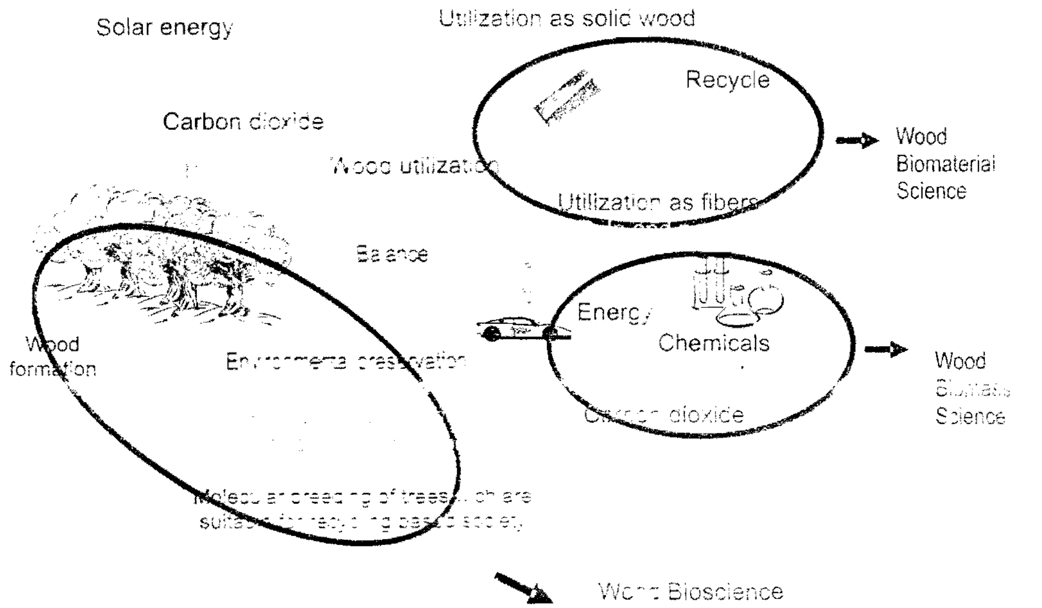
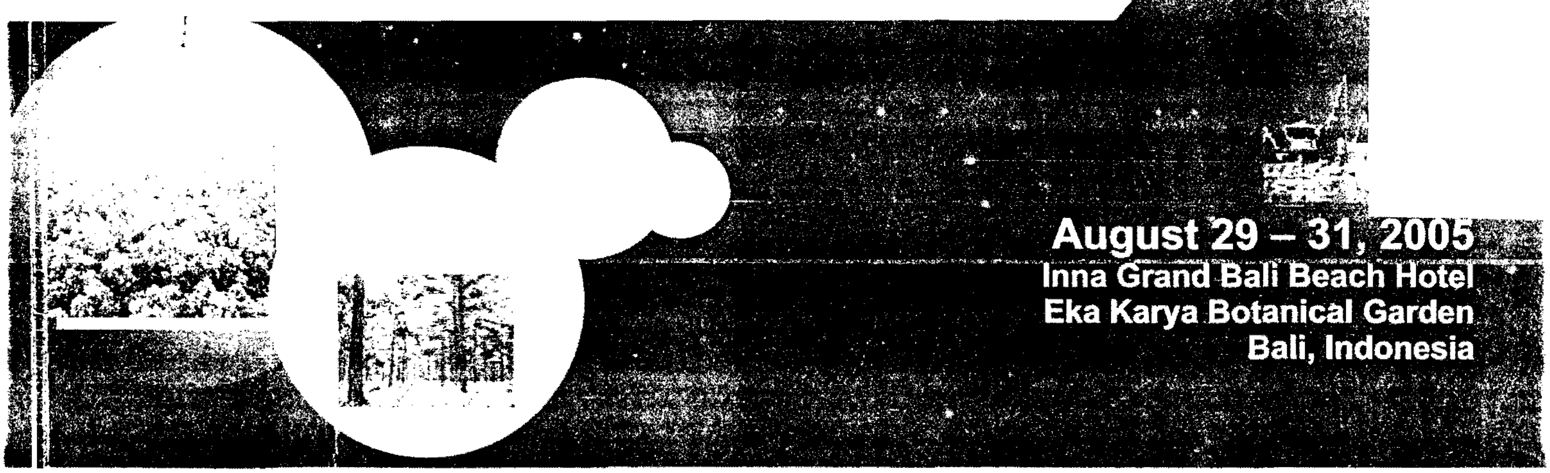
Towards Ecology and Economy Harmonization of Tropical Forest Resources

Proceedings of the 6th International Wood Science Symposium
LIPI - JSPS Core University Program in the Field of Wood Science





August 29 – 31, 2005
Inna Grand Bali Beach Hotel
Eka Karya Botanical Garden
Bali, Indonesia

Research and Development Unit for Biomaterials, Indonesian Institute of Sciences LIPI
Research Institute for Sustainable Humanosphere, Kyoto University RISH

TOWARDS ECOLOGY AND ECONOMY HARMONIZATION OF TROPICAL FOREST RESOURCES

PROCEEDING OF THE 6TH INTERNATIONAL WOOD SCIENCE SYMPOSIUM
LIPI – JSPS CORE UNIVERSITY PROGRAM IN THE FIELD OF WOOD SCIENCE

ORGANIZED BY

RESEARCH AND DEVELOPMENT UNIT FOR BIOMATERIALS
INDONESIAN INSTITUTE OF SCIENCES - INDONESIA

RESEARCH INSTITUTE FOR SUSTAINABLE HUMANOSPHERE
KYOTO UNIVERSITY

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE

AUGUST 29 – 31, 2005
BALI, INDONESIA

EDITED BY

EDITOR : WAHYU DWIANTO

SUPERVISOR : EUIS HERMIATI
SUBYAKTO
SULAEMAN YUSUF

FORMATTED TEAM : FAIZATUL FALAH
YUSUP AMIN
FIRDA AULYA SYAMANI
FITRIA
IKA WAHYUNI
TITIK KARTIKA
TEGUH DARMAWAN

TOWARDS ECOLOGY AND ECONOMY HARMONIZATION OF TROPICAL FOREST RESOURCES

PROCEEDING OF THE 6TH INTERNATIONAL WOOD SCIENCE SYMPOSIUM

AUGUST 29 – 31, 2005, BALI, INDONESIA

LIPI – JSPS CORE UNIVERSITY PROGRAM
IN THE FIELD OF WOOD SCIENCE

ORGANIZED BY

RESEARCH AND DEVELOPMENT UNIT FOR BIOMATERIALS
INDONESIAN INSTITUTE OF SCIENCES

RESEARCH INSTITUTE FOR SUSTAINABLE HUMANOSPHERE
KYOTO UNIVERSITY

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE

ISBN 979-99842-0-3

Content

Wood Biomass Science

Wood Bioscience

Environmental Science

Full Papers

Wood Material Science

Wood Biomass Science

Wood Bioscience

Full Papers

Appendix

Non-Destructive Testing on Six Tropical Woods using Ultrasonic Method

Lina Karlinasari, Surjono Surjokusumo, Yusuf S. Hadi, and Nareswoto Nugroho

Department of Forest Products, Faculty of Forestry,
Bogor Agricultural University
E-mail: karlinasari@ipb.ac.id

Non destructive testing (NDT) using ultrasonic method was carried out on six tropical wood species consisting of four hardwood species, Sengon (*Paraserianthes falcataria*), Meranti (*Shorea sp.*), Manii (*Maesopsis eminii*) and Mangium (*Acacia mangium*), and two softwood species, Agathis (*Agathis loranthifolia*) and Pine (*Pinus merkusii*). The ultrasonic velocities propagation was measured to determine the dynamic modulus of elasticity (MOEd). Static modulus of elasticity (MOEs) and modulus of rupture (MOR) were also observed.

The objective of this study was to obtain correlations between dynamic test by ultrasonic (MOEd) and static bending test (MOEs and MOR) on small clear wood specimens.

Results showed that softwoods have higher velocities value and better reproducibility than those hardwoods. Poor correlation was found between ultrasonic velocities value and MOEs for each species. Meanwhile, MOEd has 50% higher value than that of static MOE (MOEs). However, there were significant correlation ($\alpha = 0.05$) between MOEd and MOEs, as well as between MOEd and MOR for all wood tested, except for Meranti and Manii wood species. The compared data for ultrasonic velocity and bending strength between hardwoods and softwood species denoted that for all parameters developed were highly statistically significant ($\alpha = 0.05$), except for relationship between ultrasonic velocity and MOEs in hardwood was non significant.

Key words: non-destructive testing, ultrasonic velocity, dynamic MOE (MOEd), static MOE (MOEs), MOR

Introduction

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 20 kHz-500 kHz. 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.

Several wood and wood based materials, including small clear wood specimens, lumber, veneer, and wood composites, have been investigated. The 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; Olievera et al. 2002a).

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 transducers, their size, the position and dynamic characteristics of the equipment) (Olievera et al. 2002b)

The objective of this study was to obtain correlations between dynamic test by ultrasonic (MOEd) and static bending test (MOEs and MOR) on small clear wood specimens.

Materials and Methods

Materials. The species studied were consisted of four hardwood species, Sengon (*Paraserianthes falcataria*), Meranti (*Shorea sp.*), Manii (*Maesopsis eminii*) and Mangium (*Acacia mangium*), and two softwood species, Agathis (*Agathis loranthifolia*) and Pine (*Pinus merkusii*). The pieces were small clear wood specimens conditioned to achieve equilibrium moisture content (EMC) about 15-18%. The dimension of small clear wood specimens tested was determined in accordance with BS 373-1957 for bending test (2 x 2 x 30) cm.

Ultrasonic wave propagation and dynamic MOE test. The ultrasonic wave propagation was measured by ultrasonic device Sylvatest Duo (f=22kHz). The application and measurement consists of positioning two accelerometer transducers on the material to be evaluated. The ultrasonic wave is 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 are 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 was used to express the dynamic modulus of elasticity (MOEd). The MOEd was calculated by the following equations:

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

Where, MOEd is dynamic Modulus of Elasticity (kg/cm^2), ñ 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. Bending strength property test for the specimens were performed by one point loading method in universal testing machine (UTM, Instron with loading capacity ± 5 ton). Each specimen was tested to destruction to determine the static modulus of elasticity (MOEs) and modulus of rupture (MOR).

Wood density and Moisture content (MC). The density of each specimen was determined in accordance with British Standard (BS). The MC was measured using gravimetry method.

Results and Discussions

Table 1 shows the mean values, and coefficient variation of the physical (MC, density, ultrasonic velocity) and mechanical properties (MOEd, MOEs, MOR).

Table 1. Mean values and coefficient variation of physical and mechanical properties of 6 tropical woods

Wood Species (n=24)		MC (%)	Density (kg/m^3)	Ultrasonic velocity (m/s)	MOEd (kg/cm^2)	MOEs (kg/cm^2)	MOR (kg/cm^2)
Hardwood							
1. Sengon	Mean	13.54	261	6559	115819	32416	363
	CV (%)	2.5	20.8	6.4	36.9	41.9	33.0
2. Meranti	Mean	14.74	433	5044	112522	52253	513
	CV (%)	3.8	4.4	6.8	11.8	10.4	11.5
3. Manii	Mean	14.19	507	5665	161008	70204	754
	CV (%)	10.7	17.4	5.6	11.8	9.3	10.6
4. Mangium	Mean	19.27	631	6213	246544	80081	885
	CV (%)	6.5	6.5	4.0	8.1	14.5	10.2
Softwood							
5. Agathis	Mean	15.93	512	6159	198476	85666	713.4
	CV (%)	3.1	8.7	10.8	21.3	10.8	10.5
6. Pine	Mean	15.33	635	6850	295997	105969	838.2
	CV (%)	2.1	16.3	5.5	13.4	10.0	8.7

CV: coefficient of variation

The mean values of ultrasonic velocity of Sengon, Meranti, Manii, and Mangium were 6561 m/s, 5070 m/s, 5668 m/s, and 6225 m/s, respectively. Meanwhile, for softwood the mean values of ultrasonic velocity of Agathis and Pine were 6159 m/s and 6850 m/s, respectively. The mean values of ultrasonic velocity showed that softwoods have higher values and better reproducibility than those hardwoods. These are compatible with previous study in Olievera *et al.* (2002a) and Bucur (1995). Some factors influences of ultrasonic velocity are (1) Fiber lengths and direction; ultrasonic velocity is greater in the long fiber and longitudinal direction (propagation through the fibers). It is slower in radial direction (propagation through the rays) and tangential direction (disoriented propagation); (2) Density, ultrasonic velocity is greater in high density, (3) Moisture content, when the moisture content of wood is low the ultrasonic velocity is faster.

The results of MOEd values were 50 percent higher than those MOEs values. It is considered to because of micro structural characteristic and viscoelatic properties of wood. The accuracy of the determination of MOE of wood by dynamic test is said to be higher than that static test. The difference may be due to the rate of loading in static test in which creep effects influence the measured static deflection and also may be related to viscoelastic nature of wood (Bodig, 1982). Wood is highly impact-absorber 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 (Olievera et al. 2002b). 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. Olievera, *et al.* (2002a,b) used ultrasonic method and obtained 17-20 percent higher values than static test values for
Brazilians wood species.

Least squares regression analysis method has been used in the field of wood properties, because mechanical properties of wood are in linearly related (Bodig and Jayne, 1982; Bucur, 1995). Regression parameters and statistical analysis are presented in Table 2. Figure 1, 2, 3, 4, 5 and 6 show relationship between MOEd-MOEs; and MOEd-MOR for each species.

Statistical analyses are developed with the purpose to verifying the existence of relations among the variables under study (ultrasonic velocity, MOEd, MOEs and MOR) and the levels of significance of the parameters obtained.

Correlation generally seemed slightly better for MOEd and MOEs for each species compared to ultrasonic velocity values and MOEds. The regression model developed seemed highly significant (á = 0.05) for MOEd and MOEs. Close correlation of MOEd and MOEs for solid clear wood was reported by stress wave mode (Ross and Pellerin, 1991). The statistically high correlation coefficient and the significant regression models developed indicate that MOEd may be good predictor of the MOEs, however, for some species (except Meranti and Manii wood) MOEd also as good indicator of the MOR. Even though for some species were statistically significant (á = 0.05), the correlations values obtained were relatively low ($r < 0.5$). This fact seems that these might be due to the small sample size ($n = 24$). Another study with large sample is needed as comparing data.

The regression models shown that for all parameters developed were highly statistically significant (á = 0.05) both softwoods and hardwoods, except for relationship between ultrasonic velocity and MOEs in hardwood was non significant.

Conclusion

Non-destructive testing using ultrasonic waves method was carried out for six tropical small, clear wood species.

Results showed that softwoods have higher velocities value and better reproducibilities than those hardwoods. The compared data for ultrasonic velocity and bending strength between hardwoods and softwood species denoted that for all parameters developed were highly statically significant ($\alpha = 0.05$), except for relationship between ultrasonic velocity and MOEs in hardwood was non significant.

Table 2. Summary of regression parameters of 6 tropical woods for relationship between ultrasonic velocity, MOEd, MOEs and MOR

Wood species	Parameter (x and y)	Regression model	r	R^2	Significance of model ($\alpha = 0.05$)
		Hardwood			
1. Sengon	V and MOEs	y = -7.2977x + 80280	0.228	0.052	0.282^{ns}
	MOEd and MOEs	y = 0.4339x - 14846	0.772	0.596	9.8E-06**
	MOEd and MOR	y = 0.0041x - 88.789	0.836	0.699	3.63E-07**
	MOEs and MOR	y = 0.0077x + 114.62	0.867	0.752	4.03E-08**
2. Meranti	V and MOEs	y = 10.565x - 1042.9	0.635	0.403	0.000**
	MOEd and MOEs	y = 0.2601x + 22992	0.634	0.402	0.000**
	MOEd and MOR	y = 0.0016x + 339.31	0.355	0.126	0.088^{ns}
	MOEs and MOR	y = 0.005x + 256.83	0.458	0.210	0.024243*
3. Manii	V and MOEs	y = 7.9884x + 24949	0.397	0.158	0.054^{ns}
	MOEd and MOEs	y = 0.1549x + 45266	0.454	0.206	0.025*
	MOEd and MOR	y = 0.0014x + 522.8	0.342	0.116	0.101^{ns}
	MOEs and MOR	y = 0.0104x + 23.941	0.843	0.712	2.21E-07**
4. Mangium	V and MOEs	y = 0.2738x + 78380	0.006	3.35 E-05	0.978^{ns}
	MOEd and MOEs	y = 0.2682x + 13964	0.458	0.21	0.024*
	MOEd and MOR	y = 0.0028x + 183.32	0.627	0.39	0.001**
	MOEs and MOR	y = 0.0062x + 390.78	0.795	0.63	3.43E-0**
Hardwood	V and MOEs	y = -4.091x + 82755	0.131	0.017	0.202^{ns}
	MOEd and MOEs	y = 0.2869x + 13622	0.817	0.668	3.00E-24**
	MOEd and MOR	y = 0.0033x + 113.57	0.873	0.762	4.72E-31**
	MOEs and MOR	y = 0.0102x + 30.453	0.952	0.906	3.44E-50**
Softwood					
5. Agathis	V and MOEs	y = 7.3171x + 40603	0.524	0.274	0.008**
	MOEd and MOEs	y = 0.1529x + 55319	0.699	0.488	0.000**
	MOEd and MOR	y = 0.0008x + 549.35	0.463	0.214	0.022*
	MOEs and MOR	y = 0.0067x + 142.57	0.816	0.666	1.16E-06**
6. Pinus	V and MOEs	y = 11.352x + 28212	0.401	0.161	0.052^{ns}
	MOEd and MOEs	y = 0.1716x + 55170	0.638	0.408	0.000**
	MOEd and MOR	y = 0.0013x + 453.95	0.699	0.489	0.000**
	MOEs and MOR	y = 0.0057x + 236.42	0.823	0.677	8.07E-07**
Softwood	V and MOEs	y = 14.621x + 721.73	0.654	0.428	4.48E-07**
	MOEd and MOEs	y = 0.1894x + 48997	0.849	0.720	2.51E-14**
	MOEd and MOR	y = 0.0012x + 482.7	0.779	0.607	6.67E-11**
	MOEs and MOR	y = 0.0061x + 188.88	0.898	0.807	4.51E-18**

r coefficient correlation : R^2 coefficient determination; ns = no significance; * significance; ** very significance

Poor correlation was found between ultrasonic velocities value and MOEs for each species. Meanwhile, MOEd has 50% higher value than that of static MOE (MOEs). However, there was significant correlation ($\alpha = 0.05$) both between MOEd and MOEs, and between MOEd and MOR for all wood tested, except for Meranti and Manii wood species.

The compared data of ultrasonic velocity and bending strength between hardwoods and softwood species shown that for all parameters developed were highly statistically significant ($\alpha = 0.05$), except for relationship between ultrasonic velocity and MOEs in hardwood was non significant.

References

1. Ayarkwa, J., Y. Hirashima and Y. Sasaki. 2001. Predicting Modulus of Rupture of Solid and Finger Jointed Tropical African Hardwoods Using Longitudinal Vibration. Forest Products Journal. Vol. 51(1): 85-92.
2. Bodig. J. and B.A. Jayne. 1982. Mechanics of Wood and Wood Composites. Van Nostrand Reihold. New York. Pp. 247-269, 645-650.
3. Bodig. J. 2000. The Process of NDE Research for Wood and Wood Composites. In Proceeding: 12th International Symposium on Nondestructive Testing of Wood. 13-15 September 2000. University of Western Hungary, Sopron. Hungary. Pp. 7-22.
4. Bostrom. L. 1994. A Comparison between Four Different Timber Strength Grading Machines. In Proceeding: 9th International Symposium on Nondestructive Testing of Wood. 22-24 September 1993. Washington State University, USA. Pp. 157-167
5. Bucur. V. 1995. Acoustic of Wood. CRC Press Inc, Boca Raton. Pp. 105-106, 120-123
6. Oliveira. F.G.R., J.A.O. de Campos, and A. Sales. 2002a. Ultrasonic Measurements in Brazilian Hardwoods. Material Research Journal. Vol. 5 No 1. Pp. 51-55.
7. Olievera. F.G.R., J.A.O. de Campos. E. Pletz and A. Sales. 2002b. Assessment of Mechanical Properties of Wood Using an Ultrasonic Technique. In Proceeding: 13th International Symposium on Nondestructive Testing of Wood. 19-21 August 2002. University of California, Berkeley Campus, California, USA. Pp. 75-78.
8. Ross. R.J. and R.F.Pellerin.1991.NDEof green material with stress wave. Preliminary results using dimension lumber. Forest Products Journal. Vol.41 (6): 57-59.
9. Ross. R.J., B.K. Brashaw, and R.F. Pellerin. 1998. Nondestructive Evaluation of Wood. Forest Products Journal. Vol. 48:1. Pp. 14-19.
10. Tsoumis. G. 1991. Science and Technology of Wood. Structure, Properties, Utilization. Van Nostrand Reihold, New York. Pp. 327-361
11. Wang. X., R.J. Ross. M. McCellan, R.J. Barbour. J.R. Erickson, J.W. Forsman, and G.D. McGinnis. 2001. Nondestructive Evaluation of Standing Trees With A Stress Wave Method. Wood and Fiber Science. 33(4): Pp. 522-533.
12. Zombory. B. 2001. "In Situ" Nondestructive Testing of Built in Wooden Members. NDT.net. March 2001, Vol. 6 No. 3. (05/27/2005)

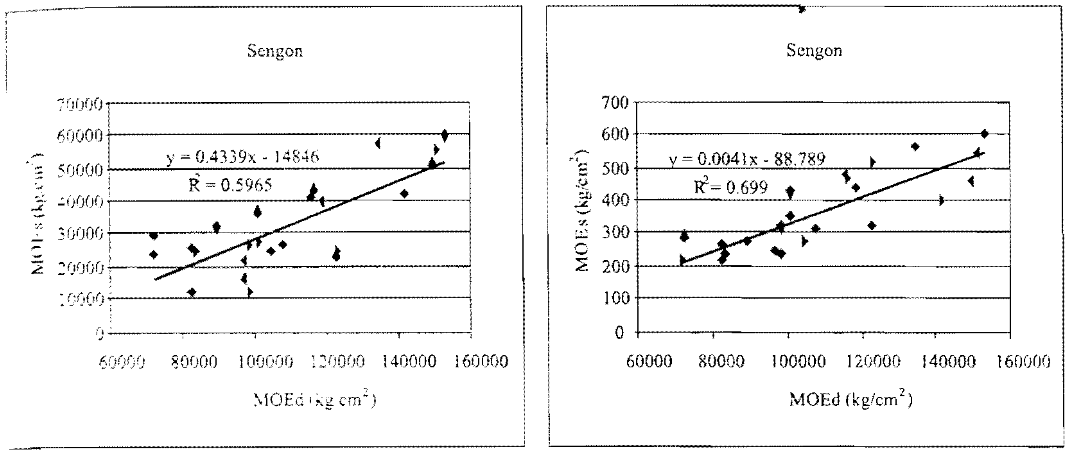


Figure 1. Relationship between MOEd and MOEs; MOEd and MOR on Sengon species

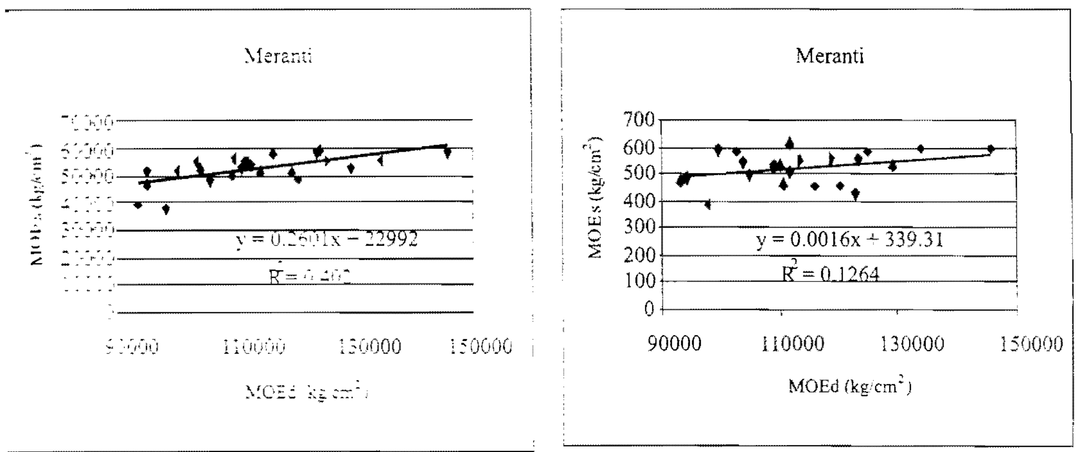


Figure 2. Relationship between MOEd and MOEs; MOEd and MOR on Meranti species

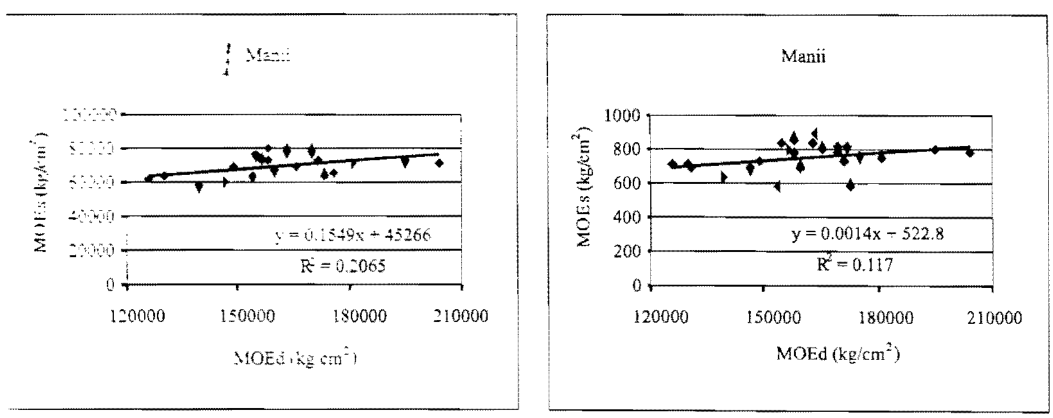


Figure 3. Relationship between MOEd and MOEs; MOEd and MOR on Manii species

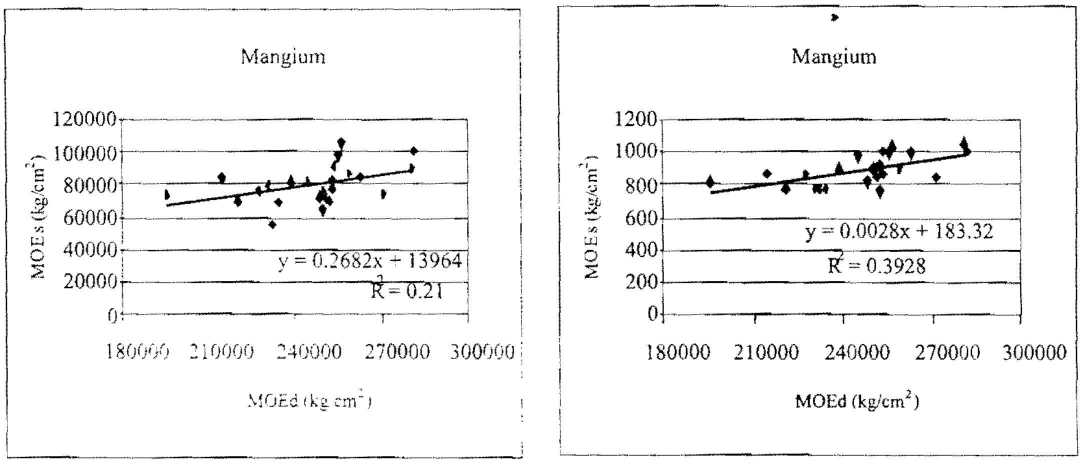


Figure 4. Relationship between MOEd and MOEs; MOEd and MOR on Mangium species

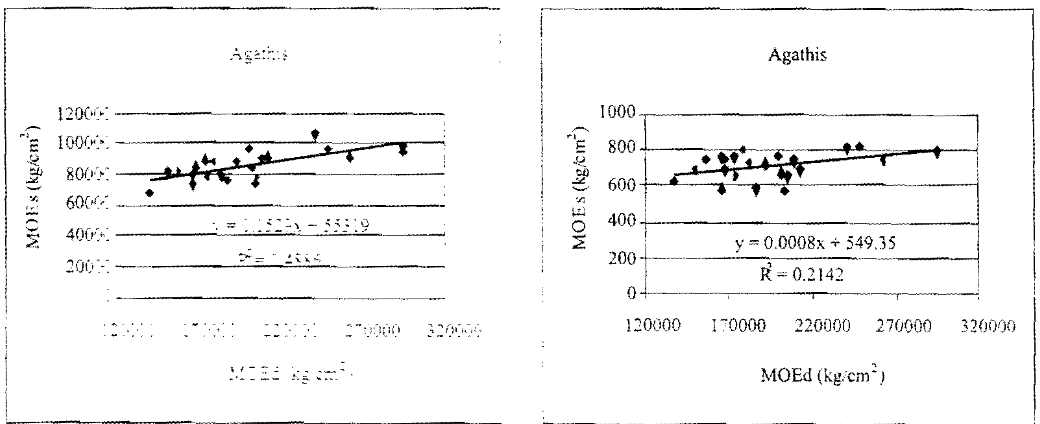


Figure 5. Relationship between MOEd and MOEs; MOEd and MOR on Agathis species

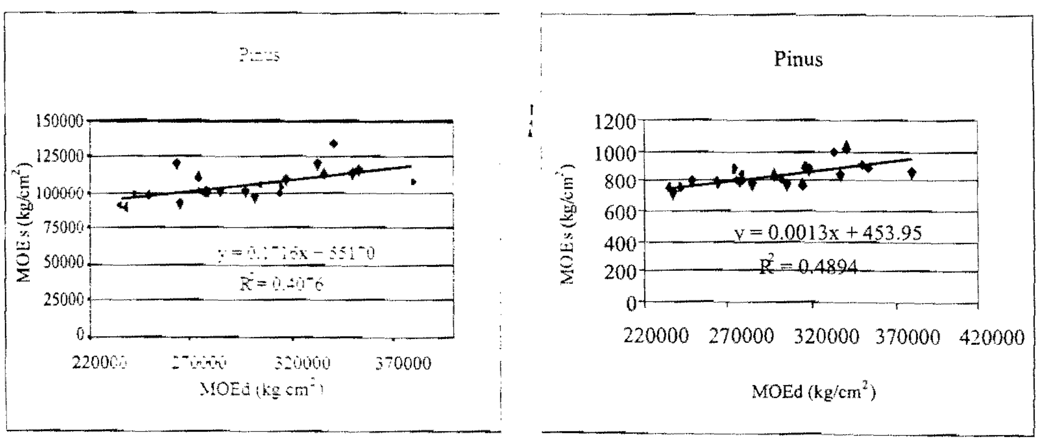


Figure 6. Relationship between MOEd and MOEs; MOEd and MOR on Pinus species