DEVELOPMENT OF PARTICLEBOARD FROM TROPICAL FAST-GROWING SPECIES FOR ACOUSTIC PANEL

L Karlinasari[1,]*, D Hermawan[1], A Maddu[2], B Martiandi[1] & YS Hadi[1]

[1]Department of Forest Products, Faculty of Forestry, Bogor Agricultural University (IPB), Kampus IPB Darmaga, Bogor 16680, Indonesia
[2]Department of Physics, Faculty of Mathematics and Natural Science, Bogor Agricultural University (IPB), Kampus IPB Darmaga, Bogor 16680, Indonesia

Received February 2011

KARLINASARI L, HERMAWAN D, MADDU A, MARTIANDI B & HADI YS. 2012. Development of particleboard from tropical fast-growing species for acoustic panel. The aim of this study was to determine the acoustical properties of sound absorption as well as physical and mechanical properties of particleboard made from some tropical fast-growing species. Sengon or jeunijing or albizia (*Paraserianthes falcataria*), African wood or manii (*Maesopsis eminii*) and acacia (*Acacia mangium*) wood from commercial wood markets were used in the study. A commercial diphenylmethane diisocyanate (MDI) adhesive was used to manufacture boards with density targets of 0.5 and 0.8 g cm^{-3}. The panels were tested for their mechanical and physical properties. Sound absorption coefficient was evaluated using impedance tube method. For particleboard with density of 0.5 g cm^{-3}, sound absorption was good at high frequencies (f > 1000 Hz). On the other hand, for the 0.8 g cm^{-3} particleboard, sound absorption was good at low frequencies (f < 250 Hz). In middle frequencies (f = 250–800 Hz), sound absorption coefficient decreased significantly. An increase in board density improved board properties, namely, modulus of rupture (MOR), internal bonding (IB) and screw holding power. Based on the findings of this study, particleboards made from tropical fast-growing species are recommended for architectural acoustic in building construction at low and high frequencies of sound.

Keywords: Architectural acoustics, sound absorption, isocyanate adhesive, impedance tube method

KARLINASARI L, HERMAWAN D, MADDU A, MARTIANDI B & HADI YS. 2012. Pembangunan papan serpai daripada spesies tropika cepat tumbuh bagi tujuan menghasilkan panel akustik. Tujuan kajian ini adalah untuk menentukan ciri akustik penyerapan bunyi serta ciri-ciri fizikal dan mekanik papan serpai yang dibuat daripada spesies tropika cepat tumbuh. Kayu sengon yang juga dikenali sebagai jeunijing atau albizia (*Paraserianthes falcataria*), manii (*Maesopsis eminii*) dan akasia (*Acacia mangium*) yang diperoleh daripada pasaran komersial diguna untuk kajian ini. Perekat komersial difenilmetana diisosianat (MDI) diguna untuk menghasilkan papan yang mempunyai ketumpatan sasaran 0.5 g cm^{-3} dan 0.8 g cm^{-3}. Panel diuji untuk ciri-ciri mekanik serta fizikal. Pekali penyerapan bunyi dinilai menggunakan kaedah tiub impedans. Papan serpai yang mempunyai ketumpatan 0.5 g cm^{-3} mempunyai penyerapan bunyi yang baik pada frekuensi tinggi (f > 1000 Hz). Sebaliknya papan serpai berketumpatan 0.8 g cm^{-3} menunjukkan penyerapan bunyi yang baik pada frekuensi rendah (f < 250 Hz). Dalam julat frekuensi sederhana (f = 250 Hz–800 Hz), pekali penyerapan bunyi berkurangan dengan signifikan. Peningkatan ketumpatan bunyi menghasilkan ciri papan yang lebih baik khususnya modulus kepecahan (MOR), ikatan dalaman dan kuasa memegang skru. Daripada keputusan kajian, papan serpai yang dibuat daripada spesies tropika cepat tumbuh disyorkan untuk akustik seni bina dalam pembinaan bangunan pada frekuensi bunyi rendah dan tinggi.

INTRODUCTION

The use of wood-based composite panels as building construction material is usually to function both as structural and non-structural components. In building construction and interior design, acoustic panels are commonly used as partitions, ceiling boards and flooring systems (Smith 1989).

The acoustic capacity of a wall between two rooms can be expressed by noise reduction. Noise reduction is defined as the average of the sound absorption coefficients at 250, 500, 1000 and 4000 Hz (Bucur 2006). Sound absorption is necessary to keep the reflection or bounding

*E-mail: karlinasari@ipb.ac.id

of sound waves in a room to a minimum since such reflection and bounding adversely affect the clarity at which the source can be heard. Sound absorption characteristics are affected by density, porosity, fibre fineness, bulk elasticity and thickness of material as well as surface treatment and range of sound frequency (Smith 1989, Bucur 2006).

There are many lignocellulosic materials used as sound absorber in the form of composite board such as wood (Wassilieff 1996), rice straw (Yang et al. 2003), rice husk (Ajiwe et al. 1998), wheat straw (Saadatnia et al. 2008), bamboo (Koizumi et al. 2002), coir fibre (Zulkifli et al. 2008, 2009, 2010) and oil palm (Zulkifli et al. 2009). On normal solid wood surface, only 5–10% of sound waves are absorbed and 90–95% are reflected. Wood modified into composite can increase porosity. Porous particleboard of wood may qualify as sound absorber (Smith 1989).

In an earlier study of solid wood of fast-growing species, we found that the sound absorption value for manii (*Maesopsis eminii*) and acacia (*Acacia mangium*) wood was about 0.35 in a frequency range of 500–1000 Hz (Karlinasari & Mardikanto 2008). The sound absorption of the former was 0.20 if the frequency range was between 250 and 500 Hz, and increased gradually until 0.4 when the frequency was 1500 Hz (Martiandi et al. 2010).

There has been a shift in the source of wood supplies from natural forests to plantations, which are dominated by fast-growing species. Due to their availability, particles from three of these fast-growing species were used to produce composite panels. This study aimed to determine the sound absorption and physical and mechanical properties of these low- (specific gravity < 0.59) and medium-density (0.59–0.80) particleboards.

MATERIALS AND METHODS

The study was carried out from July till October 2010. Three fast-growing species used in this study were sengon or jeunjing or albizia (*Paraserianthes falcataria*), African wood or manii (*M. eminii*) and acacia (*A. mangium*) which had densities of 0.30, 0.48 and 0.63 g cm^{-3} respectively. Lumber of these species measuring 60 × 80 × 4000 mm were obtained from commercial wood markets in Ciampea village area, Bogor, West Java. Commercial synthetic adhesive used was diphenylmethane diisocyanate (MDI) (95% by weight solid content) because of its very low emission level.

Sample preparation

The lumber were cut into chips of approximately 30 × 5 × 50 mm. The chips were fed into a disc flaker to produce flakes which were then processed into particles suitable for board making. The size of the final particle was 0.5 × 2–3 × 10 mm. The particles were than dried to about 10% moisture content.

Low- and medium-density particleboards of 350 × 350 × 10 mm were fabricated to target densities of 0.5 and 0.8 g cm^{-3}. Adhesive content used was 12% based on the weight of the oven-dried particles. The particles prepared were placed into a rotary drum mixer. Particles were then slowly sprayed with the adhesive while the mixer rotated. Mat was made manually using a forming box.

Hot pressing was conducted for 10 min at temperature 150 °C and pressure 2.5 N mm^{-2} to form composite board. The board samples were then conditioned at room temperature (25 °C) and 65% relative humidity for two weeks before testing. The experiment was conducted in three replicates.

Physical and mechanical properties

Both physical and mechanical properties were examined using standard methods for particleboard JIS A 5908–2003 (JIS 2003). Moisture content, density, bending strength or modulus of rupture (MOR), internal bonding (IB) and screw holding power of board were determined in this study. Modulus of rupture testing was performed with one centre point loading using a universal testing machine (Instron type 3369). The compaction ratio (CR) was calculated based on the following formula:

$$CR = \frac{d_{PB}}{d_W}$$

where d_{PB} = density of particleboard and d_W = density of wood.

Acoustical properties

Measurements of sound absorption coefficients were made using an impedance tube following JIS A 1405–1963 (JIS 1963). Two different impedance tubes were used to cover the frequency range from 100 to 4000 Hz. The larger tube, with a diameter of 98 mm, was used for frequencies up to 1600 Hz. The smaller tube, with a diameter of 44 mm, was used at 1600 until 4000 Hertz. For this test, cylindrical specimens (44- and 98-mm diameter) were prepared as shown in Figure 1.

RESULTS AND DISCUSSION

Physical–mechanical properties

Physical and mechanical properties of the particleboards are given in Table 1. Moisture content and its distribution in the board contribute substantially to the final properties of the board (Maloney 1993). In this study, moisture content of the particleboards ranged between 9.65 and 10.43%. The average actual densities of acacia, manii and sengon wood were 0.46, 0.48, and 0.48 g cm^{-3} respectively for the targeted low-density boards, i.e. 0.5 g cm^{-3}. For medium-density boards (target density 0.8 g cm^{-3}), the actual densities were 0.73, 0.71 and 0.71 g cm^{-3} respectively. Producing the particleboards manually may have led to uneven density distribution so that actual mean panel density varied from density target.

Results of this study showed that as density of the boards increased, MOR, IB, screw holding power and compaction ratio values also increased. Compaction ratio is the ratio of board density to wood species density. It is related to sufficient interparticle contact area which has a strong influence on board performance. A low-density wood provides a high compaction ratio, since

Figure 1 Sample materials for measurement of sound absorption coefficients, (a) acacia, (b) manii and (c) sengon particleboards

Table 1 Properties of particleboards from tropical fast-growing species

Particleboard	Wood density (g cm^{-3})	MC (%)	Board density (g cm^{-3})	CR	MOR (N mm^{-2})	IB (N mm^{-2})	SHP (N)
Acacia	0.63						
Low density		9.83	0.46	0.73	6.9	0.5	233
Medium density		9.84	0.73	1.16	15.2	0.8	737
Manii	0.48						
Low density		10.06	0.48	1.00	5.9	0.3	224
Medium density		10.43	0.71	1.48	12.1	0.5	645
Sengon	0.30						
Low density		9.65	0.48	1.60	5.1	0.3	365
Medium density		9.87	0.71	2.37	14.6	0.7	765
JIS standard for particleboards (JIS A 5908–2003)							
Type 13		5–13	0.4–0.9	-	Min 13.0	Min 0.2	Min 400
Type 8		5–13	0.4–0.9	-	Min 8.0	Min 0.15	Min 300

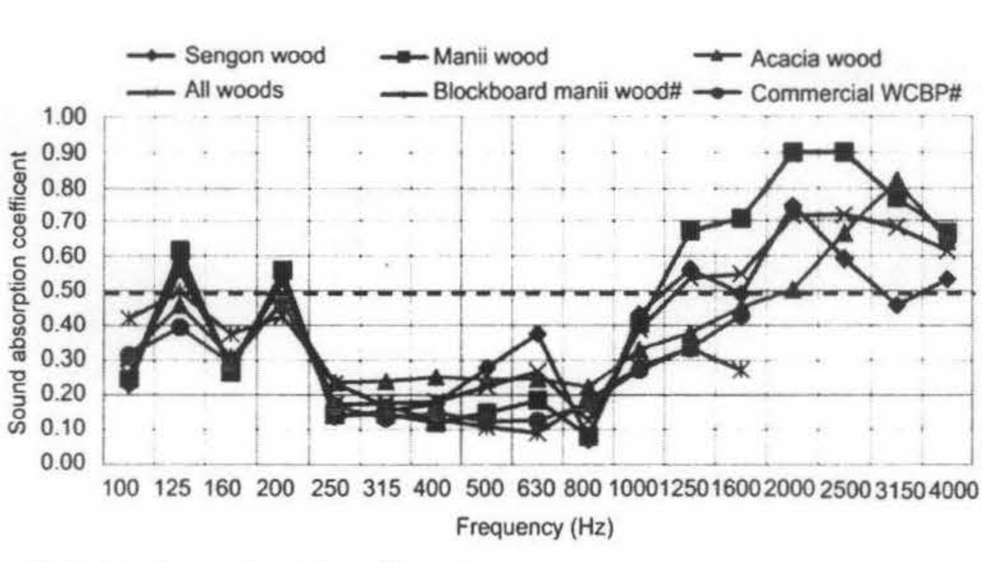
MC = moisture content, CR = compaction ratio, MOR = modulus of rupture, IB = internal bonding, SHP = screw holding power there is higher surface contact to achieve good bonding between the particles compared with high-density wood. This leads to a more uniform product with greater capacity to transmit loads between particles, resulting in higher flexural and internal bonding properties in particleboards made from low-density wood (Maloney 1993, Dias et al. 2005). A compaction ratio of at least 1.3 produces satisfactory contact between particles (Maloney 1993). The compaction ratios for the lower-density wood species, i.e. manii and sengon, were 1.0 to 2.37 (Table 1). Strength properties (MOR, IB, screw holding power) of sengon particleboard were higher than manii (Table 1) since the wood density of the former was lower than the latter. In the high-density wood species, i.e. acacia, the compaction ratio was relatively low with values at 0.73 and 1.16, but the strength property was generally high. In this case, the wood itself is much stronger as a result of cell thickening which provides high strength to the particleboard (Paridah et al. 2010).

Medium-density particleboards had MOR, IB and screw holding power sufficiently high to meet the requirements of JIS A 5908 (JIS 2003) Types 8 and 13 for base and decorative particleboards (Table 1), except for MOR in manii. On the other hand, the low-density particleboards did not have enough strength in MOR and screw holding power as required by the standard. However, all board composites had higher IB than the minimum value which was stipulated in the JIS standard (JIS 2003).

Sound absorption

Sound absorption coefficients of particleboards from the three fast-growing species of this study are shown in Figures 2 and 3. In the low resonance frequency (< 250 Hz), low-density particleboards had lower sound absorption than medium-density particleboards, with values fluctuating from about 0.20 to 0.65. In middle frequencies (250–800 Hz), most sound absorption values of both low- and medium-density particleboards were below 0.4. As frequencies increased above 1000 Hz (high frequency), the low-density particleboard showed fluctuation in the sound absorption coefficients, reaching a maximum 0.9 at 2000 Hz. For frequency exceeding 2000 Hz, sound absorption coefficients for most of the samples were over 0.5 (Figure 2). Sound absorption for the medium-density board also fluctuated in high frequency with a maximum value of 0.7 at 1250 Hz, thereafter decreasing until 2000 Hz before rising again to below 0.6 (Figure 3).

Also shown in Figure 2 are experimental data from Martiandi et al. (2010) for low-density board from solid wood of manii (blockboard) and commercial wood–wool cement-bonded particleboard. At frequency range of 100 to 1600 Hz, the sound absorption was below 0.5. Sound absorption coefficient of the boards fluctuated in low frequency and then decreased in the middle frequency and continued to increase in high frequency up to 1600 Hz. It



WCBP = Wood cement-bonded particleboard
# Source: Martiandi et al. 2010

Figure 2 Sound absorption coefficient at different frequencies for low-density particleboard (0.5 g cm^{-3})

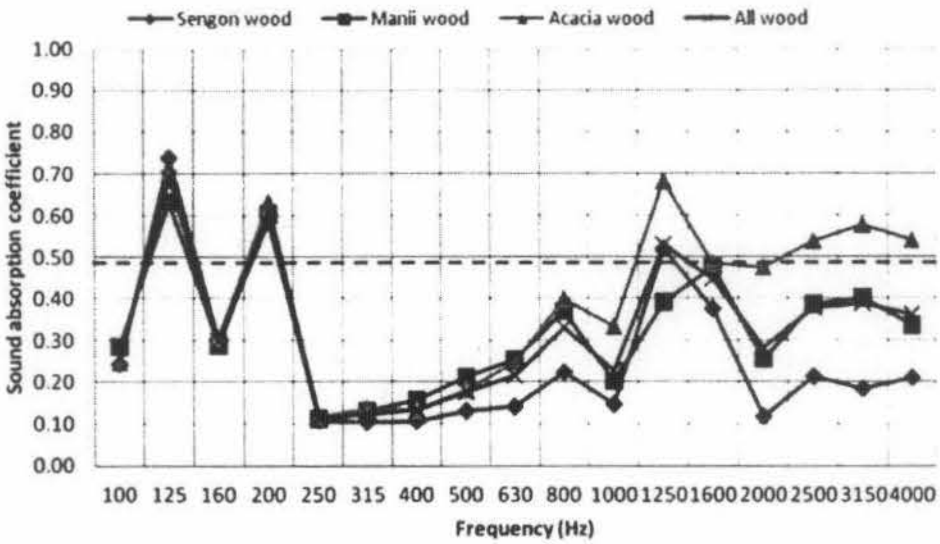


Figure 3 Sound absorption coefficient at different frequencies for medium-density particleboard (0.8 g cm^{-3})

was interesting that in the same density range, the particleboard observed from some fast-growing species had better sound absorption. Similar to the wood particleboard, fibreboard and plywood tested by Yang et al. (2003), higher sound absorption was also observed in this study at frequency range 100–4000 Hz.

The average value of sound absorption from all particleboards of fast-growing species studied showed that the boards reflected sound in middle frequency and absorbed it at low and high frequencies. Medium-density composite boards had sound absorption coefficients higher than low-density boards at low frequency. However, in high frequency (> 1000 Hz), low- density particleboards possessed good absorbing sound properties compared with medium-density boards.

In the low frequency (< 250 Hz), fluctuations of sound absorption at each frequency tested had almost similar values for each wood species of particleboards in the same density boards. The reason was probably due to the response of specific characteristics of wood or other natural fibre material to low sound frequency in the same board density. Board density is closely related to material porosity. Porous material provide frictional drag as the sound waves flow through the material (Wassilieff 1996). Meanwhile, in high frequency, the ability of the particleboard to absorb more sound vibrations per second did not show any specific trend.

In general, porous sound absorbing materials with low density have good insulating properties over a wide frequency range. The large pores give better acoustic insulating properties. It has been reported that sound absorption fluctuated in different frequencies because of material characteristics including raw materials used (Wassilieff 1996, Yang et al. 2003, Zulkifli et al. 2008, 2009, 2010)

Low- to medium-density particleboards can function as highly efficient acoustical absorption materials. However, higher board density increases mechanical properties and the performance of the board will determine its utilisation.

There are numerous environmental and health problems associated with commercial absorption materials such as rockwool, glasswool and mineral fibres. The use of wood waste from fast-growing species as composite boards can partially or completely substitute these materials. In terms of function as noise reduction system, the composite boards made from fast-growing species can be designed as part of multi-layer acoustic absorber for many purposes such as roof and wall sheathing, subflooring and interior surfaces for wall and ceiling in building construction and interior design.

CONCLUSIONS

The study of low- and medium-density particleboards made from fast-growing species (acacia, manii and sengon) demonstrated that they had good sound absorption at low and high frequency range. Low-density particleboard

(0.5 g cm^{-3}) showed better sound absorption at high frequency while medium-density particleboard (0.8 g cm^{-3}), at low frequency. Higher-density particleboard had impact on mechanical properties. Except for MOR of manii, all board properties (MOR, IB and screw holding power) of medium-density particleboards met the Japanese Standard Types 8 and 13 for base and decorative particleboards. The particleboard made can be used as an alternative to synthetic-based commercial products for architectural acoustic in building construction.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of National Education, Republic of Indonesia through Higher Education DP2M No. 409/SP2H/PP/DP2M/VI/2010. Thanks to D Sistiani and ES Kusuma for laboratory work.

REFERENCES

AJIWE VIE, OKEKE CA, EKWUOZOR SC & UBA IC. 1998. A pilot plant for production of ceiling boards from rice husks. *Bioresource Technology* 66: 41–43.

BUCUR V. 2006. *Acoustics of Wood*. Second edition. Springer-Verlag, Heidelberg.

DIAS FR, DO NASCIMENTO MF, MARTINEZ-ESPINOSA M, LAHR FAR & VALARELLI ID. 2005. Relation between the compaction rate and physical and mechanical properties of particleboards. *Materials Research* 8: 329–333.

KOIZUMI T, TSUJIUCHI N & ADACHI A. 2002. The development of sound absorbing materials using natural bamboo fibers. Pp 157–166 in Brebbia CA & de Wilde WP (eds) *High Performance Structure and Composites Book*. WIT Press, Southampton.

KARLINASARI L & MARDIKANTO TR. 2008. *Acoustical Properties of Wood for Musical Instrument*. Bogor Agricultural University, Bogor. (In Indonesian)

JIS (JAPANESE INDUSTRIAL STANDARD). 1963. *JIS 1405: Methods of Test for Sound Absorption of Acoustical Material by the Tube Method*. Japanese Standards Association, Tokyo.

JIS (JAPANESE INDUSTRIAL STANDARD). 2003. *JIS A 5908: Particleboards*. Japanese Standards Association, Tokyo.

MARTIANDI B, MARDIKANTO TR & KARLINASARI L. 2010. Physical, mechanical and acoustical properties of composite board from manii wood. Pp 49–56 in Nawawi DS et al. (eds) *Proceedings of the 13th National Seminar of MAPEKI*. 11 November 2010, Bali. (In Indonesian)

MALONEY TM. 1993. *Modern Particleboard and Dry-Process Fiberboard Manufacturing*. Miller Freeman Inc. San Francisco.

PARIDAH MT, SAIFULAZRY SOA, JALALUDDIN H, ZAIDON A & RAHIM S. 2010. Mechanical and physical properties of particleboard made 4-year-old rubberwood of RRIM 2000 series clones. *Journal of Tropical Forest Science* 22: 440–447.

SAADATNIA M, EBRAHIMI G & TAJVIDI M. 2008. Comparing sound absorption characteristic of acoustic boards made of Aspen particles and different percentage of wheat and barely straws. Pp 1–6 *Proceedings of the 17th World Conference on Nondestructive Testing*. 25–28 October 2008, Shanghai.

SMITH WR. 1989. Acoustic properties. Pp 4–8 in Schniewind AP et al. (eds) *Concise Encyclopedia of Wood and Wood-Based Materials*. Pergamon Press, London.

WASSILIEFF C. 1996. Sound absorption of wood-based materials. *Applied Acoustics* 48: 339–356.

YANG H, KIM D & KIM H. 2003. Rice straw–wood particle composite for sound absorbing wooden construction materials. *Bioresource Technology* 86: 117–121.

ZULKIFLI R, MOHD NOR MJ, TAHIR MFM, ISMAIL AR & NUAWI MZ. 2008. Acoustic properties of multi-layer coir fibers sound absorption panel. *Journal of Applied Science* 8: 3709–3714.

ZULKIFLI R, MOHD NOR MJ, ISMAIL AR, NUAWI MZ, ABDULLAH S, TAHIR MFM & RAHMAN MNA. 2009. Comparison of acoustic properties between coir fibre and oil palm. *European Journal of Scientific Research* 33: 144–152.

ZULKIFLI R, ZULKARNAIN & MOHD NOR MJ. 2010. Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel. *American Journal of Applied Sciences* 7: 260–264.