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Acoustic Properties of *Albizia Adianthifolia* (schum.) Wood in Relation to Moisture

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Abstract: Moisture in wood has been found to influence properties and performance of wood in service. The hygroscopic nature of wood makes it continuously absorb moisture from the environment and as such render wood unstable. Meanwhile, little or no information has been provided on few acoustic property of wood with respect to moisture. This study thus aim at providing more information about the acoustic properties of *A. adianthifolia* wood in relation to moisture. Three tress of *A. adianthifolia* wood were fell and samples were taken axially and radially. Acoustic test was done on the sample at green state, oven dried (OD) state and at equilibrium moisture content (EMC) state. many of the acoustic properties obtained at EMC were best such that mean fundamental frequency was 807.94HZ, specific elastic modulus – 12.65GPa, damping factor – 0.009, velocity of sound – 3542.66m/s, acoustic coefficient – 5.76, Sound quality – 126.01 and acoustic conversion efficiency – 731.75$m^4kg^{-1}s^{-1}$. Optimal acoustic performance of this wood species was not recorded at oven dried state. Thus, this study revealed that a little amount of moisture in wood may be needed for optimal acoustic performance, and as such the wood of *A. adianthifolia* performed better at ambient temperature. However, studies into other wood species are needed to substantiate this claim.

Keywords: Moisture, Acoustic Properties, *Albizia Adianthifolia* Wood

1. Introduction

The hygroscopic nature of wood has made it have high affinity for moisture, and thus take moisture from its environment. However, the rate at which it takes up this moisture is dependent on the relative humidity and temperature of the air, as well as the amount of moisture present in the wood [1].

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 [2]. However, acoustic properties of wood is needed to be examined before recommending it for any acoustic purposes.

Notwithstanding, moisture in wood has been found to render wood unstable, thus influencing wood properties and performance during service. There has been many studies on the influence of moisture on physical and mechanical properties of a wood affecting its performance in service. However, only little or no information has been provided on all the major acoustic properties of wood with respect to variation in moisture. Moreover, only selected acoustic parameters were capture in literatures reviewed. There is therefore need to capture more acoustic properties of wood with respect to moisture.

This study thus aim at providing information on the acoustic properties of *Albizia adianthifolia* wood in relation to variation in moisture content with the view of determining the extent at which moisture can hinder the optimal acoustic performance of the wood.

Typically, *A. adianthifolia* wood is a tall tree with a few large widely spreading branches and more or less horizontal branchlets producing flat crown. The wood is widespread in tropical Africa and S. Africa. It is commonly called 'ayinre bona bona' in Yoruba, Southwestern, Nigeria. The tree grows to about 36m high [3].

2. Materials and Method

Three trees of *A. Adianthifolia* wood having 25 ± 2cm diameter at breast height (DBH) were fell. From each tree, bolts of 60cm in length were collected axially (top, middle and base), and wood samples of $20 \times 20 \times 300\ mm^3$ (R x T x L) were obtained for the acoustic property test from the radial section (inner, middle and outer) of the bolt using circular machine and planning machine (figure 1). 5 samples were taken from each position, thus making a total of 135 samples. Acoustic property test of the wood samples was done at three different moisture state (green, oven dried and at equilibrium moisture content). The samples were oven dried at 103 ± 2°C for 24 hours after which they were stored at ambient temperature for one month to reach equilibrium moisture content.

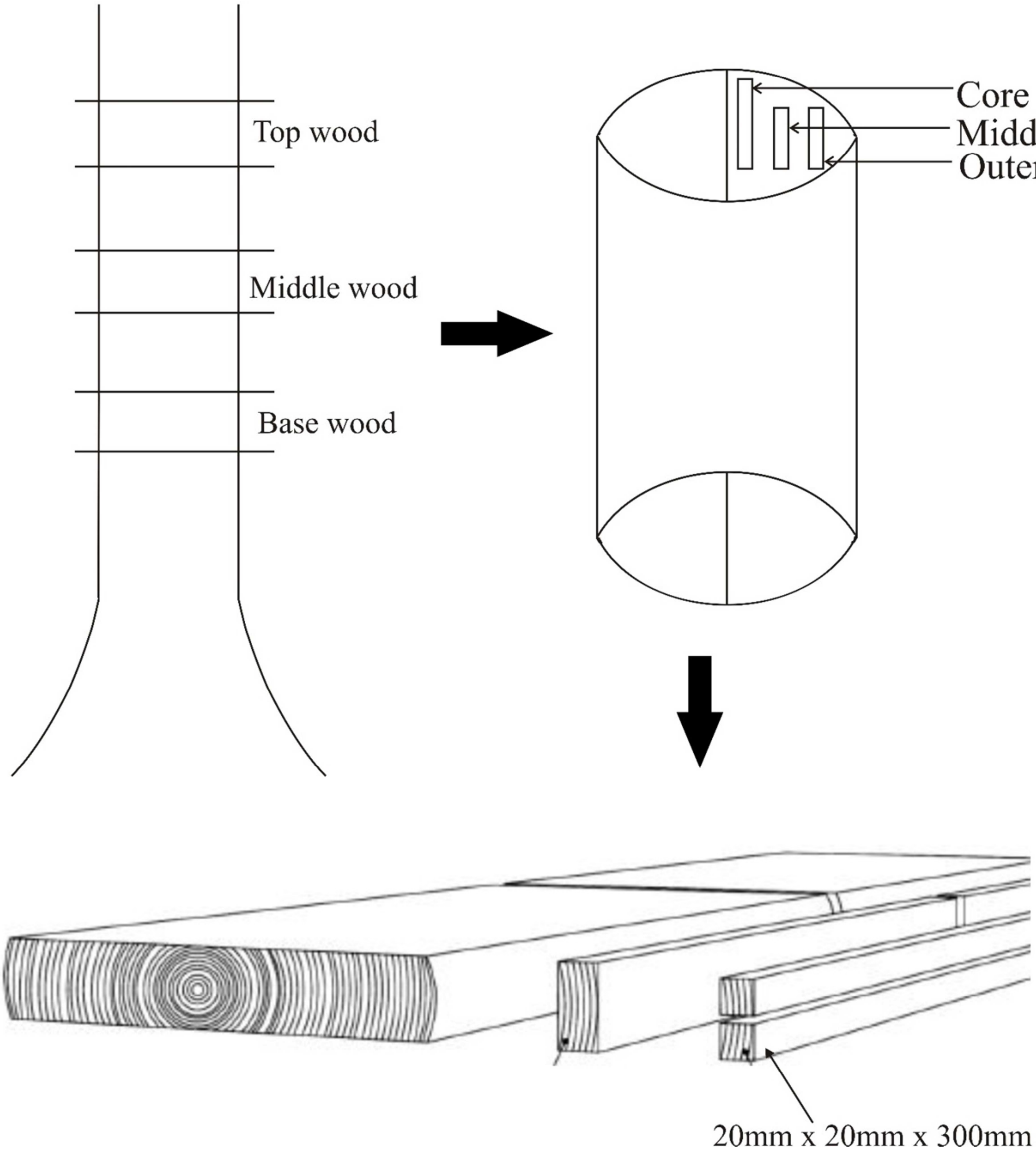
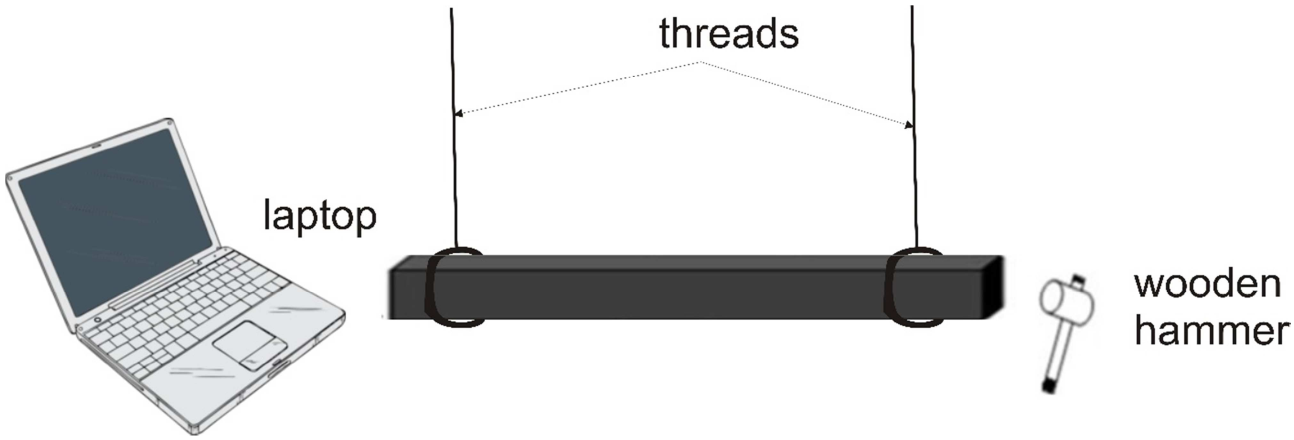


Figure 1. *Samples collection position.*

Acoustic property test.

The longitudinal free vibration test was used, and the experiment was set up as figure 2. Each sample was tied with a thread on both sides, and suspended from a top with the threads - This is done to ensure no external sound is produced during testing. A wooden hammer was used to hit the wood from one end while the sound fundamental frequency was obtained from the other end using a Fast Fourier Transform (FFT) spectrum analyzer, and the response vibrating sound was recorded in a wave format file using a recording software (Audacity), thus generating a sound wave. After which relevant equations were used to determine other acoustic parameters [4-6].



Note: the experiment was conducted in an enclosed place at room temperature having ensured a total silence, and the FFT analyzer showing no sound signal.

Figure 2. *The set-up of longitudinal free vibration test.*

2.1. Dynamic Longitudinal Elastic Modulus (E)

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

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.

$$I = \frac{(bh^3)}{12} \quad (2)$$

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

2.2. Specific Longitudinal Elastic Modulus (Es)

$$Es = \frac{E}{\rho_s} \quad (3)$$

where $\rho_s = Relative\ Density\ (Specific\ gravity)$

$$\rho_s = \frac{\frac{oven\ dried\ mass}{green\ volume}}{density\ of\ water} \quad (4)$$

2.3. Velocity of Sound C

$$c = \left(\frac{E}{\rho}\right)^{0.5} \quad (5)$$

2.4. Acoustic Co-efficient of the Vibrating Body (K)

$$K = \left(\frac{E}{{\rho_s}^3}\right)^{0.5} \quad (6)$$

where $E = longitudinal\ elastic\ modulus$

$\rho_s = specific\ gravity$

After each impulse, the sample will start vibrating. Due to the internal friction, the vibration energy will reduce after a while. This attenuation occurs due to the material damping which is affected by the type of material. Therefore decrement in vibration energy as a function of time could lead to damping of sound.

2.5. Damping Factor

$$Damping\ factor\ due\ to\ internal\ friction\ (tan\delta) = \frac{\lambda'}{\pi} \quad (7)$$

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

$$\lambda^1 = \left(\frac{1}{n}\right) ln\left(\frac{X_1}{X_{n+1}}\right) \quad (8)$$

where $n = number\ of\ successive\ peaks$

$X_1\ and\ X_{n+1}$ are the first and (n+1) th amplitude of vibration respectively

2.6. Sound Quality Factor (Q) Impedance (Z) and Acoustic Conversion Efficiency (ACE)

$$Q = \frac{1}{tan\delta} \quad (9)$$

$$ACE = \frac{K}{tan\delta} \quad (10)$$

where K is the acoustic coefficient of the vibrating body

$$z = c\rho\ z = impedance, c = velocity\ of\ sound \quad (11)$$

3. Results

Percentage representation of acoustic properties of *A. Adianthifolia* wood with respect to variation in moisture content (green, equilibrium moisture content (EMC) and oven dried (OD) were shown in figures 3-7. Figure 3 - fundamental and resonance frequency, Figure 4 - dynamic and specific elasticity, figure 5 - damping factor and sound quality, figure 6 – speed of sound and acoustic coefficient while figure 7 shows impedance and acoustic conversion efficiency.

Whereas, table 1 shows the analysis of variance done on the properties tested while table 2, table 3 and table 4 showed the mean values of acoustic properties tested of *A. Adianthifolia* wood at green state, equilibrium moisture content (EMC) state and oven dried (OD) state.

Table 1. *Summary Analysis of variance showing P-value for Acoustic Properties of A. adianthifolia wood with respect to moisture variation.*

Source of variance	Variable	Sum of Squares	df	Mean Square	P-value
Moisture Content	FF	182051.20	2	91025.58	0.01*
	E	1.61	2	0.80	0.74ns
	Es	139.86	2	69.929	0.01*
	tan	0.00	2	0.00	0.01*
	c	3500151	2	1750076	0.01*
	K	48.91	2	24.45	0.01*
	Q	19793.20	2	9896.60	0.01*
	Z	1.27E+12	2	6.37E+11	0.02*
	ACE	1448009	2	724004.50	0.01*
	RF	287940	2	143970	0.05*

Table 2. *Acoustic properties of A. adianthifolia wood at green state (40 – 70% MC).*

		FF (Hz)	E (GPa)	Es (GPa)	Tan Ө	C (m/s)
top	inner	545.00	5.32	5.71	0.025	2389.71
	medium	660.00	7.74	8.37	0.021	2893.95
	outer	632.00	7.50	7.68	0.019	2771.18
middle	inner	629.00	6.41	7.61	0.017	2758.03
	medium	632.00	6.89	7.68	0.015	2771.18
	outer	542.00	4.76	5.65	0.020	2376.55
base	inner	679.00	9.18	8.86	0.012	2977.27
	medium	687.00	9.86	9.07	0.014	3012.34
	outer	646.00	8.36	8.02	0.015	2832.57
MEAN		628.00a	7.34a	7.63a	0.018a	2753.64a

Table 2. *Continued.*

		K ($m^4kg^{-1}s^{-1}$)	Q	Z ($kgm^{-2}s^{-1}$)	ACE ($m^4kg^{-1}s^{-1}$)	RF (Hz)
top	inner	2.57	40.00	2224417.26	102.69	2097.50
	medium	3.13	47.62	2675220.16	149.07	2075.33
	outer	2.84	52.63	2708136.71	149.25	1708.00
middle	inner	3.27	58.82	2325935.88	192.38	2057.67
	medium	3.09	66.67	2485518.49	205.98	2114.00
	outer	2.82	50.00	2004818.70	140.86	1934.33
base	inner	2.87	83.33	3083951.10	239.52	1878.00
	medium	2.77	71.43	3271656.60	198.11	1813.67
	outer	2.72	66.67	2950591.67	181.28	1695.67
MEAN		2.90^a	59.69^a	2636694.06^b	173.24^a	1930.46^a

MC – Moisture content.

Table 3. *Acoustic properties of A. adianthifolia wood at EMC state (5% - 8% MC).*

		FF (Hz)	E (GPa)	Es (GPa)	Tan Ө	C (m/s)
top	inner	708.50	5.63	9.66	0.010	3106.62
	medium	804.67	7.31	12.58	0.013	3528.29
	outer	828.00	9.20	13.21	0.010	3630.60
middle	inner	832.67	6.96	13.46	0.007	3651.06
	medium	831.67	7.85	13.31	0.007	3646.68
	outer	729.67	5.75	10.26	0.007	3199.43
base	inner	847.67	8.98	13.86	0.007	3716.83
	medium	887.33	10.59	15.15	0.008	3890.76
	outer	801.33	9.03	12.37	0.008	3513.67
MEAN		807.94^b	7.92^a	12.65^b	0.009^b	3542.66^b

Table 3. *Continued.*

		K ($m^4kg^{-1}s^{-1}$)	Q	Z ($kgm^{-2}s^{-1}$)	ACE ($m^4kg^{-1}s^{-1}$)	RF (Hz)
top	inner	5.34	101.01	1807567.17	539.96	1867.50
	medium	6.09	75.09	2069104.69	456.51	2077.67
	outer	5.23	105.30	2526422.65	549.90	1623.00
middle	inner	7.07	151.32	1887024.26	1090.33	2206.00

		K ($m^4kg^{-1}s^{-1}$)	Q	Z ($kgm^{-2}s^{-1}$)	ACE ($m^4kg^{-1}s^{-1}$)	RF (Hz)
	medium	6.20	155.95	2155210.81	951.75	2104.67
	outer	5.72	145.37	1792791.68	843.81	1853.33
	inner	5.77	138.89	2402244.45	798.00	2430.33
base	medium	5.60	130.56	2718098.44	729.43	2244.00
	outer	4.82	130.56	2563723.73	626.06	2054.33
MEAN		5.76^b	126.01^c	2213576.43^a	731.75^c	2051.20^{ab}

Table 4. *Acoustic properties of A. adianthifolia wood at oven dried state (0% MC).*

		FF (Hz)	E (GPa)	Es (Gpa)	Tan Θ	C (m/s)
	inner	720.00	5.82	9.97	0.012	3157.04
top	medium	800.67	7.22	12.33	0.014	3510.76
	outer	724.33	6.84	10.09	0.011	3176.03
	inner	838.50	7.01	13.52	0.009	3676.64
middle	medium	802.00	7.04	12.37	0.010	3516.59
	outer	744.33	5.69	10.65	0.011	3263.72
	inner	876.67	9.43	14.78	0.010	3844.01
base	medium	860.00	10.16	14.22	0.010	3770.91
	outer	795.67	8.57	12.17	0.011	3488.84
MEAN		795.80^b	7.53^a	12.23^b	0.011^b	3489.39^b

Table 4. *Continued.*

		K ($m^4kg^{-1}s^{-1}$)	Q	Z ($kgm^{-2}s^{-1}$)	ACE ($m^4kg^{-1}s^{-1}$)	RF (Hz)
	inner	5.40	83.33	1844238.55	450.36	1905.00
top	medium	5.99	71.43	2056721.38	428.05	2546.00
	outer	4.68	90.91	2153346.87	425.86	2070.00
	inner	7.09	111.11	1905724.13	788.13	2111.00
middle	medium	6.18	100.00	2002407.07	617.58	2191.00
	outer	6.11	90.91	1744188.20	555.19	1986.00
	inner	6.03	100.00	2452475.35	602.51	2445.00
base	medium	5.28	100.00	2694001.64	527.83	2264.67
	outer	4.95	90.91	2457595.67	450.25	2131.33
MEAN		5.75^b	93.18^b	2145633.20^a	538.42^b	2183.33^b

Means of individual acoustic properties in Tables 2-4 having the same alphabetical superscripts are not significantly different with respect to varying moisture contents ($P \leq 0.05$).

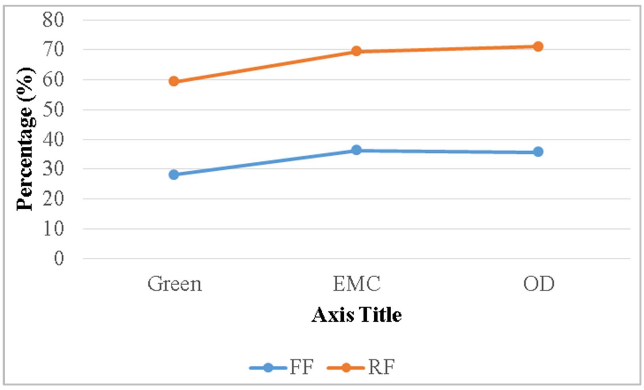


Figure 3. *Fundamental and Resonance Frequency (FF & RF).*

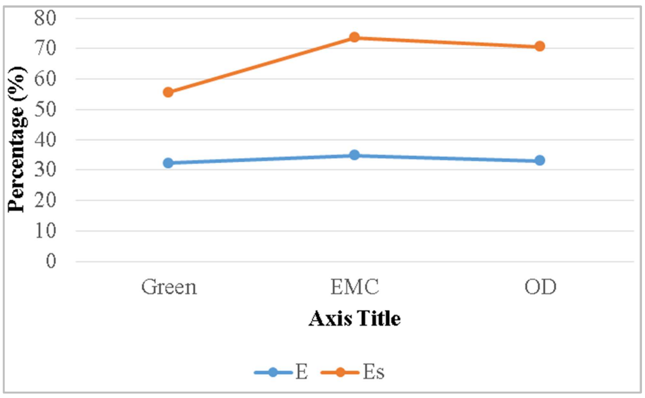


Figure 4. *Dynamic and Specific Longitudinal Elastic modulus (E and Es).*

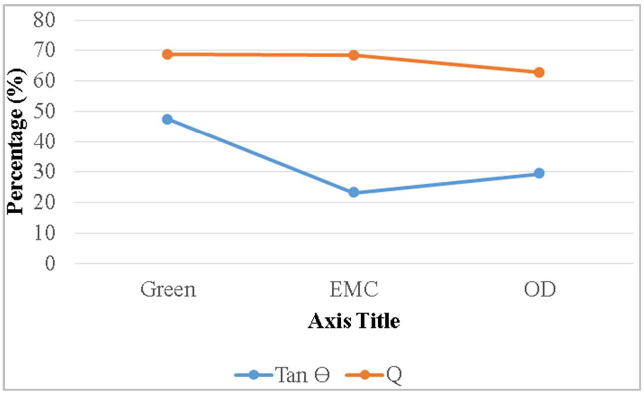


Figure 5. *Damping Factor and Sound Quality (Tan Θ and Q).*

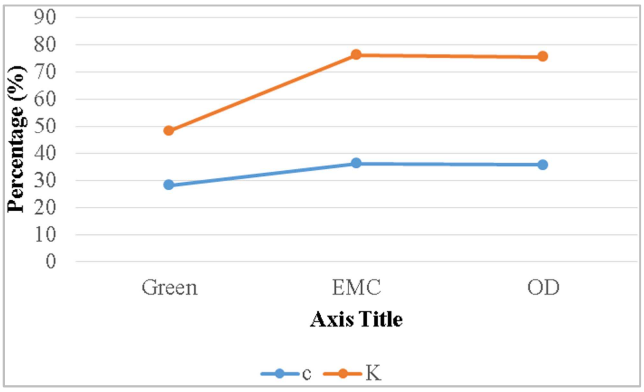


Figure 6. *Velocity of sound and Acoustic coefficient (c and K).*

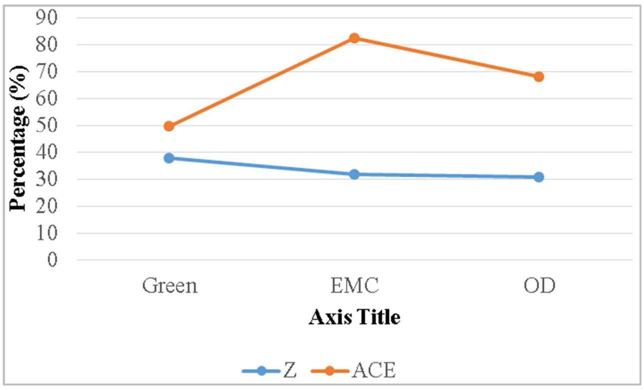


Figure 7. *Impedance and Acoustic Conversion Efficiency (Z and ACE).*

4. Discussion

Sound frequency of a material is measured by the number of whole cycle of a vibration per second produced as a result of particle disturbance in the travel medium [7]. Frequency of a sound thus measures the pitch of the sound. Therefore the higher a sound frequency, the higher the pitch of the sound. Furthermore, frequency can be subdivided into 2, namely the fundamental frequency and the resonance frequency. The fundamental frequency represent the lowest obtainable frequency from a sound, while resonance frequency represents the highest sounded frequency of that sound. Hence, they both influence the pitch of sound of a material.

With the obtained result, pitch of sound of *A. adianthifolia* wood was lowest at its green state while pitch of sound at EMC and OD are relatively the same. This therefore suggests that moisture can affect the frequency of sound generated from a wooden material, and as such inhibit pitch of sound.

Contrarily, dynamic longitudinal elasticity were not significantly different with respect to moisture. However, there were significant difference in values of specific longitudinal elasticity. This thus implies that moisture may not have influenced E but shows that moisture in wood kept at EMC and OD will aid a better elasticity.

Lower value of damping factor of wood approximating to zero means that the sound generated by the wood can vibrate for a longer time after disconnecting the vibration source [8-9]. Therefore, since value of damping factor at EMC was lowest, sound at EMC dampens slowest and as such performed best. However, damping factor at EMC and OD can be assumed to perform similarly owing to a non-significant difference between them.

Meanwhile, the more the quality factor (Q) of a wood, the lesser its wave damping [8]. Meaning, a material with high damping factor can be associated with a poor acoustic quality. This thus justifies the reason Q at EMC had highest value. As such, the best sound quality was obtained at EMC.

Similarly, velocity of sound and acoustic coefficient were highest at EMC. However, non-significant difference recorded between EMC and OD implies that these parameters performed the same for the two moisture difference. The higher the c and K of a wood, the better the acoustic performance of the wood. Therefore, acoustic performance of *A. adianthifolia* wood in respect to c and K was better at EMC and OD, thus indicating that moisture could stall acoustic performance of a wood since these parameters are poorest at green state.

On the other hand, Acoustic impedance of a medium is the rate of resistance of a medium to sound flow travelling through it [10]. Thus, a high value of impedance should imply a high rate of reflection of sound wave by the medium with which it travels in.

The significantly highest value of Z at green state was anticipated because the presence of moisture was expected to inhibit the passage of the sound wave. With high value of impedance, a high sound quality should be expected but poorest sound quality was recorded. This therefore could mean that sound waves were lost due to the obstruction of moisture. This implies that moisture dampens sound, hence lower c, Es and Tan Θ.

ACE is the efficiency with which vibrational energy is converted into sonic energy and that it should be accepted as an overall estimation of acoustic properties [9, 11]. Therefore, a higher value of ACE means a better acoustic performance. Since highest value of ACE was recorded at EMC, then acoustic performance of *A. adianthifolia* wood was best at EMC.

This study against report that acoustic properties of wood changes with ambient humidity [12]. However, it partially supports findings that Es and Tan Θ is reduced with an increase in moisture [13-14]. Although, lowest Es and Tan Θ were recorded at green state, highest Es and Tan Θ were not recorded at oven dried (0% MC) either. It could therefore mean that a little amount of moisture is needed in wood for optimal acoustic performance.

Akin to the stated above, many scholars opined that velocity of acoustic wave decreases with moisture content up to the fiber saturation point (FSP) [15-19]. This could therefore explain why velocity of sound obtained in this study was not significantly different for EMC and OD.

Consequently, since many of the acoustic properties tested at EMC and OD are not significantly different from each other, this study thus opined that majority of the acoustic properties of wood will be the same provided moisture content of the wood is below FSP.

5. Conclusion

This study was able to determine the acoustic properties of *A. adianthifolia* wood in relation to moisture variation. It thus found out that acoustic performance of the wood performed best at EMC, while its performance at green state was poorest. Hence, wood should be allowed to naturally assumed equilibrium in its moisture content where best acoustic performance is required. Notwithstanding, moisture can make the acoustic property of wood unstable. In order to substantiate this claim, more similar studies should be done on other wood species.

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