

SELECTED ACOUSTIC PROPERTIES OF *Aningeria robusta* (A.CHEV) WOOD IN RELATION TO FIBRE AND PHYSICO-MECHANICAL PROPERTIES

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Abstract:

The composition of wood makes wood a unique material for musical instrument and other acoustic applications. However, fibre properties, physical and mechanical properties has been highlighted to influence acoustic performance of wood. Notwithstanding, insufficient information about interaction between these properties has hindered the efficient utilization of lesser used wood species for acoustic purposes. This work thus endeavoured to study the existing relationship between fibre, physico-mechanical and selected acoustic properties of *Aningeria robusta* wood. Three trees of *A. robusta* were felled for the fibre, physico-mechanical and acoustic tests. The tests were carried out according to standard procedures. Mean fibre length, fibre diameter, lumen width and cell wall thickness were 1.54 ± 0.05 mm, 11.71 ± 0.19 μ m, 8.79 ± 0.41 μ m, 1.46 ± 0.29 μ m respectively. Moisture content, wood density, MOR, and MOE were 55.54 ± 2.98 %, 0.43 ± 0.18 g/cm³, 123.91 ± 4.74 N/mm², 5876.89 ± 382.82 N/mm², while Speed of sound, specific elastic modulus, sound radiation coefficient, and acoustic impedance were 3711.46 ± 183.35 m/s, 14.06 ± 0.70 (GPa), 8.90 ± 0.39 , $1.6 \times 10^6 \pm 47017.33$ kg/m²s respectively. Correlation analysis was positively significant for MOE and acoustic properties. Wood density also had a negative significant correlation with acoustic properties except for acoustic impedance. The findings of this study reveals that relationship existed between these properties. However, it can be species dependent.

Key words: Correlation, Relation, Fibre, Physico-mechanical, Acoustic.

INTRODUCTION

The composition of wood makes wood to be an outstanding material; it is versatile, inexhaustible and renewable. Wood can produce sound by direct striking, and can amplify or absorb sound waves originating from other bodies. For these reasons, it is a unique material for musical instrument and other acoustic applications. Also, some wood are acoustic in nature and has the ability to produce sound effect. Because of this unique property, wood is used in producing a number of musical instruments such as guitar, violin, piano, xylophone and percussion. However, physical and mechanical properties has been highlighted to influence acoustic performance of wood. For instance, Tsoumis (1991) reported that the pitch of sound produced depends on the frequency of vibration, which can be affected by the dimensions, density, moisture content, and modulus of elasticity of the wood thus stating that smaller dimensions, lower moisture content, and higher density and elasticity produce sounds of higher pitch. Also, George, (2014) stated that the velocity of sound in wood is reduced by moisture, thus contributes to faster damping of sound in wood.

Of the lesser used wood species (LUWS) in Nigeria, *Aningeria robusta* is fast becoming popular due to its excellent performance in structural applications especially in roofing, and in recent times, door frames and furniture. *Aningeria robusta* belongs to the family Sapotaceae, a hardwood. It is referred to as 'agengre' in Cote d'Ivoire, 'landosan' in Nigeria and 'osan' in Uganda (TRADA 1979; Ajala and Ogunsanwo 2011), 'mukali' in Angola, 'mukangu' in Kenya (Chudnoff 1980; Ajala and Ogunsanwo 2011) and 'asafonia' in Ghana (Okai 2003).

However, an important research area of wood utilization which has not found enough concentration and popularity is the acoustic. Whereas, the potential utility of any wood is dependent upon its basic anatomical, physical and mechanical properties. These properties are the underlying factors determining the behaviour and recommendation of wood for general and peculiar uses (FAO 1998). Similarly, Poku *et al.* (2001) stated that maximum utilization of lesser used wood species in the timber market requires technical information that relates to utilization of the species. Therefore, the successful utilization of *A. robusta* for acoustic purposes also requires technical information of its anatomical, physical and mechanical properties in relation to its acoustic properties. Thus, there is need to study the anatomical, physical and mechanical properties in relation to the acoustic properties of *A. robusta* wood.

OBJECTIVE

The objective of this study is to find an existing relationship between fibre, physico-mechanical and selected acoustic properties (speed of sound, sound radiation coefficient, longitudinal modulus of elasticity, specific modulus of elasticity and acoustic impedance) of *A.robusta* wood.

MATERIALS AND METHOD

SAMPLE COLLECTION AND PREPARATION

Three trees of *Aningeria robusta* with at between 25 ± 2 cm DBH obtained from Gambari Forest Reserve were fell. From each tree, bolt of 50cm in length was collected at the base, middle and top portion to determine the physical and mechanical properties of the wood. Circular machine and planning machine were used to collect wood samples of dimension 20X20X20mm, 20x20x60mm from the bolts for fibre characteristics and physical properties respectively while, 20x20x300mm was collected for mechanical (Modulus of elasticity and modulus of rupture) and acoustic properties. This is in accordance with ASTM (1991). 5 samples of 20x20x60mm, 20x20x300mm and 20x20x300mm were collected from the top, middle and base wood of each tree for physical properties, mechanical properties and acoustic properties respectively. Thus, making a total of 135 samples. Meanwhile, 1 dimension of 20X20X20mm was collected axially for fibre characteristics test. The samples were oven dried and kept at room temperature and humidity for one month prior testing.

DETERMINATION OF FIBRE CHARACTERISTICS

Dimension of 20X20X20mm wood samples obtained from top, middle and base of the trees were used to study axial variation in fibre dimensions. For the fibre dimensions determination, small wood slivers were obtained each at the different sampling height. The fibre measurements were conducted in accordance with ASTM D 1030-95 (2007) and ASTM D 1413-61 (2007). Maceration of the slivers was carried out using acetic acid and hydrogen peroxide (1:1) and placed in an oven for 2hours at a temperature of 100°C then the solution was vigorously agitated for individual fibres to be separated. The macerated fibres were randomly selected and dropped on a standard slide, 7.5cm x 2.5cm using a procedure adopted by Dutt et al. (2012). All the characteristics namely, fibre length (FL), fibre diameter (FD), lumen width (LW) were viewed under a stage micrometer mounted on a Zeiss light microscope (Standard of 25 fibres) under 80× in swollen state, and cell wall was calculated using eq. 1. Twenty five (25) fibres were measured from each sample slide.

$$CWT = \frac{FD - LW}{2} \quad (1)$$

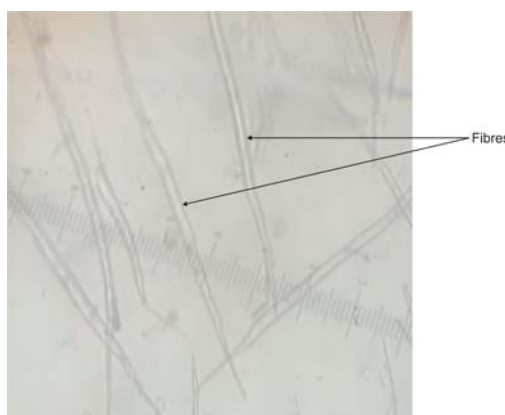


Fig. 1.
Sample of fibres of *A.robusta* wood.

DETERMINATION OF PHYSICAL PROPERTIES

Wood Density

The 20x20x60mm wood samples collected were oven dried to a constant weight at $103^{\circ}\text{C} \pm 2$ for 24 hours and the weight afterward was recorded. The volume of samples at green weight was recorded and the following formula was adopted for the calculation of wood density (ASTM D 2395-14).

$$\rho = \text{Density (g/cm}^3\text{)} \quad \rho = m/v \quad (2)$$

m = oven-dried mass (g)
 v = green volume (cm³)

Moisture Content

Moisture content of the wood samples were determined according to BS 373: (1957). The samples were weighed when wet (original weight), it was then dried to a constant weight at $103^{\circ}\text{C} \pm 2$ in an oven for 24 hours, after which it was re-weighed. The loss of weight of the wood samples on drying to a constant weight was noted. Calculation of the loss in weight as a percentage of the samples weight after drying was done by using the formula below

$$M.C. = \frac{w_1 - w_0}{w_0} \times 100 (\%) \quad (3)$$

where:

MC = Moisture Content (%)
 w_1 = Initial weight of wood sample (g)
 w_0 = oven dry weight of wood sample (g)

DETERMINATION OF MECHANICAL PROPERTIES

Mechanical test was conducted according to British standard 373 (1989). This involved the use of standard test specimen (10x10x300mm) in a universal testing machine. The test sample was prepared in such a way that growth rings will be made parallel to one edge. Load was applied at the rate of 0.2mm/sec, with the growth rings parallel to the direction of loading, that is, specimen was loaded on the radial face until failure occurred.

Modulus of Rupture (MOR)

From the graph generated by the universal testing machine, the peak and breaking force were recorded; hence "MOR" was calculated as thus:

$$MOR = \frac{3PL}{2bd^2} (N / mm^2) \quad (4)$$

where:

MOR = modulus of rupture
P = load needed for failure (N)
L = span of the material between support (length) (mm)
b = width of the material (mm)
d = thickness of the material (mm)

Modulus of Elasticity (MOE)

Graph generated from universal testing machine was used to obtain the force needed to reach elastic limit and its displacement. The modulus of elasticity was then calculated using eq. 5.

$$MOE = \frac{PL^3}{4\Delta bd^3} (N / mm^2) \quad (5)$$

where:

P = load in Newton (N)
L = span / length (mm)
b = width (mm)
d = depth (mm)
 Δ = the displacement at beam centre at proportional load

DETERMINATION OF ACOUSTIC PROPERTIES

Speed of Sound

The speed, c, with sound travels through a material, is defined as the root of the material's Young modulus E, divided by the material's density, ρ . Mathematically:

$$c = \sqrt{\frac{E}{\rho}} \quad (6)$$

where:

c = speed of sound (m/s)

E = modulus of elasticity (N/mm²)

ρ = density (g/cm³)

(Newtons – laplace equation – Wegst, 2006)

Specific Longitudinal Elastic Modulus (Es);

$$E_s = \frac{E}{\rho_s} \quad (\text{GPa}) \quad (7)$$

where ρ_s = Relative Density (Specific gravity)

$$\rho_s = \frac{\frac{\text{oven dried mass}}{\text{green volume}}}{\text{density of water}} \quad (8)$$

Sound radiation coefficient (K):

$$K = \left(\frac{E}{\rho_s^3} \right)^{0.5} \quad (9) \quad (\text{Roohnia 2005})$$

where E = longitudinal elastic modulus, and ρ_s = specific gravity

Acoustic Impedance (z)

The acoustic impedance, z , of a material, is defined as the product of material's speed of sound, c , and its density, ρ .

Mathematically,

$$z = c\rho \quad (\text{kg/m}^2\text{s}^{-1}) \quad (10) \quad (\text{Wegst 2006})$$

Experimental design

The experiment was laid in a completely randomized design with 3 treatments (top, middle and base wood) replicated thrice. Descriptive statistics and correlation analysis were used. IBM SPSS statistics 20 was the software used for the analysis.

RESULTS AND DISCUSSION

RESULTS

The following Tables shows the mean values of properties, and correlation analysis done in this study. Table 1 shows the fibre properties, and it thus revealed that *A.robusta* wood had a mean fibre length of 1.54±0.05 mm, while its mean fibre diameter, lumen width and cell wall thickness were 11.71±0.19µm, 8.79±0.41µm, 1.46±0.29µm respectively.

Meanwhile, Table 2 and Table 3 shows the physico-mechanical properties of the wood and the selected acoustic properties tested respectively. The moisture content was 55.54±2.98%, wood density was 0.43±0.18g/cm³, MOR was 123.91±4.74N/mm², and MOE was 5876.89±382.82N/mm². Speed of sound - 3711.46±183.35m/s, specific elastic modulus - 14.06±0.70 (GPa), sound radiation coefficient - 8.90±0.39, and acoustic impedance - 1.6 x 10⁶±47017.33kg/m²s. Whereas, Table 4 shows the correlation between these properties.

Table 1

Fibre properties of A. robusta

	TREE 1	TREE 2	TREE 3	MEAN
FL (mm)				
TOP	1.73	1.37	1.51	1.54
MIDDLE	2.04	1.34	1.52	1.63
BASE	1.44	1.44	1.54	1.47
MEAN	1.74±0.17	1.38±0.03	1.52±0.01	1.54±0.05
FD (µm)				
TOP	11.83	10.67	11.48	11.33
MIDDLE	12.21	10.99	12.43	11.88
BASE	12.64	11.41	11.73	11.93
MEAN	12.23±0.23	11.02±0.21	11.88±0.29	11.71±0.19

LD (µm)				
TOP	10.13	8.16	10.45	9.58
MIDDLE	8.43	6.67	9.6	8.23
BASE	9.12	8	8.59	8.57
MEAN	9.23±0.49	7.61±0.47	9.55±0.54	8.79±0.41
CWT (µm)				
TOP	0.85	1.26	0.52	0.88
MIDDLE	1.89	2.16	1.42	1.82
BASE	1.76	1.71	1.57	1.68
MEAN	1.5±0.33	1.71±0.26	1.17±0.33	1.46±0.29
FL – Fibre Length	FD – Fibre Diameter	LD – Lumen Diameter	CWT – Cell Wall Thickness	

Table 2

Physico-mechanical properties determined for *A. robusta*

	TREE 1	TREE 2	TREE 3	MEAN
MC (%)				
TOP	58.02	62.65	65.12	61.93±2.08
MIDDLE	38.79	48.44	57.65	48.29±5.44
BASE	65.88	48.49	54.77	56.38±5.08
MEAN	54.23±8.04	53.19±4.72	59.18±3.08	55.54±2.98
WOOD DENSITY (g/cm³)				
TOP	0.38	0.41	0.43	0.41±0.16
MIDDLE	0.36	0.52	0.45	0.44±0.45
BASE	0.41	0.52	0.38	0.44±0.40
MEAN	0.38±15	0.48±0.36	0.42±0.21	0.43±0.18
MOR (N/mm²)				
TOP	122.1	129.51	129.56	127.06±2.47
MIDDLE	95.04	116.33	145	118.79±14.47
BASE	116.73	136.87	124.08	125.893±5.88
MEAN	111.29±8.27	127.57±6.0	132.88±6.26	123.91±4.74
MOE (N/mm²)				
TOP	5807.8	6435.92	6609.44	6284.39±243.50
MIDDLE	5754.87	5576.14	5660.49	5663.83±51.62
BASE	6862.52	3176.22	7008.62	5682.45±1253.82
MEAN	6141.73±360.71	5062.76±975.37	6426.18±399.81	5876.89±382.82

MOR = Modulus of rupture, MOE = modulus of elasticity

Table 3

Acoustic Properties of *Aningeria robusta*

	TREE 1	TREE 2	TREE 3	MEAN
SPEED (m/s)				
TOP	3907.29	3974.12	3900.2	3927.2±23.54
MIDDLE	3988.99	3282.02	4363.87	3591.63±208.74
BASE	4080.01	2482.82	4283.83	3615.55±569.41
MEAN	3992.1±49.88	3246.32±430.87	3895.97±225.16	3711.46±183.35
Es (GPa)				
TOP	15.267	15.77	15.19	15.41
MIDDLE	15.91	10.76	12.50	13.06
BASE	16.66	6.17	18.35	13.72
MEAN	15.95±0.41	10.90±2.77	15.35±1.69	14.06±0.70
K				
TOP	10.27	9.73	8.96	9.66
MIDDLE	11.03	6.33	7.80	8.39
BASE	9.91	4.82	11.21	8.65
MEAN	10.40±0.33	6.96±1.45	9.33±1.00	8.90±0.39
Z x 10⁶ (kg/m²s⁻¹)				
TOP	1.5 x 10 ⁶	1.6 x 10 ⁶	1.7 x 10 ⁶	1.6 x 10⁶±60882.23
MIDDLE	1.4 x 10 ⁶	1.7 x 10 ⁶	1.6 x 10 ⁶	1.6 x 10⁶±74184.56
BASE	1.7 x 10 ⁶	1.3 x 10 ⁶	1.6 x 10 ⁶	1.5 x 10⁶±127276.2
MEAN	1.5 x 10⁶±73171.2	1.5 x 10⁶±128714.5	1.6 x 10⁶±31123.33	1.6 x 10⁶±47017.33

Table 4

Correlation analysis between fibre, physico-mechanical properties and selected acoustic properties of *A.robusta* wood

	FL	FD	LD	CWT	MC	WD	MOR	MOE
c	0.27	0.44	0.50	-0.29	0.38	-0.75*	-0.11	0.85*
Es	0.32	0.27	0.39	-0.28	0.36	-0.88*	-0.40	0.93*
K	0.54	0.32	0.41	-0.26	0.18	-0.97*	-0.49	0.79*
Z	-0.41	-0.06	0.08	-0.13	0.57	-0.12	-0.02	0.82*

c – Speed of sound

D – wood density

* significant at $P \leq 0.05$

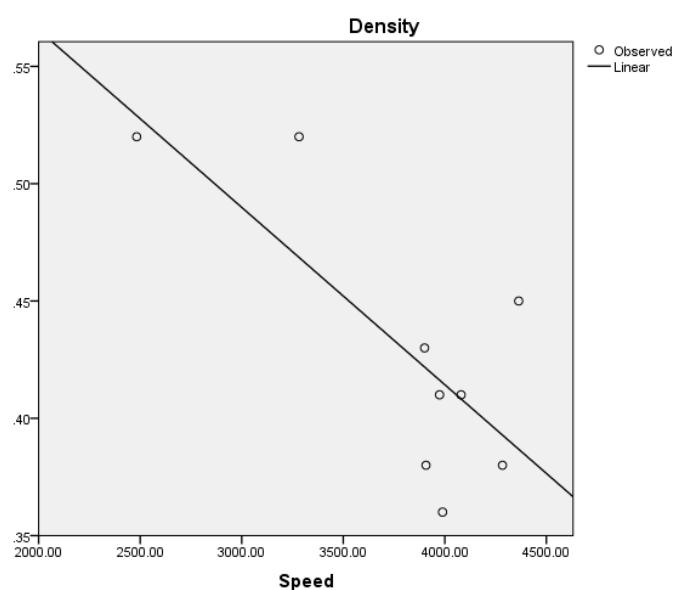


Fig. 2.

Graphical representation of correlation between wood density and speed of sound.

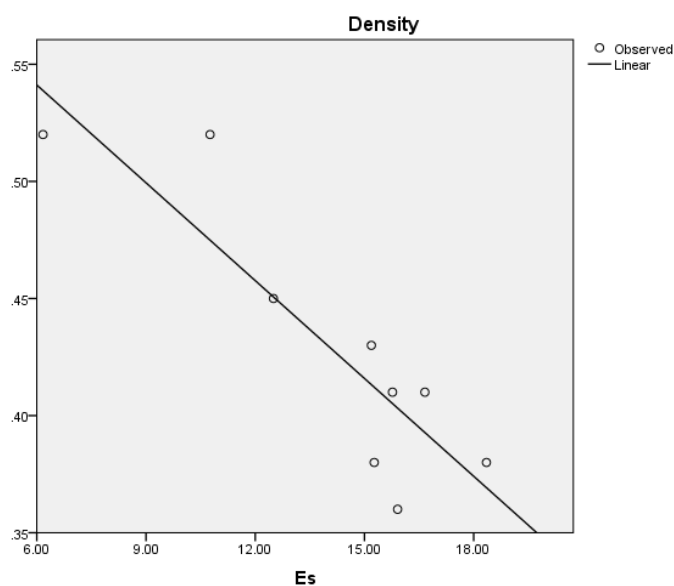


Fig. 3.

Graphical representation of correlation between wood density and specific elastic modulus.

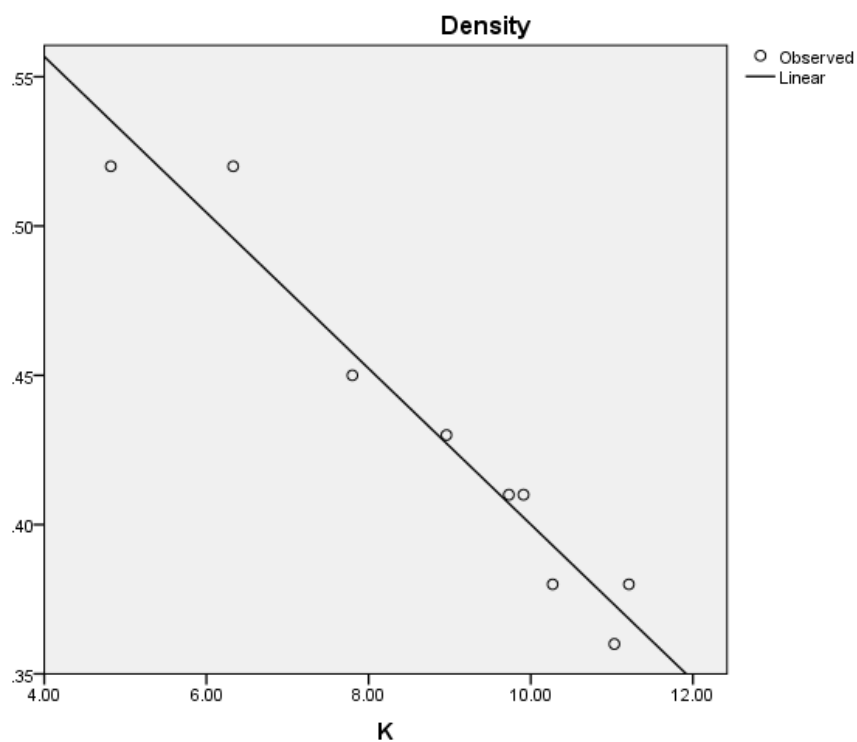


Fig. 4.

Graphical representation of correlation between wood density and sound radiation co-efficient.

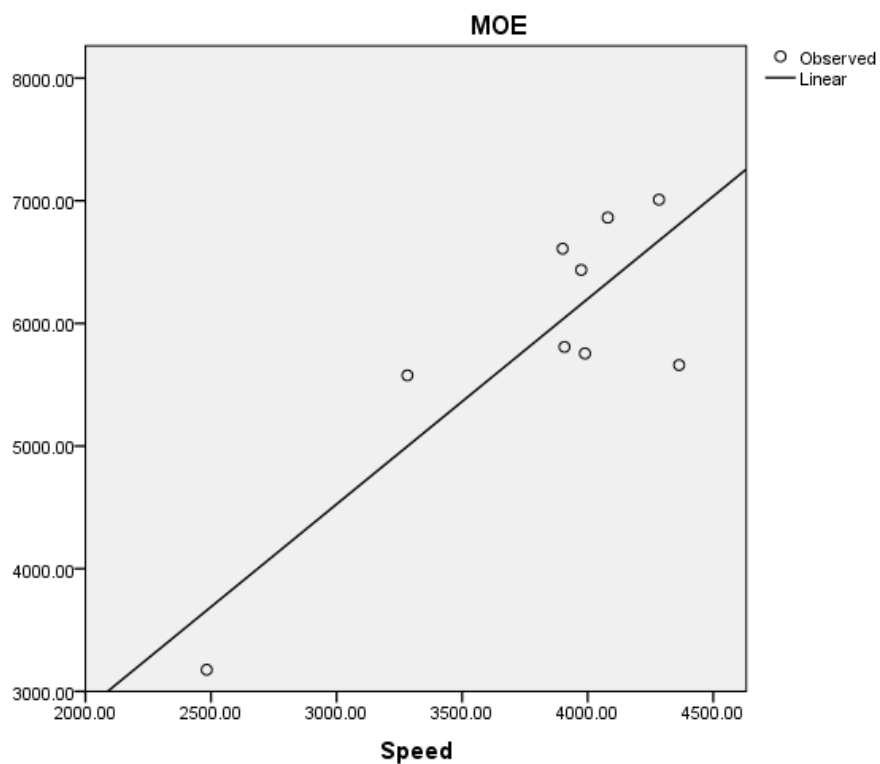


Fig. 5.

Graphical representation of correlation between MOE and speed of sound.

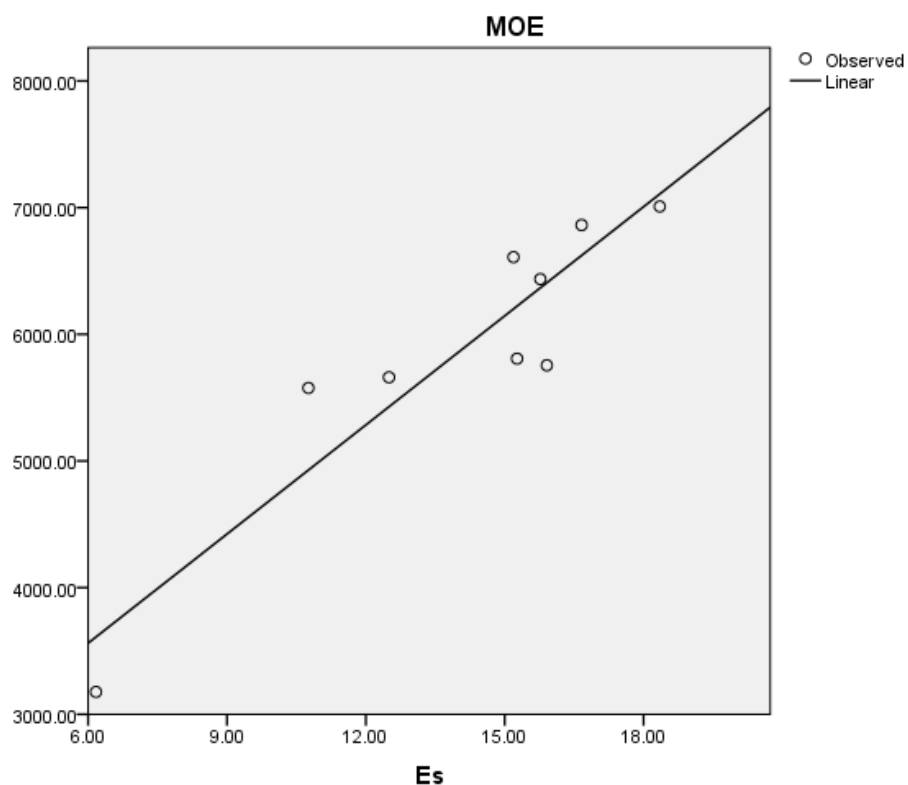


Fig. 6.
Graphical representation of correlation between MOE and specific elastic modulus.

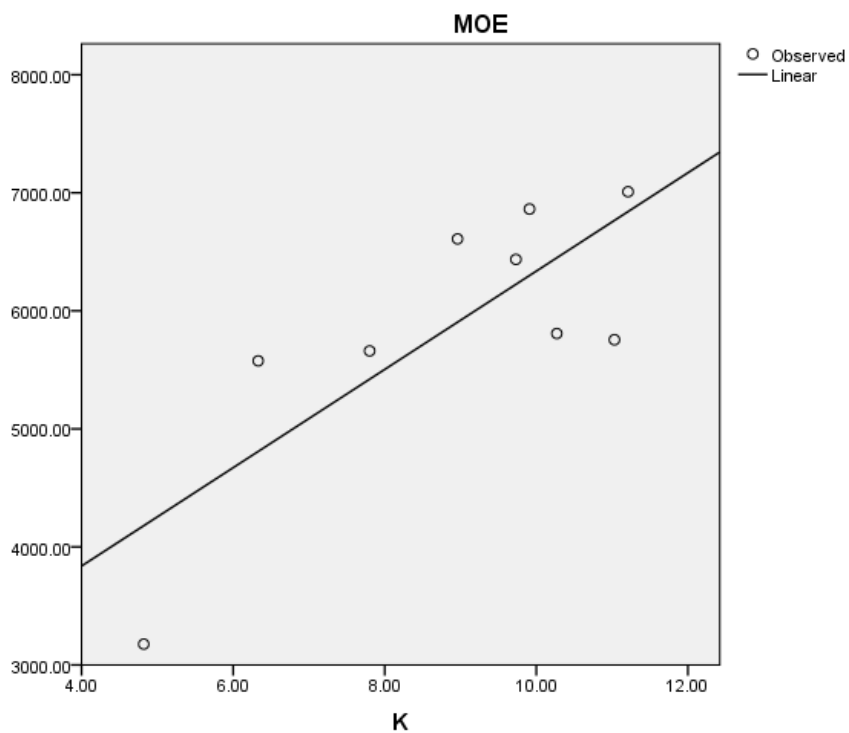


Fig. 7.
Graphical representation of correlation between MOE and sound radiation co-efficient.

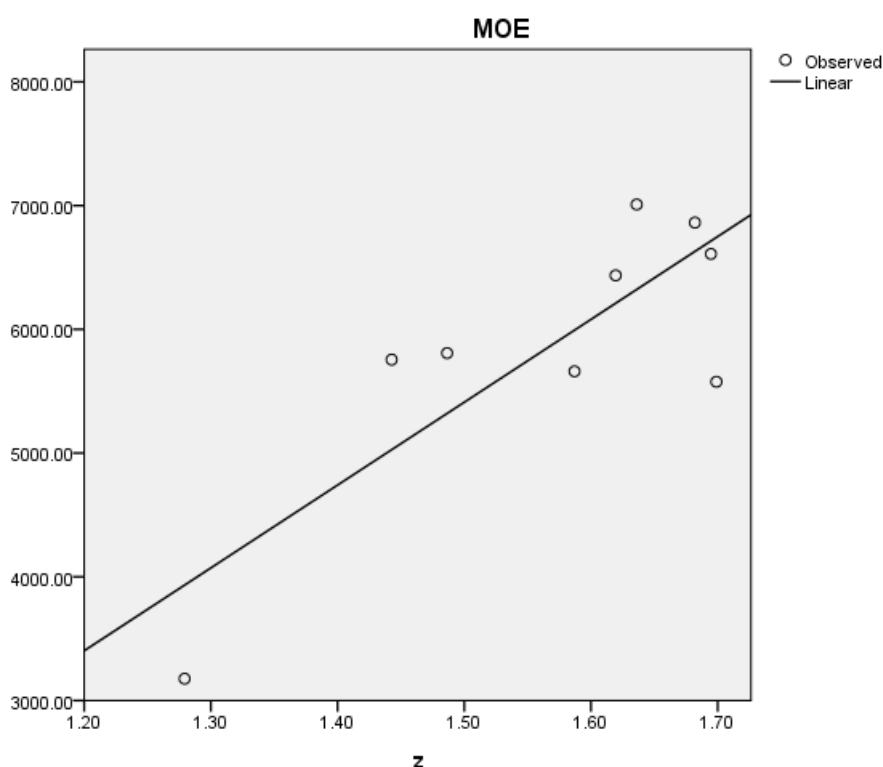


Fig. 8.

Graphical representation of correlation between MOE and speed of sound.

DISCUSSION

Acoustic properties

Speed of sound is defined as the distance traveled per time. Thus, it can be shown that speed of sound in the middle wood covers the lowest distance in a sec. The speed of sound of *A. robusta* in this study (3711m/s) was similar to *G. arborea* (3069m/s) and *Brachystegia eurycoma* (3712m/s) (Noah *et al.* 2012) at equilibrium moisture content. Therefore, the value of speed of sound obtained in this study is in accordance with George (2014) who stated that speed of sound in wood is between 3,500m/s – 5,000m/s.

Es of a material can be contributory to a better acoustic performance such that a high Es combined with low density leads to high radiation ratio. For instance, choice of wood species for soundboards of western string instruments were represented by higher specific dynamic modulus (Iris 2012). Also, Holz (1996) reiterated that a high specific modulus of elasticity should ensure sufficient radiation at lower frequencies. Therefore, the need for a high Es is essential. However, Es for *A. robusta* compared relatively lower to *Afzelia sp.* (16.9GPa), *Milletia sp.* (18.9 GPa), *Bamboo* (15 GPa). (Mohammed *et al.* 2014; Baar *et al.* 2016).

Acoustic coefficient 'K' is also referred to as radiation ratio which describes the average amplitude or loudness, while acoustic Impedance 'z' is related to the transmission of vibration from one medium to another (Barlow 1997; Wegst 2006). Also, acoustic impedance of a medium was stated to mean the rate of resistance of a medium to sound flow travelling through it (NDT 2015). A high value of acoustic impedance therefore implies a high rate of obstruction to the free flow of high frequency sound wave by the medium with which it travels in. When this happens, it will affect the rate of penetration and absorption of the sound wave by the medium and therefore affect the resulting acoustic properties such as speed of sound (Schubert and Wolfe 2013). High value of acoustic impedance could be a disadvantage because it may reduce the speed of sound, but on the other hand it could help to maintain harmonic sound generated by the wood.

Correlation between fibre, physico-mechanical properties, and the selected acoustic properties

Although, fibre properties considered in this study does not have a significant association with the acoustic properties, FD and LD still had a good degree of correlation $\geq 50\%$ with sound radiation coefficient and speed of sound respectively. This is a pointer that fibre properties can have a reasonable correlation with acoustic of wood. Notwithstanding, Baar *et al.* (2016) recorded a significant correlation between fibre length and Es for *Afzelia sp.*, and a non-significant correlation between fibre length and Es of *Milletia sp.*, thus suggesting that correlation between fibre properties and acoustic properties can be species dependent.

With the afore-mentioned, it can be concluded that the correlation exhibited between fibre properties and acoustic properties in this study is thus limited to *A.robusta*.

A negative correlation between wood density and speed of sound in Table 4 implies an inversely proportional relationship. It shows that the lesser the wood density, the higher the speed of sound in the wood. This finding is against Shander (2015), Adrian (2015), Paul (2015); they all argued that since sound wave needs a medium to propagate, and this propagation depends on how closely the particles are together in the solid, then it is expected that sound wave will cover a longer distance in shortest time possible with denser medium.

Meanwhile, the above research findings was supported by NDT (2015) stating that a denser medium can transmit sound slower if the medium is denser as a result of larger molecules in it. Similarly, Integrated Publishing (2015) on acoustic of sound quality highlighted that a denser material may pass sound slower, thus supporting the findings of this study. Therefore, the resulting lower speed value of at the middle wood despite having a higher density axially may be due to existing larger molecules in the middle wood which may be attributed to thicker cell wall.

The assertion by George, (2014) that speed of sound is reduced by moisture content was not found to be significant in this study. This could have been because this study did not consider more than one wood species, or adequate influence of moisture on acoustic properties were not adequately captured. However, wood density was found to negatively correlate with Es and K. this thus mean that a lower density wood is expected to have higher elasticity and radiation ratio.

MOE had an excellent degree of association with all the acoustic properties. This implies that elasticity of a wood is very essential to acoustic performance of wood, such that a wood with higher elasticity will have a higher speed of sound, Es, K, and Z.

CONCLUSION AND RECOMMENDATION

This work was able to study the wood of *A.robusta* for its fibre properties, physico-mechanical properties, acoustic properties, and existing correlation between them. It was therefore concluded based on the findings of this study that wood density and wood elasticity correlated well with selected acoustic properties of *A.robusta* wood. However, this relationship could be species dependent, and as such, more studies into the existing relationship between other anatomical properties and acoustic properties of other wood species is recommended.

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