engineering design criteria for their efficient construction. *Materials and Design,* Vol.32, 2391–2395.

371. Tankut, N. (2007) The effect of adhesive type and bond line thickness on the strength of mortise and tenon joints. *International Journal of Adhesion & Adhesives*, Vol. 27, 493–498.

372. Tankut, N., Tankut A. N. and Zor, Mustafa (2014) Mechanical properties of heat-treated wooden material utilized in the construction of outdoor sitting furniture. *Turk J Agric For*, Vol. 38, 148-158.

373. Tarlue, M. (2014) Gov't To Import Timber. http://www.dailyguideghana.com/govt-to-importtimber/ (accessed on 12/08/15).

374. Taylor, M. A., Gartner, L. B. and Morrel, J. J. (2002) Heartwood formation and Natural durability – A review. *Wood and Fiber Science*, 34(4), 587 – 611.

375. Tejada, J. J. and Punzalan, J. R. B. (2012) On the Misuse of Slovin's Formula. *The Philippine Statistician*, Vol. 61(1), 129-136.

376. Teles, C. D. M. and Valle, Â. D. (2001) Wood Structures: Acting Before Deterioration. In P. B. Lourenço and P. Roca (Eds.), Historical Constructions, Guimarães. Province of Minho, Portugal, 857-866.

377. Tettey, W. J., Puplampu, K. P. and Berman, B. J. (2003) Critical Perspectives in Politics and SocioEconomic Development in Ghana. BRILL, 451 pp.

378. Thompson, R. (1991) The Chemistry of Wood Preservation. Royal Society of Chemistry. UK. 315 pp.

379. Tout, R. (2000) A review of adhesives for furniture. *International Journal of Adhesion and Adhesives*, Vol. 20, 269-272.

380. Trevallion, D. and Strazzari, S. (2003) Design and Technology. Pascal Press, 236 pp.

381. Tsoumis, G., 1991. Science and Technology of Wood. London: Chapman and Hall. 494 pp.

382. U.S. Department of Agriculture (2011) The Encyclopedia of Wood. Skyhorse Publishing, Inc. 496 pp.

383. Uetimane Jr. E., Terziev, N. and Geoffrey, D. (2009) Wood Anatomy of Three Lesser Known Species from Mozambique. *IAWA Journal*, Vol. 30(3), 277 – 291.

384. Uetimane, Jr. E. and Ali, A. C. (2011) Relationship between mechanical properties and selected anatomical features of ntholo (pseudolachnostylis maprounaefolia. *Journal of Tropical Forest Science*, Vol. 23(2), 166–176.

385. Ulker, O., Imirzi, O. and Burdurlu, E. (2012) The effect of densification temperature on some physical and mechanical properties of Scots Pine (*Pinus sulvestris L.*). *BioResources*, Vol. 7(4), 5581-5592.

386. Unger, A., Schniewind, A. and Unger, W. (2001) Conservation of Wood Artifacts: A Handbook. Berlin: Springer. 578 pp.

387. Union of Concerned Scientists (2011) What's Driving tropical Deforestation Today? The Root of the Problem. http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/UCS_DriversofD eforestation_Chap7_Timber.pdf. 15pp.

388. United Nations (2011) World Population Prospects. The 2010 Revision. Available at http://esa.un.org/wpp/unpp/panel_population.htm (accessed on 14/12/2012).

389. Unsal, O., Ayrilmis, N. (2005) Variations in compression strength and surface roughness of heattreated Turkish river red gum (*Eucalyptus camaldulensis*) wood. *Journal of Wood Science*, 51, 405– 409.

390. Upton, D. A. J. and Attah, A. (2003) Commercial timbers of Ghana -The potential for lesser used species. Forestry Commission of Ghana. 58 pp.

391. Usher, M. B. (1975) Studies on a Wood Feeding Termite Community in Ghana, West Africa. Biotropica, 7, 217-233.

392. Van de Kuilen, J. W. G., Van Otterloo, J., Ravenshorst, G. and de Vries, P. (2014) Load carrying capacity of large mortise and tenon joints in wooden mitre gates. World Conference on Timber Engineering. Quebec City Canada, August 10-14, 2014.

393. Venmalar, D. and Nagaveni, H. C. 2005. Evaluation of Copperised Cashew Nut Shell Liquid and Neem Oil as Wood Preservatives. Institute of Wood Science and Technology. Malleswaram. Bangalore, India. IRG/WP 05-05-0368368. [on line] http://www.navimpex.com/vertinnov/fic_bdd/produits_pdf_fr_fichier/12242579720_Neem+Cashew_wood_preservative.pdf.

394. Venn, T. J. and Whittaker, K. (2003) Potential Specialty Timber Markets for Hardwoods of Western Queensland, Australia. *Small-scale Forest Economics, Management and Policy*, 2(3): 377-395.

395. Vick, C. B. (1999) Adhesive bonding of wood materials. *In*: Wood Handbook Wood as an Engineering Material. Madison, Forest Products Society, 23-76.

396. Vlosky, P. R. and Aguirre, A. J. (2001) Increasing Marketing Opportunities of Lesser Known Wood Species and Secondary Wood Products in Tropical Central America and Mexico. 63pp.

397. Wagner, T., Mulrooney, J., Shelton, T., and Petersen, C. (2009). United States Department of Agriculture Forest Service Termiticide Report – Termiticide Efficacy Results for 2008, Pest Management Professional, 27-34.

398. Wahab, R., Mustafa, T., M., Shafiqur, R., Mohammed, S. A., Othman, S., Mahmud, S. and Mat, R. M. S. (2012) Relationship between Physical, Anatomical and Strength Properties of 3-year-old Cultivated Tropical Bamboo *Gigantochloa scortechinii, ARPN Journal of Agricultural and Biological Science*, 7(10), 782-791.

399. Walford, G. B. (1997) Effect of Finger Length on Fingerjoint Performance. In: *Proceedings of Engineering our nation's future* at the IPENZ Annual Conference, 105-109.

400. Walia, Y. K., Kishore, K., Vasu, D. and Gupta, D. K. 2009. Physico-chemical Analysis of *Ceiba pentandra* (Kapok). *Int J Theor Applied Sci*, 1, (2), 115-118.

401. Walker, J. C. F. (2006) Primary Wood Processing: Principles and Practice. Springer Science & Business Media. 606 pp.

402. Walker, J. C. F., Butterfield, B. G., Harris, J. M., Langrish, T. A. G. and Uprichard, J. M. (2013) Primary Wood Processing: Principles and practice. Springer Science & Business Media. 595 pp.

403. Walter K, Paulsson M, Wackerberg E. (2009) Energy efficient refining of Black spruce TMP by using acid hydrogen peroxide: Part 1. A pilot plant study. Stockholm: SPCI; *Nordic Pulp & Paper Research Journal*, Vol. 24(3), 255-265.

404. Wan-Mohd-Nazri, W., Jamaludin, K., Rudaini, M. H., Rahim, S. and Nor, Y. M. Y. (2012) Anatomical Properties of Leucaena leucocephala Wood: Effects on Oriented Strand Board. *Research Journal of Forestry*, Vol. 6(3), 55-65.

405. Wansi, J. D., Chiozem, D. D., Tcho, A.T., Toze, F.A., Devkota, K. P., Ndjakou, B. L., Wandji, J. and Sewald, N. (2010) Antimicrobial and antioxidant effects of phenolic constituents from *Klainedoxa gabonensis*. *Pharmaceutical Biology*, Vol. 48(10), 1124–1129.

406. Ward, S. and Gilbert, S. (2001) Livelihoods among the Anloga Carpentry Cluster in Kumasi, Ghana. ITDG research report for DFID contract 745 620 007 CW 002.

407. Wengert, G. (1998) Types and Properties of Woodworking Adhesives. http://www.woodweb.com/knowledge_base/Types_and_Properties_of_Woodworking_Adhesives.ht ml (accessed on 03/04/15).

408. Wheeler, E. A. and Manchester, S. R. (2007) Review of the wood anatomy of extant Ulmaceae as context for new reports of late Eocene *Ulmus* woods. *Bulletin of Geosciences*, 82(4), 329–342.

409. Wiedenhoeft, A. C. and Miller, R. B. (2005) Structure and Function of Wood. *In*: Handbook of wood chemistry and wood composites. Rowell, R. M. (ed.). London: CRC press. 9-33.

410. Wilczyński, A. and Warmbier, K. (2003). Effect of joint dimensions on strength and stiffness of tenon joints. *Folia Forestalia Polonica* Seria B 34, 53-66.

411. Wimmer, R. (1995) Intra-annual cellular characteristics and their implications for modeling softwood density.*Wood Fiber Science*, Vol. 27(4), 413-420.

412. Winandy, J. E. (1994) Wood Properties. *In*: C. J. Arntzen (ed.) Encyclopedia of Agricultural Science. Academic Press. 549-561.

413. Woodcock, D. (2000) Wood specific gravity of trees and forest types in southern Peruvian Amazon. *Acta Amazonica*, Vol. 30, 589-599.

414. World Conservation Monitoring Centre (2012) Global Biodiversity: Status of the Earth's Living Resources. Springer Science & Business Media. 585 pp.

415. World Wildlife Fund (2015) Overview. http://www.worldwildlife.org/industries/timber (accessed on 2/11/15).

416. Xiao, H., Yali, W. and Shashi, K. (2009) The global competitiveness of the Chinese wooden furniture industry. *Forest Policy and Economics*, Vol. 11, 561–569.

417. Yang, H., Ji, C., Nie, Y. and Hong, Y. (2012) China's Wood Furniture Manufacturing Industry: Industrial Cluster and Export Competitiveness. *Forest Products Journal*, Vol. 62, 214–21.

418. Yang, M-J. and Lin, T-Y. (1986) Studies on the strength of mortise and tenon joints (I). *For. Prod. Ind*., Vol. 5(2), 41-48.

419. Yuksel, M., Yildirim, N., Kasal, A., Erdil, Y. Z.and Demirci, S. (2014) Effect of the Panel Type and Panel Thickness on Moment Resistance of Screw-Jointed Corner Joints and Stiffness of FourMember Cabinets. *BioResources,* Vol. 9(4), 6340-6349.

420. Zhang, J. L. and Eckelman, C. A. (1993) The bending moment resistance of single-dowel corner joints in case construction. *Forest Prod J*, Vol. 43(6), 19–24.

421. Zhang, S. Y. (1997) Wood specific gravity mechanical property relationship at species level. *Wood Sci Tech*, Vol. 31, 181-l 91.

422. Zhou, J., *Fu, W., Qing, Y., Han, W., Zhao, Z. and Zhang, B.* (2015) Fabrication and Performance of a Glue-Pressed Engineered Honeycomb Bamboo (GPEHB) Structure with Finger-jointed Ends as a Potential Substitute for Wood Lumber. *BioResources,* 10(2), 3302-3313.

423. Zhu, Y., Wang, W. and Cao, J. (2014) Improvement of Hydrophobicity and Dimensional Stability of Thermally Modified Southern Pine Wood Pretreated with Oleic Acid. *BioResources*, 9(2), 24312445.

424. Ziemińska, K., Butler, D. W., Gleason, S. M., Wright, I. J. and Westoby, M. (2013) Fibre wall and lumen fractions drive wood density variation across 24 Australian angiosperms. AoB PLANTS, Vol. 5, 1-14.

425. Zikmund, W. G. (2003) Business Research Methods, 7th. edn, Thomson/SouthWestern, Ohio. 748 pp.

426. Zimmermann, M. H. (1982) Functional xylem anatomy of angiosperm trees. *In*: P. Baas (ed.), New perspective in wood anatomy Vol. 1, 59-70.

427. Zobel, B. J. and Jett, J. B. (1995) Genetics of Wood Production. New York: Springer-Verlag. 337 pp.

428. Zwerger, K. (2012) Wood and Wood Joints: Building Traditions of Europe, Japan and China. Berlin: Walter de Gruyter. 304 pp.

429. Zziwa, A., Bukenya, M., Sseremba, O. E. and Kyeyune, R. K. (2006) Non-traditional tree species used in the furniture industry in Masaka District, central Uganda. *Uganda Journal of Agricultural Sciences*, Vol. 12(1), 57-66.

APPENDICES

Appendix A: Questionnaire for wooden furniture manufacturers

Dear participant, I am grateful to you for taking time to respond to this survey. Your answers will be coded for computer analysis. The purpose of this assignment is to explore furniture joint configuration types employed by manufacturers. At no time will your name be released or associated with your responses. There are no foreseeable risks to you as a participant in this study, nor are there any direct benefits. However, your participation is extremely valued.

PART A:

1. Size of company a. Small scale [ ] b. Medium scale c. Large enterprise [ ] d. others (specify)……………………………………………
2. Location of Shop/Company a. Accra [ ] b. Kumasi [ ]
3. Furniture product(s) manufactured? a. Office chairs and tables [ ] b.. Living room and dining hall furniture [ ] c. Bedroom furniture (e.g., bed, wardrobe, dressing mirror) [ ] d. Others (specify) …..…………………………………
4. Give reasons for your choice of furniture product(s). a. Profitability [ ] b. Market availability [ ] c. Ease of manufacturing [ ] d. Others (specify)…………………………
5. Where do you market your furniture products? Local/Domestic market [ ] Export/International market [ ]
   Reason(s): a. Market availability [ ] b. Profitability [ ] c. inability to meet international demand d. others (specify)………………………………………..

Choice and source of timber materials

6. List the wood species used in furniture production ……………………………………………………………………………………………
7. Give reason(s) for the choice of wood species provided. a. Availability [ ] b. Strength [ ] c. Durability [ ] d. Aesthetics [ ] e. Profitability [ ] f. Consumers choice [ ] g. Price [ ] h. Others (please specify)……………………………………
8. Where do you get wood for furniture production? a. bought from timber markets [ ] b. bought from sawmills [ ] c. bought from timber contractors directly from the forest[ ] d. others (specify) ………………………………………………………………..

9. Can you list any Lesser Utilized Species (LUS) you have ever used for furniture production? ……………………………………………………………………………………….
10. If you have never used any LUS, can you explain why?..
11. If you have used any LUS for production, what advantages did it/they have over the traditional species widely used for furniture a. High strength [ ] b. Durability [ ] c. Aesthetics [ ] d. Workability (processing, finishing etc.) [ ] e. Profitability [ ] f. Easily marketable [ ] g. Availability [ ] h. None i. other (please specify) ……………………………

Utilization of *K. gabonensis*

12. Have you ever used *Klainedoxa gabonensis* (Kroma) for furniture production? a. Yes [ ] b. No [ ]
13. If no, why? a. Species unknown [ ] b. Unavailability of the species in the market [ ] c. Difficulty to process [ ] d. Lack of technical data (properties, workability) [ ] e. Others (specify) ……………………………………………………………………….
14. If yes:
    I. How long have you been using it? a. less than 2 years [ ] b. between 2 and 5 years [ ] c. between 5 and 10 years d. over 10 years
    II. What advantage(s) do you derive from using the species for furniture? a. High strength [ ] b. beauty and durability [ ] c. ease of working [ ] d. Profitability [ ] e. Consumers preference [ ] f. others (specify) [ ]
    III. What challenges do you encounter in using the species for furniture? a. drying challenges [ ] b. difficult to saw [ ] d. poor to finishes [ ] e. others (specify) ……………………………………………………………….

Challenges faced as a furniture manufacturer

15. List the general challenge(s) you face as a furniture manufacturer? ………………………………………………………………………………………………
………………………………………………………………………………………………

PART B: Joint configuration for furniture

16. What kind of joints do you frequently use for standard office chair? Mortise and Tenon [ ] Dovetail [ ] Tongue-in-groove [ ] Others (please specify)…………………………

Reason(s): a. Consumer preference [ ] b. Cost [ ] c. Strength [ ] d. Preferred choice for furniture product manufactured [ ] d. others (specify)
……………………………………………………………………

17. Give in the tables below, the specific dimensions for mortise and tenon and dovetail joints used for standard office chair:

a. **Mortise and Tenon joint**

Parts of joint	**Leg and rail dimensions**			**Tenon dimensions**			**Mortise dimensions**		
	Thickness	Width	Length	Thickness	Width	Length	Thickness	Width	Length
Rail									
Leg									

Reason(s) for using these dimensions: …………………………………………………

b. **Dovetail joint**

Parts of joint	**Leg and rail dimensions**			**Tail dimensions**			**Socket dimensions**		
	Thickness	Width	Length	Thickness	Width	Length	Thickness	Width	Length
Rail									
Leg									

Reason(s) for using these dimensions: …………………………………………………

Choice of fastener(s)

18. What fastener(s) do you use for constructing office chair? a. Nails [ ] b. Screws [ ] c. Glue [ ] d. Others (please specify)…………………………………………………
19. Give reason(s) for the choice of fastener:..
20. If glue, what type of glue do you use? ....
21. List the advantage(s) of the glue mentioned?

....

22. What challenge(s) is/are encountered in using the glue type mentioned?

.... **Appendix B:**

Physical and mechanical properties of *K. gabonensis* and *E. cylindricum*

		Physical property		Strength property (Nmm^{-2})			
Replicate	**Timber species**	**MC (%)**	**Density (kgm^{-3})**	**MOR**	**MOE**	**Shear**	**Compressive**
				Heartwood			
1	***K. gabonensis***	43.90462	993.5849	245.1013	31382.9	24.55345	92.0669778
2		41.1547213	945.4398	176.0423	23665.52	24.53592	97.507702
3		41.2640449	961.3415	201.5461	31432.58	33.91215	87.0161427
4		43.6157864	775.8379	271.4331	36781.75	32.0369	94.1582008
5		42.9772918	806.9544	240.6298	33585.5	38.27604	79.9272512
6		42.5420778	898.5907	229.0372	34529.47	37.55748	90.3301994
7		40.2203857	859.6657	264.3119	32492.48	35.87502	103.763649
8		41.074856	1202.871	222.4128	30455.49	27.97095	89.6390325
9		41.245242	977.3892	224.7314	31217.29	28.74208	90.7378107
10		40.4980729	794.0313	197.2403	27424.84	38.38119	83.5603081
11		40.557554	899.4972	132.2719	19806.83	31.70391	88.7351988
12		38.7205387	819.9781	231.8525	36583.02	29.04001	98.358369
13		39.3762751	961.3415	169.0868	28517.86	31.31835	90.294755
14		39.1608392	819.9781	200.0556	33784.23	23.67716	78.1018617

15	39.7837223	870.7251	188.463	27921.67	34.66575	88.203532
16	39.6414343	1202.871	267.7897	37046.72	40.01108	80.6361404
17	38.6520737	945.4398	133.5802	23913.93	28.006	87.7250318
18	46.1538462	993.5849	218.4382	28468.18	37.01419	86.3072535
19	42.4971363	1161.6	202.0429	31366.34	33.8771	98.12798
20	48.7465181	870.7251	270.7707	29312.79	30.6699	100.43187
21	50.2463054	961.3415	194.0937	32012.21	39.9585	91.9252
22	51.806113	1161.6	203.0366	26398.07	38.90696	85.7755867
23	52.0598108	846.3326	205.0239	29610.88	38.38119	83.7375304
24	52.7084601	961.3415	209.3297	34165.13	29.42558	98.8014247
25	52.7846535	819.9781	238.8081	30852.95	38.03068	78.7753063
26	53.4536403	945.4398	257.8532	32774.01	32.00185	93.3075338
27	53.3882204	794.0313	226.0562	32641.53	34.06988	94.1582008
28	52.8843156	794.0313	181.0106	23367.42	42.0791	94.0518674
29	51.6525024	1034.18	207.0112	2898.157	31.54618	96.9760352
30	32.1486706	977.3892	223.5721	29991.78	34.50802	92.315089
31	31.3858696	833.1038	205.0239	24741.98	34.66575	102.558537
32	27.3035613	1223.854	267.7897	32012.21	32.43999	80.6361404
33	30.3393214	961.3415	235.4959	23533.03	29.09259	90.294755
34	31.6903295	977.3892	218.4382	20601.75	38.38119	88.203532
35	34.2055056	1182.121	209.3297	33999.52	32.24721	98.8014247

36	35	1052.026	205.0239	29710.25	35.87502	102.558537
37	35.297212	977.3892	133.5802	29610.88	30.19671	93.3075338
38	32.6993226	859.6657	240.6298	35125.66	33.8771	83.7375304
39	66.433957	819.9781	128.9597	32774.01	35.69976	78.7753063
40	44.8877147	1141.305	202.0429	30273.32	28.006	92.8644781
41	40.4980729	1182.121	229.0372	32633.25	41.55333	86.3072535
42	40.557554	833.1038	209.1641	30852.95	27.97095	85.7755867
43	38.7205387	928.7595	222.4128	32774.01	34.0874	99.1913137
44	39.3762751	819.9781	271.4331	34165.13	37.01419	98.8014247
45	39.1608392	1182.121	221.4192	28468.18	31.31835	100.43187
46	39.7837223	833.1038	201.5461	30852.95	31.70391	84.1805861
47	39.6414343	1161.6	193.9281	26000.61	40.01108	78.1018617
48	38.6520737	961.3415	251.7256	23152.13	30.79258	87.7250318
Mean	**42.0948548**	**958.0711**	**214.1586**	**29493.4**	**33.45137**	**90.577203**

Sapwood

1	42.0664207	806.9544	186.3945	30146.29	34.53556	98.1872644
2	48.2561464	945.4398	183.1301	28987.44	27.59571	71.7128455
3	43.7517791	977.3892	225.5667	28057.1	33.35709	79.5437316
4	40.8474576	806.9544	220.9966	31745.82	38.10369	66.3065222
5	39.5677473	977.3892	232.4218	29705.6	30.4764	76.6523275
6	39.2206336	977.3892	234.054	32627.2	32.32594	95.8530579
7	45.9248555	703.8556	223.2817	32529.26	28.25041	79.3329001

8	44.4718117	885.0506	267.6768	33443.28	36.67971	76.3511396
9	46.0228858	806.9544	176.1118	28285.61	33.04611	85.6879654
10	44.6573751	728.2805	250.2126	36887.17	32.70239	70.477975
11	41.8717802	819.9781	200.1048	29460.77	29.88717	84.5886294
12	41.4437734	714.8595	218.5483	34585.81	32.99701	84.4380355
13	42.1052632	794.0313	208.7553	27942.85	35.17389	73.8663392
14	43.1878113	856.519	148.6423	19129.1	35.69766	86.0644503
15	47.8014184	929.682	250.8654	31223.52	34.73197	80.5978894
16	43.9858811	806.9544	244.4999	31158.24	32.86607	89.0010326
17	40.8242829	899.4972	223.1184	28595.72	30.26362	70.2520841
18	43.3086013	794.0313	248.7436	31092.95	33.16068	95.8530579
19	45.542522	833.1038	197.3301	28775.26	29.167	66.0655719
20	46.1803561	945.4398	199.4519	32153.86	38.16916	92.6152877
21	40.6993007	1182.121	246.2953	34585.81	31.52393	86.6969449
22	58.0934695	977.3892	189.9853	26114.81	27.79212	72.0592117
23	38.2217403	977.3892	229.9736	31958	30.96743	84.0314318
24	38.9084031	977.3892	242.5413	34063.51	27.82486	77.0739906
25	46.1453744	977.3892	194.2289	26620.79	28.49593	70.1767871
26	40.035482	961.3415	185.5784	26180.1	32.73513	96.425315
27	50.1456876	1202.871	114.8562	21153	32.32594	72.9627754
28	44.1906373	945.4398	139.2736	16680.84	33.5535	70.6737472
29	47.6506198	977.3892	111.9183	18835.31	30.86922	83.850719
30	45.8863444	768.4827	118.8061	24988.61	31.24568	81.6219283

31	45.6235698	961.3415	197.8197	26653.43	33.22615	80.5978894
32	44.5462353	870.7251	200.1048	24564.25	33.04611	70.1767871
33	44.8076367	961.3415	225.5667	27143.08	28.25041	76.3511396
34	45.1161489	961.3415	184.7623	31092.95	30.4764	85.3566587
35	46.3339838	945.4398	183.4566	28775.26	35.69766	66.5775914
36	38.6363636	945.4398	214.3047	23992.98	30.96743	77.0739906
37	44.5607271	945.4398	209.4082	32953.63	28.25041	96.425315
38	41.6919262	961.3415	222.3024	34585.81	26.61366	78.1582672
39	42.2570016	2034.407	262.7803	31060.31	32.99701	66.3065222
40	42.9997228	977.3892	173.6635	17496.93	36.67971	89.0010326
41	43.9858811	833.1038	159.79	31092.95	29.33067	98.8649372
42	40.8242829	725.9384	170.2359	33296.39	32.65329	70.2520841
43	43.3086013	833.1038	214.4679	33443.28	38.16916	65.1620081
44	45.542522	1182.121	220.6702	28285.61	34.83017	97.1331066
45	46.1803561	833.1038	237.1552	32153.86	35.17389	72.0592117
46	40.6993007	1467.244	240.0931	28595.72	32.70239	95.8530579
47	58.0934695	652.8299	166.8084	29526.06	27.79212	82.179126
48	44.5607271	703.8556	194.0657	26310.67	33.16068	85.5373714
Mean	**44.1830066**	**932.343**	**203.9754**	**28932.02**	**32.21955**	**80.6684803**

Heartwood

E.							
1	***cylindricum***	39.1076115	479.3142	182.3754	9143.863	21.14566	57.6480102
2		43.5897436	498.4325	69.6509	11743.52	1.048545	71.4354155
3		35.839599	498.4325	2.749378	8856.11	19.44177	68.8074805
4		23.5682819	595.3681	113.9464	13856.58	19.17964	70.8246982
5		29.5121951	530.1515	33.90899	13214.39	18.69905	65.4207756
6		39.1076115	508.0828	183.5973	7482.802	18.45876	67.1789011
7		43.5897436	420.4918	211.0911	8179.336	10.22331	70.1954744
8		43.0079156	509.6122	39.40775	10017	17.01701	46.4515267
9		23.5682819	459.4483	91.64592	11764.51	13.41264	74.8221204
10		29.5121951	509.6122	219.0338	8911.685	16.36167	51.5778505
11		38.9542484	499.4454	217.2008	11490.34	13.41264	72.212692
12		43.4227331	449.6132	7.026187	9661.323	18.5243	63.5701172
13		42.8383706	410.9105	212.6185	6447.88	15.72818	61.0162085
14		23.4906696	350.4968	70.26187	7589.011	16.05585	51.2632386
15		29.4046173	511.3133	196.4278	7753.264	3.189324	51.0781727
16		38.9572439	405.1915	45.82296	9483.485	21.23304	59.258083
17		43.4259955	479.3142	193.0674	11732.4	15.99031	71.2688562
18		42.8416821	511.3133	62.9302	11176.66	3.12379	68.6594279
19		23.4921865	489.3463	177.1821	11017.34	19.70391	70.7506719
20		29.4067191	519.8473	98.36662	9636.623	18.17478	61.3123139
21		39.0154491	519.8473	50.40526	11164.31	17.0607	59.4061357

22	43.4893835	460.4354	44.29553	7424.757	18.58983	65.8834402
23	42.9060279	519.8473	151.2158	7438.342	18.69905	67.3639669
24	23.5216531	511.3133	200.0936	9163.622	19.92236	68.8444937
25	29.4475541	382.5358	46.12845	10992.64	17.0607	71.1208036
26	39.017252	489.9056	226.0599	11979.4	14.63594	69.0295595
27	43.4913469	498.4325	224.5325	10041.7	19.00488	51.3557715
28	42.9080211	479.3142	8.859106	10265.23	11.62137	65.3282427
29	23.5225656	459.4483	102.3379	9765.062	15.55342	72.9344488
30	29.4488189	479.3142	165.8791	14159.16	15.50973	45.5261974
31	38.8628065	555.0506	44.29553	11176.66	18.69905	74.8221204
32	43.3231397	479.3142	151.2158	9483.485	13.41264	51.2632386
33	42.7372837	401.3912	70.26187	8911.685	11.90535	72.212692
34	23.4443471	555.0506	62.9302	11380.43	15.55342	65.8834402
35	29.3404462	488.8431	98.9776	7438.342	17.01701	64.7730451
36	38.8675771	533.0261	212.6185	10523.35	13.36895	56.2600164
37	43.3283358	615.8391	88.59106	7589.011	21.23304	61.0162085
38	42.7425575	713.2829	180.848	11017.34	13.41264	59.258083
39	12.7051646	914.0663	98.36662	12007.8	11.38108	51.0781727
40	29.3437946	552.2803	50.40526	10017	17.91264	68.6594279
41	35.0923483	852.986	25.35537	9636.623	16.05585	63.5701172

42	23.5682819	577.3936	193.0674	11764.51	11.9272	61.3123139
43	29.5121951	934.9187	200.0936	9163.622	18.45876	59.4061357
44	39.1076115	934.9187	64.45763	11164.31	15.99031	67.3639669
45	43.5897436	615.8391	196.4278	7753.264	19.17964	70.7506719
46	43.0079156	533.0261	211.0911	11490.34	10.22331	68.8444937
47	19.2493738	489.3463	183.5973	9385.921	18.5243	71.2688562
48	27.1209947	543.999	39.40775	10992.64	16.36167	51.5778505
Mean	**34.757284**	**535.973**	**121.2526**	**10051.01**	**15.59165**	**63.5597072**

Sapwood

1	33.1103679	463.5654	136.4744	9943.582	28.39395	78.6561125
2	32.197615	380.3758	44.26741	7815.743	9.851641	80.8470906
3	33.2783505	463.5654	64.0536	12800.1	19.43792	28.4827148
4	32.259432	577.3936	116.705	7994.275	3.051687	16.4323355
5	29.3674068	577.3936	20.45691	11273.98	19.33841	74.2741564
6	36.3906651	498.4325	117.5266	9698.927	10.58139	70.4399448
7	30.1636603	479.3142	99.50107	8643.603	8.690673	104.947849
8	33.8218493	361.9407	119.7903	11042.55	20.59889	84.9004
9	35.6066548	447.9803	122.8085	11426.06	21.29547	92.0210787
10	32.7510917	463.5654	126.8664	11329.52	22.32375	64.4147551
11	33.6794797	394.1104	122.8085	10075.83	18.675	39.2185074
12	30.1777125	369.4805	96.76789	8059.076	14.76088	1.09548903
13	36.519166	447.9803	95.44322	9501.88	21.32864	1.31458684
14	35.6160372	514.256	101.9492	8104.039	19.63694	29.2495572
15	35.5259489	311.1456	120.7293	10739.7	9.718959	82.3807752

16	37.6006441 57.0749786	343.2613	46.95028	6770.999	14.80068
17	33.8898164 30.1259484	290.1303	87.57905	8094.782	19.33841
18	38.0079681 10.9548903	321.7709	62.37681	9669.833	15.02624
19	36.3597973 68.3585156	387.2269	129.1133	10860.05	16.31989
20	52.1256039 100.784991	557.2705	117.3539	8902.806	22.95399
21	32.5111201 85.6672423	402.1821	79.81548	7871.286	11.01261
22	38.6333771 47.3251262	417.2911	121.3413	9702.894	26.27104
23	33.1491713 60.3614457	407.9749	146.0489	11271.33	19.83596
24	36.1331729 71.5354338	479.3142	35.21271	9989.868	10.38237
25	33.9991913 35.1651979	479.3142	24.31354	10454.05	10.28286
26	39.0570078 35.1651979	479.3142	111.8926	12022.49	4.743383
27	33.9905839 77.7797213	537.4058	132.6346	12564.7	19.43792
28	31.6434474 55.8699407	514.256	126.8664	11149.67	4.345337
29	33.4784488 53.6789626	577.3936	119.7735	11136.44	13.59991
30	31.3674706 58.0609187	557.2705	122.7582	10514.89	6.965807
31	37.3668262 20.8142916	479.3142	117.3539	8359.274	9.718959
32	35.9363785 33.6315133	577.3936	87.57905	9434.435	10.38237
33	34.7412245 26.4012857	428.3775	46.95028	9669.833	15.68965
34	37.6391097 28.6652964	577.3936	96.76789	11042.55	26.27104
35	30.7475884 29.2495572	577.3936	35.21271	9708.184	4.743383

36	40.2365918	557.2705	101.9492	11273.98	18.675	64.9990159
37	35.3410283	514.256	120.7293	11398.29	8.060433	165.053681
38	37.4044134	618.4359	91.38537	9415.92	19.0067	104.947849
39	38.3428451	597.7804	87.52874	8097.427	22.95399	37.6117901
40	31.7149406	597.7804	129.1133	8104.039	14.80068	23.2243675
41	34.4146079	577.3936	95.44322	11329.52	16.31989	82.3807752
42	33.1330034	577.3936	121.7354	11426.06	19.33841	30.1259484
43	40.713496	557.2705	111.8926	8094.782	19.83596	68.3585156
44	33.2906778	577.3936	117.4847	10824.34	11.01261	64.4147551
45	32.3344476	450.3675	146.0489	10860.05	10.28286	84.9004
46	34.9270731	597.7804	86.18731	8902.806	14.76088	39.2185074
47	33.1441735	597.7804	118.2141	10739.7	19.43792	57.0749786
48	37.791532	577.3936	88.03178	11288.52	19.63694	51.8531475
Mean	**35.0340045**	**490.4176**	**99.37056**	**9987.389**	**15.49851**	**56.4481154**

Appendix C: Swelling and shrinkage characteristics of *K. gabonensis* and *E. cylindricum*

		Swelling (%)				Shrinkage (%)			
Replicate	**Species**	**Longitudinal**	**Tangential**	**Radial**	**Volumetric**	**Longitudinal**	**Tangential**	**Radial**	**Volumetric**
				Heartwood					
1	***K. gabonensis***	0.040234253	6.24417521	5. 536271	12.171253	0.029545007	2.75	1.45	4.1884409
2		0.071043225	6.31453535	5.524111	12.26717	0.216663384	1.35	0.25	1.8098291
3		0.031592012	3.76532399	3.337945	7.2628288	0.019685039	2.1	1.05	3.1470193
4		0.063375659	2.71633683	4.831625	7.7474476	0.38408509	3.65	2.25	6.1796145
5		0.037856857	3.17220544	4.209309	7.5557437	0	2.75	2.05	4.743625
6		0.088908646	5.64629025	3.118192	9.0374017	0.177270041	3.05	1.75	4.9154807
7		0.141971831	7.67045455	4.929319	13.138271	0.098483356	2.1	1.35	3.5167636
8		0.042304952	5.39007092	4.357747	10.029232	0.009848336	4.75	1.39607	6.0890066
9		0.084717423	7.56953944	3.118	11.017529	0.275753398	1.65	1.85185	3.7374775
10		0.064595166	7.87578758	4.372904	12.665822	0.049241678	1.25	2.47619	3.7426602
11		0.147108747	6.08439647	5.668954	12.263179	0.029545007	2.15	0.75	2.912568
12		0.17368843	7.08705357	4.707396	12.322819	0.128028363	1.85	1.05	3.0049154
13		0.117984907	9.47196516	3.920168	13.897674	1.024226906	3.25	1.2	5.3900483
14		0.18552461	7.37581535	2.31201	10.062169	0.216663384	0.05	2.46615	2.7261323

15	0.194157424	6.67759115	5.647976	12.921537	0.433326768	0	2.38892	2.8118904
16	0.137952518	5.23038605	5.290363	10.950304	0.019696671	0	3.15789	3.1769694
17	0.073521221	7.53205128	4.280814	12.217742	0.275753398	2.25	1.22549	3.7141623
18	0.198319852	6.59109992	5.083229	12.231506	0.433326768	1.6	0.35	2.3693012
19	0.033432144	4.19392074	3.417812	7.7910978	0.659838487	2.25	2.28155	5.1104947
20	0.147644401	4.2997543	3.097543	7.6892473	0.837108529	7.25	4.25	11.935295
21	0.255330586	8.1732734	4.267631	13.077696	0.54165846	6.55	3.15	9.9839102
22	0.362448541	4.54963235	3.81171	8.9281434	0.393933425	5.5	4.35	9.9668235
23	0.251476301	7.15736041	5.436937	13.267565	0.748473508	6.1	0.98961	7.7251044
24	0.170163222	8.46153846	5.540754	14.665913	1.063620248	5.3	2.85	8.9774918
25	0.166885472	5.53505535	5.304205	11.318316	0	6.15	2.2	8.2147
26	0.086838414	5.51142006	4.181736	10.019085	0.078786685	6.55	3.05	9.4716056
27	0.109382325	6.60853603	4.858205	11.910074	0.344691747	5.6	4.8	10.44097
28	0.029254242	3.45821326	3.436273	7.0446256	0.039242617	6	3.95	9.748431
29	0.093886219	4.55469703	5.17288	10.066426	0	6.7	2.4	8.9392
30	0.093635046	6.38477801	3.793338	10.523704	0.029545007	4	1.08374	5.0684499
31	0.109265247	4.31388661	3.661587	8.251583	0.019696671	0.65	2.04878	2.7046311
32	0.115666081	4.39330544	4.420414	9.1340074	0.994681899	3.35	0.75	5.0290249
33	0.570786517	6.92906929	2.504979	10.233246	0.029545007	2.3	0.54563	2.8617933
34	0.064623955	1.02871839	2.882011	4.0075473	0.098280098	4.05	1.65773	5.7333265

35	0.33832228	4.17690418	3.441196	8.1264181	0.177270041	3.4	2.23084	5.7224178
36	0.109885181	5.90640618	4.473001	10.765182	0.049154542	1.65	2.41546	4.0727796
37	0.064610997	6.70241287	3.399535	10.401084	0.029417533	1.4	1.79437	3.1977384
38	0.046782062	7.43691899	4.783305	12.62862	0.068938349	0.3	1.84825	2.2101655
39	0.027163456	3.42172797	4.836915	8.4536012	0.019696671	2.4	1.05	3.4438221
40	0.04479785	5.12477718	2.70926	8.0212503	0.196367207	0.25	1.0628	1.5039394
41	0.701155108	8.17669173	5.567307	14.999934	0.009848336	6.7	2.4	8.948168
42	0.293058889	5.1010101	3.287352	8.8741836	0.768170179	4	1.08374	5.7698455
43	0.036125536	6.89655172	5.437767	12.750054	0	0.65	2.04878	2.6854634
44	0.107150032	4.44444444	5.013636	9.7984322	0.994681899	3.35	0.75	5.0290249
45	1.3191836	5.87412587	4.861298	12.485553	0.029545007	2.3	0.54563	2.8617933
46	1.643612325	4.98164181	3.287782	10.215431	0	0.65	2.04878	2.6854634
47	0.151697675	5.3133515	2.156081	7.7471946	0.009848336	3.35	0.75	4.084322
48	1.749745677	8.15118397	3.727707	14.145656	0.019696671	2.3	0.54563	2.852224
Mean	**0.233101398**	**5.82659138**	**4.22951**	**10.564594**	**0.251518328**	**3.0739583**	**1.86237**	**5.1073818**

Sapwood

1	0.256444864	6.38646288	3.941436	10.863193	0.965136892	2.1728634	1.93237	4.9891638
2	0.004456527	4.7501237	4.391361	9.354953	0.354540083	3.7662965	1.25543	5.311349
3	0.077982265	4.34083601	3.702219	8.2881417	0.531810124	3.1385804	2.65572	6.212389
4	0.073414905	5.65675935	3.668539	9.613232	0.551506795	1.9797199	1.78658	4.2618577

5	0.075896245	5.88780714	4.39738	10.627995	0.039393343	3.0420087	1.69	4.7181529
6	0.075911496	6.12048193	4.195021	10.656196	0.118180028	2.2694351	1.83486	4.1760352
7	0.004444938	7.46867168	4.084672	11.863387	0.38408509	3.8145823	2.84887	6.9136845
8	0.180328599	5.09927798	4.110626	9.6168311	0.019667617	1.5451473	1.014	2.5626497
9	0.159953791	4.07582938	4.56778	9.0038616	0.039342972	1.2071463	1.11057	2.342751
10	0.017794386	4.6253469	4.589534	9.4466346	0.039219531	2.3177209	2.07629	4.383405
11	0.352450423	5.49199085	4.100411	10.204649	0.03936233	3.6214389	1.44858	5.0549425
12	1.120945278	4.65793304	2.75034	8.7418059	0.482568446	2.7522936	1.83486	4.9973311
13	0.915546425	9.90415335	8.841642	20.716675	0.295450069	3.2351521	0.42857	3.9345252
14	1.35277622	8.95447724	8.705618	20.041861	0.768170179	2.5591502	1.73829	4.9884556
15	1.001999506	13.6549841	9.025222	25.154202	0.059008655	2.8488653	1.49686	4.3595526
16	0.865067333	12.5895599	11.21048	26.294551	0.393933425	2.945437	1.352	4.6347797
17	0.755011136	4.72143532	3.214542	8.9038239	0.147725034	3.8628682	2.31772	6.2297856
18	0.01780389	7.1040724	3.930348	11.333454	0.118180028	3.283438	1.40029	4.7504492

19	0.582882823 3.3090838	6.66666667	7.082191	14.886779	0.590900138	1.6900048	1.06229
20	0.862088219 1.9426861	14.4408252	11.48274	28.681635	0.649990152	1.0622887	0.24143
21	0.383141762 5.4832377	12.2975709	11.27093	25.433303	1.132558598	3.0902945	1.352
22	0.280432539 4.5070034	7.46768789	4.797015	12.93876	0.216663384	2.5108643	1.83486
23	0.018080322 4.8664118	6.30272953	3.922987	10.492945	0.098483356	2.8971511	1.93143
24	0.284849165 2.4907644	6.98230512	5.15524	12.817948	0.334843411	1.5451473	0.62772
25	0.294504808 5.7493824	9.2724679	5.45667	15.574479	0.285601733	3.3800097	2.17286
26	0.208207401 5.6386599	4.79683973	4.772156	10.026516	0.47272011	3.8628682	1.38095
27	0.271866295 5.8797722	6.31353665	4.544218	11.44682	0.620445145	3.3317238	2.02801
28	0.133618386 2.0479774	6.59444183	4.956557	12.027345	0.029354207	1.4002897	0.62772
29	0.247149982 3.1519913	7.44525547	4.626303	12.693834	0.039254171	1.5934331	1.54515
30	0.109323754 3.4186448	7.2815534	5.170696	12.952105	0.019696671	1.9797199	1.44858

31	0.175825154	1.42993327	1.021002	2.6456953	0.196966713	1.8348624	1.49686	3.4947169
32	0.084576007	7.82778865	5.083987	13.405572	0.117866614	1.8831482	1.352	3.3237753
33	0.123523335	4.89651691	4.240489	9.4797086	0.216663384	2.945437	2.60744	5.6808714
34	0.542475127	6.2633833	5.255567	12.454874	0.502265117	3.2351521	1.88315	5.5342413
35	0.833389191	4.95867769	4.686658	10.793441	0.570585342	2.3177209	1.014	3.8599312
36	0.284862242	14.9537792	11.1769	28.166103	0.374236754	2.1728634	1.40029	3.9037053
37	0.824341532	8.90642616	8.190391	18.797579	0.22651172	3.0420087	2.84887	6.0175757
38	0.813533633	8.54368932	6.813098	16.882079	0.147725034	3.1868662	0.96572	4.2634433
39	0.821483581	11.4219114	7.12809	20.344722	0.512113453	3.5731531	2.22115	6.1977837
40	0.917881948	14.3654822	12.55652	29.907364	1.107375915	2.7040077	2.41429	6.1044377
41	0.240158011	5.44854155	4.185816	10.126267	0.216663384	7.7740222	12.7475	19.704844
42	0.332412461	7.06679574	4.169475	11.901661	0.502265117	12.892323	1.88315	14.961962
43	0.103069684	2.34497134	4.827617	7.3963737	0.462871775	2.3177209	1.014	3.755781
44	1.509697161	10.8344859	8.038078	21.551211	1.029295329	7.4843071	11.0575	18.561157

45	0.883199144	13.8003136	11.25979	27.732243	0.029545007	7.8705939	3.33172	10.966404
46	0.146842878	7.31964192	5.155008	13.017693	0.147725034	3.1868662	0.96572	4.2634433
47	0.069113123	9.68229955	4.343737	14.525708	0.512113453	9.7054563	2.70401	12.596935
48	0.348369406	8.17518248	5.113205	14.10252	0.487368212	3.4282955	3.38001	7.1471799
Mean	**0.417481819**	**7.61649799**	**5.831465**	**14.456849**	**0.358290606**	**3.3387655**	**2.12005**	**5.7009388**

Heartwood

1	***E. cylindricum***	0.147984907	7.29417521	5.646271	12.191253	0.003054501	1.02	3.81	11.43097
2		0.19552461	7.26453535	6.234111	11.28717	0.021766338	3.27	3.96	10.738431
3		0.052304952	8.71532399	4.447945	12.182829	0.002068504	2.62	2.41	9.9292
4		0.147952518	8.16633683	5.941625	12.267448	0.038508509	3.27	1.09374	6.0584499
5		0.083521221	8.12220544	5.319309	7.5757437	0	6.27	2.05878	3.6946311
6		0.073375659	8.79629025	5.128192	16.057402	0.017827004	6.57	0.76	6.0190249
7		0.073432144	8.62045455	5.939319	13.558271	0.009948336	6.52	0.55563	3.902568
8		0.178908646	8.24007092	5.367747	14.149232	0.001084834	7.12	1.66773	3.9949154
9		0.481592012	8.51953944	6.128	12.195295	0.02767534	6.32	2.24084	4.4338221
10		0.119382325	8.92578758	5.382904	14.685822	0.005024168	7.17	2.42546	2.4939394
11		0.204157424	7.13439647	4.178954	12.283179	0.003054501	7.57	1.0728	9.938168

12	0.18368843	8.33705357	6.717396	15.342819	0.012902836	6.62	1.46	6.7598455
13	0.208319852	10.4219652	4.211679	14.917674	0.102522691	6.02	0.26	3.6754634
14	0.067856857	8.52581535	5.32201	11.082169	0.021766338	6.72	1.06	6.0190249
15	0.039254242	7.62759115	6.157976	13.941537	0.043432677	2.27	2.26	3.8517933
16	0.184717423	6.88038605	4.800363	16.970304	0.002069667	3.77	2.06	3.6754634
17	0.074595166	8.48205128	5.590814	18.237742	0.02767534	3.77	1.76	5.074322
18	0.487108747	8.54109992	6.593229	13.251506	0.043432677	1.67	1.36	3.842224
19	0.119265247	8.14392074	5.427812	10.811098	0.066083849	3.12	1.40607	3.7161323
20	0.157644401	7.3497543	5.107543	13.709247	0.083810853	7.72	1.86185	3.8018904
21	0.275330586	9.1232734	5.377631	16.097696	0.054265846	5.02	2.48619	10.97391
22	0.372448541	7.49963235	5.82171	13.948143	0.039493343	4.37	0.76	10.956823
23	0.261476301	8.50736041	4.646937	15.287565	0.074947351	3.32	1.06	8.7151044
24	0.220163222	9.41153846	5.750754	17.685913	0.107362025	2.37	1.21	9.9674918
25	0.103635046	8.48505535	5.714205	15.338316	0	1.32	0.55563	9.2047
26	0.176885472	6.66142006	5.591736	16.039085	0.008178669	4.67	1.09374	10.461606
27	0.096838414	7.55853603	6.868205	14.930074	0.034769175	1.67	1.85825	4.7274775
28	0.070234253	7.40821326	5.446273	8.8646256	0.004224262	4.07	1.06	4.7326602
29	0.183886219	6.50469703	5.38288	15.086426	0.0003	3.12	0.76	6.1004947
30	0.323058889	7.33477801	5.803338	15.543704	0.003254501	5.07	1.80437	12.925295

31	0.081043225	7.26388661	4.771587	16.271583	0.002269667	2.67	0.76	4.1669694
32	0.125666081	6.44330544	5.930414	15.154007	0.09976819	2.67	2.05878	4.7041623
33	0.580786517	7.87906929	3.614979	13.253246	0.003254501	3.17	2.47615	3.8517933
34	0.037163456	5.97871839	4.892011	11.027547	0.01012801	2.87	2.39892	6.7233265
35	0.34832228	6.12690418	4.551196	10.346418	0.018027004	4.37	3.16789	6.7124178
36	1.653612325	6.85640618	4.483001	12.785182	0.005215454	3.42	1.23549	5.0627796
37	0.074610997	7.65241287	4.509535	16.421084	0.003241753	1.27	0.36	4.1877384
38	0.451697675	8.68691899	4.993305	16.64862	0.007193835	5.77	2.29155	3.2001655
39	0.711155108	6.37172797	5.946915	10.373601	0.002269667	5.02	3.26	5.1784409
40	0.05479785	6.57477718	3.81926	11.04125	0.019936721	4.27	3.16	2.7998291
41	0.126782062	9.12669173	5.677307	18.019934	0.001284834	4.37	4.36	6.3800483
42	1.794745677	6.0510101	4.697352	11.894184	0.077117018	1.02	0.99961	7.1696145
43	0.062125536	7.84655172	6.947767	19.770054	0.0003	1.67	2.86	5.733625
44	0.119885181	6.59444444	6.146364	18.818432	0.09976819	2.42	2.21	3.3593012
45	0.574623955	6.82412587	5.671298	16.505553	0.003254501	3.32	3.06	4.5067636
46	0.187150032	6.63164181	4.297782	12.935431	0.0003	4.42	2.41	7.0790066
47	1.9791836	6.5633515	4.166081	17.867195	0.001284834	1.07	0.55563	5.9054807

48	0.49	9.1851184	5.737707	16.165656	0.002269667	3.32	1.95878	4.1370193
Mean	**0.308706152**	**7.73459001**	**5.352099**	**14.183714**	**0.025362249**	**3.9897917**	**1.82862**	**6.0973818**

Sapwood

1	0.083414905	6.38646288	4.761436	11.873193	0.096813689	3.5651473	1.10681	5.9791638
2	0.925546425	5.70123701	4.511361	11.164953	0.035754008	2.2271463	1.04575	6.301349
3	1.36277622	5.34083601	4.822219	9.2981417	0.053481012	3.3377209	1.06348	7.202389
4	0.299849165	6.35675935	4.788539	7.623232	0.05545068	4.6414389	1.06545	5.2518577
5	0.169953791	6.38780714	5.51738	11.637995	0.004239334	3.7722936	1.7	5.7081529
6	0.077982265	7.22048193	5.415021	11.666196	0.012118003	3.1928634	1.94237	5.1660352
7	0.280432539	7.66867168	4.204672	12.873387	0.038708509	3.965437	2.08629	7.9036845
8	0.143618386	6.29927798	4.130626	10.626831	0.002266762	4.9171511	1.84486	3.5526497
9	0.592882823	5.27582938	4.58778	10.013862	0.004234297	4.4000097	2.66572	3.332751
10	0.028080322	5.8253469	5.309534	9.4566346	0.004221953	4.3517238	2.85887	5.373405
11	0.413141762	6.69199085	4.120411	10.214649	0.004236233	2.4202897	1.45858	6.0449425
12	0.304504808	5.75793304	3.47034	9.7518059	0.048556845	3.6577161	1.12057	5.9873311
13	1.062088219	6.70415335	8.861642	20.726675	0.029845007	2.0873585	1.84486	4.9245252
14	0.823533633	9.15447724	7.725618	17.051861	0.077117018	2.6134331	1.024	5.9784556

15	0.266444864	6.85498407	9.045222	22.164202	0.006200865	2.5651473	2.01423	5.3495526
16	0.250158011	7.78955988	11.23048	23.304551	0.039693343	4.8828682	1.01424	5.6247797
17	1.011999506	5.42143532	4.334542	9.9138239	0.015072503	10.725456	2.02212	7.2197856
18	0.875067333	8.3040724	4.323483	13.043454	0.012118003	4.4482955	3.04871	5.7404492
19	0.775011136	7.56666667	8.841912	15.196779	0.059390014	3.0322668	2.01227	4.2990838
20	0.02780389	9.64082519	10.50274	28.691635	0.065299015	3.077572	2.05757	2.9326861
21	0.352412461	10.4975709	12.29093	23.443303	0.11355586	3.0923445	3.06053	6.4732377
22	0.294862242	8.66768789	4.817015	14.54876	0.021966338	4.0805265	2.07234	5.4970034
23	0.085896245	7.70272953	4.842987	11.502945	0.010148336	2.7100048	3.01324	5.8564118
24	1.017881948	7.98230512	6.27524	13.727948	0.033784341	2.0822887	1.02209	3.4807644
25	0.095911496	10.4724679	6.17667	16.584479	0.028860173	4.1102945	2.01227	6.7393824
26	0.018794386	5.99683973	5.192156	14.036516	0.047572011	4.0332354	1.53	6.6286599
27	0.362450423	7.51353665	5.264218	12.45682	0.062344514	4.2551521	1.03197	6.8697722

28	0.821483581	7.79444183	5.776557	12.037345	0.003235421	3.5791502	1.43857	3.0379774
29	1.532697161	8.64525547	5.346303	12.703834	0.004225417	3.8688653	1.26543	4.1419913
30	0.257149982	8.4815534	6.090696	14.962105	0.002269667	2.5268614	1.79658	4.4086448
31	0.190328599	7.62993327	2.041002	4.5556953	0.019996671	2.3820039	1.84486	4.4847169
32	0.119323754	9.02778865	6.103987	11.415572	0.012086661	3.9997199	1.362	4.3137753
33	0.014456527	7.09651691	5.060489	10.489709	0.021966338	3.3477209	1.41029	6.6708714
34	0.094576007	7.3633833	6.075567	11.164874	0.050526512	2.8548624	1.74829	6.5242413
35	0.281866295	6.15867769	5.506658	11.403441	0.057358534	3.9614341	0.55143	4.8499312
36	0.070113123	16.1537792	11.1969	23.076103	0.037723675	4.7862965	2.32772	4.8937053
37	0.123723335	9.90642616	8.210391	16.607579	0.022951172	4.1585804	1.362	7.0075757
38	0.360369406	9.74368932	7.733098	16.592079	0.015072503	4.9997199	1.94143	5.2534433
39	0.552475127	12.6219114	8.04809	20.254722	0.051511345	4.0620087	1.07229	7.1877837
40	0.843389191	15.5654822	11.57652	27.917364	0.111037591	3.2894351	1.50686	7.0944377

41	0.834341532	6.64854155	5.105816	11.136267	0.021966338	6.5931531	2.63772	20.694844
42	0.176842878	8.26679574	4.189475	11.911661	0.050526512	3.7240077	1.06736	15.951962
43	1.123945278	6.54497134	4.847617	9.2063737	0.046587177	8.7940222	3.39001	4.745781
44	0.185825154	7.03448594	8.058078	20.561211	0.103229533	9.0922887	1.024	19.551157
45	0.113069684	8.00031364	11.27979	27.742243	0.003254501	4.8345823	2.97572	11.956404
46	0.228207401	8.51964192	6.075008	13.027693	0.015072503	4.8828682	3.34172	5.2534433
47	0.893199144	8.88229955	5.063737	15.935708	0.051511345	4.303438	2.71401	13.586935
48	0.014444938	8.37518248	6.033205	16.21252	0.049036821	4.5308643	11.0675	8.1371799
Mean	**0.434048485**	**7.99256285**	**6.349649**	**14.614765**	**0.036129061**	**4.1003555**	**2.01219**	**6.6909388**

Appendix D: ANOVA and LSD for physical and mechanical properties of *K. gabonensis* and *E. cylindricum*

Table D1: ANOVA for mc for *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**7**	**214.1**	**30.5854001**	**109.66**	**0.0002**
Replicate	2	10.64	5.31	19.07	0.0090[i]
Species	1	181.88	181.88	45.78	0.0212[ii]
Stem position	1	8.06	8.06	28.91	0.0058[iii]
Replicate*Stem position	2	10.64	5.32	19.07	0.0090[iv]
Species*Stem position	1	5.57	5.57	19.97	0.0111[v]
Error	**4**	**1.1156528**			
Corrected Total	**11**	**215.2134534**	**0.2789132**		

R-Square	Coeff Var	Root MSE	MC Mean
0.994816	1.361533	0.528122	38.78879

[i]Significant at p(0.0090)<0.05; [ii]Significant at p(0.0212)<0.05; [iii]Significant at p(0.0058)<0.05; [iv]Significant at p(0.0090)<0.05; [v]Significant at p(0.0111)<0.05

Table D2: LSD for mc for *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	42.1808676[a]
	Sapwood	44.1830066[b]
E. cylindricum	Heartwood	34.7572840[c]
	Sapwood	35.0340045[c]

*Least Significant Means with same superscripts not significantly different

Table D3: ANOVA for the Density of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**7**	**597651.21**	**85378.74**	**59.64**	**0.0007**
Replicate	2	32280.42	16140.2	11.27	0.0227[i]
Species	1	560364.76	560364.76	1284.55	0.0008[ii]
Stem position	1	3849.24	3849.24	2.69	0.1764
Replicate*Stem position	2	872.47	436.23	0.30	0.7531
Species*Stem position	1	284.33	284.33	0.20	0.6789
Error	**4**	**5726.39**	**1431.60**		

Corrected Total	**11**	**603377.61**

R-Square	Coeff Var	Root MSE	Density Mean
0.990509	5.188121	37.83646	729.2903

[i]Significant at p(0.0227)<0.05; [ii]Significant at p(0.0008)<0.05

Table D4: LSD for Density of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heart wood	958.427763[a]
	Sapwood	932.342963[a]
E. cylindricum	Heartwood	535.972989[b]
	Sapwood	490.417605[c]

*Least Significant Means with same superscripts not significantly different

Table D5: ANOVA for Swelling of the anisotropic directions of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**31**	**1088.961304**	**35.127784**	**152.11**	**<.0001**
Replicate	2	8.11	4.06	17.56	<.0001[i]
Species	1	7.28	7.28	2.78	0.2376
Stem position	1	22.05	22.04	34.36	<.0001 [ii]
Type of swelling	3	1020.43	340.14	1472.89	<.0001 [iii]
Replicate*Stem position	2	5.24	2.62	11.35	0.0009 [iv]
Replicate*Stem position*Type of swelling	12	7.70	0.64	2.78	0.0294 [v]
Species*Stem position	1	3.14	3.14	13.61	0.0020 [vi]
Species*Type of swelling	3	3.09	1.03	4.47	0.0184 [vii]
Stem position*Type of swelling	3	8.79	2.93	12.69	0.0002 [viii]
Species*Stem position*Type of swelling	3	3.12	1.04	4.51	0.0179[ix]
Error	**16**	**3.694966**	**0.230935**		
Corrected Total	**47**	**1092.656270**			

R-Square	Coeff Var	Root MS	Swelling Mean
0.996618	7.351966	0.480557	6.536447

[i]Significant at p(<.0001)<0.05; [ii]Significant at p(<.0001)<0.05; [iii]Significant at p(<.0001)<0.05; [iv]Significant at p(0.0009)<0.05; [v]Significant at p(0.0294)<0.05; [vi]Significant at p(0.0020)<0.05; [vii]Significant at p(0.0184)<0.05; [viii]Significant at p(0.0002)<0.05; [ix]Significant at p(0.0179)<0.05

Table D6: LSD for Swelling of the anisotropic directions of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Type of swelling	Least Significant Mean*
K. gabonensis	Heartwood	Longitudinal	0.2331014^{a}
		Radial	4.2295103^{b}
		Tangential	5.8265914^{c}
		Volumetric	10.5645938^{d}
	Sapwood	Longitudinal	0.4174818^{a}
		Radial	5.8314646^{c}
		Tangential	7.6164980^{e}
		Volumetric	14.4568486^{f}
E. cylindricum	Heartwood	Longitudinal	0.3087062^{a}
		Radial	5.3520986^{g}
		Tangential	7.7345900^{e}
		Volumetric	14.1837139^{f}
	Sapwood	Longitudinal	0.4340485^{a}
		Radial	6.3496490^{c}
		Tangential	7.9925629^{e}
		Volumetric	14.6147653^{f}

*Least Significant Means with same superscripts not significantly different

Table D7: ANOVA for shrinkage of the anisotropic directions of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**31**	**222.46**	**7.18**	**7.82**	**<.0001**
Replicate	2	0.95	0.47	0.52	0.6068
Species	1	6.62	6.62	2.17	0.2786
Stem position	1	0.14	0.14	0.19	0.6671
Type of shrinkage	3	190.8	63.6	69.29	<.0001[i]
Replicate*Stem position	2	6.1	3.05	3.33	0.0620
Replicate*Stem position*Type of shrinkage	12	8.45	0.70	0.77	0.6742
Species*Stem position	1	1.32	1.31	1.44	0.2482
Species*Type of shrinkage	3	7.19	2.40	2.61	0.0873
Stem position*Type of shrinkage	3	0.08	0.27	0.03	0.9929
Species*Stem position*Type of shrinkage	3	0.81	0.27	0.30	0.8284
Error	**16**	**14.69**	**0.92**		
Corrected Total	**47**	**237.15**			

R-Square	Coeff Var	Root MS	Shrinkage Mean
0.938074	35.14326	0.958049	2.726125

[i] Significant at p (<.0001)<0.05; $F_{(0.05, 3,16)}$= 3.24<F (34.36)

Table D8: LSD for shrinkage of the anisotropic directions of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Type of shrinkage	Least Significant mean*
K. gabonensis	Heartwood	Longitudinal	0.25151833[a]
		Radial	1.86237326[b]
		Tangential	3.07395833[c]
		Volumetric	5.10738176[d]
	Sapwood	Longitudinal	0.35829061[a]
		Radial	2.12004523[b]
		Tangential	3.33876549[ce]
		Volumetric	5.70093880[dh]

E. cylindricum	Heartwood	Longitudinal	0.02536225[f]
		Radial	1.82862326[b]
		Tangential	3.98979167[ce]
		Volumetric	6.09738176[gh]
	Sapwood	Longitudinal	0.03612906[f]
		Radial	2.01218635[b]
		Tangential	4.10035553[c]
		Volumetric	6.69093880[gh]

*Least Significant Means with same superscripts not significantly different

Table D9: ANOVA for Shear strength parallel to the grain of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**7**	**907.87**	**129.70**	**290.70**	**<.0001**
Replicate	2	0.3	0.14	0.34	0.7336
Species	1	897.83	897.83	2012.39	<.0001[i]
Stem position	1	1.28	1.28	2.87	0.1655
Replicates*Stem position	2	7.52	3.76	8.43	0.0368[ii]
Species*Stem position	1	0.94	0.94	2.11	0.2200
Error	**4**	**1.7845975**	**0.4461494**		
Corrected Total	**11**	**909.6509705**			

R-Square	Coeff Var	Root MSE	Shear strength Mean
0.998038	2.760686	0.667944	24.19486

[i]Significant at p(0.0001)<0.05; [ii]Significant at p(0.0368)<0.05

Table D10: LSD for Shear strength parallel to the grain of *K. gabonensis* and *E. cylindricum*

Species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	33.4513680[a]
	Sapwood	32.2379218[b]
E. cylindricum	Heartwood	15.5916460[c]
	Sapwood	15.4985052[c]

*Least Significant Means with same superscripts not significantly different

Table D11: ANOVA for Compressive strength parallel to the grain of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**2050.36**	**292.91**	**2.87**	**0.1623**
Replicates	2	125.67	62.84	0.62	0.5843
Species	1	1394.07	1394.07	13.67	0.0209[i]
Stem position	1	474.2	474.19	4.65	0.0972
Replicate*Stem position	2	56.37	28.19	0.28	0.7718
Species*Stem position	1	0.05	0.05	0.00	0.9832
Error	**4**	**407.797541**	**101.949385**		
Corrected Total	**11**	**2458.161995**			

R-Square	Coeff Var	Root MSE	Compressive strength Mean
0.834105	13.72289	10.09700	73.57779

[i]Significant at p (0.0209)<0.05

Table D12: LSD for Compressive strength parallel to the grain of *K. gabonensis* and *E. cylindricum*

Wood species	**Stem position**	**Least Significant mean***
K. gabonensis	Heartwood	90.5772030[a]
	Sapwood	80.66848[b]
E. cylindricum	Heartwood	63.55971[c]
	Sapwood	56.448[c]

*Least Significant Means with same superscripts not significantly different

Table D13: ANOVA for the MOR of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**7**	**30826.56**	**4403.79**	**77.99**	**0.0004**
Replicate	2	64.66	32.33	0.57	0.6044
Species	1	29693.48	29693.47	525.87	<.0001[i]
Stem position	1	843.20	843.20	14.93	0.0181[ii]
Replicate*Stem position	2	110.48	55.24	0.98	0.4509
Species*Stem position	1	114.73	114.73	2.03	0.2272
Error	**4**	**225.86014**	**56.46503**		
Corrected Total	**31052.41628**				

R-Square	Coeff Var	Root MSE	MOR Mean
4.710526	7.514322	159.5219	

[i]Significant at p(<.0001)<0.05; [ii]Significant at p(0.0181)<0.05

Table D14: LSD for MOR of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Square mean*
K. gabonensis	Heartwood	214.556275[a]
	Sapwood	203.975396[b]
E. cylindricum	Heartwood	121.252646[c]
	Sapwood	99.371[d]

*Least Significant Means with same superscripts not significantly different

Table D15: ANOVA for the MOE of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Model	**7**	**1109640401**	**158520057**	**85.01**	**0.0003**
Replicate	2	39000504	1950252	1.05	0.4312
Species	1	1105172367	1105172367	592.66	<.0001[i]
Stem position	1	292980	292980	0.16	0.7121
Replicate*Stem position	2	88726	44363	0.02	0.9766
Species*Stem position	1	185825	185825	0.10	0.7680
Error	**4**	**7459054**	**1864764**		

Corrected Total	**11**	**1117099456**

R-Square	Coeff Var	Root MSE	MOE Mean
0.993323	6.961493	1365.563	19615.96

[i]Significant at p (<.0001)<0.05

Table D16: LSD for MOE of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	29493.4037[a]
	Sapwood	28932.0171[a]
E. cylindricum	Heartwood	10051.0139[b]
	Sapwood	9987.3888[b]

*Least Significant Means with same superscripts not significantly different

Appendix E: Fibre and vessel characteristics of *K. gabonensis* and *E. cylindricum*

Replicate	Species	Fibre length (µm)	Fibre diameter (µm)	Fibre lumen width (µm)	Fibre double wall thickness (µm)	Vessel lumen diameter (µm)
			Heartwood			
1	***K. gabonensis***	1504.012	32.406	22.298	10.108	12.683
2		1933.336	31.751	19.98	11.771	19.792
3		1643.712	24.989	15.435	9.554	25.542
4		1354.946	25.302	12.999	12.303	10.43
5		1615.658	20.796	14.15	6.646	10.43
6		1399.161	24.999	12.806	12.193	15.625
7		1913.741	19.659	9.219	10.44	21.475
8		1825.504	30.674	15.206	15.468	14.741
9		1672.293	15.62	7.071	8.549	19.833
10		2168.702	23.161	12.589	10.572	19.819
11		2200.245	22.298	9.34	12.958	13.76
12		1693.287	21.828	15.787	6.041	25.286
13		2084.165	26.076	15.206	10.87	14.024
14		1591.553	22.343	8.062	14.281	30.98
15		2109.552	20.987	11.768	9.219	30.32
16		1560.698	23.376	11.715	11.661	22.597
17		1762.751	25.044	14.008	11.036	19.833
18		1634.948	18.179	7.5	10.679	24.962
19		1977.062	17.499	8	9.499	21.337

20	1646.946	21.953	7.211	14.742		14.024
21	1645.339	22.298	9.617	12.681		10.725
22	1731.28	25.109	18.384	6.725	10.95	
23	1928.647	19.006	13.341	5.665	10.272	
24	1691.754	21.799	13.124	8.675	11.808	
25	1539.957 30.4 9.552 20.848 21.411 26 1693.98 22.769 12.999 9.77 24.76 27 1915.446 19.646 8.514 11.132 19.633					
28	1834.616	15.913	11.313	4.6	22.613	
29	2195.27	30.869	11.236	19.633		25
30	1692.588	25.553	11.236	14.317		11.506
31	1614.079	31.035	23.048	7.987	11.99	
32	1834.388	28.656	15.236	13.42	13.021	
33	1823.317	26.385	11.543	14.842		11.47
34	1738.248	25.538	7.632	17.906		11.47
35	2210.484	25.004	11.543	13.461		10.338
36	2109.889	13.462	12.337	1.125	13.176	
37	1560.575	25.123	11.648	13.475		13.542
38	1489.376	27.499	17.182	10.317		17.815
39	2098.153	17.356	14.3	3.056	9.827	
40	2030.898	18.397	10.198	8.199	11.243	
41	1942.019	20.024	16.446	3.578	10.95	
42	1913.707	23.031	17.463	5.568	10.938	
43	1947.153	25.518	7.632	17.886		13.114

44	1850.6	16.65	12.727	3.923	15.625	
45	1693.611	16.918	7.5	9.418	12.204	
46	2287.603	20.717	19.006	1.711	8.621	
47	2085.531	17.923	8.139	9.784	12.608	
48	1793.257	13.756	10	3.756	8.136	
49	1734.542	20.011	10.977	9.034	19.935	
50	1806.419	19.999	10.511	9.488	13.052	
51	1864.184	21.4	14.84	6.56	15.634	
52	1504.273	18.453	13.224	5.229	12.292	
53	1406.446	26.385	10.965	15.42	9.827	
54	2148.259	21.259	13.5	7.759	11.423	
55	1694.114	20.26	14.577	5.683	8.869	
56	1582.103	16.56	11.412	5.148	16.869	
57	1863.857	19.588	10.265	9.323	13.512	
58	1825.885	20.855	12.97	7.885	14.226	
59	2004.643	21.318	11.51	9.808	9.604	
60	1823.455	22.326	13.509	8.817	9.389	
61	1976.863	16.193	12.903	3.29	12.672	
62	1792.288	17.008	14.523	2.485	19.278	
63	2012.032	18.336	16.65	1.686	11.458	
64	1760.689	23.055	17.155	5.9	13.052	
65	1943.982	17.999	8.276	9.723	25.313	
66	1690.168	21.309	11.661	9.648	15.023	
67	2003.544	23.435	16.807	6.628	13.79	
68	1978.697	21.129	13.403	7.726	11.134	
69	1699.987	26.612	15.924	10.688		14.024

70	1937.913	12.815	7.566	5.249	11.049	
71	1927.695	23.716	14.088	9.628	42.861	
72	1875.951	21.1	11.236	9.864	26.337	
73	1525.085	24.499	10.977	13.522		14.593
74	1842.553	23.999	11.884	12.115		10.546
75	1623.899	20.717	8.5	12.217		12.148
76	1940.096	21.505	10.307	11.198		13.062
77	1435.047	20.099	15.008	5.091	13.176	
78	1919.701	23.448	16.51	6.938	23.257	
79	1724.71	24.998	15.732	9.266	22.78	
80	1551.732	28.07	19.499	8.571	15.167	
81	1968.484	29.515	12.815	16.7	10.469	
82	1822.217	14.499	6.5	7.999	13.35	
83	2135.914 19.999 14.508 5.491 7.933 84 1710.896 17.499 11.423 6.076 13.701					
85	1587.587 26.999 13.462 13.537 11.506 86 1650.513 24.285 12.348 11.937 22.613					
87	2346.395	23.9	16.03	7.87	24.083	
88	1999.431 24.999 11.013 13.986 25.398 89 2158.191 25.223 18.506 6.717 23.53 90 2197.341 22.499 12.499 10 21.373					
91	1507.86	25.004	20.554	4.45	24.167	
92	2060.281	26.574	12.97	13.604		21.167
93	1659.237	30.102	10.499	19.603		22.94
94	1791.112	23.333	12.499	10.834		13.34
95	1503.519	25.479	18.499	6.98	20.307	

96	1880.7	19.811	7	12.811		21.974
97	1807.231	25.401	18.867	6.534	29.208	
98	1788.249	25.401	12.499	12.902		19.633
99	1903.981	19.137	19.038	0.099	21.582	
100	1928.999	27.383	16.92	10.463		12.259
101	2047.462	26.626	20.596	6.03	7.292	
102	2108.828	26.743	20.651	6.092	22.828	
103	1710.758	18.384	14.999	3.385	26.172	
104	1552.004	26.399	19.505	6.894	26.172	
105	1896.556	19.038	18.607	0.431	24.694	
106	1473.977	20.155	14.499	5.656	22.207	
107	1982.442	26.766	21.029	5.737	20.588	
108	2200.181	22.202	14.508	7.694	22.094	
109	1779.999	31.502	21.707	9.795	29.792	
110	2070.002	23.333	10.124	13.209		27.333
111	2123.532	20.055	15.7	4.355	9.786	
112	1879.842	28.177	11.313	16.864		15.66
113	1487.629	20.717	15.811	4.906	10.338	
114	1668.555	23.435	14.883	8.552		29.729
115	1553.416	22.553	17.67	4.883	22.402	
116	1817.498	23.033	16.905	6.128	22.691	117 2160.664 17.658 11.661 5.997 9.317 118
	2036.564 20.717 16.799 3.918 14.996					

119 1943.399 20.933 11.423 9.51 16.957 120 1827.54 24.964 12.539 12.425 9.389 121 1966.087 11.768 8.86 2.908 16.901

122	2262.532	25.499	24.186	1.313	15.625	
123	1734.882	25.317	17.733	7.584	20.286	
124	1389.483	24.422	19.091	5.331	10.272	
125	2202.701	22.637	14.212	8.425	13.062	
126	2018.99	35.105	9.656	25.449		14.593
127	2139.902	16.324	13.999	2.325	8.102	
128	1791.427	22.298	14.703	7.595	8.869	
129	1807.116	17.204	14.577	2.627	15.185	
130	1815.218	18.384	9.823	8.561	7.882	
131	2169.655	19.999	11.768	8.231	8.086	
132	2165.556	21.271	9.192	12.079		34.9
133	2056.685	25.104	10.547	14.557		12.511
134	2340.516	22.802	10.404	12.398		12.768
135	2043.468	29.739	16.324	13.415		17.061
136	2000.254	17.613	12.499	5.114	12.811	
137	1980.835	21.592	8.276	13.316		14.741
138	2053.762	22.61	12.806	9.804	12.081	
139	2023.019	19.234	14.115	5.119	14.024	
140	2106.475	25.004	13.601	11.403		9.389
141	1501.104	19.678	14.577	5.101	19.383	
142	2071.567	24.999	18.914	6.085	13.021	

143	2309.848	22.05	12.747	9.303	11.558	
144	2209.638	28.305	12.379	15.926		21.161
145	1633.934 13.647 12.093 1.554 23.51 146 2069.162 23.048 12.419 10.629 16.383 147 2007.948 27.576 14.421 13.155 18 148 1727.089 23.816 19.911 3.905 22.75 149 1424.718 24.417 13.792 10.625 11.256 150 2253.031 16.378 9.34 7.038 11.74 151 2190.755 23.753 21.271 2.482 12.771 152 1827.568 26.076 13.341 12.735 11.22					
153	1575.758	24.999	14.317	10.682		11.22
154	2112.674	18.006	15.239	2.767	10.088	
155	2118.605	14.499	9.486	5.013	12.926	
156	2078.805	23.43	12.97	10.46	13.292	
157	1734.905	27.499	13.086	14.413		17.565
158	2021.582	18.027	13.582	4.445	9.577	
159	1852.233	22.005	16.03	5.975	10.993	
160	1973.983	24.02	17.327	6.693	10.7	
161	1647.2	23.504	7.5	16.004		10.688
162	1928.424	20.886	13.2	7.686	12.864	
163	1893.73	28.934	22.637	6.297	15.375	
164	2078.456	25.112	13.901	11.211		11.954
165	2213.008	25.499	14.395	11.104		8.371
166	2036.681	20.505	11.045	9.46	13.302	
167	1995.351	23.307	15.115	8.192	25.563	
168	2211.297	31.751	16.918	14.833		15.273
169	1800.003	25.499	10.44	15.059		14.04

170	1534.04	30.804	11.51	19.294		11.384
171	2020.056	19.999	11.011	8.988	14.274	
172	1861.222	14.079	10.7	3.379	11.299	
173	1740.265	16.1	8.602	7.498	43.111	
174	2169.608	29.718	8.5	21.218		19.587
175	2147.816	26.499	16.977	9.522	14.843	
176	1752.729	19.312	16.007	3.305		10.796
177	1847.327	19.038	14.141	4.897	12.398	
178	2033.92	19.038	13.086	5.952	13.312	
179	1834.174	25.961	21.592	4.369	13.426	
180	2020.31	23.307	16.076	7.231	23.507	
181	1960.831	26.195	13.2	12.995	23.03	
182	2488.526	20.838	13.005	7.833	15.417	
183	2344.783	24.883	18.357	6.526	10.719	
184	2547.292	26.924	14.008	12.916		12.933
185	2219.865	21.868	21.189	0.679	20.042	
186	1605.412	24.009	12.747	11.262		21.792
187	1562.622	24	15.048	8.952	10.68	
188	2029.824	19.961	15.7	4.261	10.68	
189	1995.13	19.143	11.011	8.132	15.875	
190	1979.856	26.637	19.808	6.829	21.725	
191	1714.408	23.344	17.506	5.838	14.991	
192	1938.081	15.296	11.661	3.635	20.083	
193	1896.751	16.007	10.977	5.03	20.069	
194	2012.697	23.021	13.865	9.156	14.01	

195	1601.403	30.804	23.6	7.204	25.536	
196	1635.44	19.319	18.607	0.712	14.274	
197	2121.456	20.554	19.299	1.255	31.23	
198	1801.387	23.837	14.705	9.132	30.57	
199	2037.964	26.569	11.543	15.026		21.847
200	2044.799	21.919	10.735	11.184		20.083
201	1928.94	25.238	17.007	8.231	18.212	
202	2067.487	24.863	12.499	12.364		21.587
203	2363.932	26.418	8.5	17.918		14.274
204	1836.282	18.58	9.013	9.567	10.975	
205	1490.883	24.04	16.984	7.056	11.2	
206	2304.101	20.939	10.793	10.146		10.522
207	2120.39 18.821 9.708 9.113 12.358 208 2241.302 26.507 18.499 8.008 7.886 209 1892.827 22.202 18.607 3.595 19.685 210 1908.516 25.163 19.724 5.439 12.802					
211	1216.618	26.475	13.829	12.646	15.384	
212	2271.055 24.621 7.905 16.716 12.042 213 2266.956 17.563 12.348 5.215 9.577 214 2158.085 18.506 15.628 2.878 11.173					
215	2141.916	22.901	16.62	6.281	8.619	
216	2144.868	33.134	15.556	17.578		16.619
217	2101.654	22.901	17.923	4.978	13.262	
218	2082.235	21.359	15.296	6.063	13.976	
219	2155.162	24.079	12.507	11.572		9.354
220	2024.419	26.404	10.816	15.588		9.139

221	2007.875	20.303	11.629	8.674	12.422	
222	1602.504	19.793	12.029	7.764	19.028	
223	2172.967	18.721	12.419	6.302	11.208	
224	2111.248	26.162	8.902	17.26	13.1	
225	2311.038	26.87	11.8	15.07	7.683	
226	1735.334	28.315	10.92	17.395		13.451
227	2170.562	23.299	17.269	6.03	11.256	
228	2109.348	18.799	11.629	7.17	22.363	
229	1828.489	16.299	10.44	5.859	23.833	
230	1126.118	25.799	10.92	14.879		25.148
231	2356.431	32.085	14.159	17.926		23.28
232	2298.155	27.7	21.58	6.12	21.123	
233	1928.968	23.799	14.499	9.3	23.917	
234	1677.158	24.023	13.647	10.376		21.917
235	2014.074	21.299	9.899	11.4	22.69	
236	2220.005	23.804	15.692	8.112	13.09	
237	2180.205	25.374	13.341	12.033		19.057
238	1836.305	28.902	18.746	10.156		21.724
239	2122.982	22.133	13.434	8.699	28.958	

240 1953.633 24.279 14.212 10.067 19.383 241 2075.383 18.611 12.941 5.67
21.332

242 1748.6 24.201 11.886 12.315 12.009 243 1924.717 24.201 15.392 8.809 7.042 244 1539.648 23.937 14.876
9.061 22.578

245 1411.884 30.183 12 18.183 25.922

246	2011.289	25.426	15.805	9.621	25.922	
247	1661.975	25.543	12.157	13.386		24.444
248	1590.776	22.184	12.808	9.376	16.811	
249	2099.553	25.199	14.989	10.21	12.561	
250	2132.298	17.838	11.547	6.291	14.491	
251	2043.419	18.955	12.848	6.107	11.831	
252	2015.107	25.566	14.5	11.066		13.774
253	1548.553	21.002	9.811	11.191		9.139
254	1952	30.302	13.608	16.694		19.133
255	1595.011	22.133	16.306	5.827	22.457	
256	2189.003	18.855	10.461	8.394	20.838	
257	2186.931	26.977	9.777	17.2	22.344	
258	1894.657	19.517	12.665	6.852	30.042	
259	1835.942	22.235	12.4	9.835	27.583	
260	1907.819	17.353	10.184	7.169	10.036	
261	1965.584	26.323	11.993	14.33	15.91	
262	1605.673	28.699	18.908	9.791	10.588	
263	1507.846	18.556	15.199	3.357	29.979	
264	1949.659	25.597	16.807	8.79	22.652	
265	1795.514	21.224	17.924	3.3	22.941	
266	1683.503	24.231	15.029	9.202	9.567	
267	1965.257	26.718	13.105	13.613		15.246
268	1927.285	17.85	13.548	4.302	17.207	

269	2006.043	18.118	12.828	5.29	9.639	
270	1924.855	21.917	17.82	4.097	17.151	
271	2078.263	19.123	12.756	6.367	15.875	
272	1893.688	17.956	10.123	7.833	20.536	
273	2113.432	21.211	16.496	4.715	10.522	
274	1862.089	21.199	17.707	3.492	13.312	
275	1345.382	22.6	12.016	10.584	14.843	
276	1791.568	18.653	12.829	5.824	8.352	
277	2104.944	27.585	18.229	9.356	9.119	
278	2080.097	22.459	14.807	7.652	15.435	
279	1638.865	21.46	16.289	5.171	8.132	
280	2068.208	17.76	12.847	4.913	8.336	
281	2046.416	27.788	12.148	15.64	35.15	
282	1651.329	28.055	15.8	12.255		12.761
283	1745.927	22.518	11.111	11.407		13.018
284	1952.52	23.526	12.908	10.618		13.271
285	1332.774	17.393	11.606	5.787	21.957	
286	1918.91	16.208	11.761	4.447	30.338	
287	1859.431	19.536	11.077	8.459	31.844	
288	2387.126	21.255	13.965	7.29	15.542	
289	2243.383	18.199	12.7	5.499	20.083	
290	1645.892	23.509	12.248	11.261		9.536
291	2118.465	16.635	11.528	5.107	15.41	
292	1402.612	25.329	12.52	12.809		10.088
293	1631.936	27.812	15.456	12.356		8.183
294	1542.312	21.015	14.823	6.192	13.951	

295		1253.546	24.916	15.196	9.72	11.756		
296		1514.258	22.3	11.407	10.893		22.863	
297		1297.761	25.699	10.716	14.983		21.333	
298		1215.341	25.199	11.529	13.67	25.648		
299		1724.104	13.833	12.929	0.904	23.78		
300		1575.893	21.458	11.507	9.951	21.623		
Mean	**1885.382**	**22.7280933**	**13.69038333**		**9.03771**		**16.5828**	**Sapwood**
1		1499.361	25.267	16.807	8.46	12.683		
2		1336.421	21.69	10.511	11.179		19.792	
3		1982.056	18.11	11.884	6.226	25.542		
4		1676.843	17.182	8.732	8.45	10.43		
5		2129.5 21.224	10.63	10.594		10.43		
6		2185.587	18.9	7.5	11.4	15.625		
7		2169.425	22.343	9.924	12.419		21.475	
8		2285.895	12.539	6.041	6.498	14.741		
9		2052.734	16.378	8.544	7.834	19.833		
10		2041.754	23.837	12.539	11.298		19.819	
11		2142.989	23.004	11.499	11.505		13.76	
12		1408.068	27.503	8.485	19.018		25.286	
13		1865.773	24.04	10.124	13.916		14.024	
14		2190.598	14.865	9.219	5.646	30.98		
15		1510.584	19.811	6.8	13.011		30.32	

16	1825.717	16.324	11.28	5.044	32.597	
17	2158.268	21.076	7.159	13.917		19.833
18	2067.457	14.534	14.141	0.393	24.962	
19	2308.46	24.621	9.434	15.187		31.337
20	2125.451	21.029	10.594	10.435		14.024
21	1948.989	17.463	9.5	7.963	10.725	
22	1753.878	13.582	8.141	5.441	10.95	
23	1710.077	21.259	12.806	8.453	10.272	
24	1958.177	17.102	15.787	1.315	11.808	
25	2241.317	11.543	9.055	2.488	21.411	
26	2069.189	20.517	18.607	1.91	24.76	
27	1708.282	15.999	14.326	1.673	19.633	
28	2354.967	25.004	9.513	15.491		22.613
29	1644.092	18.667	9.013	9.654	25 30 2279.285 19.006 7.211 11.795 11.506 31 1689.035 18.927 10.259 8.668 11.99 32 1878.123 14.999 10.259 4.74 13.021 33 1374.731 15.443 6.726 8.717 11.47	
34	2146.018	18.787	12.999	5.788	11.47	
35	1805.914	19.811	15.033	4.778	10.338	
36	1915.717	23.333	8.845	14.488		13.176
37	2279.644	19.525	13.647	5.878	13.542	
38	1804.784	23.048	8.276	14.772		17.815
39	1843.821	17.029	9.434	7.595	19.827	
40	2148.259	24.823	9.5	15.323		11.243

41	1939.186	18.172	8.381	9.791	10.95	
42	1804.351	16.378	7.905	8.473	10.938	
43	1835.912	16.977	9.434	7.543	13.114	
44	1883.442	24.514	11.884	12.63	15.625	
45	2173.34	20.717	11.18	9.537	12.204	
46	1663.928	15.889	11.499	4.39	18.621	
47	2007.627	20.554	13.756	6.798	12.608	
48	1879.689	19.234	9.617	9.617	18.136	
49	1504.052	24.828	6.726	18.102		19.935
50	1802.059	22.588	9.5	13.088		13.052
51	2353.874	22.939	13.656	9.283	15.634	
52	1660.172	20.407	9.219	11.188		12.292
53	1645.394	18.336	14.508	3.828	19.827	
54	2179.741	13.509	12.999	0.51	11.423	
55	1851.096	17.867	15.499	2.368	18.869	
56	1740.763	19.924	12.02	7.904	16.869	
57	1430.774	22.101	10.124	11.977		13.512
58	2337.993	22.022	15.206	6.816		14.226
59	1915.117	25.738	8.86	16.878	19.604	
60	2172.201	16.999	9.219	7.78	19.389	
61	1466.189	21.931	10.688	11.243	12.672	
62	1782.635	22.14	9.962	12.178	19.278	
63	1785.889	18.247	16.1	2.147	11.458	
64	1936.781	16.999	10.607	6.392	13.052	

65	2169.258	25.346	11.715	13.631	25.313	
66	2023.445	23.199	8.139	15.06	15.023	
67	1880.909	24.758	8.845	15.913		13.79
68	1799.877	17.413	11.313	6.1	11.134	
69	1879.478	18.384	12.01	6.374	14.024	
70	1966.31	21.799	12.747	9.052	11.049	
71	2211.575	24.519	12.348	12.171		42.861
72	1267.188	24.823	10.63	14.193		26.337
73	2087.888	21.318	14.326	6.992	14.593	
74	1628.138	19.557	13.453	6.104	10.546	
75	1955.496	16.807	13.086	3.721	12.148	
76	2007.278	18.224	12.999	5.225	13.062	
77	1502.845	24.206	14.999	9.207	13.176	
78	2005.447	22.846	13.038	9.808	23.257	
79	1268.464	24.437	9.617	14.82	22.78	
80	1956.825	23.711	12.103	11.608		15.167
81	1422.878	20.651	12.175	8.476	10.469	
82	1594.21	14.15	8.944	5.206	13.35	
83	1329.033	17.888	12.499	5.389	17.933	
84	1502.044	22.387	6.726	15.661		13.701
85	1492.057	14.577	9.617	4.96	11.506	
86	1527.067	15.507	10.124	5.383	22.613	
87	1721.384	16.507	12.97	3.537	24.083	

88	2284.561	15.507	9.192	6.315	25.398	
89	1687.28	20.155	9.394	10.761	23.53	
90	1559.209	21.029	13.509	7.52	21.373	
91	1556.725	15.889	11.672	4.217	24.167	
92	2062.928	19.499	11.473	8.026	31.167	
93	2109.736	18.721	10.7	8.021	22.94	
94	2022.045	26.869	9.3	17.569	13.34	
95	1688.131	19.722	17.923	1.799	30.307	
96	1585.911	15.531	10.735	4.796	21.974	
97	1412.987	24.667	14.577	10.09	29.208	
98	1253.824	24.697	11.067	13.63	19.633	
99	1796.177	15.008	8.86	6.148	21.582	
100	2122.54	20.395	8.902	11.493		12.259
101	2059.043	19.038	8.86	10.178		7.292
102	2120.179	14.84	12.01	2.83	22.828	
103	2248.186	16.007	8.902	7.105	26.172	
104	1841.349	19.006	13.2	5.806	26.172	
105	1800.649	19.143	13.601	5.542	24.694	
106	1725.492	18.309	10.547	7.762	22.207	
107	1677.441	20.155	19.608	0.547	30.588	
108	1778.245	21.505	14.499	7.006	32.094	
109	1969.239	24.758	11.412	13.346		29.792
110	2002.85	27.972	14.534	13.438		27.333
111	1820.894	20.862	6.8	14.062		19.786
112	1743.424	21.052	4.472	16.58	15.66	
113	1235.61	14.159	7.826	6.333	10.338	

114	1850.753	10.547	9.434	1.113	29.729					
115	1431.76	19.104	8.139	10.965		22.402				
116	2294.116	19.234	10.295	8.939	22.691					
117	2243.456	13.829	7.826	6.003	19.317					
118	1663.64	18.117	8.381	9.736	14.996					
119	1913.759	14.983	9.531	5.452	16.957					
120	1619.312	12.98	10.816	2.164		19.389				
121	1848.595	25.019	7.211	17.808	16.901					
122	2046.871	19.905	10.594	9.311	15.625	123	2104.436	14.159	6.02	8.139
	20.286									
124	2303.531	23.307	8.902	14.405	10.272					
125	1951.937	15.02	9.499	5.521	13.062					
126	1880.783	23.307	16.507	6.8	14.593					
127	1893.6	25.499	15.976	9.523	18.102					
128	1875.148	21.914	20.505	1.409	18.869					
129	1943.15	25.019	12.298	12.721		15.185				
130	1763.257	23.264	12.041	11.223		17.882				
131	2202.509	20.554	13.434	7.12	18.086					
132	1986.449	21.638	12.776	8.862	34.9					
133	1842.217	24.458	15.944	8.514	12.511					
134	2001.272	25.238	16.77	8.468	12.768					
135	1820.122	24.186	6.265	17.921		17.061				
136	1914.212	18.58	10.124	8.456	12.811					
137	1428.081	21.54	14.088	7.452	14.741					

138	2042.753	18.397	10.404	7.993	12.081	
139	1465.515	19.241	12.082	7.159	14.024	
140	1666.824	16.1	8.2	7.9	19.389	
141	1421.971	16.807	12.97	3.837	19.383	
142	1688.593	19.234	10.062	9.172	13.021	
143	1873.355	22.61	14.577	8.033	15.893	
144	2171.682	16.62	8.544	8.076	22.946	
145	1934.086	19.025	10	9.025	18.102	
146	1543.592	18.438	11.51	6.928	19.951	
147	1861.815	20.572	12.529	8.043	16.526	
148	1992.743	15.572	6.519	9.053	13.031	
149	1530.083	14.999	7.5	7.499	17.69	
150	1831.416	17.733	11.18	6.553	16.61	
151	1735.986	20.303	11.715	8.588		14.802
152	1442.769	21.73	10.511	11.219	16.791	
153	2104.762	24.458	14.773	9.685	11.99	
154	2437.244		19.557	15.115	4.442	21.663
155	2228.621	19.98	13.499	6.481	10.737	
156	2128.737	18.309	8.276	10.033	10.737	
157	1409.184	20.024	13.462	6.562	8.479	
158	1724.317	15.952	10	5.952	11.423	
159	2056.868	16.807	7.382	9.425	12.424	
160	1966.057	11.715	9.178	2.537	17.512	
161	2207.06	14.3	8.845	5.455	10.43	
162	2024.051	21.661	8.602	13.059		9.91

163	1847.589	20.796	10.965	9.831	10.378	
164	1652.478	20.886	11.768	9.118	15.13	
165	1908.677	15.074	11.401	3.673	11.506	
166	1856.777	16.77	8.514	8.256	11.979	
167	2139.917	20.554	8.276	12.278		8.235
168	1947.789	27.059	10	17.059		18.237
169	1604.882	18.705	11.448	7.257	18.398	
170	2253.567	20.005	11.236	8.769	17.777	
171	1542.692	21.359	10.511	10.848		14.593
172	2173.885	17.327	8.86	8.467	13.582	
173	1587.635	20.814	14.141	6.673	13.031	
174	1776.723	19.025	12.02	7.005	18.959	
175	1273.331	19.905	15.435	4.47	13.582	
176	2044.618	18.821	15.507	3.314	10.623	
177	1700.659	20.862	13.601	7.261	20.995	
178	2252.474	19.905	14.577	5.328	16.272	
179	1758.772	18.397	12.619	5.778	19.317	
180	1543.994	25.597	10.606	14.991		12.715
181	2078.341	24.823	12.348	12.475		22.486
182	1749.696	29.205	11.715	17.49		13.671
183	1639.363	15.296	12.776	2.52	10.482	
184	1526.374	38.667	18.56	20.107	11.049	
185	2236.593	22.36	18.445	3.915	11.267	

186 1813.717 20.401 11.704 8.697 14.072 187 2070.801 19.508 15.208 4.3 5.208 188 1364.789 19.557 8.902 10.655 23.582 189 1681.235 20.155 13.124 7.031 31.63

190	1624.489	20.669	11.499	9.17	13.701	
191	1835.381	24.253	9.013	15.24	13.582	
192	2267.858	15.008	7.211	7.797	10.482	
193	1922.045	20.614	8.746	11.868		16.087
194	1779.509	24.697	7.071	17.626		10.687
195	1698.477	16.324	15.181	1.143	14.062	
196	1778.078	17.442	8.631	8.811	8.542	
197	1864.91	16.77	8.321	8.449	10.546	
198	2110.175	21.69	15.231	6.459	13.021	
199	1165.788	20.999	11.423	9.576	17.69	
200	1986.488	20.796	12.206	8.59	14.823	
201	1526.738	27.003	9.3	17.703		16.552
202	1854.096	27.972	11.236	16.736		14.024
203	1905.878	19.319	12.499	6.82	9.575	
204	1401.445	22.676	9.34	13.336		12.543
205	1904.047	19.006	16.499	2.507	13.021	
206	1167.064	15.952	12.419	3.533	15.841	
207	1855.425	29.333	9.823	19.51	10.059	
208	1321.478	24.989	12.02	12.969		10.725
209	1492.81	21.271	15.652	5.619	10.482	
210	1227.633	16.499	13.829	2.67	11.134	

211	1400.644	17.499	8.381	9.118	10.43						
212	1600.761	20.155	11.401	8.754	13.552						
213	1437.821	19.234	11.101	8.133		17.882					
214	2083.456	18.309	11.401	6.908	11.564						
215	1778.243	19.473	12.379	7.094	14.805	216	2230.9	23.584	16.007	7.577	14.406
217	2286.987	16.324	8.746	7.578	18.117						
218	2270.825	12.529	7.382	5.147	11.243						
219	2387.295	18.867	13.086	5.781	10.987						
220	2154.134	23.048	13.829	9.219	17.313						
221	2143.154	16.918	9.219	7.699	13.75						
222	2244.389	17.087	10.816	6.271	18.869						
223	1509.468	15.913	8.746	7.167	13.582						
224	1937.173	24.025	18.927	5.098	13.868						
225	2291.998	20.08	10.124	9.956	18.152						
226	1907.314	23.264	12.103	11.161		10.005					
227	2017.117	20.796	12.648	8.148	14.593						
228	2381.044	15.402	8.381	7.021	13.441						
229	1906.184	25.123	15.787	9.336	17.402						
230	1945.221	15.304	10.124	5.18	19.389						
231	2249.659	18.794	9.604	9.19	11.99						
232	2040.586	16.71	6.726	9.984	11.47						
233	1905.751	20.554	8.485	12.069		16.354					
234	1937.312	23.021	14.508	8.513	12.672						

235	1984.842	18.438	8.845	9.593	25.264	
236	2274.74	27.734	17.102	10.632		10.113
237	1765.328	19.104	13.086	6.018	15.823	
238	2109.027	22.46	13.865	8.595	11.375	
239	1981.089	19.799	7.159	12.64	11.646	
240	1605.452	19.596	9.932	9.664	18.479	
241	2344.856	21.803	11.83	9.973	19.561	
242	1765.04	21.972	8.7	13.272		18.398
243	2015.159	18.119	11.124	6.995	16.074	
244	1720.712	21.476	7.241	14.235		17.95
245	1949.995	17.806	9.744	8.062	16.28	
246	2148.271	14.752	13.739	1.013	17.313	
247	2205.836	28.133	12.699	15.434		19.111
248	2404.931	23.789	9.685	14.104	13.145	
249	2053.337	20.071	11.324	8.747	11.183	
250	1982.183	15.299	10.419	4.88	11.979	
251	1995	16.299	8	8.299	18.237	
252	1976.548	18.955	12.48	6.475	10.113	
253	2044.55	18.034	8.359	9.675	34.693	
254	1864.657	17.109	15.341	1.768	14.216	
255	2303.909	18.273	10.634	7.639	13.114	
256	2087.849	22.384	11.794	10.59	19.73	
257	1943.617	15.124	10.7	4.424	11.888	
258	2102.672	21.329	15.341	5.988	29.582	

259	1921.522	17.667	14.006	3.661	12.347	
260	2015.612	21.467	16.987	4.48	11.47	
261	1529.481	21.16	10.255	10.905		8.869
262	2144.153	19.201	13.807	5.394	13.839	
263	1566.915	19.308	12.526	6.782	11.72	
264	1768.224	18.357	10.713	7.644	16.604	
265	1523.371	17.808	13.699	4.109	12.922	
266	1789.993	19.414	13.619	5.795	25.514	
267	1974.755	21.497	11.023	10.474		10.363
268	1390.657	18.118	13.22	4.898	16.073	
269	1425.667	18.287	16.852	1.435	11.625	
270	1619.984	17.113	15.029	2.084	11.896	
271	2183.161	25.225	9.581	15.644		18.729
272	1585.88	21.28	12.601	8.679	19.811	
273	1457.809	24.464	12.301	12.163		19.648
274	1455.325	21.996	12.601	9.395	21.324	
275	1961.528	16.602	13.579	3.023	23.2	
276	2008.336	21.323	17.207	4.116	16.53	
277	1920.645	16.504	9.946	6.558	27.563	
278	1586.731	19.994	8.582	11.412	21.361	
279	1484.511	17.91	14.286	3.624	26.395	
280	1311.587	21.754	15.029	6.725	11.433	
281	1642.024	24.221	10.419	13.802	12.229	
282	1134.21	19.638	12.016	7.622	10.232	
283	2035.486	26.934	9.946	16.988		10.884

284	1355.224	20.304	20.127	0.177	29.18		
285	1897.577	23.66	11.324	12.336		13.302	
286	2223.94	19.597	13.303	6.294	21.632		
287	2160.443	25.797	13.848	11.949		11.314	
288	2221.579	21.023	9.581	11.442		14.555	
289	2349.586	22.405	16.987	5.418	14.156		
290	1942.749	16.496	11.324	5.172	17.867		
291	1902.049	21.355	10.804	10.551		10.993	
292	1826.892	21.869	7.926	13.943		10.737	
293	1778.841	24.453	9.685	14.768		17.063	
294	1879.645	17.524	15.708	1.816	19.5		
295	2070.639	18.642	10.045	8.597	21.619		
296	2104.25	27.97	18.302	9.668	13.332		
297	1922.294	21.66	14.286	7.374	13.618		
298	1749.353	20.597	13.498	7.099	17.902		
299	1330.36	22.934	13.241	9.693	29.755		
300	2274.755	19.304	14.634	4.67	24.343		
Mean	**1862.561**	**20.05342**	**11.47688667**	**8.576533333**	**16.6608933**		

Heartwood

1	***E. cylindricum***	1435.145		16.124	10.558	5.566	39.614
2	1360.054	21.505	15.404	6.101	22.899		

3	1755.788	13.829	5.831	7.998	14.923	
4	1849.061	25.163	15.556	9.607	25.216	
5	1450.182	25.869	18.845	7.024	19.151	
6	1284.287	15.264	10.403	4.861	19.606	
7	1554.745	27.734	18.1	9.634	17.508	
8	1486.22	16.347	7.433	8.914	18.815	
9	1373.345	10.793	4.527	6.266	17.407	
10	1418.732	19.006	7.017	11.989		19.165
11	1693.424	14.705	7.632	7.073	24.351	
12	1992.652	22.191	15.853	6.338	18.88	
13	2048.197	13.829	3.905	9.924	21.092	
14	1653.005	10.606	3.605	7.001	17.337	
15	2228.664	20.814	14.648	6.166	21.373	
16	1564.078	15.507	5.831	9.676	17.243	
17	1337.989	14.035	10.1	3.935	15.634	
18	1181.588	23.031	9.861	13.17	23.616	
19	1618.515	18.336	11.768	6.568	19.278	
20	1459.634	16.71	7.35	9.36	20.426	
21	1667.613	16.65	4.242	12.408		19.799
22	1235.622	23.52	13.038	10.482		24.351
23	1389.011	18.741	9.899	8.842	24.351	
24	1491.841	14.141	6.02	8.121	31.358	
25	1369.701	11.884	6.02	5.864	23.064	

26	1618.643	21.569	10.259	11.31	24.546	
27	1483.99	16.155	8.246	7.909	17.959	
28	1854.142	24.004	11.51	12.494		29.171
29	1616.958	17.065	7.017	10.048		26.047
30	1603.806	20.303	7.5	12.803		11.888
31	1164.565	19.678	8.746	10.932		22.372
32	1469.906	20.808	12.041	8.767		26.088
33	1380.642	22.637	14.705	7.932	29.942	
34	1593.654	16.77	7.28	9.49	23.117	
35	1703.02	19.557	7.5	12.057	27.412	
36	1389.653	15.976	5.59	10.386	45.673	
37	1557.336	12.747	5.315	7.432	33.402	
38	1489.143	22.824	12.747	10.077	27.683	
39	1166.48	11.18	4.61	6.57	33.954	
40	1633.24	17.102	8.139	8.963	22.372	
41	1447.424	17.356	6.726	10.63	17.815	
42	1640.782	19.999	5.408	14.591		25.526
43	1572.903	22.588	12.999	9.589	20.037	
44	1558.575	14.395	6.8	7.595	19.46	
45	1642.338	14.141	9.708	4.433	14.923	
46	1181.788	13.536	8.062	5.474	18.779	
47	1307.817	9.486	7.905	1.581	25.441	
48	1515.709	21.953	9.861	12.092		15.668
49	1606.942	17.356	10.44	6.916	17.469	

50	1626.81	13.124	8.381	4.743	21.354	
51	1563.688	20.717	10.511	10.206		13.279
52	1331.495	27.585	9.924	17.661		15.841
53	1734.281	13.656	5.852	7.804	15.318	
54	1769.282	15.507	8.944	6.563	13.75	
55	1418.312	12.806	5	7.806	14.216	
56	1303.746	24.504	10.999	13.505		12.148
57	1474.684	12.419	6.02	6.399	18.59	
58	1403.135	21.1	13.038	8.062	21.751	
59	1512.274	24.621	15.206	9.415	26.228	
60	1224.014	16.492	9.192	7.3	15.185	
61	1648.194	18.027	9.708	8.319	20.833	
62	1388.503	18.309	7.5	10.809		8.854
63	1291.19	24.747	15.499	9.248		16.667
64	1388.097	16.03	7.5	8.53	19.334	
65	1334.833	27.389	12.97	14.419	21.512	
66	1420.776	16.378	7.905	8.473	28.432	
67	1326.882	33.707	17.888	15.819	26.69	
68	1682.603	28.713	14.602	14.111	39.928	
69	1400.23	17.334	7.5	9.834	45.691	
70	1234.464	37.511	18.499	19.012	19.122	
71	1076.209	21.638	13.601	8.037	18.057	
72	1120.149	23.69	14.848	8.842	36.099	
73	1170.546	23.344	14.499	8.845	15.14	
74	1036.585	20.247	7.106	13.141		15.389

75	1202.521	23.9	12.499	11.401		35.771
76	1419.36	26.518	11.401	15.117		25.005
77	1051.139	14.865	8.2	6.665	23.011	
78	1455.541	20.179	9.219	10.96	23.553	
79	1393.828	31.483	10.606	20.877		22.25
80	1321.859	34.09	18.999	15.091		18.296
81	1428.254	26.195	14.602	11.593		21.974
82	1332.04	17.116	10.999	6.117	23.409	
83	2058.977	24.601	14.764	9.837	22.029	
84	1563.185	24.621	8.5	16.121		16.74
85	1559.17	23.113	13.792	9.321	23.776	
86	1645.167	13.647	6.708	6.939	18.959	
87	1916.498	23.376	14.3	9.076	22.486	
88	1675.673	21.376	13.601	7.775	11.785	
89	1175.452	20.124	8.321	11.803		37.745
90	1878.555	19.137	7.615	11.522		28.66
91	1200.067	19.722	8.944	10.778		21.449
92	1413.911	15.889	9.013	6.876	29.435	
93	1818.837	16.007	7.615	8.392	22.268	
94	1639.454	27.72	11.313	16.407		39.864
95	1570.21	22.726	14.602	8.124	23.149	
96	2013.322	17.144	9.008	8.136	15.173	
97	1282.768	22.525	10.854	11.671	25.466	

98	1598.494	14.849	6.281	8.568	19.401	
99	1788.113	26.183	16.006	10.177	19.856	
100	1466.667	26.889	9.295	17.594	17.758	
101	1619.748	16.284	6.853	9.431	19.065	
102	1908.264	28.754	16.55	12.204		17.657
103	1739.294	17.367	7.883	9.484	19.415	
104	1350.696	11.813	4.977	6.836	24.601	
105	1224.842	20.026	7.467	12.559		19.13
106	1950.69	15.725	8.082	7.643	21.342	
107	1929.67	23.211	12.303	10.908		17.587
108	1600.167	14.849	4.355	10.494		21.623
109	1402.154	11.626	4.055	7.571	17.493	
110	1747.186	21.834	13.098	8.736	15.884	
111	1522.572	16.527	6.281	10.246		23.866
112	1434.056	15.055	6.45	8.605	19.528	
113	1532.794	24.051	10.311	13.74	20.676	
114	1362.911	19.356	12.218	7.138	20.049	
115	1933.709	17.73	7.8	9.93	24.601	
116	2083.084	17.67	4.692	12.978		24.601
117	1830.48	24.54	13.488	11.052		31.608
118	1578.429	19.761	10.349	9.412	23.314	
119	1688.459	15.161	6.47	8.691	24.796	
120	1435.753	12.904	6.47	6.434	18.209	

121	1973.679	22.589	10.709	11.88	29.421	
122	1831.831	17.175	8.696	8.479	26.297	
123	2011.351	25.024	11.96	13.064		12.138
124	1740.253	18.085	7.467	10.618		22.622
125	1688.355	21.323	7.95	13.373		26.338
126	1524.107	20.698	9.196	11.502	30.192	
127	1719.915	21.828	12.491	9.337	23.367	
128	1561.034	23.657	15.155	8.502	27.662	
129	1569.013	17.79	7.73	10.06	45.923	
130	1337.022	20.577	7.95	12.627	33.652	
131	1490.411	16.996	6.04	10.956	27.933	
132	1499.241	13.767	5.765	8.002	34.204	
133	1471.101	23.844	13.197	10.647		22.622
134	1720.043	12.2	5.06	7.14	18.065	
135	1585.39	18.122	8.589	9.533	25.776	
136	1955.542	18.376	7.176	11.2	20.287	
137	1718.358	21.019	5.858	15.161		19.71
138	1706.206	23.608	13.449	10.159		15.173
139	1265.965	15.415	7.25	8.165	19.029	
140	1576.306	15.161	10.158	5.003	25.691	
141	1482.042	14.556	8.512	6.044	15.918	
142	1339.745	10.506	8.355	2.151	17.719	
143	1258.654	26.369	10.311	16.058		21.604
144	1654.388	15.358	10.89	4.468	13.529	

145	1747.661	32.687	8.831	23.856		16.091
146	1348.782	27.693	10.961	16.732		15.568
147	1189.887	16.314	10.374	5.94	14	
148	1453.345	36.491	6.302	30.189		14.466
149	1384.82	20.618	9.394	11.224		12.398
150	1271.945	22.67	5.45	17.22	18.84	
151	1317.332	22.324	11.449	10.875		22.001
152	1592.024	19.227	6.47	12.757		26.478
153	1891.252	22.88	13.488	9.392	15.435	
154	1946.797	25.498	15.656	9.842	21.083	
155	1551.605	13.845	9.642	4.203	9.104	
156	1967.264	19.159	10.158	9.001		16.917
157	1638.64	30.463	7.95	22.513	19.584	
158	1548.824	33.07	24.949	8.121	21.762	
159	1742.182	25.175	17.95	7.225	28.682	
160	1674.303	16.096	13.42	2.676	26.94	
161	1659.975	23.581	8.355	15.226	40.178	
162	1743.738	23.601	18.338	5.263	45.941	
163	1283.188	22.093	15.052	7.041	19.372	
164	1409.217	12.627	7.95	4.677	18.307	
165	1617.109	22.356	18.949	3.407	36.349	
166	1608.342	20.356	17.051	3.305	15.39	
167	1728.21	19.104	15.298	3.806	15.639	
168	1665.088	18.117	14.949	3.168	36.021	
169	1432.895	18.702	13.556	5.146	25.255	

170	1835.681	14.869	12.949	1.92	23.261
171	1870.682	14.987	11.851	3.136	23.803
172	1469.01	26.7	18.65	8.05	22.5
173	1912.122	21.706	9.669	12.037	18.546
174	1181.568	20.933	15.056	5.877	22.224
175	1497.294	16.336	12.449	3.887	23.659
176	1686.913	12.104	11.052	1.052	22.279
177	1365.467	19.697	16.449	3.248	16.99
178	1518.548	26.565	20.214	6.351	24.026
179	1707.064	12.636	11.95	0.686	19.209
180	1638.094	14.487	14.242	0.245	22.736
181	1249.496	11.786	7.158	4.628	12.035
182	1123.642	23.484	14.75	8.734	37.995
183	1649.49	16.399	14.051	2.348	28.91
184	1728.47	20.08	8.771	11.309	21.699
185	1398.967	23.601	8.065	15.536	29.685
186	1300.954	15.472	9.394	6.078	22.518
187	1645.986	17.007	9.463	7.544	39.364
188	1421.372	17.289	8.065	9.224	22.649
189	1431.594	23.727	11.763	11.964	14.673
190	1261.711	15.864	10.052	5.812	24.966
191	1832.509	20.549	8.108	12.441	18.901
192	1981.884	15.135	9.954	5.181	19.356
193	1729.28	22.984	5.381	17.603	17.258

194	1477.229	16.045	15.106	0.939	18.565	
195	1587.259	19.283	8.395	10.888		17.157
196	1954.879	18.658	5.953	12.705		18.915
197	1933.031	19.788	15.65	4.138	24.101	
198	1925.551	21.617	6.983	14.634		18.63
199	1841.453	15.75	4.077	11.673		20.842
200	1789.555	18.537	6.567	11.97	17.087	
201	1625.307	14.956	7.182	7.774	21.123	
202	1536.953	11.727	11.403	0.324	16.993	
203	1303.721	21.804	3.455	18.349		15.384
204	1520.56	10.16	3.155	7.005	23.366	
205	1152.339	16.082	12.198	3.884	19.028	
206	1556.741	16.336	5.381	10.955		20.176
207	1495.028	18.979	5.55	13.429		19.549
208	1423.059	21.568	9.411	12.157		24.101
209	1529.454	13.375	11.318	2.057	24.101	
210	1433.24	13.121	6.9	6.221	31.108	
211	2160.177	12.516	3.792	8.724	22.814	
212	1664.385	12.466	8.588	3.878	24.296	
213	1660.37	21.144	9.449	11.695		17.709
214	1746.367	20.157	5.57	14.587		28.921
215	2017.698	20.742	5.57	15.172		25.797
216	1776.873	16.909	9.809	7.1	11.638	

217	1276.652	17.027	7.796	9.231	22.122	
218	1779.755	28.74	11.06	17.68		25.838
219	1301.267	23.746	6.567	17.179	29.692	
220	1316.912	22.973	7.05	15.923	22.867	
221	1202.346	18.376	8.296	10.08		27.162
222	1373.284	14.144	11.591	2.553	45.423	
223	1301.735	21.737	14.255	7.482	33.152	
224	1410.874	28.605	6.83	21.775	27.433	
225	1122.614	14.676	7.05	7.626	33.704	
226	1546.794	16.527	5.14	11.387		22.122
227	1287.103	13.826	4.865	8.961	17.565	
228	1189.79	25.524	12.297	13.227		25.276
229	1286.697	13.439	4.16	9.279	19.787	
230	1233.433	22.12	7.689	14.431		19.21
231	1319.376	25.641	6.276	19.365		14.673
232	1225.482	17.512	4.958	12.554		18.529
233	1581.203	19.047	12.549	6.498	25.191	
234	1298.83	19.329	6.35	12.979		15.418
235	1565.21	25.767	9.258	16.509		17.219
236	2008.322	22.939	7.612	15.327		21.104
237	1277.768	17.525	7.455	10.07	13.029	
238	1593.494	25.374	9.411	15.963		15.591
239	1783.113	18.435	9.99	8.445	15.068	
240	1461.667	21.673	7.931	13.742		13.5

241	1614.748	21.048	10.061	10.987		13.966
242	1703.264	22.178	9.474	12.704		11.898
243	1734.294	24.007	5.402	18.605		18.34
244	1345.696	18.14	8.494	9.646	21.501	
245	1219.842	20.927	4.55	16.377		25.978
246	1683.355	17.346	10.549	6.797	14.935	
247	1519.107	14.117	5.57	8.547	20.583	
248	1430.753	24.194	12.588	11.606		8.604
249	1638.24	14.55	12.756	1.794		16.417
250	1452.424	18.472	8.742	9.73	19.084	
251	1645.782	18.726	9.258	9.468	21.262	252 1577.903 21.369 7.05 14.319 28.182 253
	1563.575 23.958 15.049 8.909 26.44 254 1647.338 15.765 7.05 8.715 39.678					
255	1186.788	15.511	12.52	2.991	45.441	
256	1312.817	14.906	7.455	7.451	18.872	
257	1520.709	17.856	10.438	7.418	17.807	
258	2088.084	30.113	14.152	15.961		35.849
259	1835.48	32.72	7.05	25.67	14.89	
260	1583.429	24.825	18.049	6.776	15.139	
261	2016.351	15.746	13.151	2.595	35.521	
262	1745.253	23.231	14.398	8.833	24.755	
263	1112.614	23.251	14.049	9.202	22.761	
264	1536.794	21.743	6.656	15.087		23.303
265	1277.103	12.277	12.049	0.228	22	

266	1179.79	22.006	10.951	11.055		18.046
267	1276.697	20.006	7.75	12.256		21.724
268	1223.433	18.754	8.769	9.985	23.159	
269	1309.376	17.767	10.156	7.611	21.779	
270	1215.482	18.852	18.349	0.503	16.49	
271	1606.351	14.519	14.152	0.367		23.526
272	1799.555	14.637	10.549	4.088		18.709
273	1635.307	26.35	14.314	12.036		22.236
274	1546.953	21.356	17.05	4.306		11.535
275	1313.721	20.583	18.342	2.241		37.495
276	1530.56	15.986	6.258	9.728		28.41
277	1162.339	13.754	11.85	1.904		21.199
278	1566.741	19.347	13.151	6.196		29.185
279	1505.028	26.215	7.871	18.344		22.018
280	1433.059	22.939	7.165	15.774		45.941
281	1744.294	17.525	8.494	9.031	19.372	
282	1355.696	25.374	8.563	16.811	18.307	
283	1229.842	18.435	7.165	11.27	36.349	
284	1693.355	21.673	10.863	10.81	15.39	
285	1529.107	21.048	14.152	6.896	15.639	
286	1440.753	22.178	8.108	14.07	36.021	
287	1648.24	24.007	9.954	14.053	25.255	
288	1462.424	18.14	5.381	12.759		23.261
289	1553.575	20.927	18.106	2.821		23.803
290	1637.338	30.113	8.395	21.718		22.5

291	1176.788	32.72	5.953	26.767	45.441
292	1302.817	24.825	15.65	9.175	18.872
293	1510.709	15.746	10.008	5.738	17.807
294	2078.084	23.231	10.854	12.377	35.849
295	1825.48	23.251	6.281	16.97	14.89
296	1573.429	21.743	18.006	3.737	15.139
297	1186.788	12.277	9.295	2.982	35.521
298	1312.817	22.006	6.853	15.153	24.755
299	1520.709	20.006	16.55	3.456	22.761
300	1508.084	8.516	7.883	0.633	23.303
Mean	**1535.657**	**19.7225**	**10.03824**	**9.68426**	**22.5993533**

Sapwood

1	1926.359	17.463	12.369	5.094	28.703
2	1743.354	21.782	12.348	9.434	33.309
3	1453.93	12.747	6.726	6.021	25.011
4	1640.167	15.115	6.519	8.596	18.192
5	1726.275	17.007	12.041	4.966	23.776
6	1750.485	17.613	8.558	9.055	19.46
7	1444.95	22.802	9.552	13.25	19.799
8	1632.144	23.716	10.965	12.751	19.151
9	1498.82	21.147	10.049	11.098	18.699

10	1429.21	16.155	6.8	9.355	19.327	
11	1578.365	20.401	9.962	10.439	19.108	
12	1452.668	20.892	8.544	12.348	16.796	
13	1511.675	28.181	18.56	9.621	18.815	
14	2121.683	12.815	7.159	5.656	14.216	
15	1853.408	8.558	6.67	1.888		17.815
16	1199.689	26.099	18.117	7.982		18.495
17	1841.363	21.505	10.049	11.456		13.062
18	1780.568	18.741	11.401	7.34		15.327
19	1908.57	15.944	6.403	9.541		20.373
20	1533.337	21.505	7.615	13.89		16.045
21	1550.627	13.829	7.81	6.019		21.663
22	1487.484	26.518	13.086	13.432		18.08
23	987.24	15.239	7.071	8.168		17.959
24	1477.804	21.476	10.547	10.929		18.259
25	1541.292	12.093	10.387	1.706		29.463
26	1608.493	23.631	16.03	7.601		29.472
27	1454.914	20.352	10.404	9.948		25.436
28	1406.618	17.556	10.688	6.868		25.874
29	1416.784	24.051	12.999	11.052		20.01
30	1737.877	11.412	4.031	7.381		28.168
31	1168.414	29.469	17.24	12.229		17.982

32	1805.858	12.419	10.3	2.119		22.146
33	1540.114	4.242	3.286	0.956		25.441
34	1601.413	9.394	6.585	2.809		22.25
35	1895.65	9.823	7.999	1.824		20.259
36	1763.426	6.519	4.607	1.912		16.675
37	1699.813	8.276	5.051	3.225		23.438
38	1830.04	9.899	6.711	3.188		15.104
39	2067.408	9.3	5.811	3.489	21.361	
40	1456.174	9.552	5.189	4.363	22.493	
41	1560.746	10.062	8.051	2.011	23.958	
42	1475.313	12.499	9.724	2.775	23.011	
43	1661.337	11.884	11.008	0.876	17.219	
44	1927.518	6.403	6.005	0.398	19.523	
45	1338.418	10.012	9.507	0.505	18.937	
46	2058.798	18.5	10.1	8.4		24.229
47	1750.876	19.038	7.28	11.758		21.875
48	1472.321	22.802	9.708	13.094		35.363
49	1671.039	26.418	11.412	15.006		37.86
50	1461.263	27.54	9.513	18.027		35.209
51	1619.287	27.28	10.511	16.769		28.028
52	1433.223	30.301	15.556	14.745		25.141
53	1605.295	30.301	14.916	15.385		21.676
54	1524.709	22.726	11.335	11.391		26.104
55	1087.81	20.796	13.582	7.214		14.923

56	955.745	24.253	14.141	10.112	23.582
57	1620.137	24.909	9.924	14.985	22.613
58	1495.912	20.426	6.519	13.907	21.98
59	1742.611	34.123	19.848	14.275	39.367
60	1614.279	28.376	17.463	10.913	38.766
61	1612.951	14.317	3.905	10.412	24.875
62	1598.73	20.933	8.139	12.794	8.854
63	2060.926	25.302	13.892	11.41	19.833
64	1799.174	24.823	11.51	13.313	35.478
65	1706.676	9.899	4.61	5.289	22.993
66	1614.079	25.999	14.499	11.5	22.613
67	1813.632	23.853	10.404	13.449	25.141
68	1886.903	18.787	8.276	10.511	31.085
69	1529.151	12.298	5	7.298	22.846
70	1984.594	24.02	12.509	11.511	27.173
71	1967.294	29.003	16.378	12.625	8.731
72	1652.737	10.816	5	5.816	38.106
73	1823.544	18.667	9.617	9.05	30.557
74	1916.877	21.271	9.848	11.423	41.891
75	1719.056	21.707	12.98	8.727	36.57
76	1913.599	18.179	11.18	6.999	26.644
77	2050.364	18.199	7.382	10.817	35.543
78	1823.408	28.411	17.334	11.077	20.525
79	1596.62	26.855	18.787	8.068	21.531
80	1413.33	25.806	12.093	13.713	22.42

81	1739.294	22.41	9.552	12.858		26.404
82	1760.176	22.36	14.079	8.281		25.542
83	1659.467	25.738	20.395	5.343		25.521
84	1897.003	20.124	9.656	10.468		22.97
85	1558.811	18.767	7.071	11.696		19.799
86	1706.626	21.965	11.8	10.165		40.158
87	1757.69	27.72	15.62	12.1		12.864
88	1727.247	21.965	12.369	9.596		27.253
89	1875.148	26.724	16.155	10.569		29.486
90	2051.946	26.461	12.093	14.368		12.715
91	1574.616	23.435	12.041	11.394		20.755
92	1345.346	17.867	8.077	9.79		29.241
93	1304.248	13.341	5.59	7.751		27.844
94	1477.668	21.224	10.688	10.536		19.101
95	1456.202	17.719	5.831	11.888		17.685
96	1422.651	30.515	18.499	12.016		16.445
97	1427.206	15.531	9.617	5.914		28.646
98	1074.208	17.528	8.514	9.014		19.792
99	1199.752	18.499	8.514	9.985		22.45
100	1450.88	18.821	8.381	10.44		15.703
101	1403.627	22.504	16.007	6.497	17.219	

102 1401.126 23.926 13.038 10.888 14.593 103 1650.491 18.999 10 8.999
14.072

104	1561.456	15.811	5.701	10.11	20.833
105	1429.971	15.181	8.276	6.905	14.072
106	1499.062	24.051	13.453	10.598	21.411
107	1047.22	21.271	12.093	9.178	11.99
108	1687.038	24.232	9.394	14.838	19.792
109	1370.168	22.939	16.155	6.784	13.114
110	1190.476	25.631	9.617	16.014	16.045
111	1441.906	14.773	7.5	7.273	16.667
112	1661.874	17.556	12.175	5.381	26.156
113	1450.297	15.337	7.615	7.722	17.716
114	1720.729	10.307	4.472	5.835	24.479
115	1699.08	18.336	9.962	8.374	30.28
116	1535.278	17.613	6.946	10.667	38.28
117	1786.331	12.999	4.031	8.968	29.628
118	1624.609	25.163	15.041	10.122	26.69
119	1483.012	22.802	7.211	15.591	21.246
120	1432.629	17.913	12.719	5.194	28.432
121	1622.132	22.232	12.698	9.534	24.485
122	1415.919	13.197	7.076	6.121	29.167
123	1546.814	15.565	6.869	8.696	16.146
124	1252.742	17.457	12.391	5.066	18.93
125	1126.702	18.063	8.908	9.155	24.529
126	1579.091	23.252	9.902	13.35	23.958
127	1460.056	24.166	11.315	12.851	21.98

128	1328.571	21.597	10.399	11.198	18.779
129	1397.662	16.605	7.15	9.455	26.042
130	945.82	20.851	10.312	10.539	14.914
131	1585.638	21.342	8.894	12.448	21.15
132	1268.768	28.631	18.91	9.721	36.773
133	1079.076	13.265	7.509	5.756	20.226
134	1340.506	9.008	7.02	1.988	22.366
135	1560.474	26.549	18.467	8.082	16.47
136	1348.897	21.955	10.399	11.556	18.318
137	1619.329	19.191	11.751	7.44	26.357
138	1797.68	16.394	6.753	9.641	37.242
139	1433.878	21.955	7.965	13.99	28.432
140	1684.931	14.279	8.16	6.119	29.656
141	1523.209	26.968	13.436	13.532	20.098
142	1481.612	15.689	7.421	8.268	12.587
143	1199.21	21.926	10.897	11.029	14.75
144	1057.145	12.543	11.737	0.806	20.373
145	1721.537	24.081	16.38	7.701	22.128
146	1597.312	20.802	10.754	10.048	17.624
147	1844.011	18.006	11.038	6.968	18.93
148	1715.679	24.501	13.349	11.152	18.458
149	1754.351	11.862	4.381	7.481	21.757
150	1740.13	29.919	17.59	12.329	20.846
151	2162.326	12.869	12.65	0.219	32.127
152	1900.574	4.692	3.636	1.056	19.962
153	1808.076	9.844	6.935	2.909	17.005

154	1795.479	17.013	16.349	0.664	19.383
155	1915.032	21.332	18.957	2.375	14.302
156	1988.303	12.297	9.401	2.896	35.554
157	1630.551	14.665	12.061	2.604	11.183
158	2085.994	16.557	15.161	1.396	21.354
159	2068.694	17.163	16.539	0.624	34.41
160	1598.413	22.352	18.401	3.951	28.665
161	1728.64	23.266	16.074	7.192	17.313
162	1966.008	20.697	15.358	5.339	13.35
163	1354.774	15.705	11.355	4.35	6.771
164	1459.346	19.951	16.857	3.094	28.453
165	1373.913	20.442	10.45	9.992	33.059
166	1559.937	27.731	7.63	20.101	24.761
167	1826.118	12.365	12.019	0.346	17.942
168	1237.018	8.108	6.998	1.11	23.526
169	1957.398	25.649	6.376	19.273	19.21
170	1649.476	21.055	6.169	14.886	19.549
171	1370.921	18.291	11.691	6.6	18.901
172	1569.639	15.494	8.208	7.286	18.449
173	1359.863	21.055	9.202	11.853	19.077
174	1517.887	13.379	10.615	2.764	18.858
175	1331.823	26.068	9.699	16.369	16.546
176	1503.895	14.789	6.45	8.339	18.565
177	1423.309	21.026	9.612	11.414	13.966
178	986.41	11.643	8.194	3.449	17.565

179	854.345	23.181	18.21	4.971	18.245
180	1518.737	19.902	6.809	13.093	12.812
181	1394.512	17.106	6.32	10.786	15.077
182	1641.211	23.601	17.767	5.834	20.123
183	1597.68	10.962	9.699	1.263	15.795
184	1433.878	29.019	11.051	17.968	21.413
185	1684.931	11.969	6.053	5.916	17.83
186	1523.209	4.792	3.265	1.527	17.709
187	1481.612	8.944	7.46	1.484	18.009
188	1331.229	10.349	8.736	1.613	29.213
189	1520.732	9.75	6.721	3.029	29.222
190	1314.519	10.002	8.197	1.805	25.186
191	1445.414	10.512	5.037	5.475	25.624
192	1151.342	12.949	11.68	1.269	19.76
193	1760.867	12.334	10.054	2.28	27.918
194	1998.403	6.853	3.338	3.515	17.732
195	1660.211	10.462	7.649	2.813	21.896
196	1808.026	18.95	3.681	15.269	25.191
197	1859.09	19.488	16.89	2.598	22
198	1828.647	23.252	13.95	9.302	20.009
199	1976.548	26.868	15.936	10.932	16.425
200	2153.346	27.99	17.235	10.755	23.188
201	1676.016	27.73	19.649	8.081	14.854
202	1546.746	30.751	18.257	12.494	21.111
203	1405.648	30.751	23.701	7.05	22.243
204	1579.068	23.176	13.361	9.815	23.708

205	1557.602	21.246	19.461	1.785		22.761
206	1524.051	24.703	20.839	3.864		16.969
207	1528.606	25.359	23.701	1.658		19.273
208	1175.608	9.449	6.374	3.075		18.687
209	1301.152	8.85	4.658	4.192		23.979
210	1552.28	14.102	10.655	3.447		21.625
211	1505.027	9.612	5.157	4.455		35.113
212	1502.526	12.049	9.75	2.299		37.61
213	1751.891	11.434	6.93	4.504		34.959
214	1662.856	9.953	4.762	5.191		27.778
215	1531.371	9.562	4.863	4.699		24.891
216	1600.462	18.05	10.861	7.189		21.426
217	1148.62	18.588	15.906	2.682		25.854
218	1788.438	22.352	15.266	7.086		14.673
219	1471.568	25.968	11.685	14.283		23.332
220	1291.876	27.09	13.932	13.158		22.363
221	1543.306	26.83	14.491	12.339		21.73
222	1763.274	21.851	10.274	11.577		39.117
223	1551.697	29.851	6.869	22.982		38.516
224	1822.129 22.276 20.198 2.078 24.625 225 1328.102 20.346 17.813 2.533 9.104 226 1824.959 23.803 4.255 19.548 20.083 227 1641.954 24.459 8.489 15.97 35.728					
228	1452.53	34.573	14.242	20.331	23.243	
229	1538.767	28.826	11.86	16.966	22.863	

230	1624.875	14.767	4.96	9.807	25.391	
231	1649.085	21.383	11.062	10.321	31.335	
232	1343.55	25.752	9.163	16.589		23.096
233	1530.744	25.273	10.161	15.112		27.423
234	1397.42	12.349	7.206	5.143		8.981
235	1327.81	26.449	14.566	11.883		38.356
236	1476.965	24.303	10.985	13.318		30.807
237	1351.268	19.237	13.232	6.005		42.141
238	1410.275	13.748	11.791	1.957		36.82
239	2020.283	24.47	9.574	14.896		26.894
240	1752.008	29.453	6.169	23.284		35.793
241	2027.759	14.266	11.498	2.768		20.775
242	1844.754	19.117	17.113	2.004		21.781
243	1555.33	21.721	3.555	18.166		22.67
244	1741.567	22.157	7.789	14.368		26.654
245	1827.675	18.629	13.542	5.087		25.792
246	1851.885	18.649	11.16	7.489		25.771
247	1546.35	28.861	4.26	24.601		23.22
248	1733.544	27.305	7.754	19.551		20.049
249	1600.22	26.256	8.626	17.63		40.408
250	1530.61	22.86	5.35	17.51		13.114
251	1679.765	22.81	12.859	9.951		27.503
252	1554.068	34.123	16.728	17.395		29.736

253	1613.075	28.376	5.35	23.026	12.965
254	2223.083	14.317	9.967	4.35	21.005
255	1954.808	20.933	10.198	10.735	29.491
256	1350.568	25.302	13.33	11.972	28.094
257	1409.575	24.823	11.53	13.293	19.351
258	2019.583	9.899	7.732	2.167	17.935
259	1751.308	25.999	17.684	8.315	16.695
260	1648.385	23.853	19.137	4.716	28.896
261	1342.85	18.787	12.443	6.344	20.042
262	1530.044	12.298	9.902	2.396	22.7
263	1396.72	24.02	14.429	9.591	15.953
264	1327.11	29.003	10.054	18.949	17.469
265	1624.175	10.816	7.926	2.89	14.843
266	1648.385	18.667	4.65	14.017	14.322
267	1342.85	21.271	12.159	9.112	21.083
268	1733.344	21.707	16.028	5.679	14.322
269	1600.02	18.179	4.65	13.529	21.661
270	1530.41	18.199	9.267	8.932	12.24
271	1844.554	28.411	9.498	18.913	20.042
272	1555.13	26.855	12.63	14.225	13.364
273	1741.367	25.806	10.83	14.976	16.295
274	1827.475	22.41	7.032	15.378	16.917
275	1553.868	22.36	16.984	5.376	26.406
276	1612.875	19.217	18.437	0.78	17.966
277	2222.883	22.415	11.743	10.672	24.729

278	1844.554	28.17	9.202	18.968	30.53
279	1555.13	22.415	13.729	8.686	38.53
280	1743.354	21.174	10.006	11.168	29.878
281	1453.93	26.911	7.421	19.49	26.94
282	1640.167	23.885	12.15	11.735	21.496
283	1726.275	18.317	15.97	2.347	28.682
284	1998.403	13.791	12.719	1.072	24.735
285	1175.608	21.674	16.505	5.169	29.417
286	1808.026	18.169	12.443	5.726	15.896
287	1579.068	23.965	12.391	11.574	18.68
288	1976.548	18.317	8.427	9.89	24.279
289	2153.346	21.515	5.94	15.575	23.708
290	1446.746	21.27	9.306	11.964	21.73
291	1859.09	19.515	6.721	12.794	18.529
292	1301.152	21.274	11.45	9.824	25.792
293	1557.602	21.011	10.27	10.741	15.164
294	1524.051	22.985	12.019	10.966	21.4
295	1528.606	17.417	15.805	1.612	37.023
296	1502.526	12.891	11.743	1.148	20.476
297	1676.016	20.774	11.691	9.083	22.616
298	1562.28	17.269	7.727	9.542	16.72
299	1505.027	22.065	5.24	16.825	18.568
300	1828.647	11.081	6.861	4.22	26.607
Mean	**1596.737**	**19.6432667**	**10.72312333**	**8.920143333**	**22.8047933**

Appendix F: Tissue proportions for *K. gabonensis* and *E. cylindricum*

1	***E. cylindricum***	**Heartwood**	20	32	24	24
2			20	40	12	28
3			16	32	20	32
4			8	36	32	24
5			16	36	32	12
Mean			**16**	**35.2**	**24**	**24**

Replicate	Species	position	Vessels (%)	Fibres (%)	Axial parenchyma (%)	Ray parenchyma (%)
1		**Sapwood**	20	40	16	24
2			16	48	20	16
3			8	68	8	16
4			16	48	20	16
5			8	56	12	24
Mean			**13.6**	**52**	**15.2**	**19.2**
		Stem				

Replicate	Species	position	Vessels (%)	Fibres (%)	Axial parenchyma (%)	Ray parenchyma (%)
1	*K. gabonensis*	**Heartwood**	28	40	12	20
2			16	36	24	24
3			12	52	16	20
4			20	40	12	28
5			16	60	12	12
Mean			**18.4**	**45.6**	**15.2**	**20.8**

1	**Sapwood**	16	36	16	32
2		8	36	20	36
3		12	52	20	16
4		16	36	16	32
5		12	52	20	16
Mean		**12.8**	**42.4**	**18.4**	**26.4**

Table F1: ANOVA for fibre proportion in *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**11**	**1634.4**	**148.58**	**3.95**	**0.0307**
Replicate	4	715.2	178.8	4.76	0.0293[i]
Species	1	0.8	0.8	0.02	0.8876
Stem position	1	231.2	231.2	6.15	0.0381[ii]
Replicate*Species	4	187.2	46.8	1.24	0.3659
Species*stem position	1	0.8	0.8	0.02	0.9023
Error	**8**	**300.8**	**37.6**		
Corrected Total	**19**	**1935.2**			

[i]Significant: p(0.0293)<0.05; [ii]Significant: p(0.0381)<0.05.

Table F2: LSD for fibre proportion in *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	45.6[a]
	Sapwood	42.4[a]
E. cylindricum	Heartwood	52[b]
	Sapwood	35.2[c]

*Least Significant Means with same superscripts are not significantly different (p<0.05).

Table F3: ANOVA for ray parenchyma proportion in *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**11**	**632.8**	**57.5**	**1.37**	**0.3349**
Replicate	4	276.8	69.2	1.65	0.2537
Species	1	20	20	0.40	0.5614
Stem position	1	0.8	0.8	0.02	0.8936
Replicate*Species	4	200	50	1.19	0.3849
Species*stem position	1	135.2	135.2	3.22	0.1105
Error	**8**	**336**	**42**		
Corrected Total	**19**	**968.8**			

Table F4: LSD for ray parenchyma proportion in *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	20.8^{a}
	Sapwood	26.4^{b}
E. cylindricum	Heartwood	19.2_{a}
	Sapwood	24_{abc}

*Least Significant Means with same superscripts are not significantly different ($p<0.05$).

Table F5: ANOVA for vessel proportion in *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**11**	**368**	**33.5**	**2.04**	**0.1605**
Replicate	4	195.2	48.8	2.98	0.0886
Species	1	3.2	3.2	0.17	0.7040
Stem position	1	80	80	4.88	0.0582
Replicate*Species	4	76.8	19.2	1.17	0.3921
Species*stem position	1	12.8	12.8	0.78	0.4028
Error	**8**	**131.2**	**16.4**		
Corrected Total	**19**	**499.2**			

Table F6: LSD for vessel proportion in *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	18.4^{a}
	Sapwood	12.8^{b}
E. cylindricum	Heartwood	13.6^{bc}
	Sapwood	16_{abc}

*Least Significant Means with same superscripts not significantly different ($p<0.05$).

Table F7: ANOVA for axial parenchyma proportion in *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**11**	**530.4**	**48.2**	**1.53**	**0.2802**
Replicate	4	43.2	10.8	0.34	0.8426
Species	1	39.2	39.2	0.69	0.4543
Stem position	1	39.2	39.2	1.24	0.2977
Replicate*Species	4	228.8	57.2	1.81	0.2202
Species*stem position	1	180	180	5.70	0.0441^{i}
Error	**8**	**252.8**	**31.6**		

Corrected Total	**19**	**783.2**

[i]Significant: p(0.0441)<0.05.

Table F8: LSD for axial parenchyma proportion in *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	15.2[a]
	Sapwood	18.4[a]
E. cylindricum	Heartwood	15.2[ab]
	Sapwood	24[c]

*Least Significant Means with same superscripts not significantly different (p<0.05).

Table F9: ANOVA for fibre diameter of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**22.9**	**3.3**	**7.09**	**0.0386**
Replicates	2	2.1	1.0	2.26	0.2205
Species	1	8.9	8.9	13.84	0.0653
Stem positions	1	5.6	5.6	12.13	0.0253[i]
Replicates*stem positions	2	1.3	0.6	1.38	0.3494
Species*stem positions	1	5.1	5.1	11.09	0.0291[ii]
Error	**4**	**1.8**	**0.5**		
Corrected Total	**11**	**24.8**			

[i]Significant: p(0.0253)<0.05; [ii]Significant: p(0.0291)<0.05.

Table F10: LSD for fibre diameter of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	22.73[a]
	Sapwood	20.05[b]
E. cylindricum	Heartwood	19.7[b]
	Sapwood	19.6[b]

*Least Significant Means with same superscripts not significantly different (p<0.05).

Table F11: ANOVA for fibre length of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**307123.4**	**43874.7**	**64.55**	**0.0006**
Replicates	2	3141.9	1570.9	2.31	0.2152
Species	1	284175.6	284175.6	42.32	0.0228[i]
Stem positions	1	1097.7	1097.7	1.62	0.2727
Replicates*Stem positions	2	13428.6	6714.3	9.88	0.0283[ii]
Species*Stem positions	1	5279.6	5279.6	7.77	0.0495[iii]
Error	**4**	**2718.6**	**679.7**		
Corrected Total	**11**	**309842**			

[i]Significant: p(0.0228)<0.05; [ii]Significant: p(0.0283)<0.05; [iii]Significant: p(0.0495)<0.05.

Table F12: LSD for fibre length of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	1885.4[a]
	Sapwood	1862.6[a]
E. cylindricum	Heartwood	1535.7[b]
	Sapwood	1596.7[c]

*Least Significant Means with same superscripts not significantly different (p<0.05).

Table F13: ANOVA for fibre lumen width of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**24.8**	**3.5**	**28.89**	**0.0029**
Replicates	2	0.8	0.4	3.14	0.1513
Species	1	14.5	14.5	19.64	0.0473[i]
Stem positions	1	1.7	1.7	13.92	0.0203[ii]
Replicates*stem positions	2	1.5	0.7	6.01	0.0623
Species*stem positions	1	6.4	6.4	51.95	0.0020[iii]
Error	**4**	**0.5**	**0.1**		
Corrected Total	**11**	**25.3**			

[i]Significant: p(0.0473)<0.05; [ii]Significant: p(0.0203)<0.05; [iii]Significant: p(0.0020)<0.05.

Table F14: LSD for fibre lumen width of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*

K. gabonensis	Heartwood	13.7[a]
	Sapwood	11.5[b]
E. cylindricum	Heartwood	10[c]
	Sapwood	10.7[d]

[*]Least Significant Means with same superscripts not significantly different (p<0.05).

Table F15: ANOVA for fibre double wall thickness of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**4.7**	**0.7**	**1.43**	**0.3847**
Replicates	2	2.7	1.4	2.94	0.1641
Species	1	0.7	0.7	639.01	0.0016[i]
Stem positions	1	1.1	1.1	2.39	0.196
Replicates*stem positions	2	0.002	0.001	0.00	0.9976
Species*stem positions	1	0.07	0.07	0.15	0.7212
Error	**4**	**1.9**	**0.47**		
Corrected Total	**11**	**6.6**			

[i]Significant: p(0.0016)<0.05.

Table F16: LSD for fibre double wall thickness of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	9.7[a]
	Sapwood	8.9[ab]
E. cylindricum	Heartwood	9[ab]
	Sapwood	8.6[b]

[*]Least Significant Means with same superscripts not significantly different (p<0.05).

Table F17: ANOVA for vessel lumen diameter of *K. gabonensis* and *E. cylindricum*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**7**	**9586.9**	**1369.6**	**7.7**	**0.0322**
Replicates	2	111.5	55.8	0.32	0.7430
Species	1	353.4	353.4	1.5	0.3514
Stem positions	1	7626.7	626.7	43.8	0.0027[i]
Replicates*stem positions	2	486.6	243.3	1.4	0.3466
Species*stem positions	1	1008.7	1008.7	5.8	0.0738[ii]

Error	**4**	**696.7**	**174.2**
Corrected Total	**11**	**10283.6**	

[i]Significant: p(0.0027)<0.05; [ii]Significant: p(0.0738)<0.05.

Table F18: LSD for vessel lumen diameter of *K. gabonensis* and *E. cylindricum*

Wood species	Stem position	Least Significant mean*
K. gabonensis	Heartwood	144.8[a]
	Sapwood	176.9[b]
E. cylindricum	Heartwood	115.6[c]
	Sapwood	184.4[d]

*Least Significant Means with same superscripts not significantly different

Appendix G: Mass loss and visual durability ratings for *K. gabonensis* and *E. cylindricum*

Replicate	Species	Mass loss (%)	Visual durability rating
		Heartwood	
1	***K. gabonensis***	6.388013509	1
2		2.604683698	1
3		5.802881903	1
4		3.090854346	1
5		4.925059063	1
6		5.286248366	1
7		5.066871209	1
8		4.265072509	1
9		5.219226578	1
10		7.27743733	1
11		5.931262821	1
12		4.409820809	1
13		3.478010878	1
14		5.710371174	1
15		4.871631455	1
16		5.863324012	1

17	4.095987805	1
18	4.268316678	1
19	4.624976223	1
20	4.029903693	1
21	3.651247368	1
22	7.568518704	1
23	3.515756098	1
24	4.991282086	1
25	4.776783582	1
26	5.933349296	1
27	3.364520297	1
28	2.130220788	1
29	4.270084142	1
30	6.919933512	1
31	8.65656199	1
32	2.360878697	1
33	8.249402423	1
34	5.834431239	1
35	6.324638416	1
36	4.396486273	1
37	1.581571632	1
38	3.985948185	1
39	3.741077465	1
40	3.30248876	1
41	5.521936089	1
42	8.993838204	1
43	4.265072509	1
44	2.237854387	1
45	3.24648523	1
46	8.361791695	1
47	2.62075817	1
48	3.622138154	1
Mean	**4.825729364**	**1**

Sapwood

1	9.103787189	1
2	10.67561415	1
3	8.058224905	1
4	10.00613873	1
5	4.749796444	1
6	7.500020127	1
7	8.126451538	1

8	7.118231129	1
9	17.72632709	1
10	6.840164048	1
11	8.965040653	1
12	15.9450733	1
13	6.178603538	1

14	9.291875129	1
15	16.66676295	1
16	10.56941826	1
17	6.127828562	1
18	8.889009419	1
19	6.270497541	1
20	9.492489992	1
21	10.30394933	1
22	5.631474191	1
23	5.355870905	1
24	7.733497323	1
25	6.488438136	1
26	6.60622119	1
27	7.929953923	1
28	7.624390294	1
29	6.415551506	1
30	11.78996125	1
31	3.587742373	1
32	5.007887188	1
33	6.411865184	1
34	10.31556456	1
35	3.200332491	1
36	10.81653523	1
37	5.127286812	1
38	4.359132266	1
39	2.297082924	1
40	10.9695176	1
41	1.512572892	1
42	10.98410468	1
43	10.19801308	1
44	4.224148571	1
45	7.118231129	1
46	8.834249251	1
47	20.32498891	1
48	4.525069738	1
Mean	**8.208228908**	**1**

Heartwood

1	***E. cylindricum***	15.44917761	2
2		7.611671485	2
3		15.93899719	1
4		5.240563733	2
5		7.820196581	2
6		12.29243062	2
7		6.386292272	2
8		7.673838953	2
9		7.07388556	2
10		8.633487385	2
11		8.054185417	2
12		6.223083868	2
13		6.24050347	2
14		8.877864029	2
15		13.68679576	2
16		12.28116575	2
17		4.495567568	2
18		6.359108384	2
19		4.051206667	2
20		9.633981336	1
21		16.44196861	1
22		7.311359876	1
23		15.04251044	2
24		11.92083327	2
25		8.326190148	2
26		11.68993931	2
27		5.987348325	2
28		8.046618983	2
29		7.474144704	2
30		6.28864776	2
31		12.60630927	2
32		18.34180887	2
33		6.319850125	2
34		11.62319012	2
35		8.111222945	2

36	5.01456687	2
37	6.190848791	2
38	2.923261809	2
39	11.68906352	2
40	14.81490243	2
41	24.41805008	2
42	27.09202132	2
43	8.877059445	2
44	9.233728207	2
45	15.75637018	2
46	6.314670431	2
47	6.309702297	2
48	11.86997716	2
Mean	**10.00125352**	**1.91666667**

Sapwood

1	15.19192119	2
2	10.93159146	2
3	10.67652998	3
4	10.85648914	3
5	9.968425028	3
6	4.556976356	3
7	14.85775045	3
8	7.765679388	3
9	13.56167705	3
10	10.24482124	3
11	8.787431608	3
12	14.78218614	3
13	14.8983077	3
14	9.990582874	3
15	18.89023086	3
16	14.64995499	3
17	15.91297879	3
18	8.391493587	3
19	10.33817875	3
20	17.3012282	3
21	10.09730933	3
22	7.828744815	3
23	7.482075938	3
24	9.726033223	3
25	14.44586917	3
26	29.08261223	3
27	15.53645	3
28	14.09132569	3
29	10.88323808	3
30	15.58911588	3
31	15.82291041	3
32	21.76209117	3
33	13.36395356	3
34	19.69340033	3
35	7.206112859	3
36	15.41783083	3
37	12.5312765	3
38	10.24935204	3
39	19.71807459	3
40	9.110616508	3

41		8.390675848	2
42		14.12064515	2
43		17.77930061	2
44		13.54852899	2
45		11.69134131	2
46		17.31453966	3
47		13.61718683	3
48		11.88818223	3
Mean		**13.1363126**	**2.85416667**
1	***C. pentandra***	100	4
2		100	4
3		100	4
4		100	4
5		100	4
6		100	4
7		100	4
8		100	4
9		100	4
10		100	4
11		100	4
12		100	4
13		100	4
14		100	4
15		100	4
16		100	4
17		100	4
18		100	4
19		100	4
20		100	4
21		100	4
22		100	4
23		100	4
24		100	4
25		100	4
26		100	4
27		100	4
28		100	4

29	100	4
30	100	4
31	100	4
32	100	4
33	100	4
34	100	4
35	100	4
36	100	4
37	100	4
38	100	4
39	100	4
40	100	4
41	100	4
42	100	4
43	100	4
44	100	4
45	100	4
46	100	4
47	**100**	**4**
48		
Mean		

Appendix H: Strength of mortise-tenon and dovetail joints constructed from *K. gabonensis* and *E. cylindricum*

Replicate	Species	Stem position	Joint type	Joint strength (Nm)
1	***K. gabonensis***	**Heartwood**	**Mortise-tenon SS**	810
2				840
3				650
4				520
5				840
6				540
7				459

8	810
9	560
10	405
Mean	**643.4**
1	**Mortise-tenon type LS** 737.5
2	870
3	986
4	870
5	841
6	590
7	841
8	783
9	1040.25
10	870
Mean	**842.875**
1	**Dovetail SS** 988
2	874
3	400
4	875
5	810
6	690
7	875
8	520
9	586.5
10	840
Mean	**745.85**
1	**Dovetail LS** 551
2	1131

3	1015
4	1003
5	1015
6	841
7	855.5
8	870
9	928
10	928
Mean	**913.75**
1	**Sapwood Mortise-tenon SS** 494
2	795
3	520
4	546
5	526.5
6	520
7	559
8	780
9	520
10	520
Mean	**578.05**
1	**Mortise-tenon LS** 560.5
2	812
3	783
4	667
5	696
6	783
7	551
8	812
9	783
10	812
Mean	**725.95**

1	**Dovetail SS** 756
2	729
3	560
4	812
5	550
6	769.5
7	756
8	688.5
9	676
10	783
Mean	**708**
1	**Dovetail LS** 870
2	737.5
3	580
4	885
5	725
6	870
7	1032.5
8	580
9	737.5
10	737.5
Mean	**775.5**
1	***E. cylindricum*** **Heartwood Mortise-tenon SS** 450
2	560
3	476
4	756

5	532
6	434
7	476
8	840
9	756
10	840
Mean	**612**
1	**Mortise-tenon LS** 580
2	667
3	696
4	768.5
5	580
6	696
7	783
8	754
9	725
10	725
Mean	**697.45**
1	**Dovetail SS** 650
2	675
3	598
4	650
5	637
6	624
7	625
8	637
9	675.75
10	650
Mean	**642.175**

1	**Dovetail LS** 885
2	678.5
3	754
4	725
5	768.5
6	754
7	725
8	754
9	783
10	768.5
Mean	**759.55**
1	**Sapwood Mortise-tenon SS** 540
2	357.5
3	460
4	540
5	526.5
6	540
7	550
8	702
9	540
10	810
Mean	**556.6**
1	**Mortise-tenon LS** 737.5
2	870
3	841
4	841
5	435
6	580
7	551

8	725
9	580
10	580
Mean	**674.05**
1	**Dovetail SS** 690
2	460
3	667
4	690
5	667
6	575
7	598
8	460
9	460
10	690
Mean	**595.7**
1	**Dovetail LS** 590
2	580
3	768.5
4	870
5	870
6	725
7	580
8	580
9	783
10	885
Mean	**723.15**

Appendix I: List of Publications

1. **Boadu Boakye**, **K.,** Antwi-Boasiako, C. and Frimpong-Mensah, K. (*In press*) Physical and Mechanical Properties of *Klainedoxa gabonensis* Pierre ex Engl., a Tropical LesserUtilized Species with Engineering prospects. *Journal of Forestry Research*.

2. **Boadu Boakye**, **K.** and C. Antwi-Boasiako (*In press*) Anatomical characteristics of *Klainedoxa gabonensis* Pierre ex Engl. in relation to its processing and prospective enduse. *Archives of Applied Science Research.*

3. Antwi-Boasiako, C. and **Boadu Boakye, K.** (2016) The level of utilization of secondary timber species among furniture producers. *South-east Eur for* 7(1):16-08.

4. **Boadu Boakye**, **K.** and C. Antwi-Boasiako (2016) Assessment of the bending Strength of Mortise-Tenon and Dovetail Joints in Leg-and-Rail Construction using *Klainedoxa gabonensis* Pierre ex Engl. and *Entandrophragma cylindricum* (Sprague) Sprague. *Wood Materials Science & Engineering*. http://dx.doi.org/10.1080/17480272.2016.1174883.

5. Antwi-Boasiako, C. and **Boadu Boakye, K.** (2016) Relationship between BioMechanical Properties of *Klainedoxa gabonensis* Pierre ex engl. and the Bending Strength of its Dovetail and Mortise-tenon joints. *In:* 70th Forest Products Society Convention, June 27th – 29th 2016, Portland, Oregon.