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Comparative Study on the Destructive and Non-destructive Evaluation of the Modulus of Elasticity of Six Hardwood Species

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INTRODUCTION & AIM

Wood is used as a raw material for variety of end products such as construction material, furniture, wood based panel, pulp and paper etc. The most widespread properties used for describing strength quality for constructional purposes are density, static and dynamic modulus of elasticity and modulus of rupture [1]. However, the traditional tests used for measuring modulus of elasticity (MoE) of wood are expensive, destructive and cumbersome to perform.

Non-destructive evaluation paves an effective way for assessing the wood properties. Non-destructive techniques based on vibration frequencies and propagation of ultrasonic and stress waves have gained popularity in measuring dynamic modulus of elasticity (DMoE) of wood [2]. A very strong relationship between static MoE and DMoE determined using different methods viz. longitudinal vibrations ($DMoE_{long}$), flexural vibrations ($DMoE_{flex}$) and ultrasound ($DMoE_{us}$) has been reported by a number of researchers. However, different methods give different values of DMoE, with the magnitude of the difference between DMoE values determined by different methods ranging from 2% to 60% [2]. Furthermore, there is a lack of data on certain commercial tropical hardwood species.

In this endeavor, the present study intends to fill this information gap by evaluating the results of non-destructive testing (NDT) methodologies in conjunction with key mechanical strength parameters for the chosen hardwood species.

MATERIALS AND METHOD

Materials

Clear and defect free specimens sizing 20 mm (width) × 20 mm (thickness) × 300 mm (length) were prepared from the air dried planks of *Acacia* spp. (*Acacia*), *Ficus* spp. (Banyan), *Swietenia* spp. (Mahogany), *Mangifera indica* (Mango), *Millingtonia hortensis* (Indian cork tree) and *Ailanthus excelsa* (Indian tree of heaven).

Methodology

A visual representation of different techniques used for determining dynamic as well as static MoE and MoR is given in figure 1.

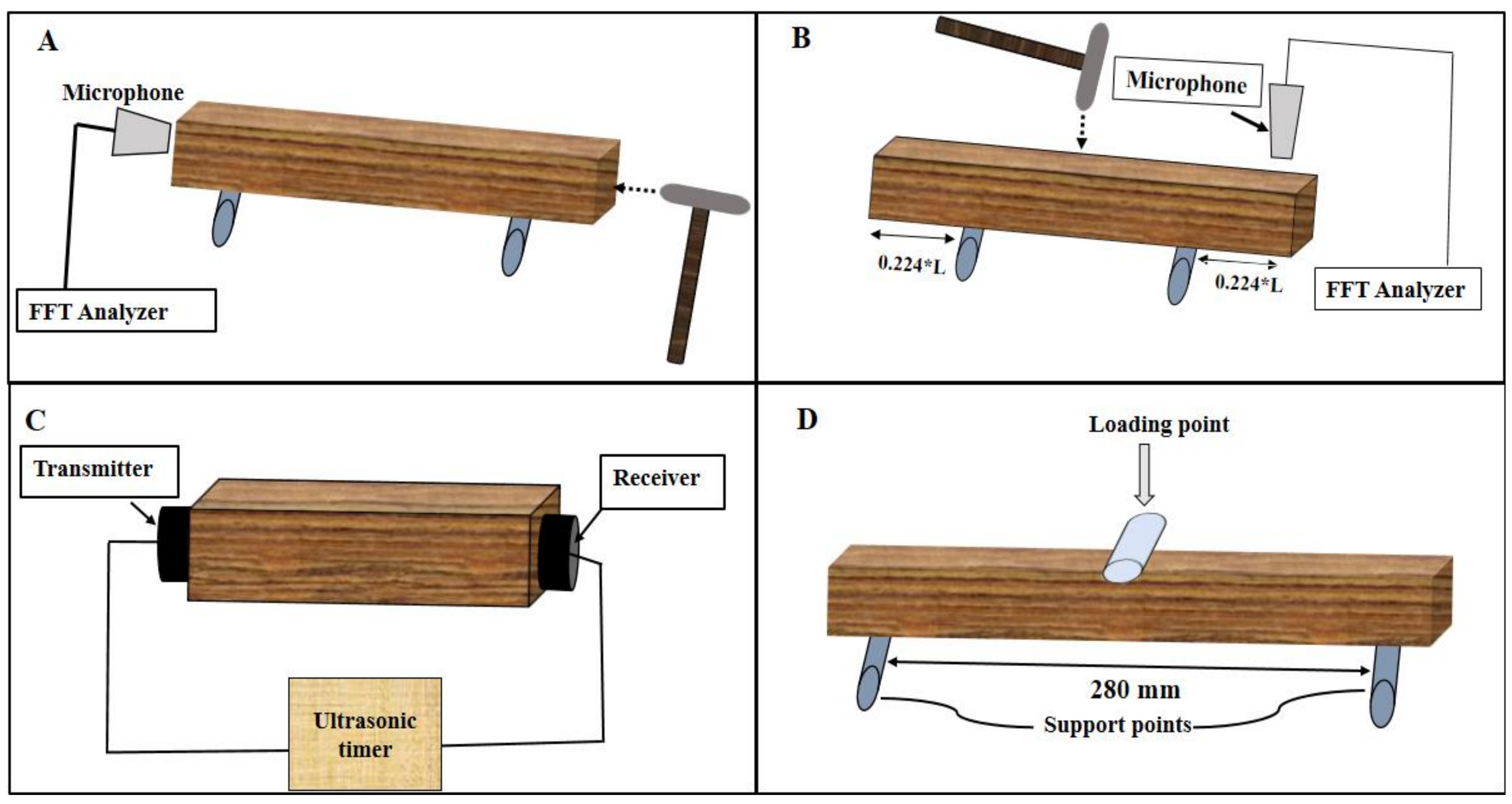

Figure 1. *Setup for measuring modulus of elasticity of wood: A - $DMOE_{long}$, B - $DMOE_{flex}$, C - $DMOE_{us}$, D - Static MOE*

The dynamic as well as static MoE was determined using different equations [2] as described in the following text.

Longitudinal resonance method

$$V = 2fl \quad (1)$$

$$DMoE_{long} = \rho V^2 \quad (2)$$

Where, f is fundamental frequency of longitudinal vibration (Hz), l is specimen length (m), V is acoustic velocity (m/s), ρ is wood density (kg/m³) and $DMoE_{long}$ is dynamic longitudinal modulus of elasticity (GPa).

Flexural resonance method

$$DMoE_{flex} = 0.946\rho f^2 l^4/h^2 \quad (3)$$

where, ρ is wood density (kg/m³), f is frequency of flexural vibration (Hz), l is length of sample (m), h is thickness of sample (mm) and $DMoE_{flex}$ is dynamic flexural modulus of elasticity (GPa).

Ultrasound method

$$V = l/t \quad (4)$$

$$DMoE_{us} = \rho V^2 \quad (5)$$

Where, l is the length of sample (m), t is transit time (seconds), V is ultrasonic pulse velocity (m/s) and ρ is density of sample (kg/m³) and $DMoE_{us}$ is dynamic modulus of elasticity using ultrasound method (GPa).

Static bending test

$$MoE = Pl^3/4dbh^3 \quad (6)$$

$$MoR = 3P'l/2bh^2 \quad (7)$$

Where, l is span length of sample (mm), P is load at elastic limit (N), d is deflection at elastic limit (mm), b is width of sample (mm), h is thickness of sample (mm) and P' is maximum load (N), MoE is modulus of elasticity (GPa) and MoR is modulus of rupture (MPa).

RESULTS & DISCUSSION

The average values of the $DMoE_{long}$, $DMoE_{flex}$, $DMoE_{us}$, Static MoE and MoR are summarized in table1. The values of DMoE measured using different methods were observed to be higher than static MoE.

Table1. *Static and dynamic moduli of elasticity (MoE) and modulus of rupture (MoR) values for each species (values in parenthesis indicates standard deviation)*

Species	$DMoE_{long}$ (GPa)	$DMoE_{flex}$ (GPa)	$DMoE_{us}$ (GPa)	Static MoE (GPa)	MoR (MPa)
Acacia spp.	11.84 (1.09)	10.96 (1.20)	16.10 (1.45)	9.37 (1.18)	97.39 (9.58)
Ficus spp.	10.83 (0.72)	9.82 (1.19)	13.91 (0.62)	8.74 (0.53)	87.64 (5.80)
Swietenia spp.	13.47 (0.71)	12.68 (0.87)	17.5 (0.58)	10.02 (1.13)	100.37(12.51)
Mangifera indica	8.77 (0.26)	8.18 (0.95)	11.94 (1.65)	6.77 (0.71)	66.96 (4.93)
Millingtonia hortensis	10.12 (0.69)	9.09 (0.76)	12.96 (0.6)	7.81 (0.31)	57.41 (2.72)
Ailanthus excelsa	5.83 (0.52)	5.23 (0.4)	7.46 (0.76)	4.31 (0.25)	28.8 (2.63)

Regression analysis (figure 2.) shows a strong linear relationship between static and dynamic MoE ($DMoE_{long}$, $DMoE_{flex}$, $DMoE_{us}$).

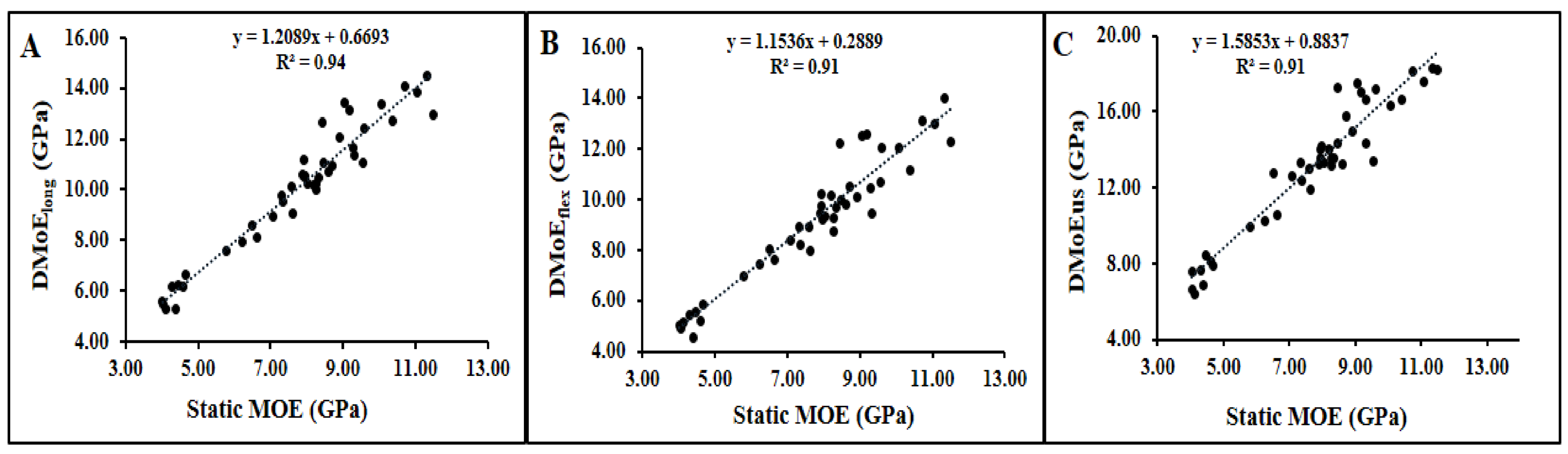

Figure 2. *Relationship between static MoE and dynamic MoE determined by three methods : A- $DMoE_{long}$ vs Static MoE, B- $DMoE_{flex}$ vs Static MoE, C- $DMoE_{us}$ vs Static MoE*

A strong correlation was observed between MoE predicted by longitudinal and flexural vibration demonstrating the interchangeability of both the methods, except for a higher value of the longitudinal resonance method.

CONCLUSION

A very strong relationship was observed between dynamic and static MOE. The results of this study indicates that the non-destructive methods (resonance vibrations and ultrasound) presents good potential of being utilised as a simple, reliable and fast method for assessment of the stiffness of studied timber species**.**

FUTURE WORK / REFERENCES

1. Lin, C. J., Tsai, M. J., & Wang, S. Y. (2006). Nondestructive evaluation techniques for assessing dynamic modulus of elasticity of moso bamboo (*Phyllostachys edulis*) lamina. *Journal of Wood Science*, *52*, 342-347.
2. Chauhan, S., & Sethy, A. (2016). Differences in dynamic modulus of elasticity determined by three vibration methods and their relationship with static modulus of elasticity. *Maderas. Ciencia y tecnología*, *18*(2), 373-382.