Makara Journal of Science 16/2 (2012) 110-114

The Acoustical Properties of Indonesian Hardwood Species

Lina Karlinasari[1*)], Hans Baihaqi[1], Akhiruddin Maddu[2], and Tarcisius Rio Mardikanto[1]

1. Department of Forest Products, Faculty of Forestry, Institut Pertanian Bogor, Bogor 16680, Indonesia
2. Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Pertanian Bogor, Bogor 16680, Indonesia

*)*E-mail: l_karlinasari@yahoo.com*

Abstract

The acoustical properties of four Indonesian tropical hardwood species were evaluated in this study. The objectives of this study were to determine acoustical parameters e.g. logarithmic decrement, sound absorption, sound velocity as well as density and wood stiffness; and to evaluate the potential of those species for acoustical purposes. Sonokeling (*Dalbergia latifolia*), Mahoni (*Swietenia mahagony*), Acacia (*Acacia mangium*) and Manii wood (*Maesopsis eminii*) were selected in this research. Three different cutting plane patterns of sawn timber (quarter-sawn, flat-sawn, and plain-sawn) were converted into small specimens. The methods for determining acoustical properties were longitudinal vibration testing and time of flight of ultrasonic wave method. The result showed no significant difference (α=0.05) of acoustical properties in logarithmic decrement, sound absorption, and ultrasonic velocity means on quarter-sawn, flat-sawn, and plain-sawn for all wood species tested. We found that Mahoni and Sonokeling had good acoustical properties of logarithmic decrement, ultrasonic wave velocity, and ratio of wood stiffness to wood density; and is preferred for crafting musical instruments. Acacia and Manii woods are recommended for developing acoustic panels in building construction because those species possess higher sound absorption values.

Abstrak

Sifat Akustik beberapa Jenis Kayu Berpori (*Hardwood*) Indonesia. Informasi sifat akustik untuk kayu tropis Indonesia masih sangat terbatas. Penelitian ini bertujuan untuk menguji beberapa sifat akustik dari jenis kayu Sonokeling (*Dalbergia latifolia*), Mahoni (*Swietenia mahagony*), Akasia (*Acacia mangium*) dan Manii (*Maesopsis eminii*). Paramater sifat akustik yang diuji terdiri dari kapasitas damping berupa *logarithmic decrement*, penyerapan suara, dan kecepatan gelombang suara; selain itu diuji pula kerapatan dan sifat kekakuan atau modulus elatisitas kayu. Pengujian dilakukan pada contoh uji dari 3 pola kayu gergajian yaitu radial, tangensial, dan campuran (*quarter-sawn, flat-sawn, and plain-sawn*) dengan menggunakan metode vibrasi longitudinal dan waktu tempuh rambatan gelombang suara ultraonik untuk pengujian sifat akustik. Hasil penelitian menunjukkan tidak ada pengaruh yang nyata dari pola penggergajian terhadap nilai sifat akustik kayu. Berdasarkan sifat akustik yang diuji maka jenis kayu Mahoni dan Sonokeling memiliki sifat akustik *logarithmic decrement* yang rendah, kecepatan gelombang suara ultrasonik yang tinggi, dan rasio kekakuan bahan terhadap kerapatannya yang besar; sehingga jenis kayu tersebut direkomendasikan baik untuk komponen alat musik. Sementara itu, jenis kayu Akasia dan Manni lebih cocok digunakan sebagai komponen akustika bangunan, kaitannya dengan sifat penyerapan bunyinya yang lebih baik.

Keywords: *acoustical properties, logarithimic decrement, sound absorption, ultrasonic wave velocity, tropical wood species*

1. Introduction

Materials used for making musical instruments are dominated by temperate wood species such as Spruce *(Picea spp.)*, which is known as the best resonance wood, Maple *(Acer spp.)*, and Fir *(Pseudotsuga sp.)* [1-2]. Other wood species such as African Blackwood (Rosewood) and Ebony are used for woodwind instruments, and Honduras Rosewood (*Dalbergia stevensonii*) is considered for percussion instruments. Generally, the characteristics of those species are homogeneous in anatomical structure, straight grain, fine texture, and sophisticated selection in bending behavior. The excellent acoustical quality of a musical instrument is related to the age of wood; old wood being the best. The acoustical parameter used to understand resonance wood characteristics is the damping capacity, sound velocity, as well as density and wood stiffness.

 doi: 10.7454/mss.v16i2.1405/*Makara J. Sci.* 16/2 (2012) 110-114

The damping or loss coefficient is commonly measured both logarithmic decrement expressed as tanδ and through quality factor 'Q'. These two methods of determination shall be equivalent [3].

The acoustical properties are also important in relation to architectural acoustics. Wood as a building material has a wide range of applications including structural application for acoustical insulation in floors, ceilings, and walls. Wood is characterized by low density, high sound velocity, and relatively low loss factor when compared to other materials having the same density. The important parameters for building acoustic are sound absorption sound insulation expressed transmission loss and noise reduction [1,4].

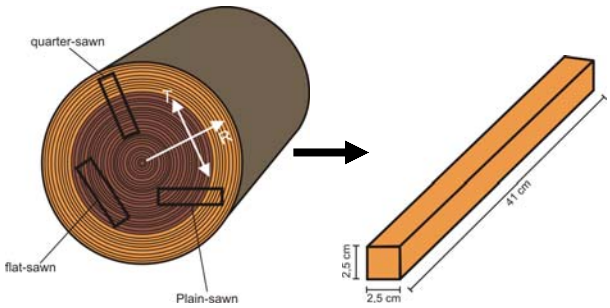
Research on acoustical properties of tropical woods in Indonesia is still limited. This is partially due to concern on the quality of wood resonance from imported woods. Hardwood species is known as porous wood with heterogeneous elements based on anatomical study. Only a few tropical hardwood species were known to be used for musical instruments, namely, Sonokeling (*Dalbergia latifolia*), Mahoni (*Swietenia mahagoni*), and Meranti (*Shorea* sp.).The previous studies only concentrated on the quality tone assessment of the combination of some tropical woods for guitar manufacturing without information on the basic acoustical properties of each wood [5-6].

Besides Mahoni (*S. mahagoni*) and Sonokeling (*D. latifolia*), the fast growing species of Acacia (*Acacia mangium*) and Manii wood (*Maesopsis eminii*) are widely planted species in community and plantation forests in Indonesia. Those woods have been used for utility purposes such as furniture, packaging, and structural timber. A comprehensive study has been carried out in order to determine acoustical parameters e.g. logarithmic decrement, sound absorption, sound velocity as well as density and Young's modulus; and to evaluate the potential of those species for acoustical purposes.

2. Methods

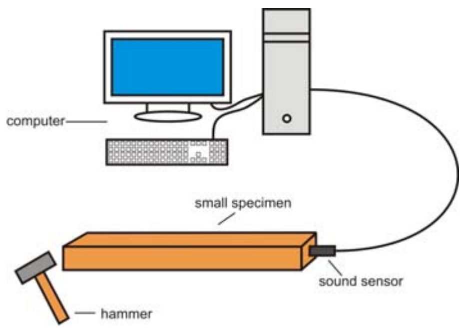
Four tropical hardwood species, namely Mahoni, Sonokeling, Acacia, and Manii wood were used in this study. Two logs of each wood species with a diameter of about 30 cm were taken from community forests in and around Ciampea village, Bogor, West Java, Indonesia. The sawn timber was cut into different cutting plane patterns. Three series of sawn timber were radial plane (quarter-sawn), tangential plane (flat-sawn), and mixed plane (plain-sawn) with three replications for each sample. Quarter-sawn refers to a cutting parallel to the rays, while flat-sawn describes a cutting perpendicular to the rays, and plain-sawn is a cutting at right angles to the rays. The sawn timbers were converted to produce assorted planks with radial or tangential dimensions of (3 x 20) cm and a longitudinal dimension of 100 cm. The planks used were air-dried prior to cutting into small specimens with dimensions of 2.5 cm x 2.5 cm x 41 cm (thickness x width x length) (Fig.1).

Testing of the acoustical properties was carried out using a vibration testing system as shown in Fig. 2(a). The technique involved introducing excitation source into the specimen by mechanical impact using a hammer. A sound detector at the other end of the wood received the sound and transmitted it into a Frequency Analyzer. The data, as sonic sound waves were analyzed by *DataStudio®* program. The frequency varied in the range of 0.5-1 kHz.

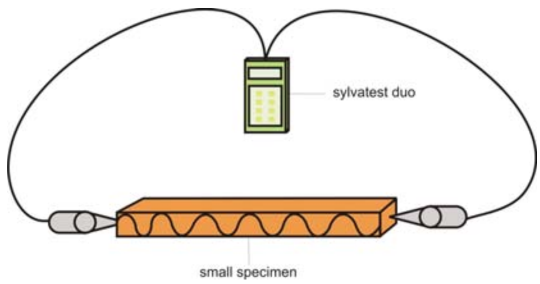


(a) (b)

Figure 1. Section for Sample of Wood: (a) Cross Section of Discs with Cutting Direction of Sawn Timber, (b) Small Specimen



(a)



(b)

Figure 2. Acoustical Properties Testing: (a) Longitudinal Sonic Vibration Testing, (b) Nondestructive of Ultrasonic Wave Propagation Testing

The acoustical properties of the wood were then determined from the oscillation spectrum. Damping capacity was expressed in logarithmic decrement which was calculated with Eq. 1.

$$\tan\delta = \ln\frac{A_1}{A_2} \qquad (1)$$

where δ is logarithmic decrement, A_1 is wave high on the first period (V), A_2 is wave high on the second period (V). Logarithmic decrement is related to the damping ratio (ξ) by the Eq. 2.

$$\xi = \frac{\tan\delta}{2\pi} \qquad (2)$$

A sound absorption (SA) value was evaluated by the Eq. 3.

$$SA = \frac{A_1 - A_2}{A_1} \times 100\% \qquad (3)$$

The ultrasonic wave velocities of wood samples were also determined in this study which was adopted from non-destructive testing of time of flight method (TOF). The sound velocity was generated by stress waves through the ultrasonic pulse method. The SylvatestDuo® equipment was used in this research. This equipment used an ultrasonic pulse generator to impart a stress wave with a frequency 22 kHz. The wave propagation time which passes longitudinally between two transducers mounted into each end of the wood sample was used for ultrasonic wave velocity measurement (Fig. 2b). Pre-drilled on each ends of the specimens were needed to insert tightly the transducers.

The wood stiffness or wood elasticity expressed by the Young's modulus was determined by ultrasonic wave testing and can be calculated by Eq. 4.

$$Ed = \frac{V_{us}^{2} x \rho}{g} \qquad (4)$$

where Ed is dynamic Young's modulus (GPa), ρ is density of specimen (g/cm^3), Vus is ultrasonic wave velocity (m/s), and g is constant gravitational (9.82 m/s^2). The density of the specimen was calculated by dividing mass over the volume. Mass was obtained by weighing the specimen. The moisture content of those small specimens was determined by the gravimetric method. The static bending modulus of elasticity (Es) was performed in this study with one centre point loading using a universal testing machine (Instron® type 3369).

3. Results and Discussion

Table 1 denotes the results of acoustical properties of four Indonesian hardwoods species based on three different cutting plane patterns on tree growth of sawn timber. Analysis of variance shown in Table 2 indicated no significant difference of acoustical properties in logarithmic decrement, sound absorption, and ultrasonic velocity means on quarter-sawn, flat-sawn, and plain-sawn for all wood species tested.

A cutting plane pattern in sawing logs pertains to grain direction. In terms of physical properties, quarter, flat, or plain sawn have characteristics that relates to shrink-swell, drying, check-shakes-split, figure pattern, until cost to obtain the sawn timber [7-8]. Specifically, quarter-sawn is more likely by the lushest due to the growth ring pattern. When timber is quarter sawn, it is viewed from the end of the piece of wood. The grain is seen vertically. The great deviation in grain from being quartered is affected on the strength of timber and it will be implicated on the sound of timber and thus the sound of the instrument in term of musical component. It is also easier and economical way of producing timber than flat sawn [9]. Parfitt *et al*. [10] stated that a good tonewood board was usually obtained from quartersawn material. From the study it can be concluded that there is no significant difference of acoustical properties in term of type of the sawn timber pattern. It is probably due to the characteristics of tropical hardwood species which have active secondary metabolism in a year into regenerate wood cell structure. It also leads to be no clearly in transition of growth ring between early wood and latewood. From the aspect of wood resonance, some criteria are needed to be fulfilled such as macroscopic structural parameters (width and regularity of annual rings, the proportion of the latewood zone, the density pattern in annual rings) and the microscopic and submicroscopic structural parameter (tracheid length, ray distribution patterns, microfibril angle, index of cristalinity) [1,10].

Table 3 shows the average of acoustical properties and Young's modulus values of specimens. The acoustical properties of logarithmic decrement were taken into consideration of damping ratio. The logarithmic decrement value of Acacia wood (0.080) and Manii wood (0.097) are higher than Sonokeling wood (0.068) and Mahoni wood (0.068). This is in line with the sound absorption values in which the values of Acacia and Manii wood are also higher than the other two species. Result found by Bremaud [3] noted that most damping coefficient tan δ of tropical hardwoods species were in broad distribution of tan δ. The soundboard of violin and guitar of Spruce, maple, cedar wood for violin and guitar had damping coefficient of about 0.020 [1]. Review by Wegst [11] stated that wood for soundboards, violin back and ribs possessed logarithmic decrement 0.003 to 0.05, and wood for wind instrument was in logarithmic decrement of 0.004 to 0.01. The lower the logarithmic decrement, the higher the material acoustic value is. In musical instruments, low damping due to internal friction appears to be desirable. The value of internal friction is expressed by logarithmic decrement.

Table 1. Acoustical Properties of Indonesian's Hardwood Species Based on Cutting Plane Pattern

Wood Species	Logarithmic decrement				Sound absorption				Vus (m/s)			
	QS	FS	PS	Av	QS	FS	PS	Av	QS	FS	PS	Av
Sonokeling	0.062	0.068	0.074	0.068	0.286	0.353	0.326	0.322	6187	5813	6262	6087
Mahoni	0.076	0.067	0.061	0.068	0.358	0.289	0.312	0.320	5476	5325	5114	5305
Acacia	0.074	0.084	0.081	0.080	0.333	0.377	0.393	0.368	5245	5198	5410	5284
Manii wood	0.079	0.106	0.107	0.097	0.356	0.437	0.424	0.406	5536	5413	5002	5317

Note: Vus = ultrasonic wave velocity, QS = quarter-sawn, FS = flat-sawn, PS = plain-sawn, Av = Average

Table 2. ANOVA Summary of Acoustical Properties (α = 5%)

Wood Species	Logarithmic decrement	Sound absorption	Vus (m/s)
Sonokeling	0.752 ns	0.475 ns	0.279 ns
Mahoni	0.655 ns	0.510 ns	0.194 ns
Acacia	0.816 ns	0.476 ns	0.672 ns
Manii wood	0.651 ns	0.659 ns	0.347 ns

Note: ns = no significant

Table 3. Summary of Density, Acoustical Properties, and Modulus of Elasticity of Indonesian's Hardwoods Species

Wood Species	MC (%)	ρ (g/cm^3)	Logarithmic decrement	Sound absorption	Vus (m/s)	Ed (GPa)	Es (GPa)	Ed/ρ	Es/ρ
Sonokeling	11.02	0.73	0.068	0.322	6087	30.0	10.9	41.10	14.93
Mahoni	12.15	0.60	0.068	0.320	5305	18.7	7.4	31.17	12.33
Acacia	17.24	0.58	0.080	0.368	5284	20.1	7.2	34.66	12.41
Manii wood	12.58	0.46	0.097	0.406	5317	15.1	4.9	32.83	10.65

Note: MC = moisture content, ρ = density, Vus = ultrasonic wave velocity, Ed = dynamic wood stiffness, Es = static wood stiffness

Meanwhile, the velocity of sound indicates the wood species of Sonokeling possesses the highest values of 6087 m/s followed by Manii wood of 5317 m/s, Mahoni of 5305 m/s, and Acacia of 5284 m/s. Referring to [1], Spruce resonance wood has a density of about 0.45 g/cm^3 and longitudinal velocity in a range 5000-6000 m/s, whereas Maple wood has a density in a range 0.60-0.70 g/cm^3 and possessed sound velocity of about 3800-4900 m/s. Spruce wood is usually used for the top plate of a violin, piano, and guitar soundboard.

In building acoustics, sound absorption is correlated to the sound quality in a room. It is the acoustic capacity of a wall in the room. Materials used as a component in a room absorb some sounds which effected by characteristics of materials. Sound absorption was usually determined by an impedance tube method or a reverberation room method. The soft and porous materials usually have good sound absorption. On average for solid woods, the sound is only absorbed 5-10% and 90-95% of the sound is reflected [13]. The sound absorption depends on the frequency. In this study, using the longitudinal vibration method, the sound absorption value of Manii wood is the highest (0.406) followed by Acacia (0.368), Sonokeling (0.322), and Mahoni (0.320), respectively.

The acoustic behaviors of wood material during vibration are related to the elasticity of material along or across the grain, and to the internal friction phenomena caused by the dissipation of vibrational energy [1]. Wood elasticity is related to organization and composition of the internal structure. Modulus of elasticity or Young's modulus could be determined from static or dynamic tests. The values derived from the dynamic test are usually higher than those from the static bending test. Dynamic moduli of elasticity values obtained by vibration tests were 5-15% higher than static moduli [10, 13-14]. Using the ultrasonic method, the value of dynamic moduli elasticity could reach 50% or twice higher than those static [15]. In this study, the Ed is more than 70% higher than the Es value.

The velocity of sound in wood is directly proportional to the wood's elasticity (E) inversely proportional to density (E/ρ). Wood with higher values of E/ρ is good for musical instrument requirements [2]. According to this study, Sonokeling yielded the higher value followed by Mahoni, Acacia and Manii wood. Using ratios from the static test, the Es/ρ value of Sonokeling was 14.93, followed by Mahoni of 12.33, Acacia and Manii wood of 12.41 and 10.65, respectively. Sedik *et al.* [2] reported that for German Spruce (used for violin and

doi: 10.7454/mss.v16i2.1405/*Makara J. Sci.* 16/2 (2012) 110-114

guitar) the E/ρ was 27.0, Maple (for violin) of 14.8, Brazilian and Indian Rosewood (for guitar) of 18.1 and 17.4, respectively. For tropical species *Endospermum diadenum* the E/ρ was 27.3, *Cratoxylon arborescens*, *Macaranga gigantea*, *Dyera polyphylla*, *Commersonia bartramia*, and *Alstonia pneumatohora* were 21.4, 25.4, 24.3, 18.3, and 16.9, respectively.

Anatomical structures in macroscopic and micro-sub microscopic characteristic are influenced by acoustical properties. Karlinasari *et al*. [16] reported that microfibril angles (MFA) of Sonokeling and Mahoni were smaller than Acacia and Manii wood, whereas the index of crystallinity in Sonokeling and Mahoni was higher than the other two species. The microfibril corresponds to the vertical growth direction of the tree. The index of crystallinity points out the relative amount of crystalline material in cellulose. The good acoustical quality of wood pertains to the small microfibril angle and the optimum crystallinity index [1].

Based on the mean value of acoustical properties (Table 3), Sonokeling and Mahoni are proven to be preferred for musical instruments, especially for supporting components of violin and guitar. Meanwhile, Acacia and Manii wood are recommended for developing architectural acoustics in building construction. Using an impedance tube testing method, boards made from Acacia and Manii wood were potentially used as sound absorber panel. Boards were composed by particle dimension (particleboards) had a better sound absorption coefficient than solid (blockboard) wood and commercial wood cement-bonded particleboard [4].

4. Conclusions

The acoustical properties of selected Indonesian's hardwood species were evaluated using a longitudinal vibration testing system and time of flight of ultrasonic wave method of testing. Sonokeling (*D. latifolia*) and Mahoni (*S. mahagony)* had good acoustical properties of logarithmic decrement, ultrasonic wave velocity, and ratio of wood stiffness to wood density. This explains why those wood species are preferred for making musical instruments. Acacia and Manii wood had higher values of sound absorption compared with the other two wood species. Based on those values, those wood species are recommended for panel acoustic components in building constructions.

Acknowledgment

This work was financially supported by the Directorate General of Higher Education (DGHE), Ministry of National Education, Republic of Indonesia Fundamental Research under contract No. 318/SP2H/DP2M/III/2008.

References

[1] V. Bucur, Acoustics of Wood, Springer-Verlag, Berlin, Heidelberg, 2006, p.393.

[2] Y. Sedik, S. Hamdan, I. Jusoh, M. Hasan, J. Nondestruct. Eval. 29 (2010) 38. DOI: 10.1007/s10921-010-0063-7.

[3] I. Brémaud, P. Cabrolier, K. Minato, J. Gérard, B. Thibaut, COST IE0601+ESWM Conference Wood Science for the Preservation of Cultural Heritage, Braga (Portugal), 2008. *www.woodculther.com/ wp-content/uploads/2009/ 03/bremaud_rev11.pdf.*

[4] L. Karlinasari, D. Hermawan, A. Maddu, B. Martiandi, Y.S. Hadi, J. Trop. Forest Sci. 24/1 (2012) 64.

[5] N. Ardhianto, Undergraduate Thesis, Department of Forest Products, Faculty of Forestry, Bogor Agricultural University (IPB), Indonesia, 2002.

[6] W.K. Sejati, N. Nugroho, L. Karlinasari, National Symposium of Forest Products Technology, Bogor, Indonesia, 2009 (in Indonesia).

[7] H.E. Desch, J.M. Dinwoodie, Timber: Its Structure, Properties and Utilization, 6th ed., Timber Press Forest Grove, Oregon, USA, 1981, p.410.

[8] W. Simpson, A.T. Wolden, Physical Properties and Moisture Relations to Wood, Wood Handbook-Wood as an Engineering Material, Chapter 3, WI: USDA, Forest Service, Forest Products Laboratory, Madison, 1999, p.463.

[9] J. Bodig, B.A. Jayne, Mechanics of Wood and Wood Wompositesm, Krieger Publishing Company Malabar, Florida, USA, 1993, p.712.

[10] L.J. Parfitt, I.A. Hartley, S. Avramidis, For. Prod. J. 55/9 (2005) 74.

[11] U.G.K. Wegst, Ann. Rev. Mater. Res. 38 (2008) 323. Available oline at: *matsci.annualreview.org*. DOI: 10.1146/annurev.matsci.38.060407.132459.

[12] W.R. Smith, In: A.P. Schniewind, R.W. Cahn, M.B. Bever (Ed.), Acoustic Properties, Concise Encyclopedia of Wood and Wood-based Materials, Pergamon Press, London, 1989, p.354.

[13] G. Tsoumis, Science and Technology of Wood: Structure, Properties, Utilization, Van Nostrand Reinhold, New York, USA, 1991, p. 494.

[14] J. Ayarkwa, Y. Hirashima, Y. Sasaki, For. Prod. J. 51/1 (2001) 85.

[15] L. Karlinasari, S. Surjokusumo, Y.S. Hadi, N. Nugroho, Proceeding of the 6th International Wood Science Symposium, Bali, Indonesia, 2005.

[16] L. Karlinasari, D.S. Nawawi, M. Widyani, Bionatura: J. Life Phys. Sci. 12/3 (2010) 110 (in Indonesia).