AXIAL AND RADIAL VARIATION OF ACOUSTIC PROPERTIES OF *Albizia adianthifolia* WOOD

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Abstract: Lack of adequate information of property traits of wood species can inhibit their regular usage; hence rendering them lesser used. Studying properties of lesser used wood species such as *Albizia adianthifolia* will help to provide adequate information on its potential usage. This paper aimed at investigating the axial and radial variation of acoustic properties of *Albizia adianthifolia* wood with a view of finding possible significant variation to assist in determining its optimal uses for acoustic purposes. Three trees of *A. adianthifolia* wood were felled and 5 wood samples of $20 \times 20 \times 300\ mm^3$ each were collected axially and radially. The samples were oven dried at 103±2ºC for 24 h after which they were stored at ambient temperature of 25^0C and 60% relative humidity for one month prior to acoustic measurements. Selected wood acoustic properties were measured using the longitudinal free vibration acoustic test method. The mean fundamental frequency (FF)(Hz), resonant frequency (RF)(Hz), Velocity of sound (V)(m/s), dynamic elastic modulus (E)(GPa), specific dynamic elastic modulus (Es)(GPa), sound quality (Q), internal friction (*tan δ*), radiation ratio (K), acoustic conversion efficiency (ACE) ($m^4kg^{-1}s^{-1}$), impedance (Z) ($x10^6$)($kgm^{-2}s^{-1}$), specific gravity (γ) 807.94, 2051.20, 3542.66, 7.92, 12.65, 126.01, 0.009, 5.76, 731.75, 2.21, 0.62. FF, V, E and Z only had significant interaction between axial and radial positions. Axially, base and middle wood performed better while core and middle wood were better radially owing to their mean acoustic properties measured. Conclusively, values obtained in this study did not compare favourably with other selected wood species, and as such was not considered suitable for making soundboards but frame boards.

Keywords: Frame board, internal friction, sound, soundboard, wood

Introduction

Wood is a unique material for musical instruments and other acoustic applications because it has the ability to produce sound effect. Wood has been used to produce a number of musical instruments such as guitar, violin, piano, xylophone and percussion (Tsoumis, 1991). One of the lesser used wood species available in Nigeria is *Albizia adianthifolia*. Its tree is tall, having a few large widely spreading branches and more or less horizontal branchlets producing flat crown. The wood can be found in tropical Africa, including Nigeria. It is commonly called 'ayinre bona bona' in Yoruba, Southwestern, Nigeria. The tree grows to about 36 m high (Lock & Keay, 1991).

One of the reasons inhibiting regular use of some wood species is their poor performance in service or lack of adequate information of property traits of such species, thus rendering them lesser used. Studying acoustic properties of lesser used wood species such as *Albiziaadianthifolia* wood will help to provide adequate information on its potential use for acoustic purposes.

Although Olaoye & Okanlawon (2019) studied the acoustic properties of *A. adianthifolia* in relation to moisture, study on possible significant variation along and across the wood species was not studied.Meanwhile, selected property characteristics of wood has been found to vary axially and radially. It is therefore appropriate to investigate the possible variation in acoustic properties of *A. adianthifolia* before making final conclusions and recommendation.

This paper aimed at investigating the axial and radial variation of acoustic properties of *Albizia adianthifolia* wood with a view of finding possible significant variation to assist in determining its optimal uses for acoustic purposes.

Materials and Method

Three trees of *A. Adianthifolia* wood having 25 ± 2 cm diameter at breast height (DBH) were felled. From each tree, bolts of 60 cm in length were collected axially (top, middle and base), and wood samples of $20 \times 20 \times 300\ mm^3$ (Radial x Tangential x Longitudinal) were obtained for the acoustic property test from the radial section (core, middle and outer) of the bolt using circular machine and planning machine (Fig. 1). 5 samples were taken from each position, thus making a total of 135 samples. The samples were oven dried at 103±2ºC for 24 h after which they were stored at ambient temperature of 25^0C and 60% relative humidity for one month prior to acoustic testing.

Acoustic property test

Selected wood acoustic properties were measured using the longitudinal free vibration acoustic test method. The experiment was set up according to Jalili *et al.* (2014) (Fig. 2), however, little modification was done. The wood acoustic parameters measured were: fundamental frequency (FF), resonance frequency (RF), sound velocity (V), dynamic elastic modulus (E), specific dynamic elastic modulus (Es), acoustic coefficient (K), damping factor (tanδ), sound quality (Q), impedance (Z) and acoustic conversion efficiency (ACE).The experiment was conducted in an enclosed laboratory having ensured a total silence, and the FFT analyzer showing no sign of a sound signal.

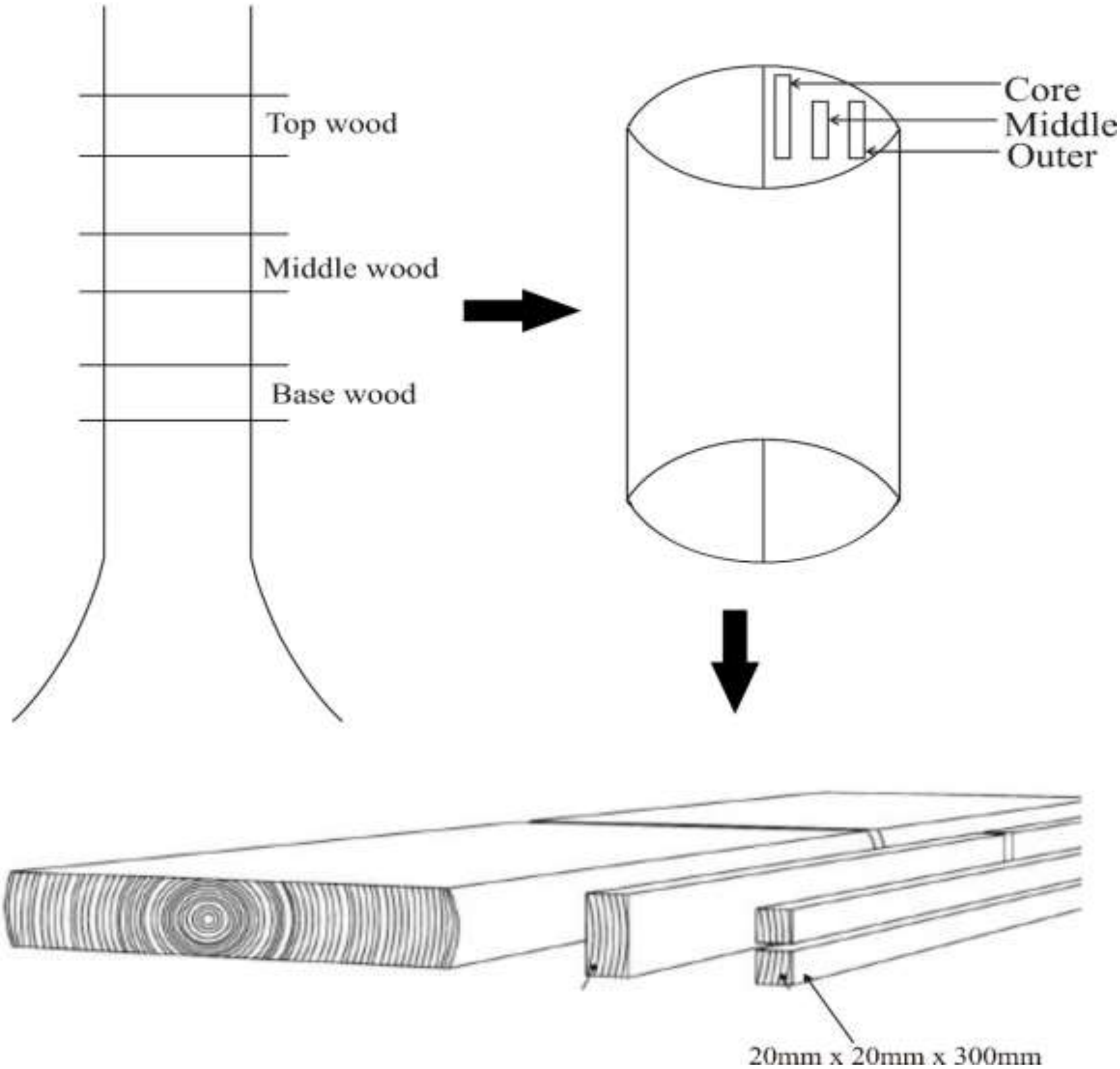

Fig. 1: Sample collection positions

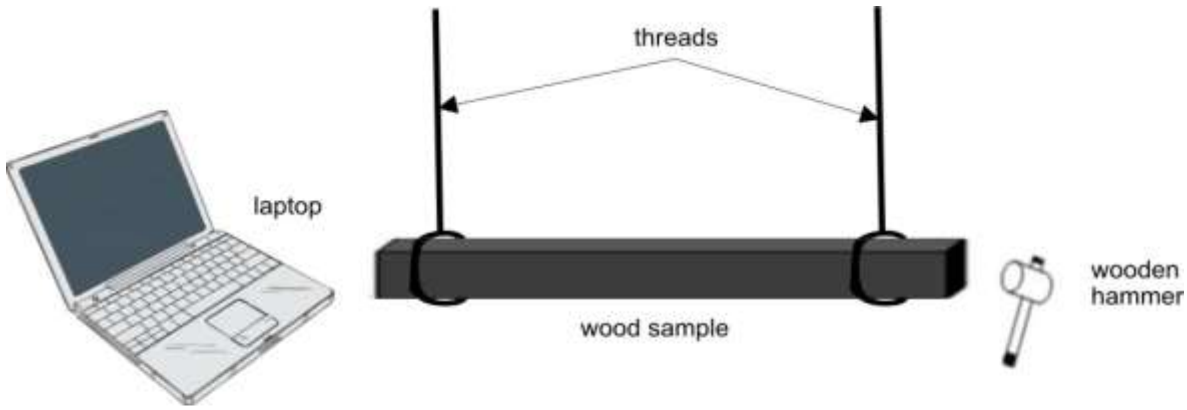

Fig. 2: The set-up of the longitudinal free vibration test

The wood was struck at one end while the sound obtained was recorded at the other end using audacity. The 1st bending natural frequency (fundamental frequency) and resonance frequency were obtained from the sound generated using Fast Fourier Transform (FFT). Hence, equation 1 (Görlacher, 1984) was used to determine the dynamic modulus of elasticity (E).

$$E = \left(\frac{2f_n}{\gamma_n \pi}\right)^2 \frac{mL^3}{I} \qquad (1a)$$

Where: m is the specimen weight, f_n is the 1st bending natural (fundamental) frequency, n is the mode number, L is the length of the sample. γ_n is for the first mode 2.267, and I is inertia.

$$I = \frac{(bh^3)}{12} \qquad (1b)$$

Where: b is the width and h is the thickness of the specimen

Meanwhile, equations 2 – 10 were used to calculate other selected acoustic parameters.

Specific longitudinal elastic modulus (Es);

$$Es = \frac{E}{\gamma} \qquad (2)$$

$$\gamma = Specific\ gravity$$

$$\gamma = \frac{\frac{oven\ dried\ mass}{green\ volume}}{density\ of\ water} \qquad (3)$$

Velocity of sound (V) (Akitsu *et al*., 1993; Ono & Norimoto, 1983);

$$v = \sqrt{\frac{E}{\gamma}} \qquad (4)$$

Acoustic co-efficient of the vibrating body (K);

$$K = \left(\frac{E}{\gamma^3}\right)^{0.5} \qquad (5)$$

Damping factor due to internal friction (tan δ);

$$\tan\delta = \frac{\lambda'}{\pi} \qquad (6)$$

$$\lambda^1 = logarithmic\ vibrating\ decrement\ factor$$

$$\lambda^1 = \left(\frac{1}{n}\right) ln\left(\frac{X_1}{X_{n+1}}\right) \qquad (7)$$

$n = number\ of\ successive\ peaks,$ $X_1\ and\ X_{n+1}\ are\ the\ first\ and\ (n+1)th\ amplitude\ of\ vibration\ respectively$ as shown in Fig. 3.

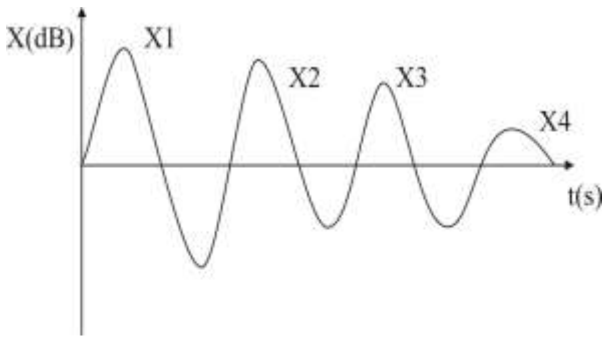

Fig. 3: The schematic view of amplitude decrement of the first mode of vibration through time

Sound quality factor (Q) and acoustic conversion efficiency (ACE) (Ross & Pellerin, 1994);

$$Q = \frac{1}{tan\delta} \qquad (8)$$

$$ACE = \frac{K}{tan\delta} \qquad (9)$$

$K = acoustic\ coefficient\ of\ the\ vibrating\ body$

Impedance (Z);

$$z = v\rho \qquad (10)$$

$v = velocity$

Statistical analysis

The experiment was laid in a completely randomized design using a 3x3 factorial experimental as presented in eq 11. Also, descriptive statistics and analysis of variance (ANOVA) were used to analyse data obtained.

$$Y_{ijk} = \mu + A_i + B_j + AB_k + E_{ijk} \qquad (11)$$

Where: μ = overall mean; Ai = effect of factor A i.e. Axial variation; Bj = effect of factor B i.e. Radial variation; (AB)ij = effect of interaction between AB; Eijk = experimental error

Results and Discussion

Table 1 and 2 shows the acoustic properties of *A. adianthifolia* measured with respect to axial and radial variation respectively, while Table 3 shows the summary of P-values obtained for all the acoustic properties measured at significant level of 5% probability. In addition, post-hoc analyses done for significant acoustic variables were presented in Table 4 and Table 5.

For axial variation, values at base wood were notably higher than middle and top wood for many of the acoustic properties, while variation at radial position did not show notable differences in values obtained among core, middle and outer position. Meanwhile, only FF, V, E and Z had a significant interaction between the axial and radial positions.

Table 1: Axial variation of acoustic properties of *A. adianthfolia* wood

		FF	RF	V	E	Es	Q	tan δ	K	ACE	Z X 10^6	γ
Top	Core	708.50	1867.5	3106.62	5.61	9.65	100.00	0.010	5.34	534.47	18.06	0.58
	Middle	804.67	2077.67	3528.29	7.37	12.45	75.00	0.013	5.96	447.06	20.88	0.59
	Outer	828.00	1623.00	3630.60	9.16	13.18	103.45	0.010	5.22	540.40	25.23	0.70
Mean		**780.39**	**1856.06**	**3421.84**	**7.38**	**11.76**	**92.82**	**0.011**	**5.51**	**507.31**	**21.39**	**0.62**
Middle	Core	832.67	2206.00	3651.06	6.89	13.33	142.86	0.007	7.07	1009.51	18.86	0.52
	Middle	831.67	2104.67	3646.68	7.87	13.30	150.00	0.007	6.16	924.12	21.59	0.59
	Outer	729.67	1853.33	3199.43	5.73	10.24	136.36	0.007	5.71	779.08	17.92	0.56
Mean		**798.00**	**2054.67**	**3499.06**	**6.83**	**12.29**	**143.07**	**0.007**	**6.31**	**904.24**	**19.46**	**0.56**
Base	Core	847.67	2430.33	3716.83	8.91	13.81	136.36	0.007	5.76	786.10	23.96	0.64
	Middle	887.33	2244.00	3890.76	10.57	15.14	125.00	0.008	5.57	696.69	27.16	0.70
	Outer	801.33	2054.33	3513.67	9.01	12.35	125.00	0.008	4.81	601.86	25.64	0.73
Mean		**845.44**	**2242.89**	**3707.09**	**9.50**	**13.77**	**128.79**	**0.008**	**5.38**	**694.88**	**25.59**	**0.69**
P. Mean		**807.94**	**2051.20**	**3542.66**	**7.90**	**12.6**	**121.56**	**0.009**	**5.74**	**702.14**	**22.15**	**0.62**

FF – Fundamental Frequency RF – Resonance Frequency V – Velocity of sound E - Dynamic elastic modulus Es – Specific dynamic modulus Q – Quality factor tan δ – damping factor K – Radiation coefficient ACE – Acoustic Conversion Efficiency Z – Impedance γ – specific gravity

Table 2: Radial variation of acoustic properties of *A. adianthfolia* wood

		FF	RF	V	E	Es	Q	tan δ	K	ACE	Z X 10^6	γ
Core	Top	708.50	1867.5	3106.62	5.61	9.65	100.00	0.010	5.34	534.47	18.06	0.58
	Middle	832.67	2206.00	3651.06	6.89	13.33	142.86	0.007	7.07	1009.51	18.86	0.52
	Base	847.67	2430.33	3716.83	8.91	13.81	136.36	0.007	5.76	786.10	23.96	0.64
Mean		**796.28**	**2167.94**	**3491.50**	**7.14**	**12.26**	**126.41**	**0.008**	**6.06**	**776.69**	**20.29**	**0.58**
Middle	Top	804.67	2077.67	3528.29	7.37	12.45	75.00	0.013	5.96	447.06	20.88	0.59
	Middle	831.67	2104.67	3646.68	7.87	13.30	150.00	0.007	6.16	924.12	21.59	0.59
	Base	887.33	2244.00	3890.76	10.57	15.14	125.00	0.008	5.57	696.69	27.16	0.70
Mean		**841.22**	**2142.11**	**3688.58**	**8.60**	**13.63**	**116.67**	**0.009**	**5.90**	**689.29**	**23.21**	**0.63**
Outer	Top	828.00	1623.00	3630.60	9.16	13.18	103.45	0.010	5.22	540.40	25.23	0.70
	Middle	729.67	1853.33	3199.43	5.73	10.24	136.36	0.007	5.71	779.08	17.92	0.56
	Base	801.33	2054.33	3513.67	9.01	12.35	125.00	0.008	4.81	601.86	25.64	0.73
Mean		**786.33**	**1843.55**	**3447.90**	**7.97**	**11.92**	**121.60**	**0.008**	**5.25**	**640.45**	**22.93**	**0.66**
P. Mean		**807.94**	**2051.20**	**3542.66**	**7.90**	**12.6**	**121.56**	**0.009**	**5.74**	**702.14**	**22.15**	**0.62**

Table 3: Analysis of variance showing P-values for acoustic properties measured

S/V	df	FF	RF	V	E	Es	Q	tan δ	K	ACE	Z	γ
Axial	2	0.08	0.01*	0.08	0.01	0.10	0.01*	0.01*	0.02*	0.02*	0.01*	0.01*
Radial	2	0.14	0.01*	0.14	0.08	0.15	0.80	0.26	0.04*	0.42	0.02*	0.01*
Axial*Radial	4	0.05*	0.63	0.05*	0.03*	0.07	0.83	0.18	0.34	0.86	0.02*	0.20
Error	18											
Total	26											

FF represents the first lowest frequency of a sound, while RF represents the frequency with the highest mode amplitude in the sound timbre. Sound frequency can be defined as the number of a whole cycle of vibration per second (Plack *et al.*, 2005), and it directly measures the pitch of the sound of a material. Values obtained for sound frequency (FF, RF) at axial position indicates that base wood had highest pitch of sound than top and middle wood. On the other hand, core wood and middle wood had the highest sound pitch radially for FF and RF, respectively. Since RF shows a significant difference between base wood and top wood, then sound pitch of base wood was significantly different from top wood while it performed seemingly with middle wood. Also, sound pitch of outer wood performed significantly poorer than core and middle wood radially. As such, base wood, core wood and middle wood of *A. adianthfolia* were most suitable for acoustic function where high pitch is required. However, sound frequency obtained in this study was lower than Olaoye *et al.* (2019) for *Gmelina arborea* wood.

Velocity of sound may be defined as the distanced travelled per unit time by a sound wave as it propagates through elastic medium. Thus, the velocity of sound at base and middle wood were highest for axial and radial position, respectively. This implies that sound will travel faster at base wood and middle wood. Furthermore, an existing interaction between axial and radial position implies that middle wood at base wood was the best in terms of sound velocity. Notwithstanding, velocity obtained was still lower than wood of *G. arborea* (Olaoye *et al.*, 2019); *A. robusta* (Olaoye *et al.*, 2016); Amboyna and Bamboo (Yoshikawa & Waltham, 2014) and Walnut (Jalili *et al.*, 2014).

Furthermore, internal friction (tan δ), specific dynamic young's modulus (Es), and acoustic conversion efficiency (ACE) are considered as the three major acoustic properties of wood (Ono and Norimoto, 1983; Tanaka 1987; Matsunaga *et al.*, 1996; Hamdan *et al.*, 2016). Also, Akitsu *et al.* (1993) opined that Internal friction is related to sound damping factor while ACE is related to the ratio of acoustic energy radiated from a musical instrument to the energy given by the string (Tanaka, 1987).

Therefore, a better acoustic wood species is associated with lower value of tan δ. As such, middle wood and core wood having the least value are most suitable axially and radially. However, Brémaud (2012) stated that an acoustically suitable species should have its average value of tan δ to be 0.006, thus implying that wood species having ≤ 0.006 can only be considered as acoustically suitable species. Consequently, middle wood and core wood of *A. adianthfolia* having least values can't still be regarded acoustically suitable on the basis of internal friction.

Tanaka (1987); Yano *et al.* (1992); Yano *et al.* (1995); Matsunaga *et al.* (1996) reported that higher Es and lower tan δ are essential for wood suitable for making soundboards of musical instruments. Also, Hamdan *et al.* (2016) highlighted a high ACE value for excellent soundboards, while lower ACE and higher tan δ is identifiable with making frame boards. Since higher Es is essential, then base wood and middle wood at axial and radial position were better for making soundboard. Nonetheless, since there was no significant difference axially and radially, performance of Es is assumed the same irrespective of the positions were the samples were taken.

Table 4: Post-hoc analysis of significant acoustic properties for axial position

Axial Position		RF	Q	tan δ	K	ACE	Z
Top	Middle	0.08	0.01	0.001	0.024	0.01	0.079
	Base	0.002*	0.02	0.001	0.62	0.07	0.001
Middle	Top	0.08	0.01	0.001	0.02	0.01	0.079
	Base	0.10	0.26	0.321	0.01	0.03	0.001
Base	Top	0.002*	0.02	0.001	0.62	0.07	0.001
	Middle	0.10	0.26	0.322	0.01	0.03	0.001

Table 5: Post-hoc analysis of significant acoustic properties for Radial position

Radial Position		RF	Q	tan δ	K	ACE	Z
Core	Middle	0.81	0.52	0.13	0.75	0.36	0.013
	Outer	0.01	0.83	0.76	0.02	0.21	0.019
Middle	Core	0.81	0.53	0.13	0.75	0.36	0.013
	Outer	0.01	0.67	0.21	0.04	0.71	0.848
Outer	Core	0.01	0.83	0.76	0.02	0.21	0.013
	Middle	0.01	0.67	0.21	0.04	0.71	0.848

Since higher ACE has been established as an essential parameter for acoustic suitability, ACE was significantly best at middle wood axially, while ACE was best at core wood radially owing to their highest values. The mean value of ACE for this study compared lower with *G. arborea* wood (Olaoye *et al.,* 2019); Dialium sp. (Hamdan *et al.,* 2016); *Endospermum diadenum* (Sedik *et al.,* 2010). Thus, no wood sample from axial or radial position of *A. adianthifolia* wood can be considered suitable for making soundboards.

Conclusion

Having measured the axial and radial variation of acoustic properties of *A. adianthifolia* wood with a view of finding possible significant variation to assist in determining its optimal use for acoustic purposes. It can be concluded that base wood and middle wood performed better axially while core wood and middle wood was better radially in the majority of the acoustic properties measured. Regardless, the acoustic properties obtained did not compare favourably with other selected wood species. Therefore, no wood samples from axial and radial position of *A. adianthifolia* wood can be recommended suitable for making soundboards of a musical instrument but can still be used as frame boards.

Conflict of Interest

Authors declare that there is no conflict of interest reported in this work.

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