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 "**Non-destructive Evaluation of Standing Tree of *Acacia mangium* Using an Ultrasonic Method**" sebagai laporan hasil penelitian Tanabe Foundation tahun 2004, telah tercatat dan tersimpan di Perpustakaan Departemen Hasil Hutan Fakultas Kehutanan IPB.

Demikian Surat Keterangan ini dibuat untuk dipergunakan sebagaimana mestinya.

Bogor, 25 JAN 2007
Ketua,

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

Non-destructive Evaluation of Standing Tree of *Acacia mangium* Using An Ultrasonic Method

Lina Karlinasari
Laboratorium of Wood Engineering
Department of Forest Products Technology
Faculty of Forestry, Bogor Agricultural University

ABSTRACT

Non-destructive testing (NDT) techniques method using ultrasonic wave propagation was carried out for evaluating standing trees. The objective of this study was to investigate the usefulness of an ultrasonic wave technique for evaluating wood strength and stiffness of *Acacia mangium* in standing trees on small, clear specimen shape which denotes the real wood strength. *Acacia mangium* came from Parung Panjang, West Java. Several sites based on planting years were used in this study (1993, 1994, and 1996), and the number of trees per site were ten trees selected on the basis of good and health trees criteria. It can be concluded that standing trees behave can not be yet used to predict of wood strength. There was a poor relationship between velocity of tree and small, clear specimens and MOEd of tree and MOEd and MOEs of small, clear specimens. However, close correlations were found between MOEd and MOEs small, clear specimen and MOEd and MOR small, clear wood specimen. Therefore, MOEd small, clear wood specimen using ultrasonic wave propagation is useful as a NDE for predicting MOEs and MOR small, clear wood specimen.

Keywords: Non-destructive testing (NDT), ultrasonic wave propagation, *Acacia mangium*, velocity, modulus of elasticity (MOE), modulus of rupture (MOR)

I. INTRODUCTION

Background:

Nature's engineering of wood through genetics, wind, and weather creates a wide variability in wood as a material. Consequently, manufacturer and users of wood products are frequently frustrated in dealing with the forest resource. Manufactures sometimes argue that wood is difficult to consistently process into quality products because of the wide range of properties that exist in this raw material. Users of wood products can be equally frustrated with the performance variability found in finished products.

It would be beneficial for forest-based industries if information on the quality and mechanical properties of wood in standing trees can be obtained before harvesting. If the quality of wood in a standing tree can be assessed, variation of wood quality during growth may be predictable; and perhaps an evaluation of these variations as influenced by seasons changes or between plantation sites and individual stands is feasible. Furthermore, a classification of stands or sites may be established. If such a database can be established, optimal timber management practices, such as pruning, thinning, and logging operations, may be developed.

In general, the quality of wood in standing tree is assessed by their annual ring width, early wood/latewood ratio, densities in the increment core extruded from a standing tree using the increment growth borer. In addition, quality assessments of standing trees may be considered to have two separate targets: biological internal quality related to wood degradability and mechanical quality of the heartwood regarding the industrial valuation of the wood products.

By definition, non-destructive testing (NDT) or evaluation is the science of identifying physical and mechanical properties of a piece of material without altering its end-use capabilities. Actually, research efforts of existing tree grading procedures consist of only visual assessment of tree quality. The applicability of vibration modes or NDT techniques on wood materials for assessing their quality has been investigated extensively in recent years, but most studies used small dimension wood specimens, with only a few studies focussed on standing trees and log.

Based on data from Indonesian Ministry of Forestry (2001), there were 131 timber estates with a target of 5.8 million ha plantation. However, this target realised until the end of 2001 were 1.8 million ha, since technical and non-technical problems are faced. Fast growing species mostly used for the development timber estates in Indonesia are *Acacia mangium*, *Paraserianthes falcataria*, *Gmelina arborea*, *Eucalyptus* sp., *Pinus merkusii*, etc. Generally, the wood is used for light construction and pulp production. Nowdays, there are about 800 thousands ha *Acacia mangium* plantation and predicted reaching 1 million ha in 2010, which it becomes Indonesia as the largest area for plantation in Asian-Pacific.

Objective:

The objective of this study is to investigate the usefulness of an ultrasonic wave technique for evaluating wood strength and stiffness of *Acacia mangium* in standing trees.

Hypothesis:

It is hypothesis that the characteristics of the resulting waves would be related to mechanical properties of wood in the tree.

II. MATERIALS AND METHODS

The experimental sites were located in Parung Panjang, West Java for *Acacia mangium* species. Several sites based on planting years were used in this study (1993, 1994, and 1996), and the number of trees per site were ten trees selected on the basis of criteria of good and health trees. After field test, for each species were felled. A 2–m- long bole section was cut from each felled tree, and sawn becoming beam dimension then shipped to Laboratory Wood Engineering, Faculty of Forestry, Bogor Agricultural University. These dimensions were the cut into small, clear specimen for further ultrasonic wave and destructive evaluation.

Field test evaluation

A surface-attaching method was used to conduct *in situ* ultrasonic wave measurements in this study. The experimental setup consisted of two accelerometer transducers and a portable digital SYLVATESTDUO ultrasound device. The ultrasonic wave was introduced into the material by one the transducers and picked up by other transducer in the trunk at about angle approximately 30°.Measurement were done in two part, on 1.3 m height from base (L1) and on 0.7 m from 1.3 m (L2) (Fig.1).

The evaluation is based on the correlation between the velocity of sound, modulus of elasticity, and density. The velocity of sound is often used to express the dynamic modulus of elasticity (MOE_d). Density was determined from the bulk weight and volume of bole section which is weighed with a platform scale.

MOE_d is determined from following formulas (Kaiserlik, 1978, Wang, S-Y, and S-T Chuang. 2001, Olieveira et al., 2002):

$$MOE_d = \frac{\rho \text{ x } v^2}{g} \qquad (1)$$

$$v = \frac{L}{t} \qquad (2)$$

where ρ is density, v is ultrasonic wave velocities (m/s), g is the gravitational constant ($9.81 m/s^2$), L is the distance between the two transducers, and t is propagation time of the pulse from transmitting transducer to the receiving transducer.

Sixty 20- by 20- by 300 mm small, clear wood specimens were then cut from dimension section for additional ultrasonic wave velocity determination and destructive evaluation of wood strength (MOR) and stiffness (MOE). The specimens were dried until conditioning moisture content.

The density of the small, clear wood specimens was determined. Moisture content (MC) and density were determined by the oven-dry method. This density and the ultrasonic wave velocities were used to calculate of MOE_d.

Static bending test (destructive) were then performed on these specimens with Universal Testing Machine. These tests were conducted according to BS-373 (1957).

MOR and MOEs are calculated from the following equation:

$$MOR = \frac{3\,P.L}{2.b.d^2} \qquad (3)$$

$$MOE = \frac{P.L^3}{4.y.b.d^3} \qquad (4)$$

where MOR and MOE is kg/cm^2, P is load in kg, L is span in cm, b=width in cm, d=depth in cm, and y is deflection in cm.

Useful mathematical relationship between ultrasonic wave properties and static elastic and strength behaviours should be attainable through statistical regression analysis.

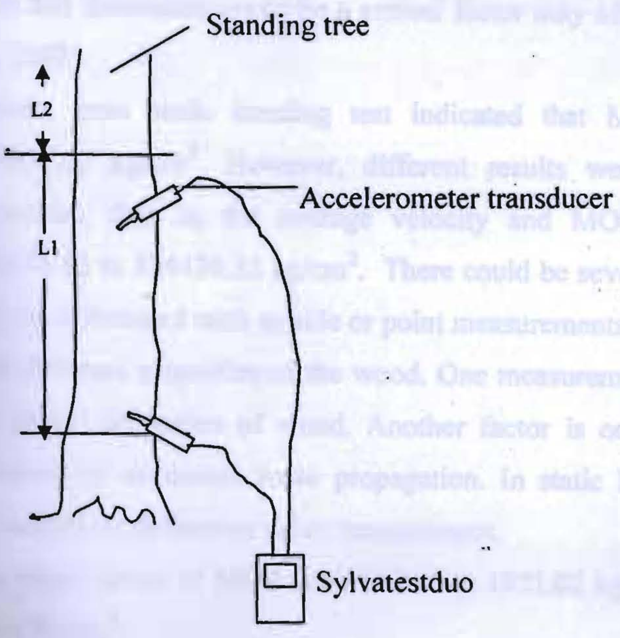

Fig. 1. Experimental setup used in field test

III. RESULTS AND DISCUSSIONS

Ultrasonic wave and bending properties

Ultrasonic wave velocity properties obtained from trees and small, clear specimen of wood are tabulated in Table 1. In trees, the measured of velocity ranged from 457.92 to12269.93 m/s for span 1.3 m for all planting years and 1994.33 to 4352.50 m/s for span 0.7 m for all planting years. It seems that more high span measurement more variant value of velocity. This fact is assumed that long span will give more obstacle, likes part of knot and spiral grain, disturbing velocity propagation.

From in situ measurement, MOEd ranged from 4785.19 to124367.18 kg/cm^2 for span 1.3 m for all planting years and 99587.21to 415871.70 kg/cm^2 for span 0.7 m for all planting years. MOEd determined from in situ measurements was in good agreement with that obtained from small, clear specimens especially for short span. Compared with the MOEd of small, clear specimens, the MOEd of trees increased about 14%. These results are in accordance with Wang *et al.* research (2001) which states that MOEd of trees are higher than MOEd small, clear specimens. As the wave travels through a tree in the longitudinal direction, the outer portion of the wood (mature wood) may have a dominating effect on the propagation of waves. This led to a higher wave velocity on a tree and increased the value of MOEd. It was also found that the diameter-to-length ratio and dimension could be a critical factor may affect the wave behaviour (Wang *et al.*, 2002).

Results from static bending test indicated that MOEs ranged from 50707.80 to 947024.00 kg/cm^2. However, different results were observed in ultrasonic wave properties, that is, the average velocity and MOEd. MOEd values ranged from 162944.16 to 324430.53 kg/cm^2. There could be several reasons for this. Some factors may be influenced such as side or point measurements of specimens. Different side may give different properties of the wood. One measurement may not be enough to predict the global properties of wood. Another factor is occurrence defect which will read different by ultrasonic wave propagation. In static bending test, defects are directly influenced on deflection value measurement.

The range values of MOR were 617.98 to 1072.02 kg/cm^2 with the average values was 869.6 kg/cm^2.

Meanwhile, the results demonstrated that in general, planting year's factor given not so different values for all parameters. It assumed that closely planting years was not give effect so significant on wood properties.

Table 1. Ultrasonic velocity and mechanical properties of *Acacia mangium*

Property[a]	Mean	Standard Deviation	Min	Max	C.V
		TREE			
Span (L1) = *1.3 m*					
Planting years '93					
Velocity (m/s)	2499.350	1099.24	1023.50	4327.17	43.98095
MOEd (kg/cm2)	169724.460	130238.95	23004.84	410808.65	76.73552
Planting years '94					
Velocity (m/s)	716.917	149.49	457.92	896.00	20.85193
MOEd (kg/cm2)	11807.048	4396.86	4785.19	17613.63	37.23932
Planting years '96					
Velocity (m/s)	3385.680	4666.93	755.67	12269.93	137.84326
MOEd (kg/cm2)	32120.227	34234.60	12122.71	124367.18	106.58269
Span (L2) = *0.7 m*					
Planting years '93					
Velocity (m/s)	3685.477	727.55	2405.33	4352.50	19.74098
MOEd (kg/cm2)	309097.539	109961.94	126935.43	415871.70	35.57516
Planting years '94					
Velocity (m/s)	3186.458	755.36	1994.33	4073.67	23.70537
MOEd (kg/cm2)	238927.230	101497.61	99587.21	364227.05	42.48056
Planting years '96					
Velocity (m/s)	3546.850	518.48	2461.67	4061.83	14.61804
MOEd (kg/cm2)	282277.932	74212.74	132974.41	362054.04	26.29066
		SCS			
Velocity (m/s)	6089.619	329.50	5000.00	6666.67	0.05411
MOEd (kg/cm2)	237635.035	30184.41	162944.16	324430.53	0.12702
MOEs (kg/cm2)	88899.717	113323.43	50707.80	947024.00	1.27473
MOR (kg/cm2)	869.600	100.10	617.98	1072.02	0.11511

[a] SCS, small, clear specimen of wood; MOEd, dynamic modulus of elasticity; MOEs, static modulus of elasticity determined by static bending test; MOR,, modulus of rupture

Ultrasonic wave and bending strength relationship

Statistical analysis procedures were used to examine the relationship between ultrasonic wave and bending strength. The results obtained from regression analyses are presented in Table 2.

Table 2. Summary of regression parameter for relationship between ultrasonic wave velocity (V), MOEd, MOEs, and MOR of *Acacia mangium*

Parameter	Regression model	Coefficient of determination R^2	Coefficient of correlation r
Vtree vs. Vscs	y = 0.0739x + 5999,6	0.0629	0.25
MOEdtree vs. MOEdscs	y = 0.0167x + 246044	0.005	0.07
MOEdtree vs. MOEsscs	y = -0.0253x + 81736	0.0439	0.21
MOEdtree vs. MORscs	y = 9E-07x + 884,02	1E-06	0.001
MOEdscs vs MOEsscs	y = 0.2712x + 6743,3	0.2824	0.53
MOEdscs vs MORscs	y = 0.0026x + 228,22	0.4518	0.67

[a] V, ultrasonic wave velocity; SCS, small, clear specimen of wood; MOEd, dynamic modulus of elasticity; MOEs, static modulus of elasticity determined by static bending test; MOR, modulus of rupture

The correlation among various parameter could be represented by linear regression models (y=bx+a). Least squares regression analysis method has been used in the field of wood properties, because mechanical properties of wood are linearly related (Bodig and Jayne, 1982; Bucur, 1995). The results are reported in terms of correlation coefficient that reflects the possible reliability of the method for prediction purpose. The square of the correlation coefficient expresses the percentage of the total variability explained by the regression line.

In general, the regression coefficient showed that correlated between velocity of tree and small, clear specimens and MOEd of tree and MOEd and MOEs of small, clear specimens were weak. Relationships between that parameter are shown in Fig. 1, 2, 3, and 4. This fact seems that standing trees can not be yet used to predict of wood strength. Several reasons can explain that some factors influenced are different moisture content (tree in wet moisture content and small, clear specimen in dry moisture content), temperature measurement, grain angle, and knot or another defect.