ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 14 N° 3 2018
pp. 50-62

LINEAR RELATIONSHIP BETWEEN SEVERAL ANATOMICAL CHARACTERISTICS OF *ENTANDROPHRAGMA CYLINDRICUM* AND THE STRENGTH OF ITS MORTISE-TENON JOINT

Kwadwo Boakye BOADU*
Dr. - Department of Wood Science & Technology, Faculty of Renewable Natural Resources, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana
Email: patrendy2000@yahoo.com

Charles ANTWI-BOASIAKO
Prof. - Department of Wood Science & Technology, Faculty of Renewable Natural Resources, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana
Email: cantwiboasiako@gmail.com

Abstract:

Wood anatomical properties (e.g. pith opening and pore size) influence joint strength. However, information on specific tissues and fibre morphology and their effect on wooden furniture joint strength is scanty. The linear relationships [using the Pearson Product-Moment Correlation Coefficient (r)] between the tissue proportions and fibre characteristics of Entandrophragma cylindricum sapwood and heartwood and the strength of their mortise-tenon joints were studied. Fibre proportions had the greatest positive linear association with joint strength (heartwood: r = 0.991; sapwood: r = 0.975), while vessels and axial parenchyma proportions in the heartwood and sapwood respectively had the greatest negative relationships with joint strength (r = -0.986 and r = -0.962 respectively). Fibre diameter had the greatest positive influence on joint strength [r = 0.996 (heartwood); r = 0.994 (sapwood)] followed by fibre double-wall thickness (r = 0.990 and 0.993 respectively) and fibre length (r = 0.968 and 0.992 respectively). However, fibre lumen diameter negatively correlated with joint strength [r = -0.987 (heartwood); -0.978 (sapwood)]. Thus, wood with more fibres, which have large diameters but small lumen, could produce joints with greater strength than those with more vessels and axial parenchyma.

Key words: *adhesive; joinery; structural product; tissue proportion; wood fibre.*

INTRODUCTION

Wooden furniture is held together by joints. Its strength and durability lie in the robustness of the joints (Proulx 1996). Several factors affect joint strength. These include the properties of the timber and adhesive used, and the geometry of the joint. Boadu and Antwi-Boasiako (2017) found that the geometry of dovetail joints improved their grain-to-gain surface connection in furniture, which offers them great resistance to bending forces. They further observed that working chairs with mortise-tenon and dovetail joints, which had longer, wider and thicker tails and tenons were stronger than those manufactured with shorter, narrower and thinner tails and tenons. Li *et al*. (2015) found that the density and mechanical properties of wood cell walls affected the shear strength of joints. Kiaei and Samariha (2011) also noted that the anatomical, physical and mechanical properties of timber are the main influence of the strength performance of wood in joints. They recommended that furniture producers must have a complete understanding of these properties to be able to select the right kind of timber for joint construction.

The influence of wood mechanical properties on joint strength has been extensively studied. For instance, Haviarova *et al*. (2013) found that the differences in the shear strength and Modulus of Elasticity (MOE) among timbers were partly responsible for variations in the strength of the joints they produced. Boadu and Antwi-Boasiako (2017) observed that joints from *Klainedoxa gabonensis* Pierre ex Engl., a lesser-utilized tropical species, were stronger than those from *Entandrophragma cylindricum* (Sprague) Sprague due to differences in some of their mechanical properties (such as shear strength and MOE). Barboutis and Vassiliou (2008) also observed a strong relationship between the shear strength of *Castanea dentata* and the bending strength of its finger joints. According to Uetimane and Ali (2011), density and mechanical properties of wood are dependent on its anatomical characteristics, which subsequently affect its joint strength. Thus, a relationship between wood anatomy and the strength of furniture joints is expected. Ntalos and Mantanis (2007) explained that variations in the anatomical structure of wood play significant roles in the bondability and durability of joints. According to Adeniyi *et al*. (2012), adequate understanding of the extent to which anatomy affects joint strength is the foremost step in achieving good furniture service life. However, unlike the case of mechanical properties, studies on the direct relationship between joint strength

[*] Corresponding author

and anatomical properties of wood are scanty. Hence, where the mechanical properties of wood cannot be determined but its anatomy is known, furniture manufacturers would be faced with the challenge of predicting the timber's joint performance.

Wood is a complex tissue whose structure comprises vessels, tracheids, fibres and parenchyma. The proportion, size, arrangement and distribution of these cells as well as their chemical composition and deposits influence wood properties and its end-uses (Carlquist 2009, Adeniyi *et al*. 2012). According to Myburg *et al*. (2013), tissue proportion and fibre morphological characteristics play important roles in improving the strength of wood and that of manufactured joints. For instance, Ntalos and Mantanis (2007) found that wood tissues controlled the bond formation process and ultimately the performance of the joint assembly. However, the specific tissues and fibre morphological characteristics, which have the greatest influence on the strength of joints of wooden products are not adequately known. Using linear correlations, this paper investigated the wood tissue and fibre properties that greatly influence the furniture joint strengths produced from the heartwood and sapwood of *Entandrophragma cylindricum*, an extensively used tropical timber for furniture construction. The study would contribute to establishing the relationships between anatomical characteristics and wooden joint strengths; thus, as a guide to timber selection for joint construction or joinery in the furniture and related industries.

MATERIALS AND METHODS

Sampling of *E. cylindricum*

E. cylindricum logs (30 – 40 years with a diameter of 60 – 80cm) were harvested from Bobiri Forest Reserve in the Ashanti Province of Ghana (Lat. 6º 39'S and 6º 44'N; Long. 1º 15'E and 1º 23'W) (Boadu *et al*. 2017). They were sawn into boards and further processed from the heartwood and sapwood into standard sizes for the various tests and devoid of defects.

Determination of Tissue Proportion

E. cylindricum wood blocks (about $2cm^3$) (Fig. 1) were softened by boiling 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 the Forestry Research Institute of Ghana (FORIG) of the Council for Scientific and Industrial Research (CSIR), Fumesua, Kumasi. Images were captured randomly at 5 different locations on each slide with Image J software at a scale of 200µm. A 25-point scale grid with an area of $9 \times 10^4 \mu m^2$ per point was laid on each image (resolution = 2048 x 1536 pixels). The number of points covering each tissue (such as fibres, vessels, ray and axial parenchyma) was counted and expressed as a percentage of the total points (i.e., 25), which represented the proportion (%) of each tissue in the wood (Uetimane *et al*. 2009, International Association of Wood Anatomists (IAWA) 1989).

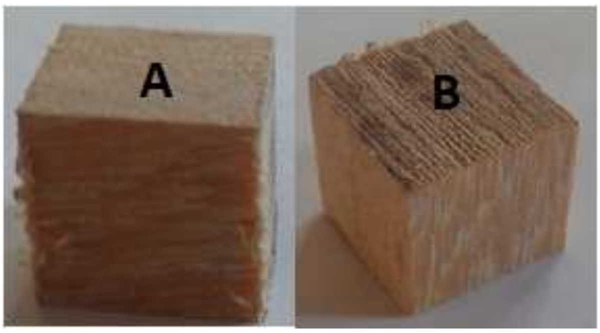

Fig. 1.
E. cylindricum samples for the tissue proportion test
A – Heartwood; B – Sapwood.

Determination of Fibre Morphological Characteristics

Match-stick sized samples (about 10mm long) were fully immersed in 99.8% glacial acetic acid and 30% hydrogen peroxide (1:1) in heat-resistant test tubes and incubated at 65ºC for maceration (IAWA 1989). The macerates were thoroughly washed with distilled water and a small sample put in glycerol on a glass slide, teased with a pin and protected with cover slips for viewing under the microscope. Photomicrographs of straight and unbroken fibres were obtained under a set magnification (40x) and a measuring scale

(50µm). Their lengths, diameters, lumen diameter and double-wall thicknesses (Fig. 2) were measured from a total of 300 fibres.

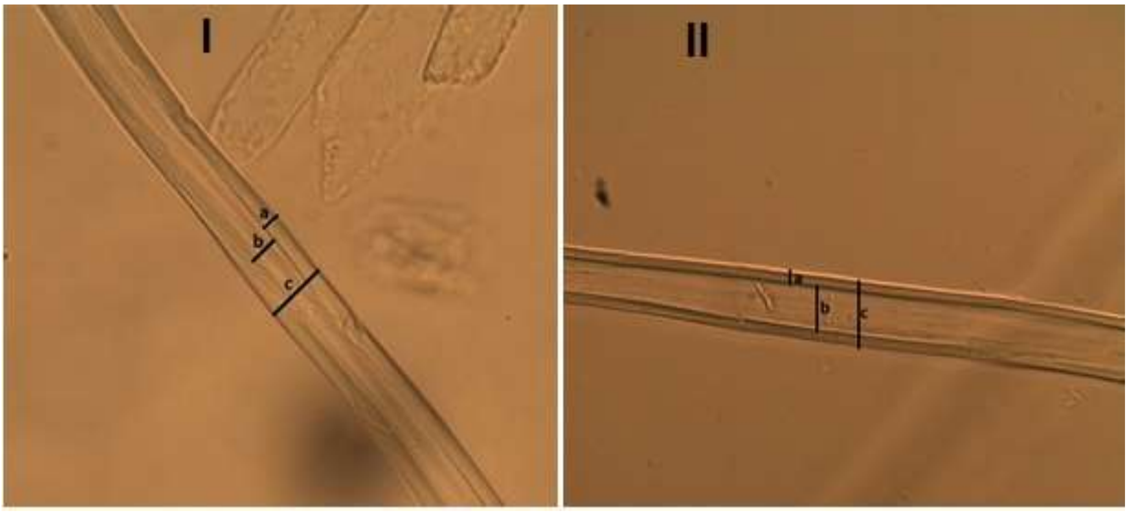

Fig. 2.
E. cylindricum heartwood (I) and sapwood (II) fibres used for the determination of morphological characteristics: a – wall thickness; b – lumen diameter; c – fibre diameter.

Determination of Mortise-Tenon Joint Strength

Straight-grained heartwood and sapwood samples of *E. cylindricum*, which had been air-dried to 12% mc, were planed and used to construct the leg (497.2 x 51 x 30mm) and rail (355 x 64 x 30mm) of a standard working chair. The positions of mortise (44 x 10 x 31.8mm) and tenon (31.8 x 44 x 10mm) on the respective leg and rail were marked and constructed (Tankut 2007, Boadu and Antwi-Boasiako 2017). The joints were assembled (Fig. 3) using Fevicol SH synthetic adhesive. Twenty replicates of the joints were each made from the sapwood and heartwood. With a Universal Testing Machine, load was applied to the rail member of the joints (Fig. 4) at a rate of 3mm/sec. The distance between the point of application of the load and the face of the joint (*L*) and the maximum load (F) that caused rupture at the face of the joint were recorded. The joint strength (*f*) was then calculated (Tankut 2007):

$$f = F \times L \text{ (Nm)} \quad (1)$$

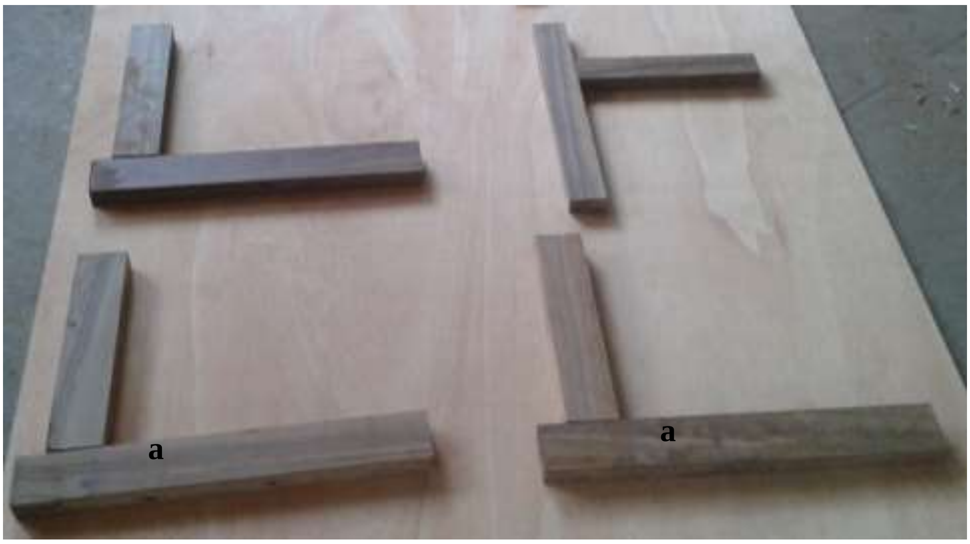

Fig. 3.
Mortise-tenon joint (a) assembled for strength test.

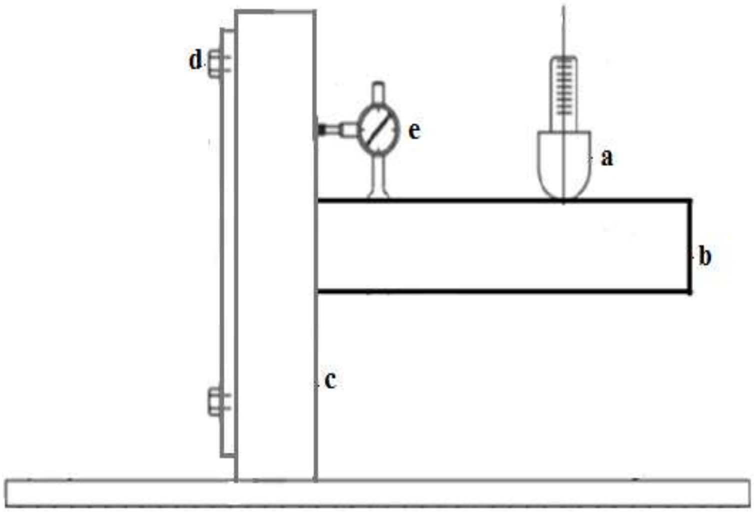

Fig. 4
Illustration of joint strength test: a – Machine cross head that applied the load; b - rail piece; c - leg piece; d - aluminium alloy plate that held the leg piece; e – dial gauge that measured deflection.

The relationship between anatomical characteristics of *E. cylindricum* and its Mortise-Tenon Joint Strength

The relationships between the tissue proportion and fibre morphology of the sapwood and heartwood of *E. cylindricum* and the corresponding strengths of their mortise-tenon joints were determined using the Pearson Product-Moment Correlation Coefficient (r). The Statistical Package for Social Scientists (SPSS) Software (Version 20) was used to analyze the relationships through a stepwise Multiple Regression Method to generate Scatterplots that described the interactions at 95% Confidence Level.

RESULTS & DISCUSSION

Tissue Proportion

Fibres formed the greatest of wood tissues in *E. cylindricum* (sapwood: 30.3±0.7%, heartwood: 51.1±1.3%) followed by vessels (sapwood: 25.4±0.9%, heartwood: 16.9±1.1%), while the least were ray parenchyma cells (sapwood: 20.2±0.9%, heartwood: 15.7±0.9%) (Fig. 5). Fibres were also greater in the heartwood than in the sapwood while vessels, ray and axial parenchyma (sapwood: 24.1±0.6%, heartwood: 16.3±1.1%) cells were greater in the sapwood than in the heartwood. Significant differences ($p<0.05$) existed between the heartwood and sapwood of *E. cylindricum* for their tissue proportions. 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 *Casuarina equisetifolia* J.R. & G. Forst. 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). Rahman *et al*. (2005) and Walker (2006) reported that ray parenchyma often forms about 15 - 30% of hardwood tissues. This ranged between 15.7±0.9% (heartwood) to 20.2±0.9% (sapwood) for *E. cylindricum*. Woodcock *et al*. (2000), Huda *et al.* (2012), Ogunwusi (2012) and Ziemińska *et al.* (2013) noted that timbers with greater amount of fibres than vessels and axial parenchyma cells were heavier with greater mechanical properties than those with fewer fibres and greater amount of vessels and axial parenchyma. Mattheck and Kubler (1997) and Rahman *et al*. (2005) noted that the amount of ray tissues was positively correlated with the density and compression strength of most hardwoods. Thus, based on the proportion of fibres, vessels and parenchyma tissues, *E. cylindricum* heartwood would be expected to be heavier and stronger than its sapwood, and the heartwood would be preferred for joinery, which needs wood of great strength.

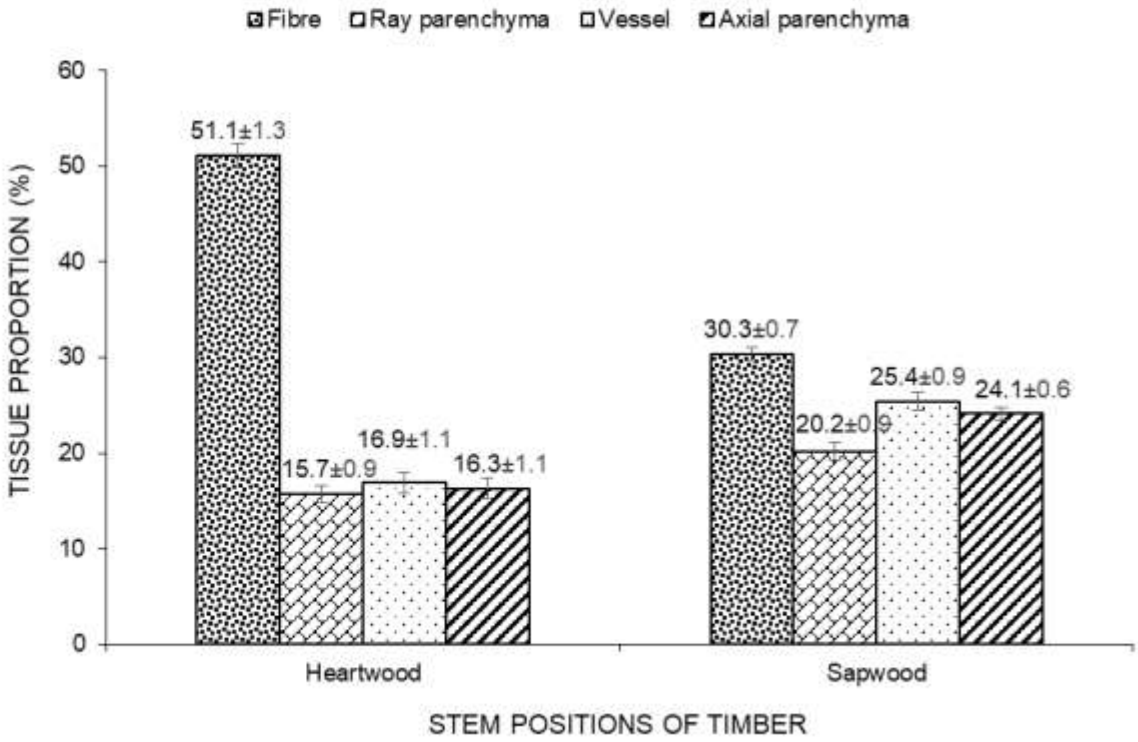

Fig. 5.
The proportion of different tissues across the stem of E. cylindricum (Bars = Standard Errors).

Fibre Morphology

Generally, greater fibre dimensions were observed in the heartwood [i.e., 20.3±0.02μm (for fibre diameter) and 9.8±0.1μm (for double-wall thickness)] than in the sapwood [i.e., 19.7±0.4μm (for fibre diameter) and 8.9±0.6μm (for double-wall thickness)] of *E. cylindricum*, except for the lumen diameter and fibre length, which were greater in the sapwood than in the heartwood. The differences were not significant ($p<0.05$) (Fig. 6). The variations between the fibre characteristics of the sapwood and heartwood are consistent with the differences in fibre morphology from the pith towards the bark of *Casuarina equisetifolia* J.R. & G. Forst. reported by Chowdhury *et al*. (2012) who noted that fibre diameter decreased from the pith to the bark of *C. equisetifolia*. Amoah *et al*. (2012) and Antwi-Boasiako and Apreko-Pilly (2016) explained that greater dimensions of fibres in the heartwood than those in the sapwood of tropical timbers could result from faster growth rate of the cambial initials during wood formation at the sapwood region, which results in smaller dimensions of cells. The greater diameter and wall thickness of fibres in the heartwood than in sapwood would increase the density and the strength properties of the former. Wider and thicker fibres of the heartwood often overlap each other better and appropriately transfer stress from one cell to the next (Boadu and Antwi-Boasiako 2017). Consequently, these would increase its load-bearing capacity than the narrower and thinner fibres of the sapwood (Sudin and Wahab 2006). Accordingly, the heartwood of *E. cylindricum* would likely give greater load-bearing capacity to wooden furniture joint than its sapwood.

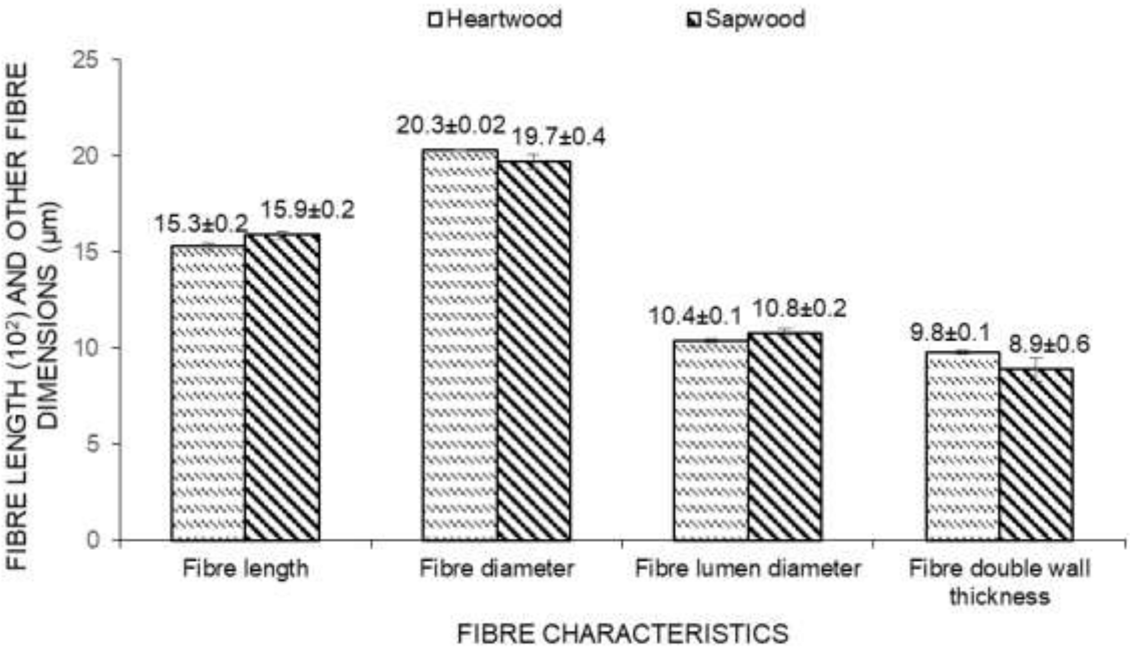

Fig. 6.
Fibre dimensions of the heartwood and sapwood of E. cylindricum (Bars = Standard Error).

The relationship between *E. cylindricum* Tissue Proportion and the Strength of its Mortise-Tenon Joints

The mean bending strength recorded for the joints made from *E. cylindricum* heartwood (697.45±15.49N/mm^2) were greater than that for the sapwood (674.05± 32.41N/mm^2). Boadu *et al*. (2017) similarly noted that the strength of structures made from sapwoods were generally lower than those from heartwoods. This could be due to several factors including the differences in the anatomical characteristics between both stem positions. Grabner *et al*. (2005) reported that the greater amount of extractives in the heartwood than in the sapwood reduces pore spaces in the former, which makes it more compact and resistant to bending. They found out that the extractive content of the heartwood of *Larix sp*. directly enhanced its transverse compression strength and MOE more than the sapwood. Yin *et al*. (2015) found greater mesopores in the sapwood than in the heartwood of Chinese fir (*Cunninghamia lanceolata*) due to deposition of extractives into those in the latter's cell wall during its transformation from the sapwood. The greater strength of joints from the heartwood than from the sapwood would make the former more appropriate for joinery by the Timber Industry. Proportions of fibre and ray parenchyma correlated positively with joint strength from both stem positions of *E. cylindricum*, while those of vessel and axial parenchyma did not (Table 1; Figs. 7-10). The amount of fibres in both stem positions had the greatest positive linear association with joint strength [r = 0.991 for the heartwood and 0.975 for the sapwood], while the proportions of the vessels in the heartwood and axial parenchyma in the sapwood had the greatest negative linear relationships with joint strength (r = -0.986 and -0.962 respectively). Tissue proportion influences the strength of wood joints through their effects on the glueability, density and mechanical properties of timber (Chowdhury *et al*. 2012). Antwi-Boasiako and Atta-Obeng (2009) explained that *Milicia excelsa* (Welw.) C. C. Berg had great strength due to the strong correlation between its vessel-fibre ratio and specific gravity (R^2 = 0.84). de Lima *et al*. (2014) found a linear relationship between the proportion of the rays and shear strength of *Eucalyptus resinifera* Smith wood, and explained that the rays act as reinforcing elements that lock the growth layers of wood and prevent slippage under shear stress. Uetimane and Ali (2011) noted that thick-walled fibres generally have large sectional areas to support great amount of loads and observed that the fibre proportion of *Pseudolachnostylis maprounaefolia* Pax had a positive relationship with its MOR (r = 0.527). The compressive strength of *Casuarina equisetifolia* was poorly correlated with the proportion of its vessels (r = -0.09) and axial parenchyma (r = -0.30) (Richter and Dalwitz 2009). According to Uetimane *et al*. (2009), the MOR of the sapwood of *Pseudolachnostylis maprounaefolia* Pax greatly associated with its fibre proportion but negatively correlated with the proportion of vessels such that the greater proportion of the vessel content generally affected the wood density and strength. Since tissue proportion influences joint strength through their effects on wood mechanical properties, tissues that enhanced timber mechanical properties (e.g. fibre and ray) are likely to contribute to the production of strong joints. Unsurprisingly, the fibre and ray proportions had the greatest positive relationships with joint strength, while vessel and axial parenchyma cells negatively correlated with joint strength. Furthermore, *E. cylindricum* heartwood, which had more fibres and ray parenchyma than the sapwood, produced stronger joints than the sapwood. Therefore, for strong furniture joints, the selection of timber must also consider the amount of fibres and ray parenchyma cells present in wood.

Table 1

Linear correlation between the tissue proportions and the strength of joint for the heartwood and sapwood of E. cylindricum

Joint strength	*Type of tissues (%)*	*Correlation Coefficient (r)*
Joint from the heartwood	*Fibres*	*0.991*
	Ray parenchyma	*0.964*
	Vessels	*-0.986*
	Axial parenchyma	*-0.955*
Joint from the sapwood	*Fibres*	*0.975*
	Ray parenchyma	*0.955*
	Vessels	*-0.959*
	Axial parenchyma	*-0.962*

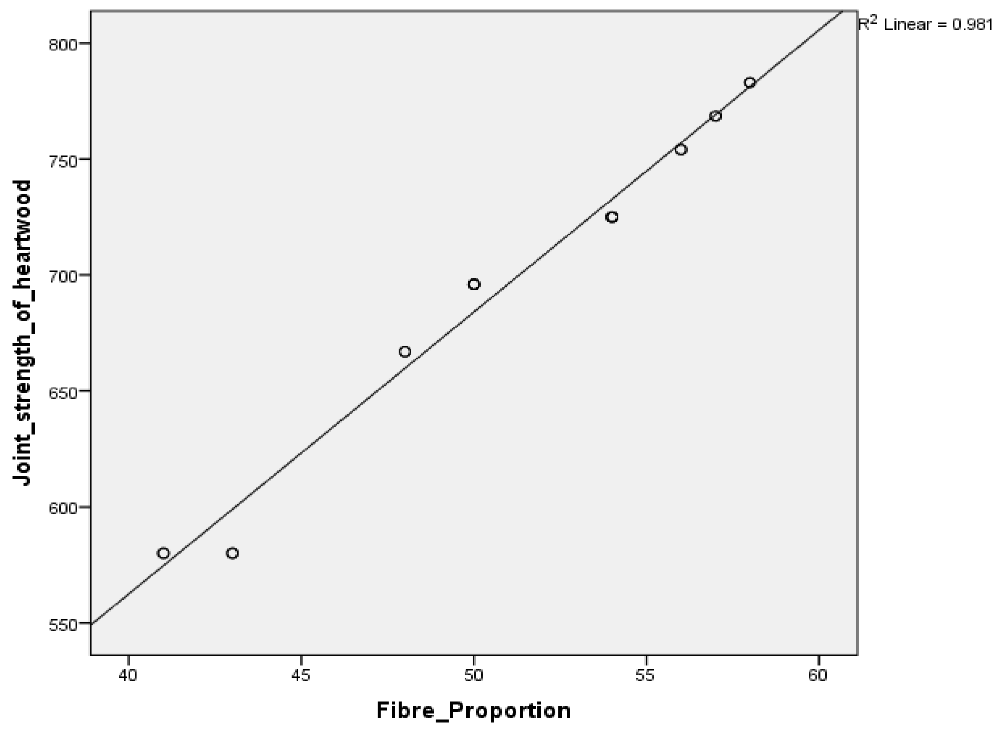

Fig. 7.
Correlation between fibre proportion and joint strength from E. cylindricum heartwood.

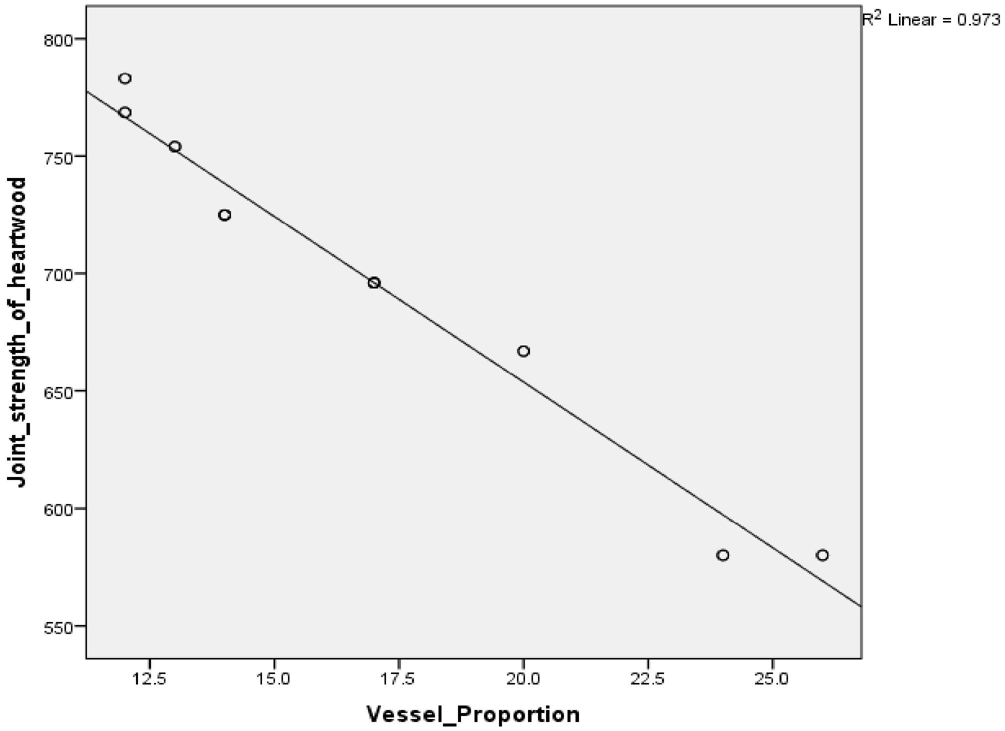

Fig. 8.
Correlation between vessel proportion and joint strength from E. cylindricum heartwood.

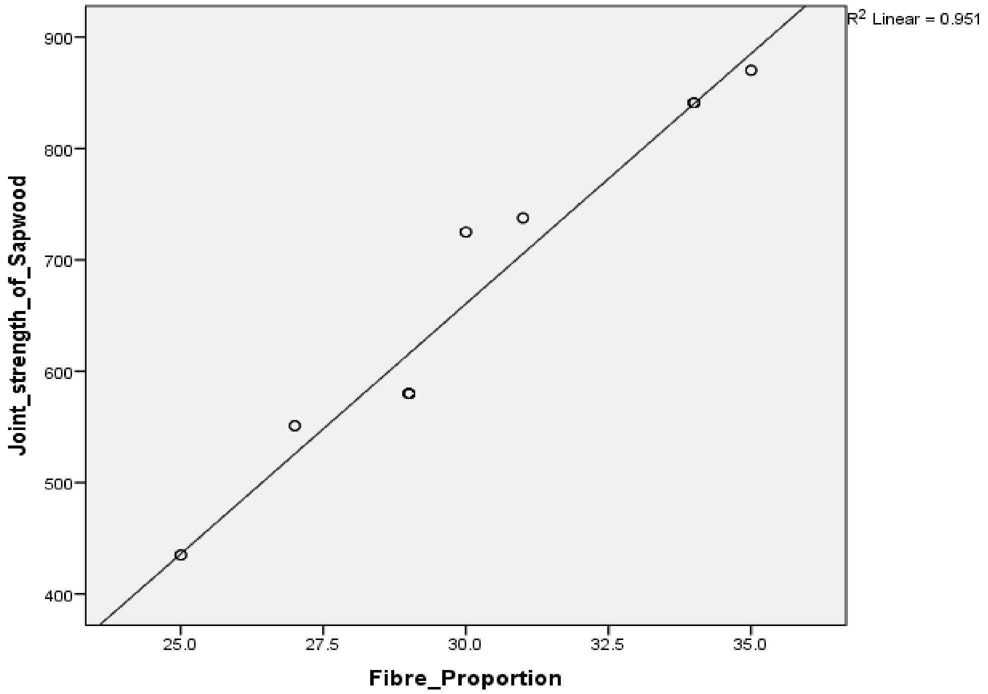

Fig. 9.
Correlation between fibre proportion and joint strength from E. cylindricum sapwood.

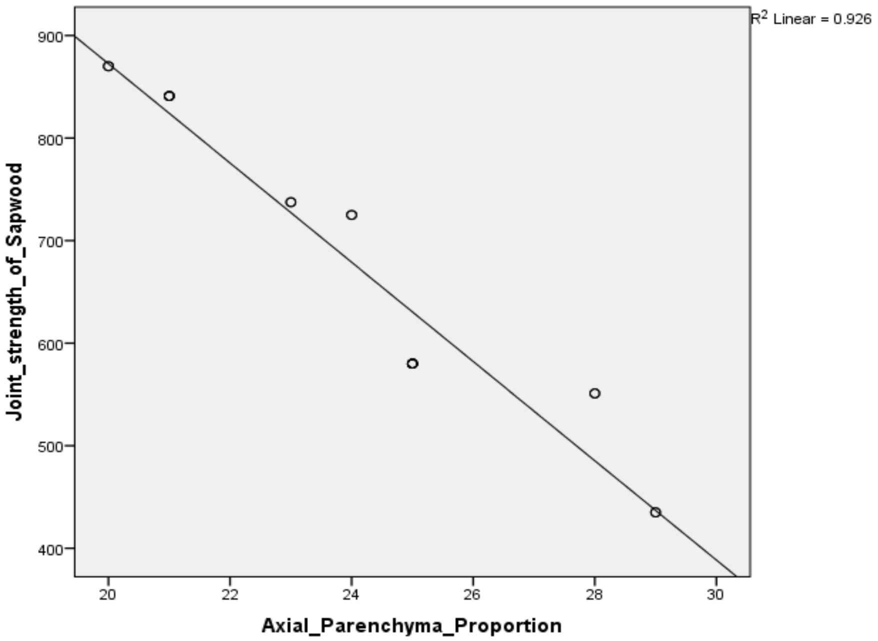

Fig. 10.
Correlation between axial parenchyma proportion and joint strength from E. cylindricum sapwood.

Relationship between *E. cylindricum* Fibre Morphological Characteristics and the Strength of its Mortise-Tenon Joints

Joint strength from the two stem positions (i.e., Heartwood and Sapwood) of *E. cylindricum* correlated positively with the timber's fibre characteristics except with fibre lumen diameter, which showed a strong negative relationship [r = -0.987 (heartwood); -0.978 (sapwood)] (Table 2, Figs. 11-14). Martinez-Cabrera *et al*. (2009) noted that increasing fraction of lumen diameter reduces the density and the strength of wood and consequently manufactured joints. It was therefore not surprising to record a negative relationship between joint strength and fibre lumen diameter. The sapwood, which had wider fibre lumen was also lower in joint strength than that of the heartwood. Fibre diameter of *E. cylindricum* had the greatest linear association with joint strength [r = 0.996 (heartwood); r = 0.994 (sapwood)] followed by fibre double-wall thickness (r = 0.990 and 0.993 respectively). Uetimane and Ali (2011) observed that the fibre diameter of *Pseudolachnostylis maprounaefolia* had a positive relationship with its MOE (r = 0.530), which is a key mechanical property that greatly determines the strength of wooden connections. Thus, fibre diameter and wall thickness likely improved *E. cylindricum*'s mechanical properties, which also resulted in the production of joints with great strength. Generally, there was a stronger relationship between joint strength and the fibre characteristics for the heartwood than for those of the sapwood except for fibre length. This could be due to the greater fibre dimensions (especially diameter and wall thickness) in the heartwood, which improved joint strength, than the sapwood (Sudin and Wahab 2006). Since fibre diameter and wall thickness were the characteristics that influenced the timber's joint performance most, they should be given more consideration during the selection of wood for furniture production.

Table 2
Linear correlation between the fibre characteristics and the strength of joint for the heartwood and sapwood of E. cylindricum

Joint strength	*Fibre characteristics*	*Correlation Coefficient (r)*
Joint from the heartwood	*Fibre diameter*	*0.996*
	Fibre wall thickness	*0.990*
	Fibre lumen diameter	*-0.987*
	Fibre length	*0.968*
Joint from the sapwood	*Fibre diameter*	*0.994*
	Fibre wall thickness	*0.993*
	Fibre lumen diameter	*-0.978*
	Fibre length	*0.992*

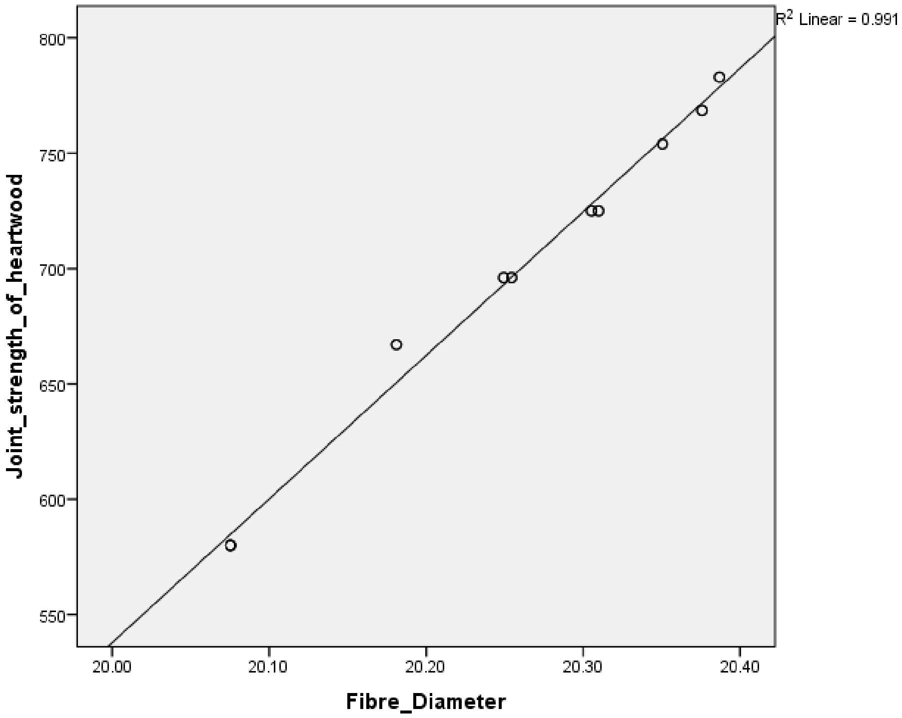

Fig. 11.
Correlation between fibre diameter and strength of joint from E. cylindricum heartwood.

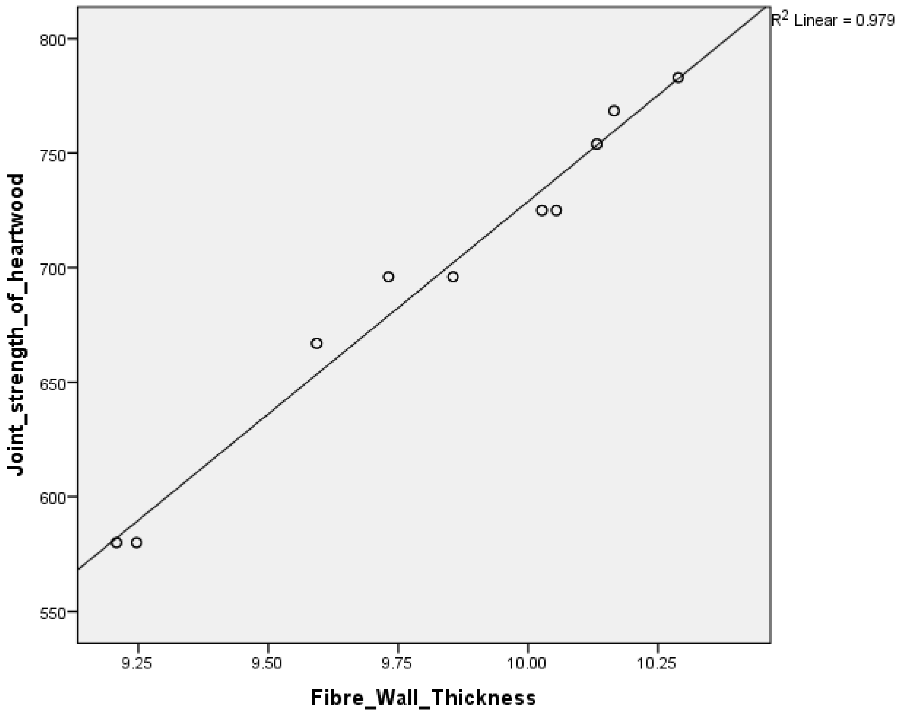

Fig. 12.
Correlation between fibre double-wall thickness and strength of joint from E. cylindricum heartwood.

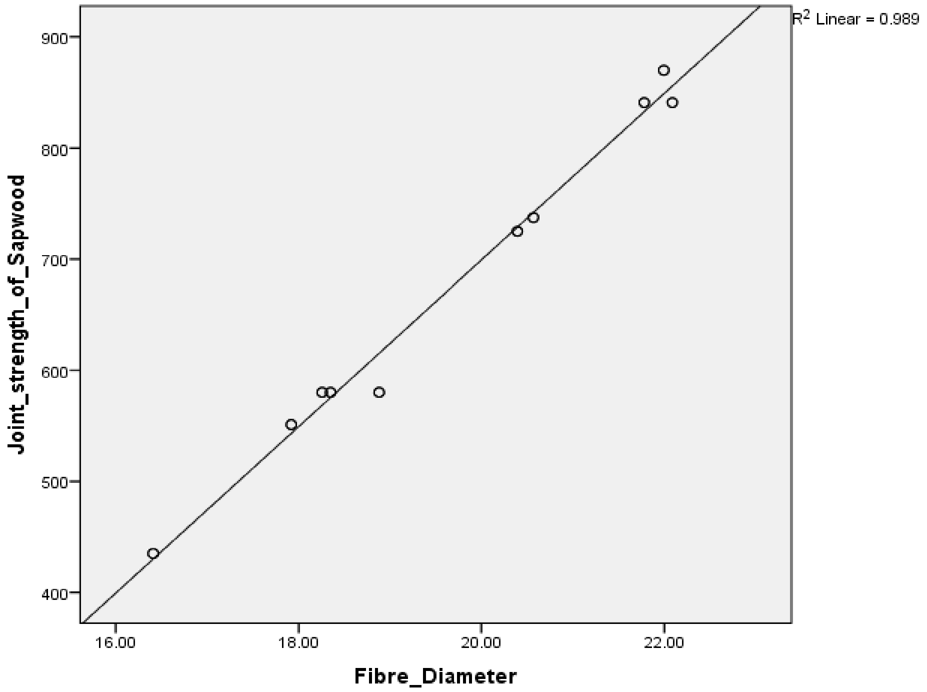

Fig. 13.
Correlation between fibre diameter and strength of joint from E. cylindricum sapwood.

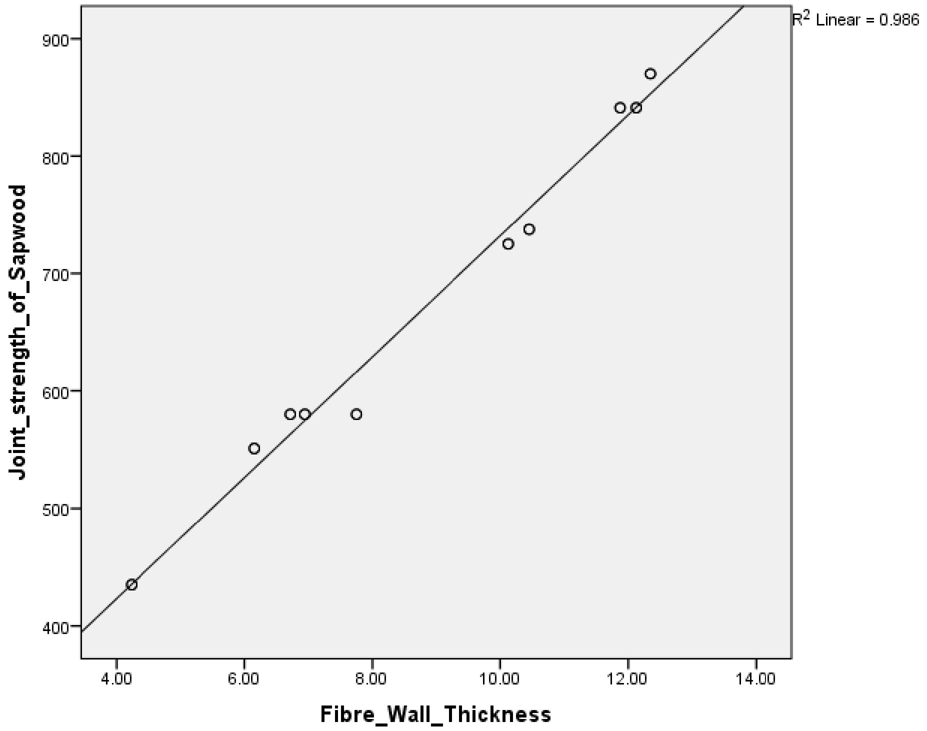

Fig. 14.
Correlation between fibre double-wall thickness and strength of joint from E. cylindricum sapwood.

CONCLUSION

- The fibre and ray contents of *E. cylindricum* had a strong positive correlation with joint strength. Thus, in the use of anatomy for the selection of timber for joint construction, the amount of these tissues in wood should be keenly considered.

- Among the fibre dimensions, diameter and wall thickness had the greatest linear association with joint strength and likely influenced *E. cylindricum*'s joint performance most.
- Fibres of the heartwood had greater dimensions (especially for the diameter and wall thickness) than the sapwood. Therefore, the fibre characteristics of the heartwood strongly correlated with joint strength than those of the sapwood.

ACKNOWLEDGEMENT

We thank the Organizing Committee of the 28th International Conference Research for Furniture Industry held at Poznan, Poland on 21st and 22nd September 2017, where the preliminary findings of this work were presented. We appreciate the assistance of the Staff of the Anatomy Department of the Forestry Research Institute of Ghana (FORIG), Council for Scientific and Industrial Research (CSIR), Fumesua, Kumasi for the anatomical studies. We also thank the Staff of the Wood Workshop, Department of Wood Science and Technology, and the strength testing laboratory, Department of Civil Engineering (all of Kwame Nkrumah University of Science and Technology) for the joints construction and mortise-tenon strength determination respectively.

REFERENCES

Adeniyi IM, Areghan SE, Alao OJ, Salaudeen GT, Falemara BC (2012) Deposits in Wood Micro-structures of some wood species. MJSS 3(15):203-208.

Amoah M, Appiah-Yeboah J, Okai R (2012) Characterization of physical and mechanical properties of Branch, Stem and Root Wood of Iroko and Emire Tropical trees. Research Journal of Applied Sciences, Engineering and Technology 4(12):1755-1761.

Antwi-Boasiako C, Apreko-Pilly S (2016) Tissue dimensions and proportions of the stem and branch woods of *Aningeria robusta* (A. Chev) and *Terminalia ivorensis* (A. Chev). African Journal of Wood Science and Forestry 4(8):254-273.

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

Barboutis O, Vassiliou V (2008) Bondability of Chestnut wood with PVAC adhesives for furniture production. Proceedings of the 7th International Symposium on Furniture, Zvolen (Slovakia) 18-19 June 2008.

Boadu BK, Antwi-Boasiako C (2017) 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 Material Science & Engineering 12(4):242-250.

Boadu BK, Antwi-Boasiako C, Frimpong-Mensah K (2017) Physical and Mechanical Properties of *Klainedoxa gabonensis* with Engineering Prospects. J Forestry Res 28:629-63.

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

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

de Lima IL, Longui EL, Freitas MLM, Zanatto ACS, Zanata M, Florsheim SMB, Bortoletto Jr G (2014) Physical-Mechanical and Anatomical Characterization in 26-Year-Old Eucalyptus resinifera Wood. Floresta e Ambiente 21(1):91-98.

Grabner M, Müller U, Gierlinger N, Wimmer R (2005) Effects of heartwood extractives on mechanical properties of larch. IAWA Bull, 26 (2):211-220.

Haviarova E, Kasal A, Efe H, Eckelman CA, Erdil YZ (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 Fiber Sci 45(3):1–7.

Huda AA, Koubaa A, Cloutier A, Hernandez RE, Périnet P (2012) Anatomical Properties of Selected Hybrid Poplar Clones Grown in Southern Quebec. BioRes 7(3):3779-3799.

International Association of Wood Anatomists (IAWA) (1989) List of microscopic features for hardwood identification. IAWA Bull 10:219-232.

Jeong GY (2013) Relationship between anatomical and mechanical properties of Loblolly pine (*Pinus taeda*). Forest Prod. J. 63(1-2):47-53.

Kiaei M, Samariha A (2011) Fiber dimensions, physical and mechanical properties of five important hardwood plants. INDJST 4(11):1460-1463.

Li R, Guo X, Ekevad M, Marklund B, Cao P (2015) Glueline shear of pine & PVAC. BioRes 10(3):3831-3838.

Martínez-Cabrera HI, Jones CS, Espino S, Schenk HJ (2009) Wood anatomy and wood density in shrubs: responses to varying aridity along transcontinental transects. Am. J. Bot. 96:1388–1398.

Mattheck C, Kubler H (1997) Wood - the internal optimization of trees. Springer-Verlag, Berlin.

Myburg AA, Lev-Yadun S, Sederoff RR (2013) Xylem Structure and Function. John Wiley & Sons Ltd., Chichester.

Ntalos G, Mantanis G (2007) ***Practical Solutions for Furniture*** and ***Structural Bonding***. Proceedings of International Workshop, Larnaka (Cyprus) 22-23 March.

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

Proulx E (1996) Yankee Magazine's Make It Last: Over 1,000 Ingenious Ways to Extend the Life of Everything You Own. Rodale Press Incorporated, Pennsylvania.

Rahman MMd, Fujiwara S, Kanagawa Y (2005) Variations in Volume and Dimensions of Rays and their Effect on Wood Properties of Teak. Wood Fiber Sci 37(3):497-504.

Richter HG, Dallwitz MJ (2009) Commercial timbers: descriptions, illustrations, identification, and information retrieval. Online at http://www.delta-intkey.com/wood/ (Accessed on 6/06/15).

Sudin M, Wahab R (2006) Variation in the decay resistance between sapwood and heartwood of Parashorea malaanonan. J Sci Technol 18(1):27-32.

Tankut N (2007) The effect of adhesive type and bond line thickness on the strength of mortise and tenon joints. Int J Adhes Adhes 27:493–498.

Uetimane Jr. E, Terziev N, Geoffrey D (2009) Wood Anatomy of Three Lesser Known Species from Mozambique. IAWA Journal 30(3):277-291.

Uetimane Jr. E, Ali AC (2011) Relationship between mechanical properties and selected anatomical features of Ntholo (*Pseudolachnostylis maprounaefolia*). J Trop For Sci 23(2):166–176.

Walker JCF (2006) Primary Wood Processing: Principles and Practice. Springer, Dordrecht.

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

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

Yin J, Song K, Lu Y, Zhao G, Yin Y (2015) Comparison of changes in micropores and mesopores in the wood cell walls of sapwood and heartwood. Wood Sci Technol 49(5):987–1001.

Ziemińska A, Butler WD, Gleason MS, Wright IJ, Westoby M (2013) Fibre wall and lumen fractions drive wood density variation across 24 Australian angiosperms. AoB PLANTS 5:1-13.