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Acoustic Analysis of Commercially Available Timber Species in Nigeria

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ABSTRACT
Several acoustic techniques have been used to determine elastic and damping properties of trees, logs and beams in different parts of the world but such acoustic data on timber are not available in standard form in Nigeria.
Ten species of locally occurring Nigerian timber (five hardwood species and five softwoods species) were sampled and subjected to acoustic analysis using a 'Portable Ultrasonic Non destructive Digital Indicating Tester (PUNDIT), with a view to assessing the stiffness and strength characteristics of the timber species by obtaining the velocity of ultrasonic longitudinal stress waves through the timber piece and hence calculating the dynamic Modulus of Elasticity (MoE) of each species.
Results obtained showed that the velocity of acoustic waves through a timber piece and hence the dynamic modulus of elasticity (MoE) of the piece is directly proportional to the strength of the wood. Of all the timber species tested, the species with the highest MoE value (8.48GPa) was Mansonia *(mansonia altissima)* while that with the lowest MoE value (1.64GPa) was Alstonia *(alstonia booeneicongensis)*. This study thus provides for the first time, valuable data on the strength characteristics of ten commercially available species of Nigerian timber represented in terms of their dynamic MoE values.
KEYWORDS: Nigerian timber**,** PUNDIT**,** Acoustic velocity**,** Modulus of elasticity**,** Timber strength

I. INTRODUCTION

Acoustics has been a useful non destructive tool in testing for various properties of timbers. This testing includes physical properties such as weight, density and strength (along and across the grain) and also acoustic properties such as the rate at which certain species transmit sound, internal friction etc .The most common way to introduce acoustic waves into logs or lumber is a light tap with a hammer. From the point of impact the waves start to spread out into the specimen (Andrews, 2002).

The way a sound wave (stress wave) propagates through a body is correlated with the body's intrinsic properties. By measuring the velocity of the travelling wave the modulus of elasticity of the material can be obtained by using the one dimensional wave equation:

$$MoE = V^2 \times \delta \quad \text{……..(1)}$$

Where; MoE stands for the Modulus of Elasticity (N/m^2), V (m/s) for velocity and δ (kg/m^3) for the density of the wood.

The MoE is a measure of the wood stiffness and strength (Ross and Pellerin, 1994). The MoE calculated by the formula above is referred to as the *dynamic* modulus of elasticity. It is higher than the *static* modulus of elasticity obtained from traditional bending tests but the two are highly correlated. The stiffness of wood (MoE) and the strength of wood (MoR) are correlated for small, defect-free samples and sawn timber and this is the principle used in strength grading machines (Shaun *et al*, 2009). Therefore, because acoustic tools provide a measure of MoE, they also provide a good estimate of wood strength.

II. LITERATURE REVIEW

In recent years, several studies have been carried out on timber in various parts of the world using acoustic tools to evaluate its various properties most especially its intrinsic properties. These studies include:

Sandoz et al (2000) used an ultrasound device, (Sylvatest®), to investigate correlations between the ultrasound parameters like stress wave velocity, maximum peak, integrated transmitted energy on a 500 ms time base, attenuation and the mechanical properties modulus of elasticity (MoE) and modulus of rupture (MoR) of British *pinar species*. They showed that MOR was best correlated with attenuation.

Divós et al (2001) used ultrasonic emission analysis to investigate the change in velocity and amplitude of a constant impact when introducing sawn notches halfway between the transmitter and the receiver which were placed 60 cm apart.

Cown (1973) used ultrasonic acoustic tests to examine 10-year-old radiata pine trees which had undergone severe silvicultural treatments

Feeny *et al* (1996) conducted experiments to test the hypotheses that acoustic tools provide reliable non-destructive predictions of mechanical properties of Scots pine (*Pinus sylvestris* L.) and that these allow comparisons of the timber quality between stands with different silvicultural histories.

Grabianowski (2003) conducted an assessment into the use of non destructive methods including acoustic methods in the testing and evaluation of Australian timber species.

Pape (1999) used acoustic emission analysis to investigate Norway spruce specie and reported that thinning reduced the juvenile wood content in stands of Norway spruce (Picea abies).

Ross and Pellerin (1994) conducted research to evaluate the use of acoustic speed in assessing the quality of standing trees in Canada.

Hansen, (2006) conducted experiments to determine the elastic and damping properties of laminated beams of Australian *pinus radiata* specie using an acoustic tool: The "PULSE" multi-channel analyser which is a sophisticated acoustic tool that can measure a variety of acoustic parameters.

From the literature reviewed, it is observed that there have been no studies that have employed the use of acoustic analysis to evaluate the properties of locally occurring timber species in Nigeria, hence the fundamental reason for this study.

III. METHODOLOGY

Apparatus:

- Portable Ultrasonic digital indicating tester (PUNDIT)
- Weighing balance
- Meter rule

PROCEDURE (as guided by Eurocode 5, referencing prEN 408 and prEN 1193).

Ten species (five hardwoods and the five softwoods) of locally grown, commercially available species of Nigerian timber were chosen for the study. The species of timber chosen are as follows:

Table 1. List of timber species used for the study.@ Source NCP 1973

	HARDWOODS	SOFTWOODS
1.	Okan (*cylicodiscus gabunensis)*	Alstonia *(alstonia booeneicongensis)*
2.	Mahogany *(khaya ivorensis)*	Ohia *(celtis zenkeri)*
3.	Mansonia *(mansonia altissima)*	Homba *(pycnanthus angolensis)*
4.	Ekki *(lophira alata)*	Obeche *(triplochiton sclexylon)*
5.	Danta *(neogrodonia verifera)*	Ayo *(holoptelea grandis)*

Five samples each were provided for the ten timber species and so a total of fifty timber samples were provided for the experiment. The selected size of all the samples used was chosen as (100×100×100) mm.

- The test pieces (timber samples) were conditioned under room temperature of 20ºC ± 2ºC and 65% ± 5% relative humidity environment until constant mass was achieved (less than 1% variation in 2 hours).
- The test pieces were then properly cleaned to get rid of sand and other particles that may interfere with results.
- The PUNDIT device was switched on, set up and standardized using the standard bar by ensuring that the instrument read 56.7µs (micro seconds) when the transducers were directly coupled with the standard bar.
- Starting from the hardwoods, the timber samples were tested by direct method by placing the two flat contact 150kHz transducers (transmitter and receiver) at both ends (opposite ends) of the sample and the transit time displayed on the screen was recorded. For every test piece the ultrasonic test was carried out twice: firstly the timber sample was tested parallel to the grain and secondly it was tested perpendicular to the grain.
- After a timber sample had been ultrasonically tested it was weighed to obtain the weight which was required to calculate the density.
- At the end of the experiment all results were carefully and properly recorded and documented for processing.

IV. RESULTS

The acoustic velocities of the samples were calculated using the formula:

$$acoustic\ velocity = \frac{path\ length}{transit\ time} \quad \text{………(2)}$$

The densities of the wood samples were calculated using the formula:

$$density = \frac{mass}{volume} \quad \text{……………..(3)}$$

The dynamic modulus of elasticity (MoE) of the wood samples was calculated using the formula:

$$MoE = \rho V^2 \quad \text{……….(4)}$$

Where: ρ is the density of the sample in Kg/m^3 and V is the acoustic velocity of the sample

Table 2. MoE of the timber species from experimental results and computation.

	WOOD TYPES	ACOUSTIC VELOCITY (m/s)	DENSITY (Kg/m^3)	MoE (GPa)
	HARDWOODS			
1	OKAN			
	Sample 1	2437.84	962	5.72
	Sample 2	2434.87	966	5.73
	Sample 3	2440.81	960	5.72
	Sample 4	2439.62	964	5.74
	Sample 5	2437.24	961	5.71
2	MAHOGANY			
	Sample 1	2560.16	1049	6.88
	Sample 2	2562.13	1051	6.90
	Sample 3	2556.89	1043	6.82
	Sample 4	2562.79	1046	6.87
	Sample 5	2558.20	1045	6.84
3	MANSONIA			
	Sample 1	2699.05	1166	8.49
	Sample 2	2699.05	1171	8.53
	Sample 3	2696.14	1160	8.43
	Sample 4	2701.97	1159	8.46
	Sample 5	2704.90	1163	8.51
4	EKKI			
	Sample 1	2623.98	1135	7.81
	Sample 2	2621.23	1139	7.83
	Sample 3	2623.29	1133	7.80
	Sample 4	2627.43	1130	7.80
	Sample 5	2625.36	1139	7.85
5	DANTA			
	Sample 1	2514.46	1020	6.45
	Sample 2	2511.93	1019	6.43
	Sample 3	2517.62	1011	6.41
	Sample 4	2515.72	1025	6.49
	Sample 5	2513.19	1022	6.46
	SOFTWOODS			
1	ALSTONIA			
	Sample 1	2129.02	362	1.64
	Sample 2	2131.74	365	1.66
	Sample 3	2129.93	359	1.63
	Sample 4	2127.21	363	1.64
	Sample 5	2127.66	360	1.63
2	OHIA			
	Sample 1	2316.96	855	4.59
	Sample 2	2315.35	859	4.60
	Sample 3	2319.65	855	4.60
	Sample 4	2317.50	857	4.60
	Sample 5	2316.42	852	4.57
3	HOMBA			
	Sample 1	2158.43	364	1.70
	Sample 2	2155.64	363	1.69
	Sample 3	2159.83	362	1.69
	Sample 4	2159.36	367	1.71

	Sample 5	2157.50	361	1.68
4	OBECHE			
	Sample 1	2222.72	550	2.72
	Sample 2	2224.20	552	2.73
	Sample 3	2221.73	547	2.70
	Sample 4	2221.24	549	2.71
	Sample 5	2224.69	551	2.73
5	AYO			
	Sample 1	2238.64	650	3.26
	Sample 2	2240.65	657	3.30
	Sample 3	2242.15	655	3.29
	Sample 4	2236.64	653	3.27
	Sample 5	2241.65	656	3.32

Table 3. MoE (Average) of the timber species computated.

	TIMBER SPECIES	MoE (Average) (Gpa)
	HARDWOODS	
1	Okan	5.72
2	Mahogany	6.86
3	Mansonia	8.48
4	Ekki	7.82
5	Danta	6.45
	SOFTWOODS	
1	Alstonia	1.64
2	Ohia	4.59
3	Homba	1.69
4	Obeche	2.72
5	Ayo	3.29

V. DISCUSSION

As mentioned earlier in the introduction of this study; timber shows great variation even within the same piece of wood. This is evident in this study as observed during the process of weighing the samples as can be seen in table 2 to 3. It is observed that for a given specie of wood, different samples of the wood with the same dimensions show different weight characteristics and hence different densities. This indicates that the physical properties of wood are not entirely the same at every point on the wood log. This is a testament to the inhomogeneous property of wood.

It is also observed from the study that the relationship between the transit time of acoustic waves through timber and the strength of the timber is that of indirect proportionality: the stiffer the timber piece, the shorter the time it takes for acoustic waves to travel through it. This phenomenon can be understood by appreciating the wave properties of sound. Acoustic wave is a type of sound wave and so is subject to reflection, refraction and deflection within a medium. In stiff (hard) timber specie the internal particles of the timber are closely spaced and compacted with little voids within the entire piece. As a result of this compact nature of the particles the sound (acoustic wave) is able to travel relatively undisturbed through the timber piece and hence the time taken is short but in weak (soft) specie there are significant voids within and between particles and hence the acoustic wave experiences a lot of reflection and deflection within the timber piece thereby resulting in transit time of the wave being long.

A direct inference from the above explained phenomenon is that: the acoustic velocity of a timber piece and hence the MoE is directly proportional to its strength.

VI. CONCLUSION

Acoustic analysis is a valuable tool in the assessment of timber either in standing trees or in cut logs. The speed of acoustic waves through a piece of timber is a direct reflection of the strength of the timber. From the final results of this study, it is seen that the denser and hence the harder the wood; the shorter the transit time and hence the higher the acoustic velocity of the sound wave through the timber piece. Considering the fact that 'modulus of elasticity (MoE)' is directly proportional to acoustic velocity, it is concluded that for timbers; the modulus of elasticity is a directly proportionality of the strength and hence the load bearing capacity.

VII. RECOMMENDATIONS

This study has been able to provide the MoE values of ten species of locally occurring timber in Nigeria thereby effectively rendering the timber species as *structural timber* (timber which is graded with its specified structural and strength characteristics). Such data is a valuable tool for the construction industry when working with timber and it is the opinion of the researchers of this study that acoustic analysis should be carried out on all the timber species available in Nigeria with a view to having standard data showing their graded strength characteristics thereby promoting and standardizing the use of timber for construction purposes in the country.

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