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INVESTIGATION INTO THE DETERMINATION OF MODULUS OF ELASTICITY OF *Gmelina arborea* (Roxb.) WOOD USING A NON-DESTRUCTIVE ACOUSTIC METHOD

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Abstract:
Wood is useful in various ways and forms owning to its versatile, inexhaustible and renewable characteristics. Thus, there is need to know its mechanical properties for appropriate recommendation where wood is needed for strength. Elasticity of wood is one of the mechanical properties to be tested for, and it can be expressed as wood's behavior under applied forces. Also, one of the indices of acoustic properties of wood is longitudinal elastic modulus which its definition is synonymous to modulus of elasticity (MOE). The conventional method of determining MOE using universal testing machine (UTM) is destructive and costly. Therefore, having a cost-free, non-destructive alternative method of determining MOE will be an added advantage and wood sample can be reused. This study thus investigate the determination of MOE through a non-destructive method. Three trees of G. arborea were obtained. Along sampling heights of each tree, samples of 20x20x300mm^3 were collected radially for acoustic and mechanical testing of the wood's elasticity. For acoustic test, wood samples were suspended and hit with a hammer at one end while frequencies of the sounds were obtained and recorded at the other side, after which necessary methods and equations were used to determine MOE. Then the samples were taken to the UTM for destructive determination of MOE. Mean values of MOE of G. arborea wood for the two acoustic methods used were 8525.80N/mm^2 and 9510.50N/mm^2 respectively, while the highest value (10718.59N/mm^2) was obtained at UTM. The values obtained from this study supported literature, however, acoustic method 1 was significantly different from UTM but acoustic method 2 was not. Therefore, acoustic method 2 was considered suitable for determining MOE of a wood, and it is thus recommended for adoption.

***Key words**: acoustic; G. arborea wood; MOE; non-destructive.*

INTRODUCTION

Wood is a hard, fibrous tissue found in many trees, which has been used for thousands of years for both domestic and industrial purposes. The composition of wood makes wood to be an outstanding material; it is versatile, inexhaustible and renewable. These properties have made wood useful in various ways and forms (Hickey 2001).

Strength properties are the ultimate resistance of a material to applied loads. With wood, strength varies significantly depending on species, loading condition, load duration and a number of assorted material, and environmental factors. The mechanical properties of wood such as elasticity are an expression of its behavior under applied forces.

Elastic properties relate the resistance of a material to deformation under applied stress to the ability of the material to regain its original dimensions when the stress is removed. Modulus of elasticity is the properties at which a body returns to its original state after it's been displaced, and its force expressed on the basis of unit area of volume is known as stress (Albert *et al.* 2002).

Meanwhile, acoustic properties can be characterized by longitudinal elastic modulus, specific dynamic modulus, the internal friction, the acoustic conversion efficiency or sound radiation coefficient (Rujinirun *et al*. 2005; Sedik *et al*. 2010; Roohnia *et al*. 2011; Bremaud 2012). Longitudinal elastic modulus can also be defined as the ratio of stress to strain which is also known as Young's Modulus. Thus, it is believed to represent the modulus of elasticity (MOE) of a material.

However, the conventional method of determining MOE of wood, such as the use of a universal testing machine (UTM) is destructive and costly. As a result, samples tested are not reusable and cost of testing samples can be high and unaffordable. Notwithstanding, many acoustic methods have been studied and are used on standing trees, logs and wood products to measure elastic properties or to reveal defects (Buccur 1996). Thus, there is a need to devise more means of determining the elasticity of a wood using a non-destructive and affordable methods, and in the long run it can help to mitigate deforestation.

OBJECTIVE

The objective of this study is to investigate the use of acoustic methods to determine the modulus of elasticity of *G. arborea* wood.
Specific objectives are to:

1. Determine modulus of elasticity of *G. arborea* wood using resonance frequency method and fundamental frequency acoustic methods.

2. Determine modulus of elasticity of *G.arborea* wood using a mechanical method.

MATERIALS AND METHOD

Three trees of *G. arborea* with 25±2cm in diameter at breast height (DBH) obtained from Gambari Forest Reserve were fell. Bolts of 60cm in length were collected from top and base of the trunk. Circular and planning machines were used to machine and trim the bolts to obtain wood samples of 20x20x300mm^3 *(RxTxL)* from the core and outer of the bolts. Five samples were taken from the core and outer of each bolts, and replicated thrice, thus making a total of 60 samples collected. These samples were used for acoustic testing, and mechanical testing of the wood's elasticity. Fig. 1 shows how the wood samples were collected, while Table 1 shows values of some of the physical characteristics of the wood species.

Samples collected were first oven dried to constant weight and then stored at room temperature and relative humidity for one month prior to testing. Hence, selected wood acoustic properties were tested using the longitudinal free vibration test methods. The setting up of this experiment was done according to Mohammad *et al.* (2014). The set up was shown in Fig. 2.

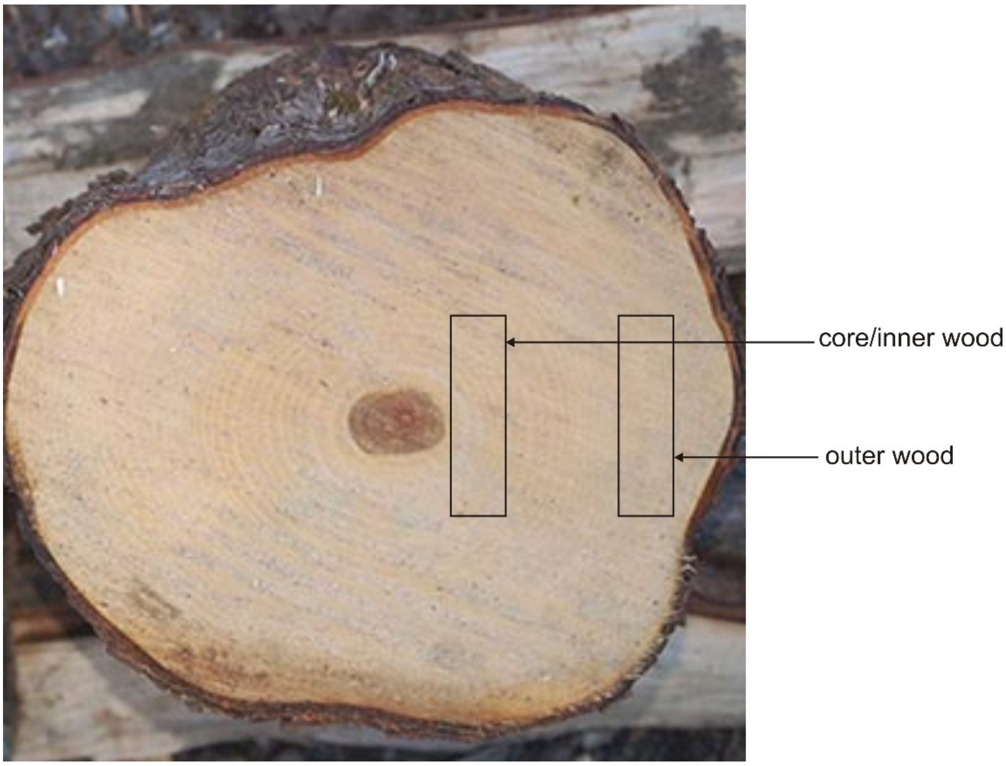

Fig. 1.
Sample collection position.

Table 1

Some physical characteristics of Gmelina arborea wood

Tree	Total height (m)	Moisture content (%)	Density (g/dm^3)	Colour	Green mass of samples (g)
1	20.2	121	0.39	light	52.48
2	21.5	105	0.41	light	54.38
3	20.7	132	0.40	light	54.34

Longitudinal free vibration test

Method 1 (the resonance frequency acoustic method)

The set – up for this technique is shown in Fig. 1. 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 resonance frequency was obtained from the computer on other end with the help of a Fast Fourier Transform (FFT) spectrum analyzer software, after which Equation 1 and 3 were used to determine the velocity of sound and longitudinal (dynamic) elastic modulus.

$$V = f \times \lambda \quad (m/s) \tag{1}$$

$where\ V = velocity, f = resonance\ frequency\ of\ first\ mode\ of\ vibration\ and$

$$\lambda = wavelength \equiv \frac{2L}{n} \tag{2}$$

$and\ l = length\ of\ the\ sample, n = number\ of\ resonance\ mode$

NB: for the first mode of vibration, n is equal to 1.
Hence, longitudinal elastic modulus (E):

$$E = \rho V^2 \quad (N/mm^2) \tag{3}$$

$$where\ \rho = Density = \frac{oven\ dried\ mass}{green\ volume} \quad (g/dm^3) \tag{4}$$

Method 2 (the fundamental acoustic method)

Having set up the experiment as Fig. 1, sounds were generated by striking the wood with a hammer, and the 1st bending natural frequency (fundamental frequency) of the sounds were obtained from the FFT, on the computer. Hence, Equation 5 was used to determine the longitudinal modulus of elasticity.

$$E = \left(\frac{2f_n}{\gamma_n \pi}\right)^2 \frac{mL^3}{I} \quad (N/mm^2) \qquad \text{(Baar } et\ al. \text{ 2016)} \tag{5a}$$

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

$$I = \frac{(bh^3)}{12} \tag{5b}$$

where: b is the width and h is the thickness of the wood sample.
Note: the experiments were conducted in an enclosed place at room temperature having ensured a total silence, and the FFT analyzer showing no sign of sound signal.

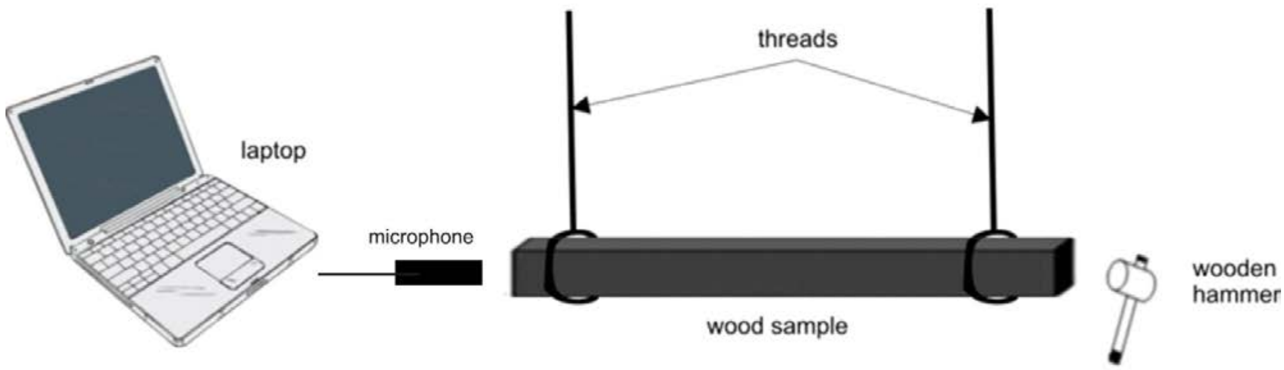

Fig. 2.
The set-up of longitudinal free vibration test.

Method 3 (Mechanical Measurement of MOE using a universal testing machine 'UTM')

The wood samples used for conducting the acoustic methods were taken to the department of forest product development and utilization, Forestry Research Institute of Nigeria (FRIN) for modulus of elasticity testing, using the UTM. The samples were mounted on the machine, and a force was applied on the wood till it reached a breaking point. Values of force applied on the wood to reach breaking point, and wood deflection were obtained from the machine. Hence, Equation 6 was used to calculate the modulus of elasticity of the wood.

$$MOE = \frac{PL^3}{4\Delta bd^3}(N/mm^2) \qquad (6)$$

where: P = Force applied;
L= length of the sample;
Δ = deflection;
b = sample width;
d = sample thickness.

RESULTS AND DISCUSSION

Tables 2, 3, and 4 show the mean values of the MOE of *G. arborea* wood for acoustic method 1, acoustic method 2, and mechanical method respectively. Meanwhile Table 5 and 6 showed the analysis of variance done between these acoustic methods of determining MOE and the mechanical method. Fig. 3-5 showed axial and radial MOE variation.

The mean MOE of *G. arborea* wood in acoustic method 1 and 2 was 8525.80N/mm^2 and 9510.50N/mm^2 respectively. Thus, values at method 2 was higher. However, the mechanical method revealed the highest value of 10718.59N/mm^2. Values recorded for all these methods were similar and in accordance with the work of Ogunsanwo *et al.* (2011) who recorded a mean MOE of *G. arborea* wood of 6910N/mm^2, 9610N/mm^2, and 10240N/mm^2 for 18, 28, and 36 years old respectively. It therefore implies that determining MOE using acoustic methods can be adopted, as it compared favourably with the mechanical method conventionally used, and as well as with literature. Notwithstanding, top wood had a mean higher elasticity than base wood, while outer wood had higher elasticity than inner wood. However, there was still need to run an analysis to determine the best fit between these methods.

Consequently, a significant difference occurred between acoustic method 1 and the mechanical method, while there was no significant difference between acoustic method 2 and the conventional method. This therefore implies that acoustic method 1 was not best suitable for determining modulus of elasticity of wood. However, since acoustic method 2 shows no significant difference with mechanical method, it is therefore considered suitable for determining MOE. This study thus recommends it for adoption, and as such can be used as supplement or substitute for the destructive mechanical method.

Table 2

MOE (N/mm^2) of G. arborea wood obtained from acoustic method 1

	TOP	BASE	**MEAN**
INNER	7038	7284.33	7161.17
OUTER	10692	9088.83	9890.42
MEAN	8865	8186.58	**8525.80**

Table 3

MOE (N/mm^2) of G. arborea wood obtained from acoustic method 2

	TOP	BASE	**MEAN**
INNER	9560.91	7637.29	8599.10
OUTER	11756.61	9087.17	10421.89
MEAN	10658.76	8362.232	**9510.50**

Table 4

MOE (N/mm^2) of G. arborea wood obtained from mechanical method, using UTM

	TOP	BASE	**MEAN**
INNER	10181.15	9470.15	9825.65
OUTER	9923.49	13299.57	11611.53
MEAN	10052.32	11384.86	**10718.59**

Table 5

Analysis of variance of MOE of G. arborea wood between mechanical method and acoustic method 1

Source of Variation	SS	df	MS	P-value
MOE Method	28850278	1	28850278	0.009* ($P < 0.05$)
Error	76598873	22	3481767	
Total	1.05E+08	23		

- - significant SS – Sum of square df – degree of freedom MS – Mean square

Table 6
Analysis of variance of MOE of G. arborea wood between mechanical method and acoustic method 2

Source of Variation	SS	df	MS	P-value
MOE Method	8756951	1	8756951	0.17^{ns} (P > 0.05)
Error	98015314	22	4455242	
Total	1.07E+08	23		

ns – Not significant SS – Sum of square df – degree of freedom MS – Mean square

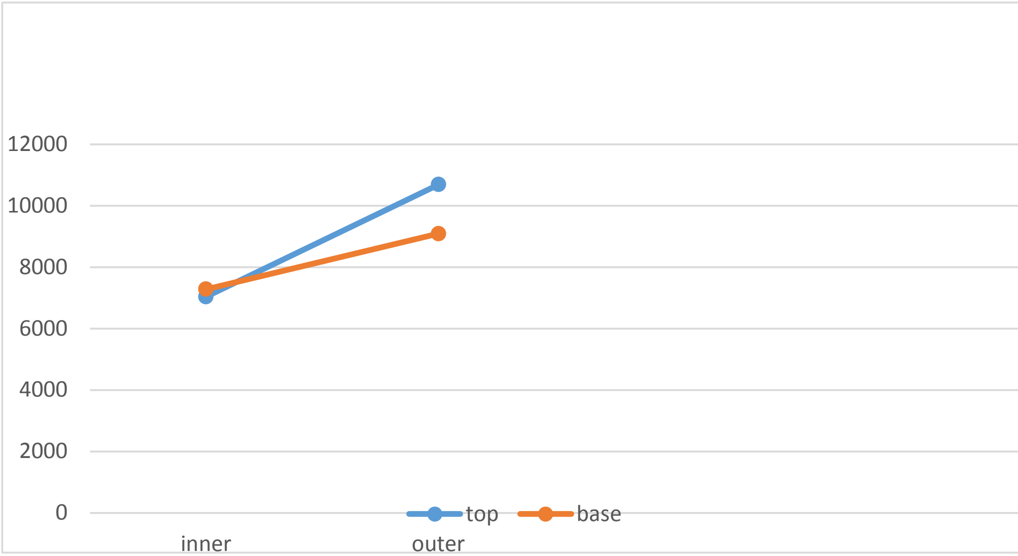

Fig. 3.
Axial and radial variation of MOE for Resonance frequency acoustic method.

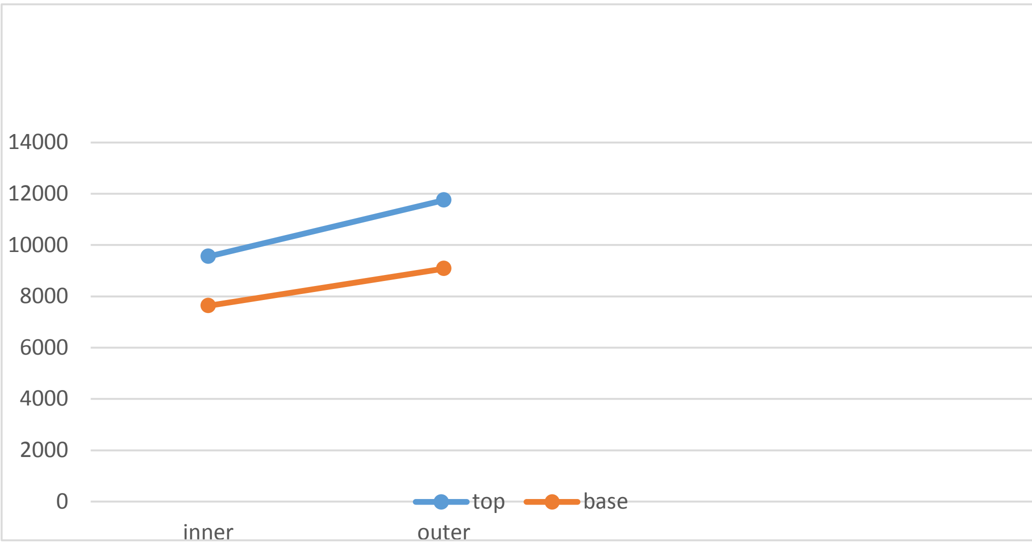

Fig. 4.
Axial and radial variation of MOE for Fundamental frequency acoustic method.

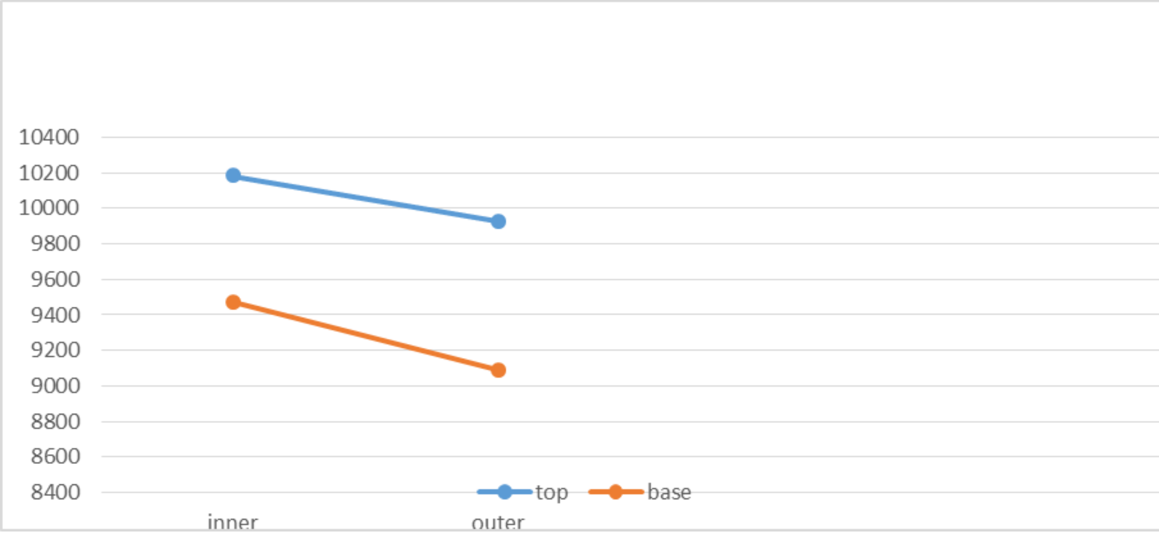

Fig. 5.
Axial and radial variation of MOE for Mechanical method, using UTM.

CONCLUSION AND RECOMMENDATION

This study successfully launched an investigation into the use of acoustic methods for determining the modulus of elasticity of *G. arborea* wood, and the following conclusions may be drawn.

1. Result of modulus of elasticity from frequency acoustic method was the same with the conventional mechanical method.
2. Acoustic methods can be used to determine the modulus of elasticity of a wood.

Therefore, acoustic method of determining modulus of elasticity was considered suitable, and as such carries the potential to substitute the destructive mechanical method commonly used. Hence, it was recommended for adoption. However, this study still recommends further studies on other wood species so as to substantiate the findings of this study.

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