Available Online at www.e-iph.co.uk
Indexed in Clarivate Analytics WoS, and ScienceOPEN

ICWEP2022

https://icwep.uitm.edu.my/index.php

International Conference on Wood and Eco-Products 2022

Best Western Hotel iCity, Shah Alam, Selangor, Malaysia 15-16 Nov 2022

Organiser: Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam Malaysia & Research Nexus UiTM,, Office of Deputy Vice-Chancellor (Research & Innovation)

E-B Environment - Behaviour Proceedings Journal

e-IPH e-International Publishing House Ltd., United Kingdom

Assessment of Bending Strength of *Eucalyptus Pellita* Wood by Acoustic Velocity (AV) Technique

Noorsyazwani Mansoor[1], Adlin Sabrina Muhammad Roseley[1,2*], Sabiha Salim[1], Roger Meder[3]

*Corresponding Author

[1] Faculty of Forestry and Environment, Universiti Putra Malaysia, Serdang Selangor 43400, Malaysia

[2] Institute Tropical Forestry and Forest Product (INTROP), Universiti Putra Malaysia, Serdang Selangor 43400, Malaysia

[3] Forest Industries Research Centre, University of the Sunshine Coast, QLD, Australia

gs56537@student.upm.edu.my, adlin@upm.edu.my, sabiha@upm.edu.my, roger@mederconsulting.com

Tel *: +60193212797

Abstract

This study was conducted to validate the bending strength of *Eucalyptus pellita* using the acoustic velocity method and the conventional method. Acoustic velocity was measured on slabs using Fakopp Microsecond Timer, which relies on the time-of-flight principle. Acoustic velocity was converted to the dynamic modulus of elasticity MOE_{dyn} based on the equation $MOE_{dyn} = \rho AV^2$. The conversion equations between MOE_{dyn} and static MOE were established using the regression method. The bending test was conducted according to standard ISO 13061. Results show that the acoustic velocity method can be used to predict the static MOE value.

Keywords: Acoustic Velocity (AV), *Eucalyptus pellita*, Bending Strength

DOI: https://doi.org/10.21834/e-bpj.v9iSI17.5974

1.0 Introduction

Non-Destructive Testing (NDT) on materials is evolving, especially in wood and fiber-based materials. The usage of NDT has been extended to the application in a forest plantation. The properties of wood on standing trees can be easily determined using this technique. Wood quality can be assessed effectively without having to destroy the wood itself. One of the NDT tools that used to evaluate wood properties is the acoustic velocity (AV). The NDT technique has evolved from applying product assessment and quality control to evaluating logs and standing trees. Among the parameters that can be measured by this method is the dynamic modulus of elasticity (MOE_{dyn}), where MOE is the most important criteria to assess wood properties, especially for structural applications. This study describes the use of acoustic velocity in determining the modulus of elasticity (MOE) of the Eucalyptus stand. *Eucalyptus pellita* is one of the forest plantation species that have high potential due to its fast-growing characteristics and application in the production of higher-value products. Furthermore, eucalyptus is also widely grown in plantations, producing raw materials for the industry suitable for solid wood applications. The current trend has shown an increasing interest in evaluating the effect of silvicultural practices on the quality of eucalyptus wood.

2.0 Literature Review

To improve the forest stands in forest plantations, the properties such as the volume of trees, wood conditions, and wood characteristics, including the mechanical, and physical properties need to be studied. The mechanical and physical properties of wood are the most important properties evaluated to produce high-quality wood-based products. Wood quality is associated with the mechanical and physical properties of the wood, such as the density and stiffness (Marini *et al*., 2021). It also described as a characteristic that needs

DOI: https://doi.org/10.21834/e-bpj.v9iSI17.5974

to be considered to produce wood-based products (Russo *et al*., 2019). In the forest plantation industry, it is important to assess the wood quality of the stands to determine the wood's quality and conditions. Many authors have discussed and conducted studies related to the characterisation of variation in wood quality (Ayanleye, 2020; Balasso *et al*., 2021; Russo *et al*., 2019).

However, visual inspection to determine wood quality is not enough to assess the trees. The mechanical and physical properties of the wood such as determining the wood density and stiffness of the woods need to be evaluated. These properties were measured by harvesting the trees to prepare small clear specimens, and the mechanical and physical properties were determined by testing the samples in the laboratory. This conventional method, however, is destructive and time-consuming, and it is not practical in forest plantations (Sharma *et al*., 2020). Therefore, relative techniques and tools that are practical to be used, portable, and non-destructive must be implied on the forest plantations to evaluate the wood quality of the stands. The utilisation of (NDT) in the evaluation of wood characteristics has been proven in the forest industry for the last two decades (Schimleck *et al*., 2019), and this method offers great potential in understanding the forest resource. NDT methods consist of various techniques, including the acoustic velocity technique, and near-infrared spectroscopy (NIR). In particular, AV techniques have been widely used to evaluate the characteristic of wood, and this technology offers an opportunity to assess the basic wood properties in standing trees and logs. The acoustic velocity measurement relies on the time-of-flight approach by propagating a stress wave through the impact of striking a hammer on the metal spikes of the transmitter probe. Some authors have researched the time-of-flight approach (Fundova *et al*., 2019) and stress wave propagation in wood is a complex dynamic process controlled by wood's properties, including the physical and mechanical properties. Hence, due to this relationship, wood properties can be estimated from the fundamentals of stress wave propagation in wood.

One of the main characteristics of mechanical properties that can be assessed using NDT technology is wood's stiffness, which was determined by the material's modulus of elasticity (MOE). In general, MOE measures the material’s strength on how much it can resist being deformed when the materials are subjected to a load during the bending test (Vaughan *et al*., 2021). The stiffness of the wood is generally higher as the MOE increases. Based on the previous and recent studies, there are correlations between the dynamic MOE of acoustic velocity and the woods. The study in LVL evaluates the potential of AV methods to predict structural properties by analyzing acoustic velocity. The study shows that the dynamic MOE was strongly correlated with the MOE of LVL with R^2 = 0.83. Tumenjargal *et al*. (2020) performed research to predict the MOE and modulus of rupture (MOR) of Larix sibirica lumber using the AV approach. A recent study by Duong *et al*. (2022) found a good correlation between dynamic MOE and static MOE. Eucalyptus has become an important tree to produce timber-based products. Eucalyptus was introduced in 2012 and established in Malaysian Borneo to replace *Acacia mangium,* which suffered a loss due to the *Ceratocystis manginecans* (Alwi *et al*., 2021). The eucalyptus covered 26% of the total planted area globally. Furthermore, due to its fast-growing characteristics, this species has the potential to be used as a substitute material to increase the timber supply, and this species has been established in forest plantations since the 1970s (Turnbull, J.W 1999). Hence, studies regarding the properties of eucalyptus, such as wood density, acoustic wave velocity assessment, and MOE, have been conducted (Japaruddin *et al*., 2022).

3.0 Method

3.1 Study Site & Sampling Method

Eucalyptus pellita were obtained from the Sabah Softwood Bhd. (SSB) plantation site in Brumas, Tawau, with an elevation range between 200-600m. The experimental site was established on October. The tree stand information was summarised in Table 1

Table 1. General characteristics of the experimental site

Site	Elevation (m)	Spacing (m)	Area of plantation (hectare)	Stand age (years)	Plot size (m)	No. of a sample (trees)*	No. of sample trees (destructive test)
SSB Plantation	200-600	3x3	1.08	11	10x10	100	6

*Number of standing trees acoustically assessed by Fakopp Microsecond Timer

3.2 Preparation of a Test Sample

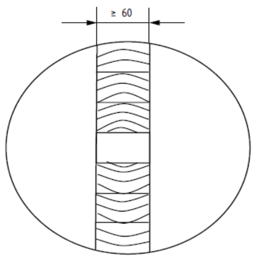


Fig. 1: General cutting pattern of a log with a diameter >180mm
(source: ISO 3129)

Six trees were selected based on the diameter classes and the AV value on standing trees was assessed to represent the population. Harvested trees were then processed into sample dimensions according to ISO 3129 (ISO 3129 Wood – Sampling method and general requirements for physical and mechanical testing of small clear wood specimens. The logs were then processed according to a specific cutting pattern for a log of more than 180mm diameter based on standard, as shown in Figure 1. Before sample processing, the wood slabs were air-dried until the moisture content of the wood reached its equilibrium state. A total of 540 small clear specimens were prepared for the bending test, and these samples were used to find the prediction and empirical data for mechanical properties. Before testing, the samples were conditioned at room temperature of (20 ± 2) °C and relative humidity of (65 ± 3) % to keep the wood's moisture content in an equilibrium state.

3.3 Acoustic Velocity (AV) Assessment

The fundamental wave equation below describes the relationship between acoustic velocity, wood density, and wood stiffness:

$$MOE_{dyn} = \rho AV^2 \tag{1}$$

Where MOE_{dyn} is the dynamic MOE (Nmm^{-2}), ρ is the wood density (kgm^{-3}), and AV is the velocity of the stress wave (ms^{-1}).

Acoustic velocity (AV) was measured on slabs. For this study, the acoustic velocity was measured from ninety-eight slabs derived from the six trees using the time-of-flight (TOF) principle of the acoustic waves. AV assessment on slabs measured the vibrational speed between two measuring points. Transmit and receiver probes with 1-2 kHz frequencies were used, and the acoustic energy was generated by striking a hammer on the transmit probe. Acoustic velocity for slabs (Vel_{slabs}) was measured using Fakopp Microsecond Timer that relies on the time-of-flight (TOF) principle using the equation (2):

$$Vel = \frac{S}{TOF} \tag{2}$$

Where Vel is the acoustic velocity (ms^{-1}), S is the distance between the two probes (m), and TOF is the time of flight (s). The transmitter and receiver probes were positioned 1m apart and inserted at a 45° angle to the tree trunk with a depth of 2cm.

The AV measurement on slabs was taken before the static bending test of small clear specimens. The dynamic MOE for slabs ($dMOE_{slabs}$) was calculated based on the above-mentioned formula, and the relationship between dynamic MOE and static MOE was established using the simple linear regression method.

3.4 Preparation of Samples & Procedure for Static Bending Test

The samples for the bending test were cut into a rectangular prism with dimensions of 320mm x 20mm x 20mm in the longitudinal, tangential and radial directions, respectively, based on standard ISO 13061 (Figure 2).

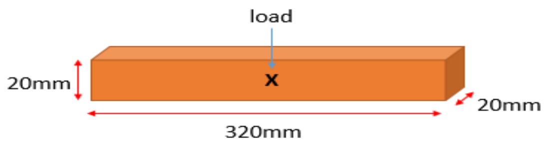
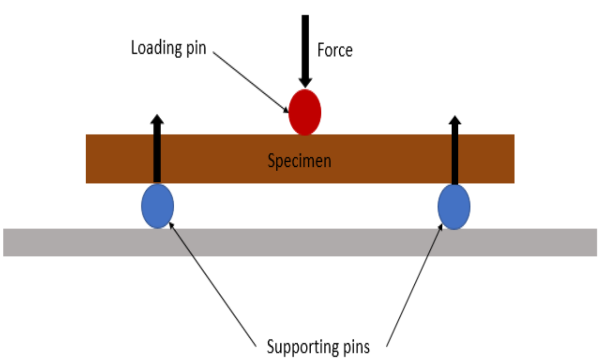


Fig. 2: Dimension of sample test

The samples were conditioned to a constant mass with a relative humidity of (65 ± 5) % and temperature of (20 ± 2) °C before the testing.



(a) (b)

Fig. 3: (a) Schematic diagram of 3-point bending test; (b) Set up for the 3-point flexure bending test

A total of 540 samples were tested in bending at the Material Testing Lab, Faculty of Forestry and Environment, UPM. The three-point flexure bending test was conducted using a 10kN Instron Universal Testing Machine, following the standard ISO 13061-3: 2014 and ISO 13061-4: 2014, respectively. The sample test was placed horizontally on top of two points, and the load was applied at the centre load of the material, with the tangential surface facing the load (Figure 3). Each sample's depth and width (mm) were measured using vernier callipers before the test. MOE and modulus of rupture (MOR) were displayed in megapascals.

3.5 Data Analysis

Statistical data analysis was performed using a two-tailed linear correlation and regression analysis between the static MOE, acoustic velocity, and dynamic MOE of slabs to establish a relationship between the non-destructive analysis and the static MOE in the small clear specimens.

4.0 Results

The descriptive statistics are summarised in Table 2. The average value of the acoustic velocity on slabs is 5.1 km s^{-1}, while the average value of the dynamic MOE is 26.7 GPa.

Table 2. Descriptive statistics of the velocity (km s^{-1}) on slabs (Vel_{slabs}) and the calculated dynamic MOE and static MOE (GPa)

	Parameter	N	Minimum	Maximum	Mean	Std. Deviation
Slab	Velocity	98	4.82	5.43	5.1733	0.10180
	dMOE	98	23.20	29.45	26.7716	1.05079
	MOE_s	98	13.95	25.57	20.60	2.64560

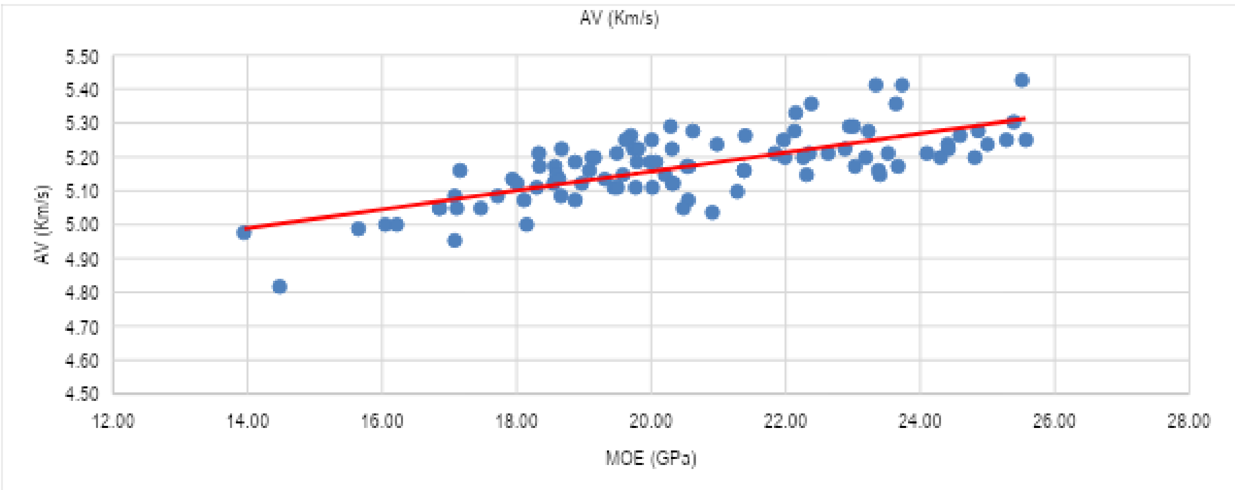
Table 3 shows the linear correlation between the acoustic velocity, dynamic MOE, and static MOE on slabs. The static MOE on slabs is strongly correlates with the acoustic velocity and dynamic MOE, with a coefficient r = 0.729 for acoustic velocity and r = 0.726 for dynamic MOE.

Table 3. Two-tailed linear correlation between the acoustic velocity, dynamic MOE, and static MOE

			N	Velocity	dMOE
Slab	MOE_s	Pearson Corr.	98	0.729**	0.726**
	Velocity	Pearson Corr.	98	1	-
	dMOE	Pearson Corr.	98	-	1

** Correlation is significant at the 0.01 level (two-tailed)

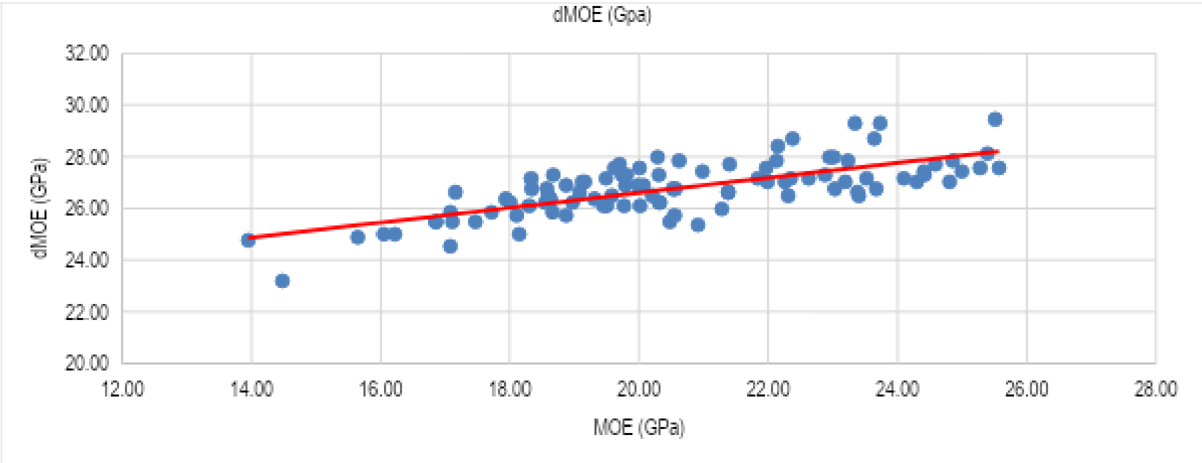
Figure 4 shows linear regression between the static MOE and acoustic velocity obtained from the slabs (A). The relationship between acoustic velocity and static MOE from slabs had an R^2 value of 0.52.



(A)

Fig. 4: (A) Relationship between static MOE and the acoustic velocity for slabs

The linear regression between the static and dynamic MOE from slabs was shown through the graph in Figures 5(A). The R^2 value for dynamic MOE and static MOE on slabs is 0.527.



(A)

Fig. 5: (A) Relationship between static MOE and the dynamic MOE for slabs

5.0 Discussion

5.1 Acoustic Velocity, Dynamic MOE, and Static MOE
A few factors influenced the distribution of acoustic velocity waves through the wood, such as the wood conditions and the percentage of the bark. Other than that, a study by Liu *et al*. (2021) shows that the increase in juvenile wood content contributes to the factors but only slows the wave propagation through the wood.

In this study, we found a correlation between the acoustic velocity and static MOE on slabs for all six trees. A study reported by Papandrea *et al*. (2022) also shows a correlation between the velocity and the MOE of logs of the poplar trees. Van & Schimleck (2022) reported that the Eucalyptus clone shows a positive correlation between the acoustic velocity and the MOE. This result indicates that the acoustic velocity that relies on the TOF principle gives a good sign of static bending properties tested on samples of *E.pellita*. Dynamic MOE also shows a positive correlation for static MOE on slabs, as shown in Figure 5(A) above. This model equations can predict the static MOE based on the dynamic MOE. A difference of 37% in dynamic MOE was measured from ultrasonic pulse velocity using a Fakopp ultrasound timer (45KHz sensor). According to the study, one of the possible reasons for the different dynamic MOE by vibration method is the difference in the frequencies of the tools used. The study also demonstrates that the wood density influences dynamic MOE in hardwood species.

6.0 Conclusion

In conclusion, this study revealed that this NDT method could predict static MOE by a positive correlation between dynamic MOE with $R^2 = 0.527$. This study also proved that applying NDT tools can provide information on the forest stands.

Acknowledgements

The authors would like to express their gratitude to Sabah Softwood Bhd. (SSB) for providing the wood materials and to the Institute of Tropical Forestry and Forest Products and Faculty of Forestry and Environment, Universiti Putra Malaysia, for the facilities and assistance provided. This research was funded by the (FRGS 2020-1) FRGS/1/2/2020/WAB03/UPM/02/2 by the Ministry of Higher Education (MOHE), Malaysia.

Paper Contribution to Related Field of Study

This paper can contribute to the benefit of plantation growers and wood processors to predict the MOE value of the same species used without having to cut down the tree.

References

Alwi, A., Meder, R., Japarudin, Y., Hamid, H. A., Sanusi, R., & Yusoff, K. H. M. (2021). Near-infrared spectroscopy of Eucalyptus pellita for foliar nutrients and the potential for real-time monitoring of trees in fertiliser trial plots. *Journal of Near Infrared Spectroscopy*, *29*(3), 158-167.

Ayanleye, S. (2020). *Assessment of some wood properties by near-infrared spectroscopy* (Doctoral dissertation, University of British Columbia).

Balasso, M., Hunt, M., Jacobs, A., & O'Reilly-Wapstra, J. (2021). Characterisation of wood quality of Eucalyptus nitens plantations and predictive models of density and stiffness with site and tree characteristics. *Forest Ecology and Management*, *491*, 118992.

Duong, D. V., Schimleck, L., Tran, D. L., & Vo, H. D. (2022). Radial and Among-clonal Variations of the Stress-wave Velocity, Wood Density, and Mechanical Properties in 5-year-old Acacia auriculiformis Clones. *BioResources*, *17*(2).

Fundova, I., Funda, T., & Wu, H. X. (2019). Non-destructive assessment of wood stiffness in Scots pine (Pinus sylvestris L.) and its use in forest tree improvement. *Forests*, *10*(6), 491.

Japarudin, Y., Meder, R., Lapammu, M., Alwi, A., & Brown, M. (2022). Non-destructive evaluation of strength and stiffness of Eucalyptus pellita. A comparison of near-infrared spectroscopy and acoustic wave velocity assessment. *Journal of Near Infrared Spectroscopy*, *30*(5), 270-278.

Liu, F., Zhang, H., Wang, X., Jiang, F., Yu, W., & Ross, R. J. (2021). Acoustic Wave Propagation in Standing Trees-Part II. Effects of Tree Diameter and Juvenile Wood. *Wood and Fiber Science*, *53*(2), 95-108.

Marini, F., Manetti, M. C., Corona, P., Portoghesi, L., Vinciguerra, V., Tamantini, S., ... & Romagnoli, M. (2021). Influence of forest stand characteristics on physical, mechanical properties and chemistry of chestnut wood. *Scientific Reports*, *11*(1), 1-10.

Papandrea, S. F., Cataldo, M. F., Bernardi, B., Zimbalatti, G., & Proto, A. R. (2022). The Predictive Accuracy of Modulus of Elasticity (MOE) in the Wood of Standing Trees and Logs. *Forests*, *13*(8), 1273.

Russo, D., Marziliano, P. A., Macri, G., Proto, A. R., Zimbalatti, G., & Lombardi, F. (2019). Does thinning intensity affect wood quality? An analysis of Calabrian Pine in Southern Italy using a non-destructive acoustic method. *Forests*, *10*(4), 303.

Schimleck, L., Dahlen, J., Apiolaza, L. A., Downes, G., Emms, G., Evans, R., ... & Wang, X. (2019). Non-destructive evaluation techniques and what they tell us about wood property variation. *Forests*, *10*(9), 728.

Sharma, V., Yadav, J., Kumar, R., Tesarova, D., Ekielski, A., & Mishra, P. K. (2020). On the rapid and non-destructive approach for wood identification using ATR-FTIR spectroscopy and chemometric methods. *Vibrational Spectroscopy*, *110*, 103097.

Tumenjargal, B., Ishiguri, F., Takahashi, Y., Nezu, I., Baasan, B., Chultem, G., ... & Yokota, S. (2020). Predicting the bending properties of Larix sibirica lumber using nondestructive-testing methods. *International Wood Products Journal*, *11*(3), 115-121.

Van Duong, D., & Schimleck, L. (2022). Prediction of Static Bending Properties of Eucalyptus Clones Using Stress Wave Measurements on Standing Trees, Logs, and Small Clear Specimens. *Forests*, *13*(10), 1728.

Vaughan, D., Auty, D., Dahlen, J., Sánchez Meador, A. J., & Mackes, K. H. (2021). Modeling variation in wood stiffness of Pinus ponderosa using static bending and acoustic measurements. *Forestry: An International Journal of Forest Research*, *94*(2), 232-243.