ACOUSTICAL PROPERTIES OF PARTICLEBOARDS MADE FROM BETUNG BAMBOO (*Dendrocalamus asper*) AS BUILDING CONSTRUCTION MATERIAL

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Acoustic panels are used to overcome noise problems; the purpose of this study was to determine the acoustical properties of particleboard made from Betung bamboo (*Dendrocalamus asper*). The acoustic parameters measured were the transmission loss (TL) value and sound absorption coefficient. Particleboards of two different densities (0.5 g/cm^3 and 0.8 g/cm^3) that were made with three particle sizes (fine, medium, and wool or excelsior) were used in this study. The sound TL value was measured in a reverberation room, while the sound absorption coefficient was determined using the impedance tube method. A single-number rating of sound transmission class (STC) was determined based on TL measurements. The results showed that sound TL and STC values of medium-density particleboard (0.8 g/cm^3) were better than low-density (0.5 g/cm^3) board. However, low-density particleboard performed well as sound absorber panels. Generally, the boards absorbed sound at low (< 500 Hz) and high frequency ranges (> 1000 Hz) and reflected sound at middle frequencies. The sound absorption coefficient was better with the fine- and medium-sized particles than with the wool size; meanwhile, boards made from wool- or excelsior-sized particles possessed higher TL and STC values.

Keywords: Betung bamboo; Sound absorption; Transmission loss; Particleboard

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INTRODUCTION

Recent population growth and urbanization have resulted in increased use of modern appliances in homes as well as a surge in industry and construction. Along with these activities, noise problems have increased. Two main acoustical properties affecting noise control in buildings are isolation from external sound sources and absorption of sounds generated within the interior space (McMullan 2002; Bucur 2006). Sound isolation or sound insulation is related to sound waves transmitted between rooms in a building. The airborne sound insulation of building elements depends on material properties and is expressed as the transmission loss (TL) factor. Sound absorption is correlated to the sound quality in a room. The sound absorption of an acoustical material is expressed as the sound absorption coefficient. Sound-absorbing materials absorb most of the sound energy striking them and reflect very little.

Sound insulation and absorption are two different things. Materials that are effective as sound insulators are typically poor as sound absorbers, and vice versa (Smith

1989, Bucur 2006). Baune (1960), summarized in Bucur (2006), examined the acoustical properties of wood and glass fiber panels with a 2-cm thickness. For the wood panels, the TL value was 22 dB, and the sound absorption coefficient was 3%. For the glass fiber panels, those values were 3 dB and 65%, respectively. Factors that influence these values include material density, porosity, and material thickness. Thicker, denser, and heavier materials have higher TL values, and more porous materials are more effective at sound adsorption (Arenas and Crocker 2010; McMullan 2002).

Certain lignocellulosic materials are used as building construction materials. In many cases, acoustic characteristics are recognized as one aspect of the total design criteria in building construction. Bamboo is a non-wood lignocellulosic material that has received increased attention as an alternative material for wood-based construction and composites. The main advantage of bamboo is its fast-growing nature; it can be harvested in 3 to 4 years. Bamboo has excellent properties in terms of mechanical strength, especially tensile strength properties, which are comparable with those of steel (Janssen 1990). Betung bamboo or giant bamboo (*Dendrocalamus asper* Backer) is commonly planted in Southeast Asia, growing anywhere from lowlands to highlands (2000 m), and is known for its large diameter as compared with other types of bamboo (Othman *et al.* 1995). Koizumi *et al.* (2002) reported that bamboo fiber materials have acoustical properties equivalent to those of glass wool, which is a good sound absorber. The sound absorption coefficient of bamboo fiberboard and resonance-type bamboo fiberboard was found to be superior, especially at high frequencies. The objective of this study was to determine sound TL values and sound absorption characteristics of particleboard of different densities made from Betung bamboo of various particle sizes.

MATERIALS AND METHODS

Preparation of Materials

The culms of approximately 3-year-old Betung bamboo from the Lido, Bogor regency, West Java, were used in this study. As the raw material, the bamboo culms were cut into parts as long as 40 cm, sliced in half, and manually chipped. There were three size classes of particles used: fine, medium, and wool/excelsior particle (Fig. 1).

(a) (b) (c)

Fig. 1. Betung bamboo particles of various sizes: a) wool, b) medium, and c) fine

Fine and medium particles were made by processing chips in a disc flaker. Medium-sized particles were manufactured by screening flakes via a disk mill to obtain particles with a width of 2 to 3 mm, thickness of 0.5 mm, and length of 10 mm. Fine-sized particles were obtained by reprocessing medium-sized particles in a hammer mill until they passed through a 10-mesh sieve. Wool or excelsior particles were made by crosscutting the culms into two parts. Wooling was carried out on a wool or excelsior-making machine (Takekawa Iron Works®). Wool particle dimensions were 50 mm in length, 0.2 to 0.5 mm in thickness, and 3 to 4 mm in width. All particles were then oven-dried at 70 to 80 °C for 2 days to a moisture content of about 10%.

Manufacture of Particleboards

Particleboards (PB) with low and medium target densities, 0.5 g/cm^3 and 0.8 g/cm^3, respectively, were manufactured using isocyanate resin (diphenylmethane diisocyanate [MDI], produced by Polyoshika's company), with a 12% resin level based on the weight of the oven-dried particles. Particleboard density is based on Maloney (1993): low-density particleboards have a density less than 0.59 g/cm^3; medium-density particlebaords are between 0.59 and 0.8 g/cm^3, and high-density particleboards are more than 0.8 g/cm^3.

The particles were then blended in a rotary drum mixer with MDI, which was slowly sprayed into the mixer while it rotated. The glued particles were then spread manually into a mat-forming box of 700 × 700 × 10 mm. The mat was then pressed at 150 °C and 2.5 N/mm^2 for 10 min. All panels were conditioned at room temperature (25 °C) and 65% relative humidity for 2 weeks before testing.

Acoustical Properties Testing

The acoustical properties tested in this study were the TL and the sound absorption coefficient (α) characteristics. The measurement of sound TL was standardized as one-third-octave bands, according to EN ISO 140-3 (1995). The testing was carried out in a reverberation room in the Laboratory of Building Acoustic, Department of Physical Engineering, Bandung Technology Institute.

Each panel was positioned as a wall in an opening between two rooms of the testing area. One room was the sound source room, which contained the noise generator, and the other was the receiving room. The sound pressure level was measured at various frequencies from 125 to 4000 Hz in both the source and receiving rooms, and the latter's reverberation times in the same operating range were recorded. The equipment used to carry out the test consisted of a noise generator, sound level meter 'Rion' type NL-31, Fast Fourier Transformer analyzer, and loudspeaker. TL was defined as the logarithm ratio of the acoustic incident energy to acoustic energy transmitted through the wall, expressed in decibels (dB). Good acoustic insulation is characterized by little energy being transmitted through the wall. Sound transmission class (STC) was calculated to determine single-number ratings based upon these measurements according to the standard ASTM E 413-1987 (1999). The single number rating of sound TL is equal to the value in decibels of the reference curve at 500 Hz in accordance with the method specified by the ASTM standard.

After TL testing, three large and three small circular specimens were cut from each panel with a bandsaw to determine the sound absorption coefficient and to conduct density sample testing. The sound absorption coefficient (α) was determined by using an impedance tube as described in the JIS A 1405-1963 (1990) method. Two different impedance tubes were used to cover the frequency range from 100 Hz 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 for 1600 to 4000 Hz.

The board density testing referred to JIS A 5908 (2003) for particleboard. The density was calculated as a ratio between weight and volume (unit g/cm^3), and three replications were done for each panel specimen.

RESULTS AND DISCUSSION

The actual mean particleboard density varied for the low- and medium-density boards. The average actual densities of particleboard composed of fine, medium, and wool particles were 0.45, 0.44, and 0.41 g/cm^3, respectively, for the low-density boards (target density of 0.5 g/cm^3). For medium-density boards (target density of 0.8 g/cm^3), the actual densities for boards made with fine, medium, and wool particles were 0.70, 0.64, and 0.65 g/cm^3, respectively. The lower actual board density may be explained by the dimensions of the boards (700 × 700 mm) and by mat forming having been done by hand, leading to an uneven distribution of particles. The bonding characteristics between particles, which transmit force to other particles during hot-pressing, could provide another reason. Consequently, after pressing and during conditioning, the board thickness increased; therefore, the board density decreased.

Transmission Loss

TL, also known as the sound reduction index, is the ability of a material to isolate a sound. The sound TL characteristics of building construction are recognized as one aspect of the total design criteria. Figure 2 shows the TL measurement for Betung bamboo particleboard of 10-mm thickness.

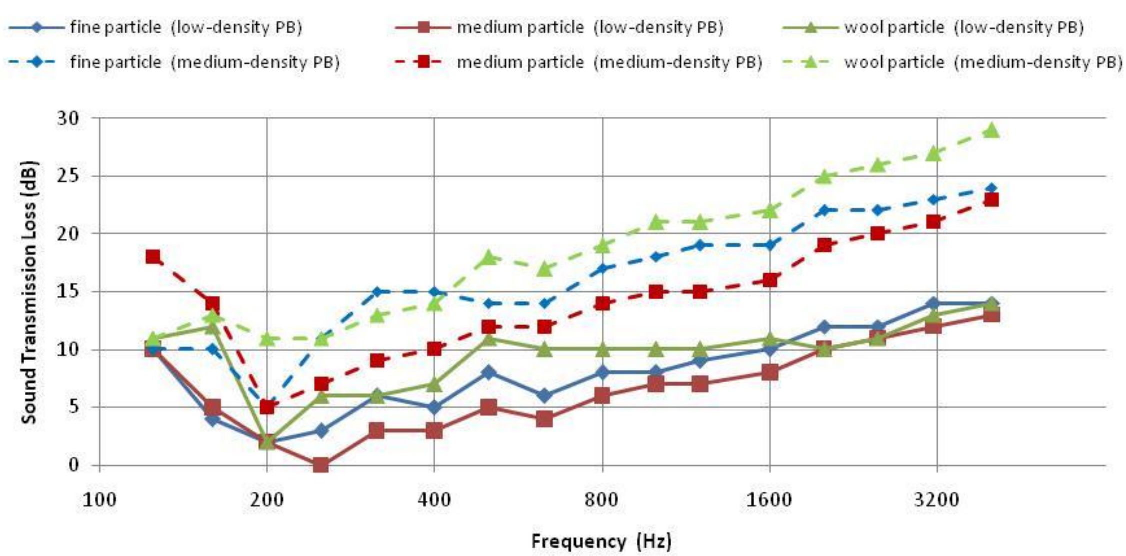

Fig. 2. TL values in the frequency range of 125 Hz to 4000 Hz for 10-mm-thick particleboard made from Betung bamboo (solid lines denote low-density particleboard (0.5 g/cm^3); dashed lines denote medium-density particleboard (0.5 g/cm^3).

The experimental results indicated that at low frequencies up to 500 Hz, the TL value was about 0 to less than 20 dB for the 10-mm-thick particleboard. The low-density particleboard composed of medium-sized particles had the lowest TL value. The TL values were higher for middle (f = 500-1000 Hz) to high frequencies (> 1000 Hz). Medium-density particleboard (0.8 g/cm^3) had a higher TL value than low-density particleboard. The TL value of medium-density board was greater than 15 dB, and it achieved a maximum of approximately 25 dB at a frequency of 4000 Hz for particleboard composed of fine and medium particles and 30 dB for particleboard made from wool or excelsior particles. Low-density particleboard showed a maximum TL value of about 15 dB at a frequency of 4000 Hz.

Density, thickness, and stiffness of material are factors determining the ability of building materials to resist the transmission of sound. For simple homogenous panels the primary physical property controlling the airborne sound TL is the mass per unit area of the panel surface of building element, which is well-known as the “mass law.” This theoretical rule applies to materials within a certain frequency range. The degree of material insulation depends on the mass law – the heavier the material, the better it insulates (Fahy 1985; Rudder 1985).

At low frequencies, the TL values depend on the stiffness of the board. The boards tend to bend as the sound waves strike them, and the stiffer the board, the more resistant it is to bending. In this study, the low-density particleboards had a lower ability to bend as the sound waves struck them. This was indicated by very low values of the sound reduction index (0 to 5 dB), especially for the smaller particle dimension. At medium frequencies, TL values increased with a controlled by mass of panel. The higher density boards of 10-mm thickness showed good insulation, especially at frequencies greater than 500 Hz. At high frequencies, the sound reduction index consistently followed the mass law until the “coincidence” effect occurred. In this situation, TL values will fall as the sound waves in the air and the bending waves in the panel become synchronized, which results in efficient tranfer of energy. The coincidence effect occurs at the “critical frequency.” The critical frequency was not achived in this study as shown in Fig. 2, in which the TL values continued to increase up to a frequency of 4000 Hz. Rudder (1985) demonstrated the critical frequency of hardboard with 3.2-mm particles was at 10,000 Hz, and with 6.3-mm particles it was at 5000 Hz.

A previous study by Mediastika (2008) showed that panels made from a rice-straw composite with 20- and 30-mm thickness had TL values of 10 and 16 dB, respectively, at a frequency of 500 Hz, and 20 and 22 dB, respectively, at a frequency of 1000 Hz. Karlinasari *et al.* (2011), who observed the sound TL of medium-high density wood wool board made from several fast-growing wood plant species, concluded that the boards with a density of 1.0 g/cm^3 possessed TL values that were higher than boards of 0.8 g/cm^3, and the boards made with isocyanate adhesive had better TL values compared with cement-bonded boards. Zulkifli *et al.* (2008) developed panels from natural multi-layer coir fiber that had an average TL index of 20 dB within a frequency range of 500 to 1000 Hz. Research conducted by Ballagh (2004) revealed that a single 19-mm-thick homogenous panel made from gypsum board had a sound TL below 40 dB within a frequency range of 50 to 5000 Hz, while a concrete block wall possessed a transmission value of greater than 40 dB for the same frequency range.

The single-number rating for airborne sound TL is the STC rating. The STC values at 500 Hz for Betung bamboo particleboard were higher for the medium-density particleboard (0.8 g/cm^3) compared with the low-density particleboard (0.5 g/cm^3). Particleboard composed of wool-sized particles seemed to possess the highest STC value, followed by boards made from fine- and medium-sized particles (Table 1).

Table 1. The STC Value of 10-mm-thick Betung Bamboo Particleboard at 500 Hz

Particleboard	Particle size		
	Fine	Medium	Wool/Excelsior
Low-density	9	7	11
Medium-density	18	15	20

Ruder (1985) reported STC values of 25 to 65 for simple to complex construction of wood-frame interior partition design; for wood-joist floor-ceiling assembly designs, STC values ranged from 35 to 65 for simple to complex construction. Similar results in another study confirmed that wood-frame walls conforming to the National Building Code of Canada had STC values of 32 to 66 for simple to complex construction (Anonymous, 2012). Recommended STC ratings are given for different types of environments; *e.g.*, normal quiet required for adjacent offices is a rating of 38 to 40, for adjacent confidential rooms, 45 to 50, for adjacent hotel bedrooms, 50 to 52, and for adjacent classrooms, a rating of 40 to 42. The research results showed that particleboard made from Betung bamboo possessed good potential for development as insulation boards with some modification, and for novel uses such as wall sheathing and subflooring in wood-frame construction.

Sound Absorption

Sound absorption coefficients for the low- and medium-density particleboard are given in Fig. 3.

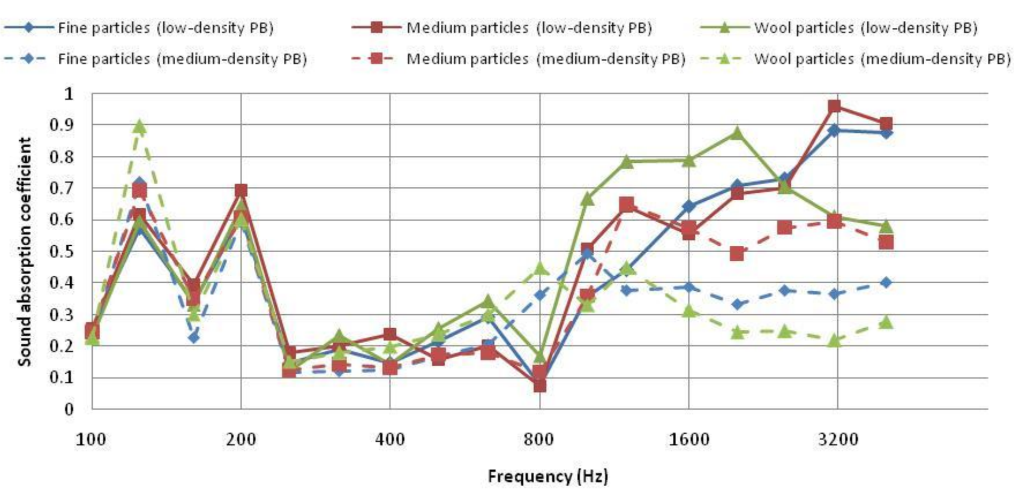

Fig. 3. Sound absorption coefficients within the frequency range of 100 to 4000 Hz for 10-mm-thick particleboard made from Betung bamboo (solid lines denote low-density particleboard (0.5 g/cm^3); dashed lines denote medium-density particleboard (0.5 g/cm^3).

Sound absorption coefficients (α) of low- and medium-density particleboard at low frequencies (< 250 Hz) fluctuated, with peak sound absorption occurring at 125 and 200 Hz. Sound absorption values at those frequencies were similar across board densities and particle types. At middle frequencies (250 to 800 Hz), the sound absorption coefficient values were low and no higher than 0.4, which means the boards reflected the sound at those frequencies. In the high frequency range (> 1000 Hz), fluctuations in sound absorption at each frequency tested showed that low-density particleboards possessed higher values than the medium-density particleboards. Moreover, it seemed that sound absorption coefficients were higher with the smaller particle size (fine and medium) than the wool/excelsior particle size, except for medium-density particleboard composed of wool-sized particles at a frequency range of 1000 to 2500 Hz, which showed higher values than fine- and medium-sized particles.

The fluctuation values trend of sound absorption at low frequencies were in line with a study on particleboard from several tropical fast-growing wood plant species conducted by Karlinasari *et al.* (2011, 2012). The authors explained that single-acoustic panels from lignocellulosic materials had a similar response at low frequencies. This was probably explained by physical characteristics of natural fiber materials, but this idea requires further research. Research by Rahman *et al.* (2012) on acoustic properties of date palm fiber demonstrated that in a low-frequency range, the values for the coefficient of sound absorption were identical for samples with the same thickness but different densities. Sihabut and Laemasak (2010) reported that at a frequency of 250 Hz, the sound absorption coefficient of oil palm frond fiberboard possessed almost similar values for rough, screen, and perforated board. As middle frequencies increased, up to 2000 Hz, the sound absorption coefficients continuously increased. In the normal incidence sound, the sound absorption by wood as base material were affected by porosity, tortuousity, air flow resitivity, and thickness of suface (Wassilieff 2003). Arenas and Crocker (2010) stated that most porous sound-absorbing materials are fibrous. Fibrous materials are composed of a set of continuous filaments that trap air between them. The most important microscopic parameter of a fiber is its diameter, which directly affects the sound-absorbing characteristics.

McMullan (2002) and Arenas and Crocker (2010) revealed that materials that possess a high value of sound absorption are usually porous materials. The sound absorption behavior observed for low-density particleboard showed that this board had higher porosity than that of medium-density particleboard. However, with regard to particle dimension, the particleboard composed of smaller particles had a higher sound absorption coefficient than wool-sized particles.

Karlinasari *et al.* (2011, 2012) studied sound absorption coefficient for particleboard made from some tropical, fast-growing species and noted that the boards reflected sound at middle frequencies and absorbed it at low and high frequencies. The maximum value of α reached in Karlinasari *et al.* (2012) was 0.7 and approximately 0.5 at 2500 and 1250 Hz, respectively, for low-density (0.5 g/cm^3) and medium-density (0.8 g/cm^3) particleboards composed of medium-sized particles. Wood wool cement-bonded board was effective for sound absorption at high frequencies (Karlinasari *et al.* 2011). Particle composite made from a mixture of rice straw and wood particles (Yang *et al.* 2003) showed that 10-mm-thick boards with a specific gravity (SG) of 0.4 and 0.6 had higher sound absorption coefficients than a board with an SG 0.8 in the 1000- to 8000-Hz frequency range and other wood-based materials in the frequency range of 500 to 8000 Hz. The maximum value of α was about 0.70 at a frequency of 4000 Hz for boards with an SG value of 0.4. Another study using all rice-straw composite showed that the maximum value for α was 0.81 at a frequency of 900 Hz for 20-mm-thick boards and 0.94 at a frequency of 1200 Hz for 30-mm-thick boards in the frequency range of 100 to

1200 Hz (Mediastika 2008). Zulkifli *et al.* (2008, 2010) concluded that a 20-mm-thick layer of coconut coir fiber with a porous backing layer resulted in a maximum sound absorption coefficient value of 0.97 at 2750 to 2825 Hz and a peak value of around 0.94 to 0.95 at 2600 to 2700 Hz for coconut coir fiber with a perforated plate. Synthetic mineral fibers such as glass wool and rock wool, which are known as good sound-absorbing materials possessed an α of 0.80 and 0.91, respectively with 5-mm thickness at a frequency of 2000 Hz (Asdrubali 2007).

Referring to the study results, the sound absorption coefficient of particleboards made from Betung bamboo indicated that the boards absorbed sound at low- and high-frequency ranges and reflected sound at middle frequencies. These products can be developed with modification to improve sound absorption properties.

The human ear is most sensitive to noises at central frequencies of 500, 1000, 2000, and 4000 Hz (Ilgun *et al.* 2010). In those frequencies, noise isolation capability of the material, as well as noise reduction in sound absorption are taken into consideration. The bamboo material used as panel board in this study was very efficient at sound insulation and absorbance in the high frequency range. Different characteristics were mostly attributable to board densities. Higher density boards are good as sound insulators, while the lower density boards are better at sound absorption. As building material, boards from bamboo can be recommended as wall and floor components with some modifications for increasing the performance for specific uses.

CONCLUSIONS

1. Low-density boards (0.5 g/cm^3) had a higher sound absorption coefficient than medium-density particleboards (0.8 g/cm^3). Meanwhile, medium-density boards were effective as insulation boards, with higher TL and STC values when compared with low-density particleboard.
2. Particleboards composed of wool or excelsior possessed higher TL and STC values compared with boards that had smaller particle sizes. The sound absorption coefficients were better with fine- and medium-sized particles than with wool size.
3. Particleboards made from Betung bamboo have promise for further development as construction material, especially for acoustical purposes. Compared with other wood or natural composites, the acoustical properties of these boards have good characteristics at the high frequency range.

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