DEPARTEMEN PENDIDIKAN NASIONAL
FAKULTAS KEHUTANAN INSTITUT PERTANIAN BOGOR
DEPARTEMEN HASIL HUTAN
Kampus IPB Darmaga PO BOX 168 Bogor 16001 Alamat Kawat FAHUTAN Bogor
Phone : (0251) 621285, Fax : (0251) 621256 - 621 285, E-mail : dhh@ipb.ac.id

SURAT KETERANGAN

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Yang bertandatangan di bawah ini Departemen Hasil Hutan Fakultas Kehutanan IPB, menerangkan bahwa Hasil Penelitian/Karya Ilmiah atas nama **Dr. Lina Karlinsari, S.Hut., MSc.F.** sebagai penulis utama/tunggal, yang berjudul "**Study on Wood Bending Strngth Evaluation Based on Non Destructive Testing Ultrasonic Method**" sebagai laporan hasil penelitian Tanabe Foundation tahun 2006, telah tercatat dan tersimpan di Perpustakaan Departemen Hasil Hutan Fakultas Kehutanan IPB

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Ketua

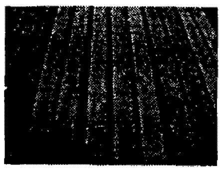
Dr.Ir. Dede Hermawan, MSc
NIP. 131 950 984

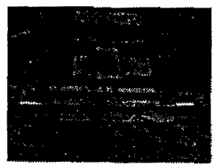
RESEARCH REPORT

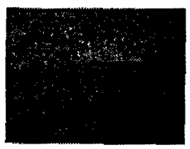
Study on Wood Bending Strength Evaluation Based on Non Destructive Testing Ultrasonic Method

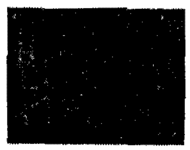
By

Lina Karlinasari









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Department of Forest Products
Faculty of Forestry, Bogor Agricultural University
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2006

Research Title	: **Study on Wood Bending Strength Evaluation Based on Non Destructive Testing Ultrasonic Method**
Field	: Wood Science
Researcher	: Lina Karlinasari, MSc.F
Laboratorium	: Wood Engineering
Department	: Forest Products
Faculty	: Forestry
University	: Bogor Agricultural University
Country	: Indonesia
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PREFACE

This research was done dealing with non-destructive testing of wood bending strength. In the forest products industry, non-destructive testing or evaluation (NDE) has been developed and is used in structural products grading programs that result in engineered material with well-defined performance characteristics. One of NDE technique, which uses ultrasonic wave propagation characteristics, has received considerable attention.

In Indonesia, non destructive testing research is still few, even for grading activity. This conditions cause the information regarding to species using this method still limited. The aim of this research is to define characteristics of some tropical hardwoods species using ultrasonic method in beam-small wood specimen for their bending strength properties.

The report is divided into five chapters. These are (1) introduction, (2) review of references, (3). materials and methods, (4) results and discussions, and (5) conclusion.

The author is thankful to Tanabe Foundation for financial support on my research and hopes this report will be useful and the cooperation research like this can be continued.

Bogor, August 2006

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I. INTRODUCTION

Background

Strength wood analysis facilitates predicting residual strength. For the progress of durability and service life of wooden constructions through appropriate maintenance, it is important to detect deterioration, both physic and biology, of wooden constructions members quantitatively and precisely, and to accurately estimate/evaluate reductions in strength. For this purpose, establishment of reliable and practical methods to evaluate residual strength of wood is essential. These methods must be not only accurate but also non destructive and practical.

Non destructive testing has been extensively used for sorting or grading of wood products. Examples include visual grading and machines stress rating (MSR) of lumber. Dynamic modulus of elasticity (MOEd) using ultrasonic methods have been used for the same purpose. It is recognized that ultrasonic method provides quick and reliable results in wood examination. The use of ultrasonic wave propagation as a nondestructive evaluation technique has proved to be a viable method to characterized wood. Research on ultrasonic techniques has evidenced the efficacy method to determine the mechanical properties of wood. The validity of this technique is tested by means of comparisons with results obtained through destructive test, providing significant correlation parameters (Oliveira *et al.*, 2002).

Determination of the mechanical properties of wood by ultrasonic propagation is based on the correlation between the speed of sound, the modulus of elasticity and the density. There are close correlation between MOEd and static modulus of elasticity (MOEs) measured by destructive testing. Several studies have shown a good relationship (R^2= 0.4-0.85) between stress wave based (both sonic and ultrasonic stress) modulus of elasticity (MOEd) and the static modulus of elasticity (MOEs) (Bostrom, 1994; Wang *et al.* 2001; Ayarkwa, *et al.* 2001; Oliveira *et al.* 2002).

Objective

The objective of this study is to obtain ultrasonic velocity characteristics of three kinds hardwoods species (tectona, African wood, and sengon) and find correlations between dynamic test by ultrasonic (MOEd) and static bending test

(MOEs and MOR) as well as to do preliminary study for evaluation of wood condition through certain method approaches.

Hypotheses

1. There are significant influence from wood dimension on ultrasonic velocity characteristics
2. Mathematical model developed can be used as predictor of wood bending strength

II. REVIEW OF REFRENCES

Non destructive testing or evaluation is defined as the science of identifying the physical and mechanical properties of an element of a given material without altering its final application capacity (Ross *et al.*, 1998). Non destructive testing method has been extensively used for sorting or grading of wood products. Examples include visual grading and machining stress rating (MSR) of lumber. Dynamic modulus of elasticity (MOEd) and ultrasonic method also have been used for the same purpose. Ultrasonic stress wave is similar to the sonic stress wave approach except that is applied at higher frequencies. Ultrasonic is a high frequency sound at the inaudible frequency range. The ultrasonic method is very popular with homogenous, nonporous materials for detection of flaws (Bodig, 2000). In case of wood the frequency is between 20kHz-500kHz. The two most frequently used methods are the through transmission and the pulse-echo methods (Zombori, 2001). The through transmission method requires two piezoelectric transducers (mainly quartz crystals) on each side of the subject being inspected. In case of pulse-echo method, only one transducer is used. It serves both the transmitter and receiver function, therefore only the reflected pulse is measured.

The use of ultrasonic wave propagation as a nondestructive testing method has proved to be a viable method to characteristic wood. Research on ultrasound method has evidence the efficacy of the method to determine the mechanical properties of wood. The validity of this method is tested by means of comparisons with results obtained through destructive test, providing significant correlation parameters.

The advantages of ultrasound method over the conventional characterization methods are its speed, versatility and lower cost. Another advantage is that the material is unaffected by the propagation phenomenon, allowing the sample to be tested a number times without becoming deformed. Another application of the nondestructive methods is the evaluation of structures that are in use, i.e., in situ evaluation, allowing for their maintenance or rehabilitation through a mapping of the deteriorated area, which permits evaluations to be made of their structural integrity without the need to remove part of the structure (Oliveira *et al.*, 2002)

Determination of the mechanical properties of wood by ultrasonic propagation is based on the correlation between the velocities of ultrasonic wave, the MOE and the density.

The factors that influence the propagation of ultrasonic waves in wood are physical properties of the substrate, geometrical characteristics of the species (macro- and micro structures), conditions of the medium (temperature, moisture content) and the procedure utilized to take the measurements (frequency and sensitivity of the transducer, their size, the position and dynamic characteristics of the equipment) (Oliveira *et al.* 2002). Density is one of the common properties used to evaluate wood. Mishiro (1996) indicated three types of relationship between ultrasonic velocity and density (for different Japanese species with density ranging between 90 and 1300 kg/m^3): sound velocity increases with density, or it is not affected by density, or it decreases with density.

The fundamental hypothesis for NDT of wood materials was first presented by Jayne (1959). He proposed that the energy storage and dissipation properties of wood materials, which can be measured nondestructively by using a variety of static and dynamic techniques, are controlled by the same mechanism that determine the mechanical behavior of such materials. As a consequence, useful mathematical relationship between these properties and elastic and strength behavior should be attainable through statistical regression analysis methods (Ross, 1992). To elaborate of Jayne's hypothesis, consider how the microscopic structure of clear, straight-grained wood affects mechanical behavior and energy storage and dissipation properties. Clear wood is a composite material composed of many tube-like cell cemented together. At the microscopic level, energy storage properties are controlled by orientation of the cells and their structural composition, factors that contribute to elasticity and strength. Such properties are observed at frequency of oscillation in vibration or speed of sound transmission. Energy dissipation properties, conversely, are controlled by internal friction characteristics, with bonding behavior between constituents contributing significantly. Rate of decay of free vibration or acoustic wave attenuation measurements are frequently used to observe energy dissipation properties.

III. MATERIALS AND METHODS

Materials

The species studied were tectona (*Tectona grandis*), African wood (Maesopsis eminii) and sengon (*Paraseriathes falcataria*) representing low, medium and high density. All the species were obtained from community forest around the Darmaga district, Bogor. The pieces were boards and small wood specimens. The dimension and geometry of the specimen was represented by Figure 1.

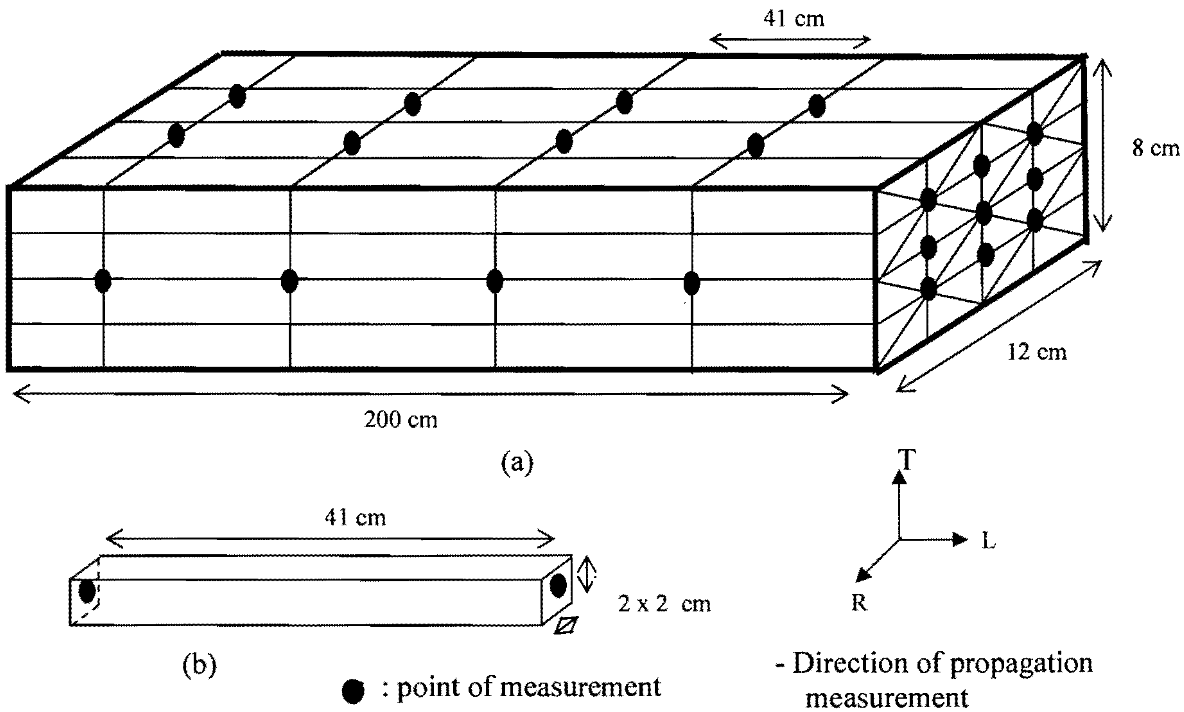


Figure 1. Detail of dimension and position of nondestructive measurement (a). Board, (b). Small specimen

Methods

The board with 12 cm width, 8 cm thickness and 200 cm length were taken to carry on the test and conditioned to achieve equilibrium moisture content (EMC) about 15-18%. Generally, there will be two form, board and small wood specimen. Those were as depicted in Figure 1a and 1b. The smallest section was (2.5 x 2.5 x 41) cm measured by non destructive and destructive testing and the board (12 x 8 x 200) cm were measured by non destructive testing. All non destructive testing was done through direct measurement (Figure 2.). Visual analysis was noted as reference of the condition of the specimen

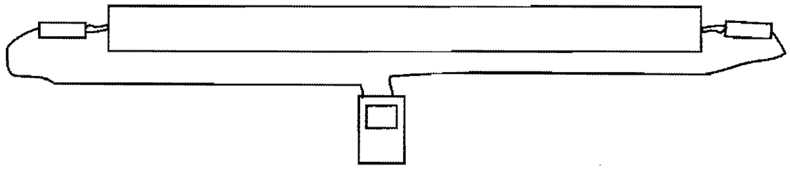


Figure 2. Direct measurement of non destructive testing

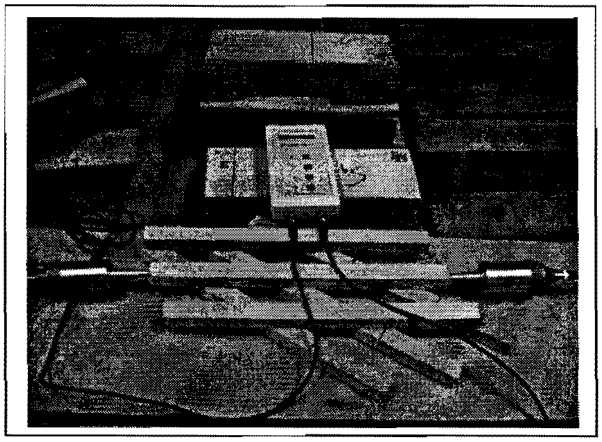


Figure 3. Nondestructive testing tools and position of measurements

The non destructive testing was developed through ultrasonic wave velocity measurement. The ultrasonic wave propagation was measured by ultrasonic device Sylvatest Duo® (f=22kHz) as shown in Figure 3. The application and measurement consists of positioning two accelerometer transducers on the material to be evaluated. The ultrasonic wave was introduced into the material by one transducer (transmitter) and picked up by the other transducer (receiver), with the time reading – in microseconds- performed by the ultrasonic instrument it self. The recorded times were used to calculate the ultrasonic velocity and dynamic modulus of elasticity, based on Equation (1, 2).

$$v = \frac{d}{t} \qquad (1)$$

where, d is the distance between the two transducers (cm), and t is propagation time of the pulse from transmitting transducer to the receiving transducer (μs).

The ultrasonic velocity is used to express the dynamic modulus of elasticity (MOEd). The MOEd is calculated by the following equations:

$$MOEd = \frac{\rho \times Vu^2}{g} \qquad (2)$$

where, MOEd is dynamic Modulus of Elasticity (kg/cm^2), ρ is density (kg/m^3), Vu is ultrasonic wave velocity (m/s) and g is gravitational constantan (9.81 m/s^2).

Static bending test was done to determine the static modulus of elasticity (MOEs) and modulus of rupture (MOR). Bending strength properties test for the specimens are performed by third point loading method (Figure 4) in universal testing machine (UTM, Senstar®). Actually, the dimension of destructive testing is in accordance with ASTM D 143-2000 for bending test (2.5 x 2.5 x 41) cm.

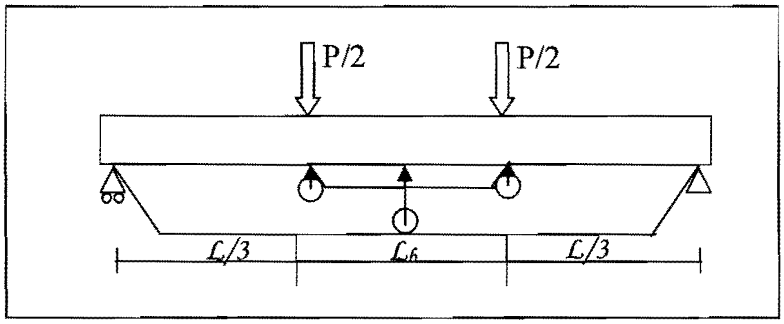


Figure 4. Destructive measurement of third point loading method

The MOEs and MOR are calculated by the following equations:

$$MOEs\ (kg/cm^2) = \frac{P' \times L^3}{4.7 \times Y' \times b \times h^3} \qquad (3)$$

$$MOR\ (kg/cm^2) = \frac{Pmax \times L}{b \times h^2} \qquad (4)$$

where
MOEs : static *Modulus of elasticity* statis (kg/cm^2)
MOR : *Modulus of rupture* (kg/cm^2)
Pmax : maximum load (kg)
L : span (cm)
b : base of specimen (cm)
h : height of specimen (cm)
P' : load at proportional limit (kg)
Y' : deflection at mid length at proportional limit (cm)

Statistical analyses were observed to find nondestructive variable values in board in which of difference vertical position and direction of propagation measurement. Relationship of velocity and density on MOEd and MOR; as well as MOEd on MOEs and MOR were assessed to find statistical correlation between statically and dynamically established moduli. Least squares regression analyses are used in this study.

IV. RESULTS AND DISCUSIONS

Beam evaluation

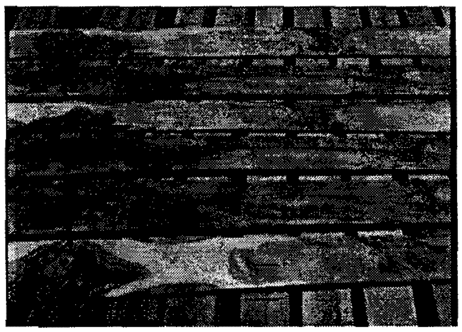
Evaluation of beam quality on three kinds species (tectona wood, African wood and sengon wood) depicted by wood defect (knots, pingul, drying defects) is shown in Table 1.

Tabel 1. Evaluation of wood quality on tectona wood, african wood and sengon wood

Wood species	SR (%) Knots	Pingul	Drying defects
Tectona	76.8	found	Not found
African wood	72.79 (many knots)	found	Some bowing
Sengon	82.9	found	Some bowing

Note: SR = *strength ratio* according to A STM D-245-2000

More details of wood condition are shown as following Figure 5.



a. Tectona wood

b. African wood

c. Sengon wood

Figure 5. Appearance of surface woods

According to ASTM D-245 which concerns with visual grading of wood with some defects parameter was shown that African wood had lower SR than other woods in which found many knots.

The velocity has been found to be influenced by wood species, wood anatomy (cell composition and structure), grow site, level of wood stress, moisture content, temperature, relative humidity, and direction of waves propagation (longitudinal, radial, tangential) (Smith, 1989). Density does not significantly effect the velocity, but the ratio of the medium's elastic modulus E to its density ρ is important; for the case of rods, the velocity sound V can be shown to be given by $V = (E/\rho)^{1/2}$. Moreover Gerhards (1982) summarized variables influencing of sound velocity as determined by a number of researcher, there are knots, slope grain and wood decay.

Table 2 shows the mean values of density, ultrasonic velocity, dynamic MOE and energy of tectona wood, African wood and sengon wood beams.

Table 2. Mean values of density (ρ), ultrasonic velocity (Vus), dynamic MOE (MOEd) and energy (e) of tectona wood, African wood and sengon wood beam (8x12x200) cm in three vertical positions

	Variable			
	ρ (g/cm^3)	Vus (m/s)	MOEd (kg/cm^2)	e (mV)
Tctona				
-Bottom-	0.77	4696**b**	173,497	5063
-Middle-	0.79	4622**b**	172,564	5289
-Top-	0.80	4163**a**	141,539	5178
Means	*0.79*	*4494*	*162,533*	*5177*
African wood				
-Bottom-	0.46	4575**a**	97,216	4422
-Middle-	0.42	4653**a**	93,305	4261
-Top-	0.40	5151**b**	107,157	4349
Means	*0.42*	*4793*	*99,226*	*4684*
Sengon				
-Bottom-	0.36	5278	101,652	4248
-Middle-	0.35	5332	100,852	4187
-Top-	0.33	5498	103,260	4464
Means	*0.35*	*5369*	*101,921*	*4300*

Notes: Mean values followed a letter denotes significant difference based on Tukey test in level 5%

Table 2 shows that ultrasonic velocity of tectona wood is a range in 4163-4969 m/s and for African wood and sengon are in a range 4574-5151 m/s and 5278-5498 m/s, respectively. Dynamic MOE are 141,539-173,497 kg/cm^2, 93,305-107,157 kg/cm^2, 100,852-103,260 kg/cm^2 for tectona, African wood, and sengon, respectively. Meanwhile, energy of tectona is a range 5063-5289 mV, African wood is 4261-4422 mv, and sengon is 4187-4464 mV. Energy is ability of sound propagation to pass a medium. The results confirms previous study by Wahyuna (2005) which denotes that there is significant influence from horizontal position (heartwood and sapwood), but no significant effects from vertical position in tree (bottom, middle and top) for ultrasonic velocity propagation and dynamic MOE values.

Direction of wave propagation (tangential, radial, and longitudinal) was observed to know the influence of that on non destructive variable (Table 3 and Figure 6). The result depicts that means values in longitudinal or axial direction is 1.51 – 2.92 higher than transversal direction (radial and tangential). Meanwhile, MOEd in axial direction is 2.21-8.49 than transversal direction and 1.07-1.117 higher in longitudinal direction than transversal for energy values. Bucur (1995) reported the same trend for some hardwood and softwood. Kollmann and Cote (1968) revealed that ratio of acoustic wave propagation between parallel and perpendicular to grain was 3.21-5.44 for spruce, pine, fir, maple beech, oak and lime species.

Table 3. Mean values of density (ρ), ultrasonic velocity (Vus), dynamic MOE (MOEd) and energy (e) of tectona wood, African wood and sengon wood beam (8x12x200) cm in three direction of sound propagation

	Variable			
	ρ (g/cm^3)	Vus (m/s)	MOEd (kg/cm^2)	e (mV)
Tectona				
-Longitudinal-	0.79**a**	4494**a**	162,325**a**	5177**b**
-Radial-	0.78**a**	3705**b**	116,545**b**	4559**a**
-Tangential-	0.79**a**	2463**c**	53,495**c**	4555**a**
African wood				
-Longitudinal-	0.42**a**	4793**a**	99,225**a**	4684**b**
-Radial-	0.42**a**	2987**b**	39,545**b**	4347**ab**
-Tangential-	0.42**a**	1797**c**	14,355**c**	4222**a**
Sengon				
-Longitudinal-	0.35**a**	5369**a**	101,921**a**	4300**b**
-Radial-	0.34**a**	2326**b**	20,646**b**	3979**a**
-Tangential-	0.34**a**	1520**c**	8,447**c**	3999**a**

Notes: Mean values followed a letter denotes significant difference based on Tukey test in level 5%

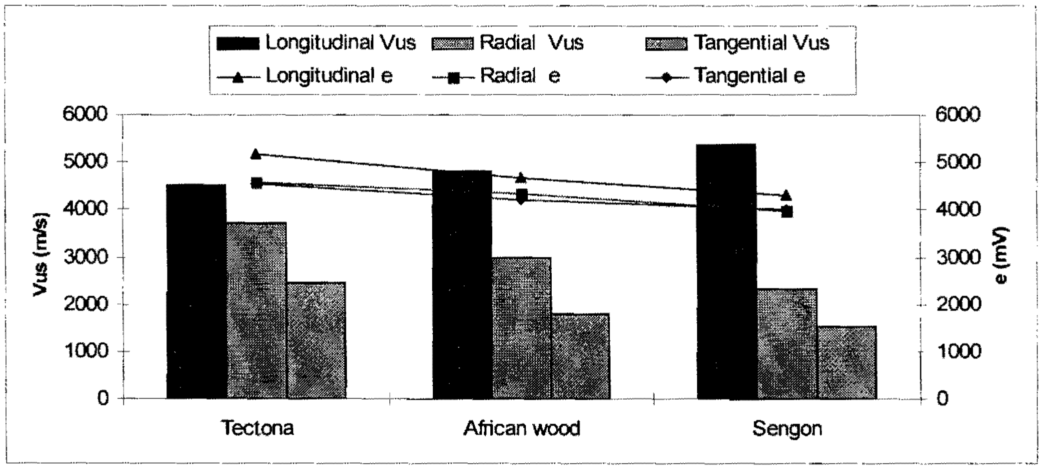


Figure 6. Histogram of direction wave propagation (longitudinal, radial, and tangential) for ultrasonic velocity and energy in three species

Table 4 shows that the fastest ultrasonic velocity is 5727 m/s for 36 cm length in tectona and 6091 m/s and 6505 m/s in African wood and sengon, respectively. Meanwhile, the highest dynamic MOE is for 36 cm length followed by 77 cm, 118 cm, 159 cm and 200 cm for all kinds' species.

Table 4. Mean values of density (ρ), ultrasonic velocity (Vus), dynamic MOE (MOEd) and energy (e) of tectona wood, African wood and sengon wood in several length beams (8x12x200) cm

	Beam length				
	200 cm	159 cm	118 cm	77 cm	36 cm
Tectona					
-ρ (g/cm^3)-	0.71**a**	0.73**a**	0.74**a**	0.75**a**	0.78**a**
-Vus (m/s) -	4493**a**	4637**a**	4856**a**	4861**ab**	5727**b**
-MOEd (kg/cm^2) -	162,285**a**	162,533**a**	178,964**ab**	182.260**ab**	239,417**b**
-e (mv)-	5177**a**	5618**bc**	5591**bc**	5303**ab**	5713**c**
African wood					
-ρ (g/cm^3)-	0.38**a**	0.39**a**	0.40**a**	0.42**a**	0.42**a**
-Vus (m/s) -	4793**a**	4938**ab**	5149**bc**	5406**c**	6091**d**
-MOEd (kg/cm^2) -	99,226**a**	105,586**bc**	109,632**bc**	118.207**c**	146,451**d**
-e (mv)-	4684**a**	4994**ab**	4871**a**	5099**ab**	5348**b**
Sengon					
-ρ (g/cm^3)-	0.31**a**	0.33**ab**	0.34**ab**	0.34**ab**	0.34**ab**
-Vus (m/s) -	5369**a**	5492**a**	5660**ab**	5856**b**	6505**c**
-MOEd (kg/cm^2) -	101,921**a**	104,311**a**	109,046**ab**	117.395**b**	134,535**c**
-e (mv)-	4300**a**	4451**a**	4738**ab**	4778**ab**	4981**b**

Notes: Mean values followed a letter denotes significant difference based on Tukey test in level 5%

Since the modulus of elasticity is directly proportional to the density, the sound velocity should be independent from density (Kollman dan Cote, 1968). The velocity of propagation is still correlated to the modulus of elasticity, but energy will be correlated to the local singularities (knots, grain, and degradation area) which cause acoustic wave attenuation. In fact, the energy damping of the waves is directly dependant of local singularities (Sandoz *et al.,* 2002). In the case of density, as mentioned before, Mishiro (1996) indicated three types of relationship between ultrasonic velocity and density (for different Japanese species with density ranging between 90 and 1300 kg/m^3): sound velocity increases with density, or it is not affected by density, or it decreases with density. In this study, the lower density the faster of ultrasonic velocity was observed for comparing all wood species. However, for each species within in wood for different length beam, the ultrasonic velocity has been found to be increase with increasing density. It might be due to the shorter dimension has fewer wood defects (e.g. knots)

The regression analyses were tested to quantify relationship of length of beam and on density ultrasonic velocity (Table 5). In long solid rods, the thickness of which may be neglected compared with the wave length in the case of the propagation of longitudinal waves along axis the rods (Kollmann dan Cote, 1968; Bucur, 1995; Iswindarto, 2006).

Tabel 5. Regression model for relationship between ultrasonic velocity, length beam and density

Wood species	Regression model	Coefficient correlation (r)
Tectonan=6)	Vus = 5901,66 – 6,424 P – 348,11 ρ	0,66
African wood(n=12)	Vus = 7102,51 – 6,750 P – 2535,82 ρ	0,85
Sengon (n=12)	Vus = 8273,98 – 5,487 P – 5546,5 ρ	0,83

Notes: n=number of beam, P = length of beam

Small specimen evaluation

Static and dynamic bending test

Analyses statistic performed shows in Table 6. for variable of physical properties and both dynamic and static bending strength properties. The mean values found for the properties studied here are compatible with those usually found in experiments with the same species (Karlinasari, 2005 and Mulyadi, 2006).

Table 6. Mean values of physical and bending strength properties in small specimen for tectona wood, African wood, and sengon wood

	Variable					
	MC (%)	ρ (g/cm^3)	Vus (m/s)	MOEd (kg/cm^2)	MOEs (kg/cm^2)	MOR (Kg/cm^2)
			Tectona			
Means	15.8	0.76	5181	205,880	96,157	628
	(20)	(270)	(270)	(270)	(113/132)	(113/132)
SD	1.9	0.09	562	37,700	18,203	125
CV (%)	11.8	11.6	10.8	17.5	18.9	2.0
Maximum	19.5	0.96	6403	320,729	148,060	996
Minimum	12.0	0.55	3657	39,697	45,098	275
			African wood			
Means	12.4	0.43	5420	129,956	62,616	423
	(20)	(197)	(197)	(197)	(73)	(73)
SD	1.1	0,06	648	28,818	20,980	125
CV	9.2	13.27	11.9	22.2	33.5	29.5
Maximum	14.0	0.76	6830	217,518	118,870	835
Minimum	9.4	0.20	4242	75,774	20,212	189
			Sengon			
Means	14.6	0.32	6416	134,776	64,510	396
	(20)	(272)	(272)	(272)	(143/144)	(143/144)
SD	1.8	0.04	319	16,387	12,371	90
CV	12.0	13.3	4.9	12.0	19.2	22.7
Maximum	19.0	0.48	7133	189,422	108,286	611
Minimum	12.3	0.25	5606	92,712	32,127	181

Notes: SD = standard deviation; CV = coefficient of variation; number in parentheses denotes number of specimen (n)

The results of MOEd values were 50% higher than those MOEs values. It is considered to because of microstructural characteristic and viscoleatic properties of wood. The accuracy of the determination of MOE wood by the ultrasonic test is said to be higher than that static test. The difference may be due to the rate of loading static test in which creep effects influence the measured static deflection and also may be related to the viscoelastic nature wood (Bodig and Jayne, 1982 and Madson, 1992). Wood is highly impact-absorbent material. In the vibration of wood species, the restored elastic force is proportional to the velocity. Therefore, when force is applied for a short time, the material shows a solid elastic behavior, with longer application of force; its behavior is equal to that of a viscous liquid. This behavior is more evident in static bending test (long duration) than in ultrasonic test. Thus, the modulus of elasticity determined by the ultrasonic method is usually greater than that obtained in static deflection (Oliveira *et al.* 2002). According to Bodig and Jayne (1982) and Tsoumis (1991), MOE obtained by vibration test proved to be 5-15 percent higher than static test. Meanwhile, Bucur (1995) reported that the value of MOE determined from dynamic was about 10 percent higher than static test for spruce and beech.

Oliveira, *et al.* (2002) used ultrasonic method and obtained 17-20 percent higher values than static test values for Brazilians wood species. Karlinasari *et al.* (2005) evaluated MOE of six tropical wood species (sengon, meranti, manii, mangium, agathis, and pine) and found that dynamic MOE of small clear specimen was about 50% greater than the static MOE when it is not corrected by Poisson's coefficient.

Relationship of velocity and density on bending strength

Relationship between velocity and dynamic MOE, static bending MOE, and MOR were analyzed for each species, and the regression parameters are presented in Table 7.

Static bending MOE and MOR appeared statistically better correlated with both density and ultrasonic velocity than only single variable of ultrasonic velocity for both the combined data of three species and sengon wood. For tectona wood, multivariable regression model of density and ultrasonic velocity seemed no difference correlated with solely single variable of ultrasonic velocity. The results followed the general relationship between density and mechanical properties. Meanwhile, the comparatively lower correlation coefficient for African wood might be due to many knots was found on sample.

Table 7. Summary of regression parameters for regression of ultrasonic velocity and density on static bending MOE and MOR for the three species

Wood species	Regression model	R	R^2	Significance of model ($\alpha = 0.05$)
1. Tectona (n=113)				
	MOEs = 20.546 Vus – 10797	0.54	0.29	0.001**
	MOEs = 31.108 Vus + 96585.52 ρ -139826	0.63	0.40	0.000**
	MOR = 0.11 Vus + 55	0.47	0.17	0.000**
	MOR = 0.175 Vus + 597.263 ρ – 742.884	0.51	0.26	0.000**
2. African wood (n=73)				
	MOEs = 1.073 Vus + 56594	0.02	0.0006	0.839 ns
	MOEs = 1.749 Vus + 50992.661 ρ + 30095.655	0.12	0.14	0.620 ns
	MOR = - 0.0049 Vus + 451.099	0.19	0.00	0.875 ns
	MOR = -0.0013 Vus + 269.926 ρ + 310.883	0.10	0.01	0.688 ns
3. Sengon (n=143)				
	MOEs = -8.4998 Vus +117522	0.15	0.02	0.078 ns
	MOEs = 9.637 Vus + 199315.1 ρ – 6321.0	0.71	0.50	0.000 **
	MOR = -0.142 Vus + 1284.184	0.34	0.12	0.000**
	MOR = -0.00244 Vus + 1538 ρ – 110.724	0.81	0.661	0.000**
All species (n=329)				
	MOEs = -12.205 Vus + 145066	0.32	0.10	0.000**
	MOEs = 18.805 Vus + 118301 ρ – 93339.9	0.73	0.53	0.000**
	MOR = -0.108 Vus + 1101.906	0.42	0.18	0.000**
	MOR = 0.0865 Vus + 742.132 ρ – 393.668	0.73	0.54	0.000**

Notes: r= coefficient correlation, r^2 = coefficient determination, ns = no significance ; **= very sig.

The regression models developed for each two species (without African wood) as well as for the combined data were highly statistically significant, except for solely Vus for predicting the static bending MOE.

Figure 7, 8, 9, 10, 11, 12, 13 and 14 graphically present data distributions of relationship of ultrasonic velocity on static bending MOE and MOR for each of three species.

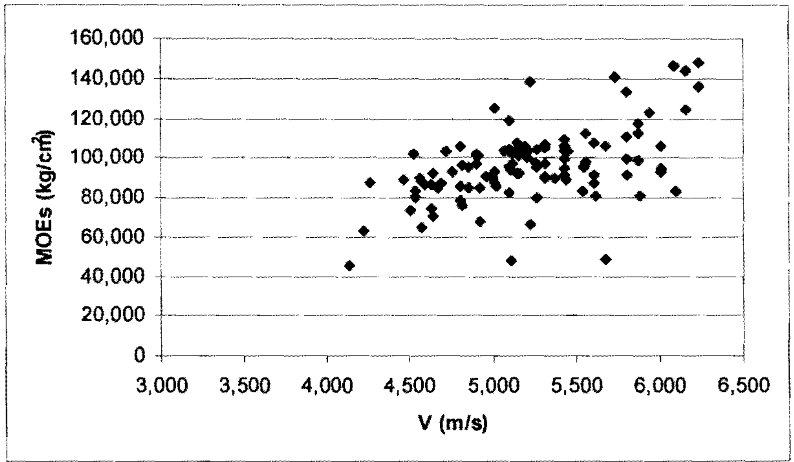


Figure 7. Relationship between Vus and MOEs of tectona wood

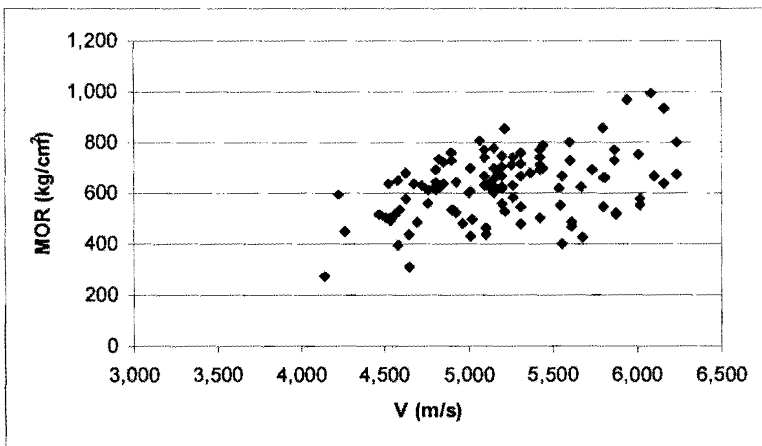


Figure 8. Relationship between Vus and MOR of tectona wood

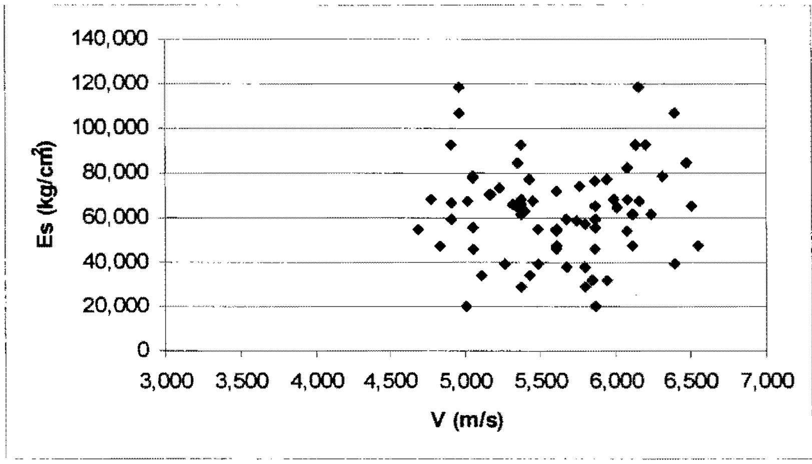


Figure 9. Relationship between Vus and MOEs of African wood

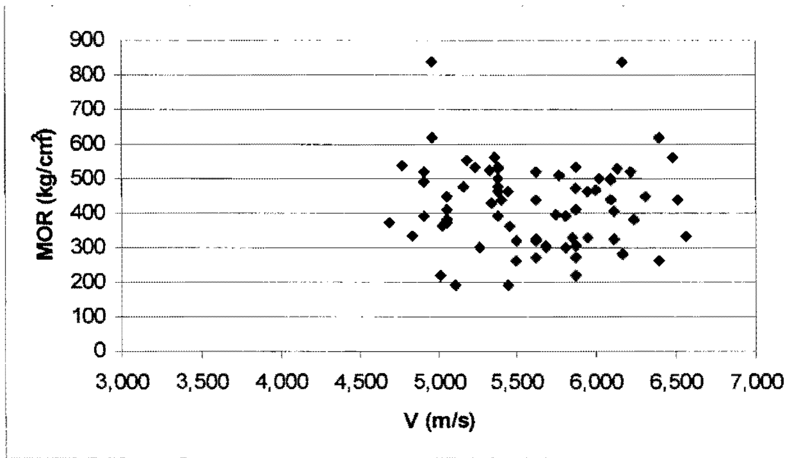


Figure 10. Relationship between Vus MOR of African wood

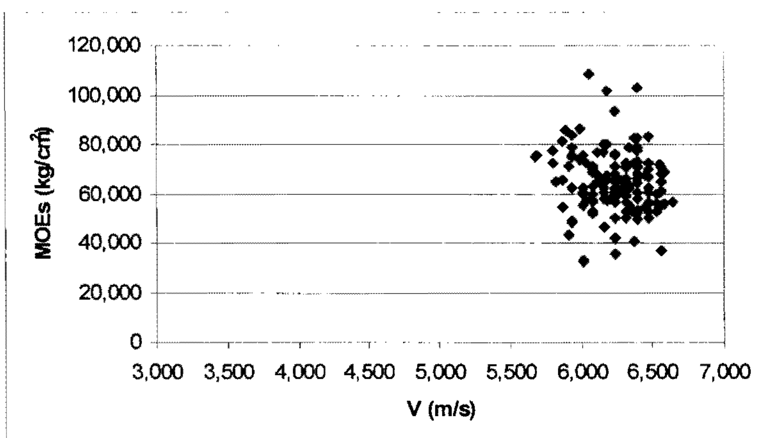


Figure 11. Relationship between Vus and MOEs of sengon wood

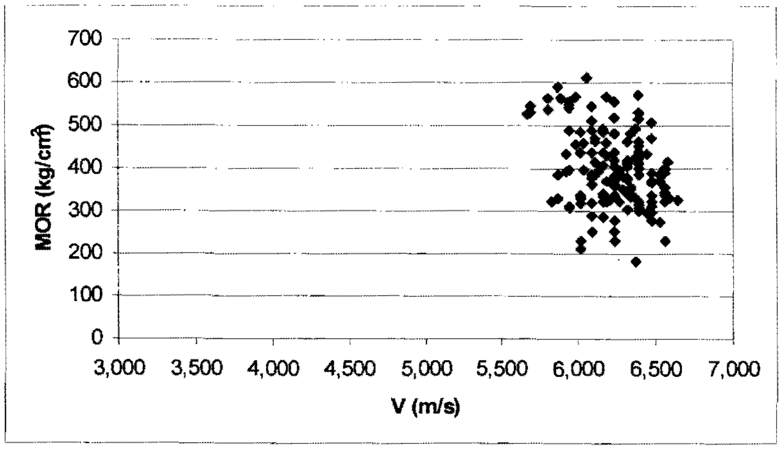


Figure 12. Relationship between Vus and MOR of sengon wood

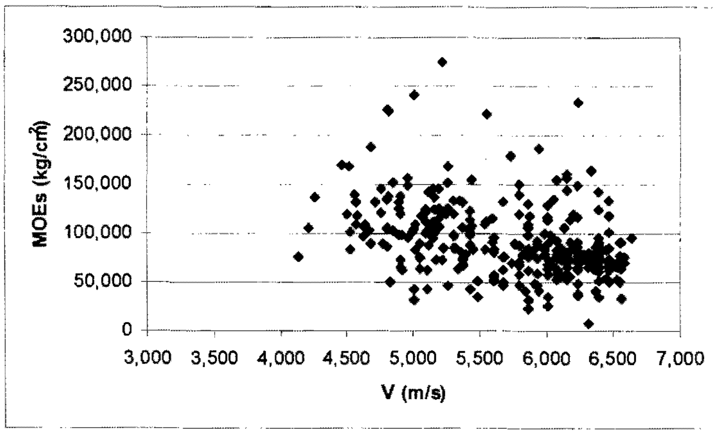


Figure 13. Relationship between Vus and MOEs of all wood species

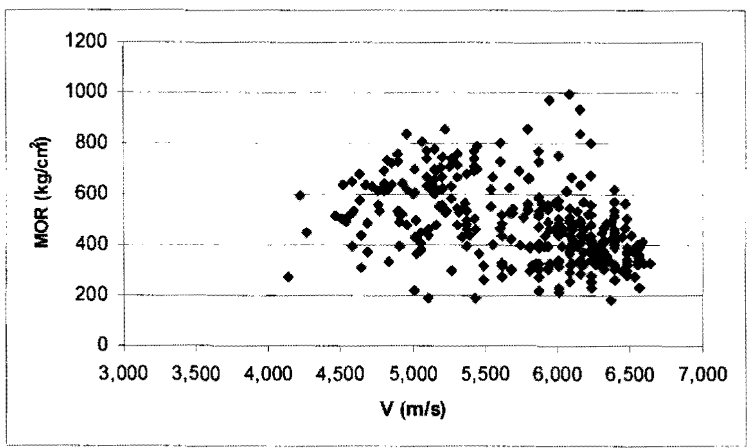


Figure 14. Relationship between Vus and MOR of all wood species

Relationship of dynamic MOE on static bending MOE and MOR

Dynamic MOE and static bending MOE were each separately correlated to MOR for each of three species, and the results are presented in Table 8 and Figure 15, 16, 17 and 18.

Table 8. Summary of regression parameters for regression of dynamic MOE on static bending MOE and MOR for the three species

Wood species	Regression model	R	R^2	Significance of model ($\alpha = 0.05$)
1. Tectona(n=113)				
	MOEs = 0.399 MOEd + 11976,347	0.64	0.41	0.000**
	MOR = 0.0023 MOEd + 145.552	0.53	0.28	0.000**
	MOR = 0.0044 MOEs + 203.086	0.64	0.41	0.000**
2. African wood (n=73)				
	MOEs = 0.0949 MOEd + 48962.252	0.12	0.01	0.309 ns
	MOR = 0.00032 MOEd + 376.575	0.07	0.05	0.558 ns
	MOR = 0.0051 MOEs + 102.36	0.86	0.74	0.000**
3. Sengon (n=143)				
	MOEs = 0.511 MOEd + 4122.01	0.68	0.47	0.000**
	MOR = 0.00378 MOEd – 111.193	0.70	0.49	0.000**
	MOR = 0.0061 MOEs + 0.9655	0.84	0.71	0.000**
All species (n=329)				
	MOEs = 0.403 MOEd + 9438.954	0.76	0.57	0.000**
	MOR = 0.00272 MOEd + 38.709	0.75	0.57	0.000**
	MOR = 0.0059 MOEs + 39.839	0.87	0.75	0.000**

Notes: r= correlation coefficient, r^2 = determination coefficient, ns = no significance ; ** = very sig.

The results for the individual species show that the correlation between static bending MOE and MOR was only slightly higher than that between dynamic MOE and MOR, except for African wood which have not good correlation for dynamic MOE and MOR relationship. For the combined data, the correlation coefficient obtained for the regression of dynamic MOE on static bending MOEs was 0.76, and those were 0.75 and 0.87 for the regression of dynamic MOE and static bending strength MOE on MOR, respectively. The regression models developed for the relationship of dynamic MOE on static bending MOE and MOR as well as between static bending MOE and MOR were all highly statistically significant (α=0.05), except for the case of African wood on relation of dynamic MOE on static bending MOE and MOR. The statistically high correlation (r >0.75) and the highly significant regression models developed for the combined data for the three species seemingly indicate that both static bending MOE and dynamic MOE may be good indicator for the MOR of some tropical hardwoods. The trend of the correlation and significant models obtained in this study compares well with similar study by Karlinasari *et al.* (2005).

Evaluation of wood condition

Another approached to evaluate the condition of wood quality is to use mapping wood condition itself. In this study, we try to do with ArcView GIS software to depict this condition. Since this method still preliminary study, we try only for one sample. The result shows that is possibility to present wood condition with this method as presented in Figure 19.

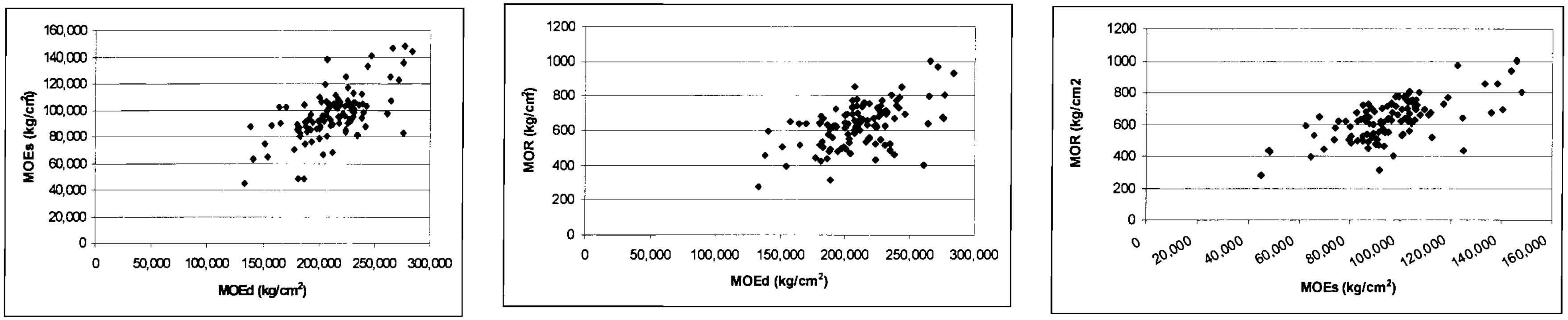


Figure 15. Relationship between dynamic MOE, static bending MOE, and MOR of tectona wood

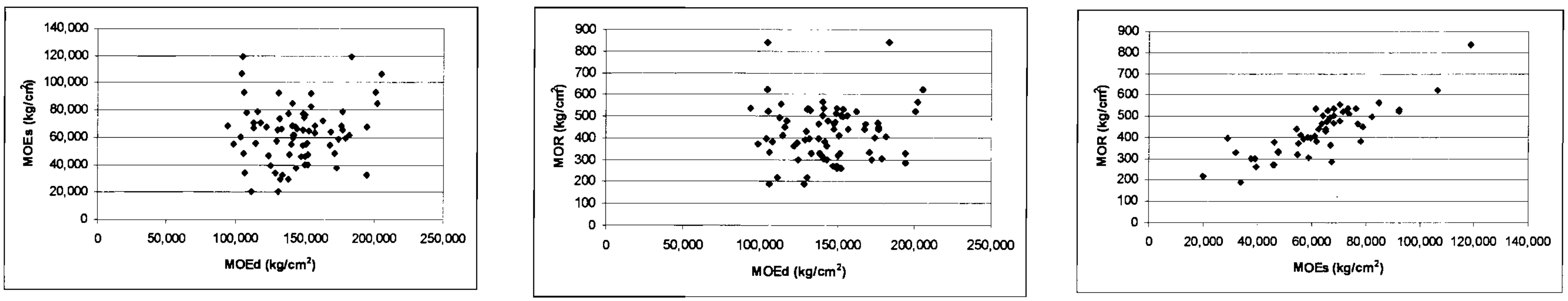


Figure 16. Relationship between dynamic MOE, static bending MOE, and MOR of African wood

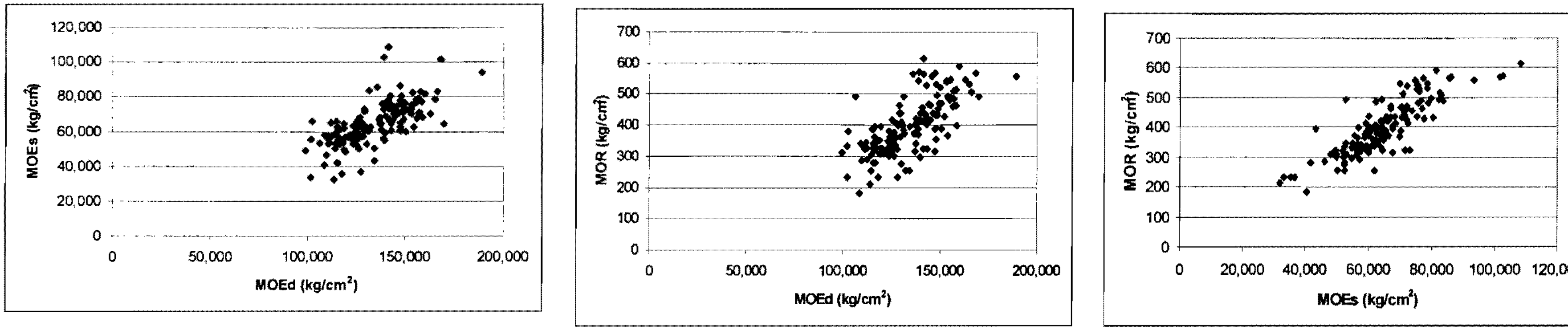


Figure 17. Relationship between dynamic MOE, static bending MOE, and MOR of sengon wood

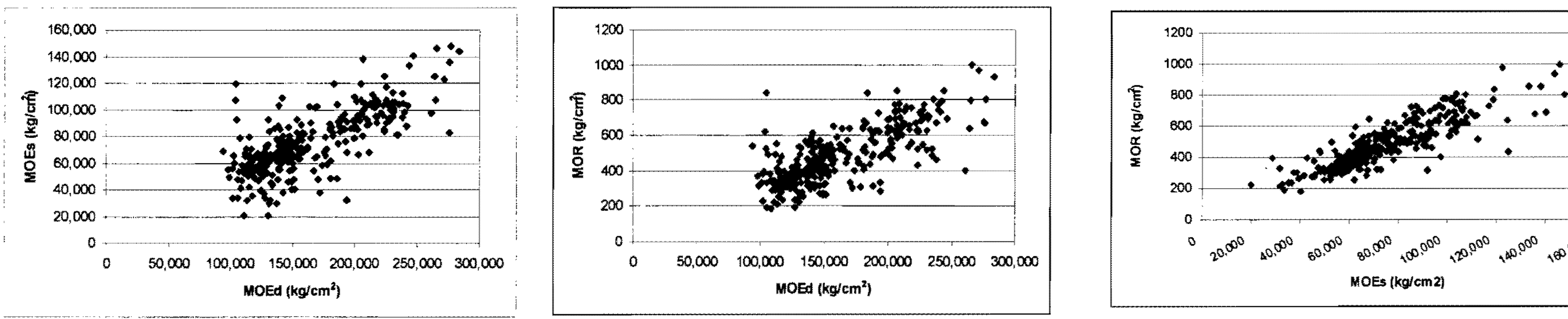


Figure 18. Relationship between dynamic MOE, static bending MOE, and MOR of all wood species

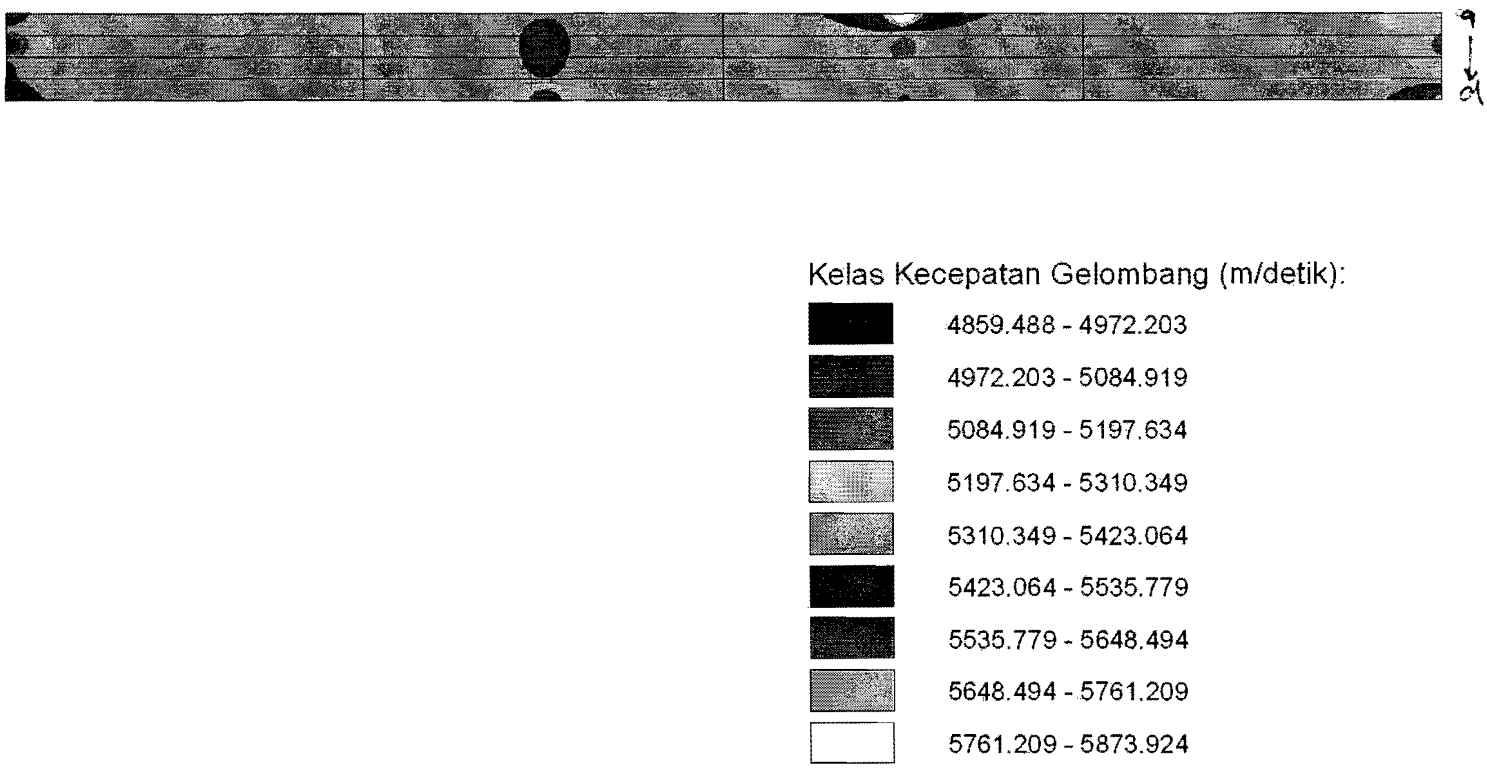


Figure 19. Example of mapping of ultrasonic velocity characteristic (m/s)

V. CONCLUSIONS

The ultrasonic velocity observed increase in proportion to the decrease of wood density. Vertical position in wood (bottom, middle, up) has no significant effect on ultrasonic velocity propagation characteristics for each tree species (tectona, African wood, and sengon). However, significant influence has been found in direction of wave propagation and measurement of nondestructive variable for difference length beam.

Combination of dependant variable of ultrasonic velocity and wood density provided better correlated with static bending MOE and MOR for both combined data of three species and for the separate specimens of tectona and sengon, except for African wood. For African wood, it seemed has many knots therefore it indicated the wider variability inherent to nondestructive test as well as destructive test.

Dynamic MOE was well correlated to static bending MOE and MOR for tectona and sengon wood. Those correlations were only slightly lower than combined three species. Regression models developed were highly statistically significant (α = 0.05). Although the static bending test is generally recognized as a more desirable method of determining MOE, the results have indicated that ultrasonic wave propagation technique may also be useful for predicting MOR of solid tropical hardwoods.

ABSTRACT

This paper reports on a study the application of ultrasonic waves in wood with the purpose of evaluating mechanical properties. The ultrasonic wave propagation method was examined as a means evaluating of ultrasonic velocity characteristics in beams and small specimens and relationship between that characteristics to static bending MOE and MOR as well as predicting the MOR from both static bending MOE and dynamic MOE for small specimens from three tropical hardwoods, tectona (*Tectona grandis*), African wood (*Maesopsis eminii*), and sengon (*Paraserianthes falcataria*).

Two forms were used in this study, board and small wood specimen. The small one was (2.5 x 2.5 x 41) cm measured by non destructive and destructive testing and the board (12 x 8 x 200) cm was measured by non destructive testing. The non destructive testing was developed through ultrasonic wave velocity measurement. The ultrasonic wave propagation was measured by ultrasonic device Sylvatest Duo® (f=22kHz). Meanwhile, the non destructing test consisting of the static modulus of elasticity (MOEs) and modulus of rupture (MOR) was evaluated. Bending strength properties test for the specimens were performed by third point loading method in universal testing machine (UTM, Senstar®)

The result for beam dimension showed that ultrasonic velocity of tectona wood was a range in 4163-4969 m/s and for African wood and sengon were in a range 4574-5151 m/s and 5278-5498 m/s, respectively. Dynamic MOE were 141,539-173,497 kg/cm^2, 93,305-107,157 kg/cm^2, 100,852-103,260 kg/cm^2 for tectona, African wood, and sengon, respectively. Meanwhile, energy of tectona was a range 5063-5289 mV, African wood was 4261-4422 mv, and sengon was 4187-4464 mV. In direction of wave propagation, the result depicted that means values in longitudinal or axial direction was 1.51 – 2.92 higher than transversal direction (radial and tangential). No significant effect of vertical position in wood on ultrasonic velocity propagation characteristics for each tree species (tectona, African wood, and sengon). However, significant influence has been found in direction of wave propagation and measurement of nondestructive variable for difference length beam.

In small specimen, the MOEd values were 50% higher than those MOEs values. It is considered to because of microstructural characteristic and

viscoleatic properties of wood. Relationship of ultrasonic velocity and density on static bending MOE and MOR appeared statistically better correlated than only single variable of ultrasonic velocity for both the combined data of three species and sengon wood. For tectona wood, multivariable regression model of density and ultrasonic velocity seemed no difference correlated with solely single variable of ultrasonic velocity. In case of African wood, it seemed has many knots therefore it indicated the wider variability inherent to nondestructive test as well as destructive test. The regression models developed for each two species (without African wood) as well as for the combined data were highly statistically significant, except for solely Vus for predicting the static bending MOE.

Dynamic MOE was well correlated to static bending MOE and MOR for tectona and sengon wood. Those correlations were only slightly lower than combined three species. Regression models developed were highly statistically significant (α = 0.05). Although the static bending test is generally recognized as a more desirable method of determining MOE, the results have indicated that ultrasonic wave propagation technique may also be useful for predicting MOR of solid tropical hardwoods.

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