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THE STRENGTH AND TERMITE RESISTANCE CHARACTERISTICS OF FIBERBOARDS PRODUCED FROM THE RENEWABLE BAMBOO BIOMASS

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ABSTRACT

This study investigated the physical, chemical, and termite resistance characteristics of fiberboard made from the trunk fiber of five bamboo species (*Giganto chloaapus, Gigantochloa atroviolacea, Giganto chloaatter, Dendrocalamus asper,* and *Bambusa vulgaris*) and its suitability as a construction material. Five types of fiberboard with a target density of 0.8 g·cm^{-3} were prepared by using a hot-pressing system at a temperature of 180°C for 15 minutes. Fiberboards were examined for the bonding strength, lignin content, and morphological characteristics. Termite resistance characteristic of fiberboards was performed by three-week laboratory feeding trials against *Coptotermes formosanus* Shiraki and *Incistermes minor* Hagenas described in Japanese International Standard (JIS) K. 1571. The results showed that the strongest bonding characteristic was *B. vulgarisfiberboard*, followed by *G. apus*, *G. atroviolacea*, and *G. atter*. The highest lignin content presented in *G. atter* (29.23%), followed by *G. atroviolacea* (28.78%), *D. asper* (26.60%), *G. apus* (26.48%), and *B. vulgaris* (23.87%). The lowest weight loss of bamboo fiberboard after termites' assay was *D.asper* (7%). In conclusion, the fiberboard made from the fiber of bamboo trunk waste hasthepotency as a promising building material. However, alltypes of bamboo fiberboard would require additional protection for applicationin the area with a high number of termite nests.

KEYWORDS: Indonesian bamboo species, *Coptotermes formosanus* Shiraki, *Incisitermes minor* Hagen, termite resistance fiberboard.

INTRODUCTION

Recently, an increasing gap between demand and supply has placed wood-based industries in a difficult position regarding obtaining solid wood. As a construction material, the high quality of the solid wood is required to provide a strong building. The use of other potential wood materials from low-cost natural sources has been suggested in facing the challenges in finding solid materials. Non-woody plant fiber such as forestry wastes has drawn significant attention in the development of alternative materials for housing. Some researchers have found that lignocellulose fibers can substitute solid wood and wood-based materials to fulfill the demand for housing building (Bouhicha et al. 2005, Binici et al. 2005, Saleh et al. 2015).

Since the 19th century, bamboo has been introduced into the agro-based composite field as a non-woody fiber. Bamboo has the potential application as a raw material for composite panel production because of its rapid growth, high bending stiffness, and dimensional stability (Chaowana 2013). Indonesia is one of the bamboo producers mainly for the raw materials of various types of handicrafts such as traditional basket and souvenirs, which are widely exported to Asian and European countries. The high demand of bamboo products from Indonesia leads to the abundant availability of bamboo fiber residues as the side product; therefore, the sustainability of bamboo trunk fibers as a resource for composite manufacturing is promising (Azmy and Abd. Razak 2000, Khalil et al. 2012).

Also, some investigations showed the potency of composite materials made from forestry fibers which have been classified as the primary source of board materials (Grigoriou et al. 2000, Lee et al. 2004, Okuda and Sato 2004). However, in the tropical and subtropical countries, wood-based materials and wood-based composite boards are vulnerable to termite attack (Chung et al. 1999, Curling and Murphy 1999). Termite species are well-known worldwide as the leading cause of damage to wood and non-woody composite products. The two most significant termite species (the species that attack and damage wood and non-woody composite products) are subterranean and dry wood termites. It is found that the strength of wood-based board and non-woody composite board and its susceptibility to biological degradation depend on the adhesive bond (Kartal and Green 2003, JISK. 1571 - 2004).

Consequently, the development of high-quality non-woody composite boards requires the right type of forestry waste. The objective of this research is to develop the new production process using bamboo trunk fibers. The process includes the construction of bamboo trunk fibers from five different bamboo species as materials for the composite board. Also, the morphological characteristics of the boards, as well as their resistance to termite attack in laboratory conditions were investigated. There is no information about the quality of bamboo fiberboard in Indonesia, as well as its susceptibility level against termite attack. The research on measuring bamboo particle board resistance to termite attack is rarely performed. Therefore, the obtained information from this research is believed to be useful for the bamboo furniture industry, bamboo fiberboard product, and other bamboo products in Indonesia.

MATERIALS AND METHODS

Materials

The trunk waste of the following five bamboo species was used as basic materials: *Giganto chloaapus, Giganto chloaatro violacea, Giganto chloaatter, Dendrocalamus asper*, and *Bambusa vulgaris*. The bamboo species were two years of age at the harvest time. A typical commercial PVAc glue was used in this research. Dry mass content in the adhesive was 46 %.

Fiber preparation and pretreatment

Bamboo trunks were used as the source of fiber which was removed by decortications. In order to obtain the homogenous length of fibers, 35 cm length of bamboo fibers were manually combed. Subsequently, the fibers were then oven-dried to achieve 5% moisture content.

Board preparation

Fiberboard with a target density of 0.8 $g{\cdot}cm^{-3}$ was manufactured to meet the dimensions 25 × 25 × 0.4 cm dimensions. The fibers were dipped into polyvinyl acetate (PVAc) resin solutions. The glue viscosity was measured with the use of RheoTec RC 01/02 viscosimeter where at the temperature of 25°C the viscosity of the glue was about 14400 mPas, and at 90°C the viscosity was about 6600 mPas. Excess impregnation PVAc resin was squeezed out by passing the fibers through a pair of rollers. Moreover, the impregnated fibers were dried at room temperature for 24 h to a resin content of 20% (dry weight) of the fibers. The medium-density fiberboard was prepared in three layers with an approximately 1:1:1 weight ratio. Hot presses with a specific pressure of 4.5 MPa and at a pressing temperature of 160°C for 10 minutes were applied to cure the PVAc resin in the consolidated mats completely. Afterward, all boards were conditioned at 20°C and ±65% relative moisture content for 7 days before tests.

Bonding strength measurement and lignin content assays

Prepared fiberboard was tested for its binding strength by the method described by TAPPI test methods Internal bond strength (Scott type), Test Method TAPPI/ANSI T 569 om-14 (Antes and Joutsimo 2015). Lignin content in fiberboard was investigated using the Klason method described in Indonesian National Standard (SNI 0492- 2008).

Termite bioassay

The subterranean and dry wood termites' bioassay was conducted following the method of JIS K. 1571- 2004 (no-choice test). Sugi (*Cryptomeria japonica*) sapwood specimens were used as the control. Then, the test specimen was placed in a plastic net to avoid direct contact with the moistened layer on the base of a cylindrical acrylic container. Termite species, i.e., *Coptotermes formosanus* Shiraki and *Incistermes minor* Hagen (150 workers and 15 soldiers) were added to each test container. The container was then maintained at 28 ± 2 °C and 80% RH for three weeks in the dark.

Morphological studies of bamboo fiberboard

The microscopic appearance of the bamboo fiberboards made from five different bamboo species before and after termites' bioassay was examined with a scanning electron microscope (Leo Supra, 50 VP, Carl Zeiss, SMT, Germany, SEM), using small samples of 1-2 mm thickness. Specimens were sputter-coated with gold to a thickness of approximately 10 nm to prevent charging during the examination. An accelerating voltage of 15 kV was used to collect the SEM images. Transverse sections of 1 μm thickness were cut using a Sorvall ultramicrotome (MT 500) with a glass and diamond knife. For anatomical characterization and lignin distribution determination, embedded samples were stained with 1%toluidine blue and viewed under a polarized microscope (Olympus Bx50) for transverse and longitudinal sections.

RESULTS AND DISCUSSION

Bonding strength and lignin content

According to the results of bonding strength measurements (Tab. 1), the bamboo trunk fiberboard with the most durable bonding was *Bambusa vulgaris*, followed by *Gigantochloa apus, Gigantochloa atroviolacea,* and *Gigantochloa atter.* Weak bonding strength was found in the fiberboard made of *D. asper* (Tukey's test: $P < 0.05$). Also, the lignin content of the bamboo trunk fiberboard differed significantly, as shown in Tab. 1. It was found that the highest lignin content presented in *G. atter* (29.23%), followed by *G. atroviolacea* (28.78%), *D. asper* (26.60%), *G. apus* (26.48%), and *B. vulgaris* (23.87%) (Tukey's test: $P < 0.05$). The fiberboard strength was evaluated by using the tensile and tear test. The fiber-to-fiber bonds mainly determined the internal bond strength of fiberboard in adhesive joints between fibers and the area of contact between fiber bonds.

Tab. 1: The bonding strength and lignin analysis of variance (ANOVA) between bamboo species fiberboard.

No	Bamboo species	Bonding strength (MPa)	Lignin (%)	Mean
1	*Gigantochloa atter*	0.23^c	29.23^a	14.73^a
2	*Bambusa vulgaris*	0.64^a	23.87^e	12.25^e
3	*Gigantochloa atroviolacea*	0.23^c	28.78^b	14.51^b
4	*Dendrocalamus asper*	0.06^d	26.60^c	13.33^d
5	*Gigantochloa apus*	0.53^b	26.48^d	13.51^c
Different letters indicate significant differences among parameters ($P < 0.05$)				

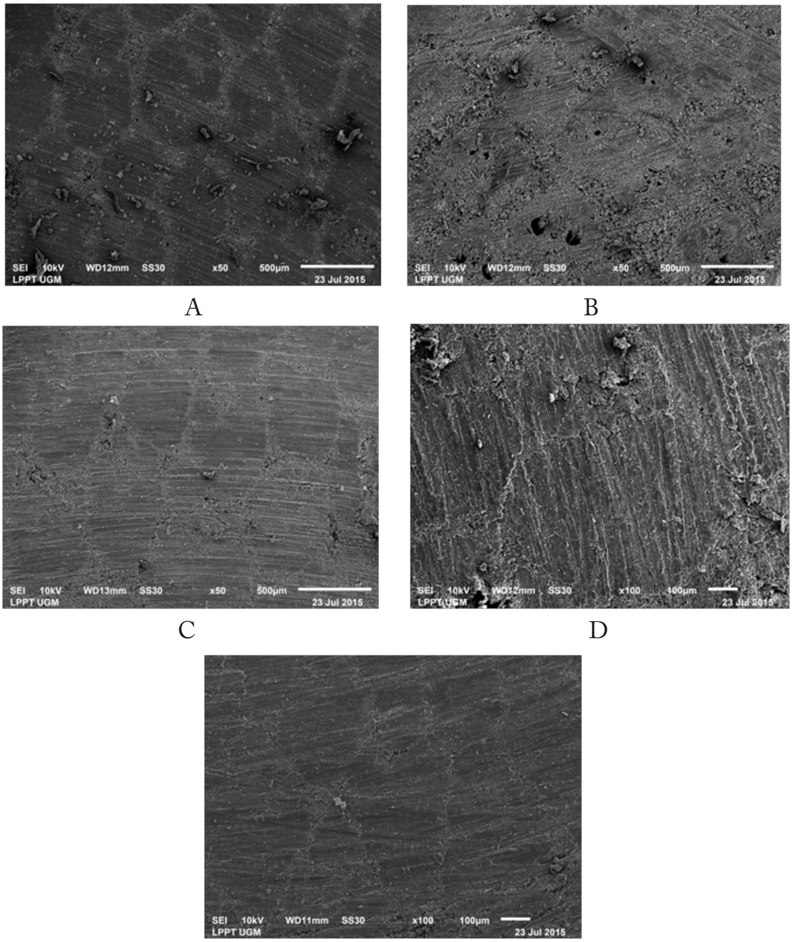
The chemical composition of the fiber also played a crucial role in the bonding activity. The formation of hydrogen bonds between cellulose molecules and the Van der Waals forces have been known to contribute to bond strength in lignin (Retulainen et al. 1998). Based on the correlation results from Pearson Correlation two-tailed testing, a weak relationship existed between bamboo trunk fiberboard strength and its lignin content. Lignin is the polymer of phenylpropane units, and the chemistry profile of it remains unclear (Li 2004). Lignin itself is hydrophobic; therefore, it cannot form the strong adhesion with the polymers (Tung et al 2004). The lignin content in bamboo fibers differed among the five species. The chemical structure of lignin in bamboo species may differ from that in wood as well, and further investigation into the chemical structure of lignin of bamboo fibers is needed.

In addition to the raw materials, the bamboo fiberboard bonding strength is also determined by adhesive and compression factors (Antes and Joutsimo 2015, Tung et al. 2004). The type of adhesive used largely determines the intensity of the bonding strength, both in the direction parallel to the fiber surface and the direction perpendicular to the surface of the bamboo fiberboard. In this study, PVAc adhesives performed well. PVAc adhesive is a substance that can unite similar/unlike material through its surface bond. The attachment of the two attached objects is caused by a pulling force between the adhesive and the adhesive material (adhesion force) and the pull force (cohesion style) between the adhesive and the adhesive/between the bonded materials. Meanwhile, the adhesive reaction to heat can be distinguished over thermoplastic adhesive that can soften if it is exposed to heat and become hardened again when the temperature is low. Examples of adhesives that belong to this type are polyvinil adhesive, cellulose adhesive, and acrylic resin adhesive. The basis of adhesion is the principle of cohesion and adhesion of a particle interconnected materials. The existence of the force causes the occurrence interactions of molecules, atoms, and ions from both surfaces (Ruhendi et al. 2007). The physical and mechanical properties of bamboo fiberboard are also determined by compression, which is done at the time of manufacturing. The compression factor is composed of temperature, pressure, and the length of time that compression is applied at the date of the manufacturing process. Compression temperature has a crucial effect on the physical property of fiberboard (Walther et al. 2007). The fiberboard is stacked with thermoplastic matrix sheets before compression and heat are applied. The viscosity of the adhesive agents during pressing and heating needs to be carefully controlled to make sure the matrix is impregnated and spread fully into the space between fibers. It can be achieved by controlling viscosity, pressure, holding time, temperature taking account of the type of fiber and matrix (Ho et al. 2012).

Vascular bundles are composed of xylem, phloem, parenchyma cells, and a fibrous sheath. The largest bundles usually have one wide metaxylem vessel element, several narrow metaxylem vessel elements, and protoxylem vessel elements. Those bundles are sometimes interconnected irregularly and also joined to the larger bundles. In one bundle, the phloem of the bamboo plant is divided into two separate areas. Also, there is pits tissue on the cell wall as the substances that could interpenetrate in the transverse direction. The vascular bundles of *Bambusa vulgaris* were larger in the inner parts, becoming smaller and denser towards the periphery of the culm wall. Each of the vascular bundles consisted of the xylem, with one or two smaller protoxylem elements and two large metaxylem vessels and the phloem with thin-walled, unlignified sieve tubes connected to the companion cells (Razak et al. 2010). More parenchyma but few fibers and conducting cells were present in the inner part of the culm wall than in the periphery. The shape of the vascular bundles changed from the periphery to the inner parts of the bamboo culm wall. The middle and inner zones showed much higher increments in fiber wall thickening. Some parenchyma cells were observed to contain starch; however, the amount was quite small. The parenchyma of older culms was filled with starch grains. The starch content in bamboo has been known to vary with seasons; starch content is higher in the dry season in comparison with the rainy season (Liese and Tang 2015). As can be observed in Fig. 1, the transverse sections of the fiberboard of five bamboo species show the differences in their anatomy. In fact, the anatomical characteristics of bamboo in different ages, heights, and zone in the radial direction of culm wall thickness are different. The characteristics are the vascular bundle frequency and size, metaxylem vessels, fiber and parenchyma (Huang et al. 2015).

The morphological microstructure of the bamboo fiberboard

The basic components of the fiberboard of five bamboo species were investigated in transverse sections by SEM (Fig. 1).



A B

C D

E

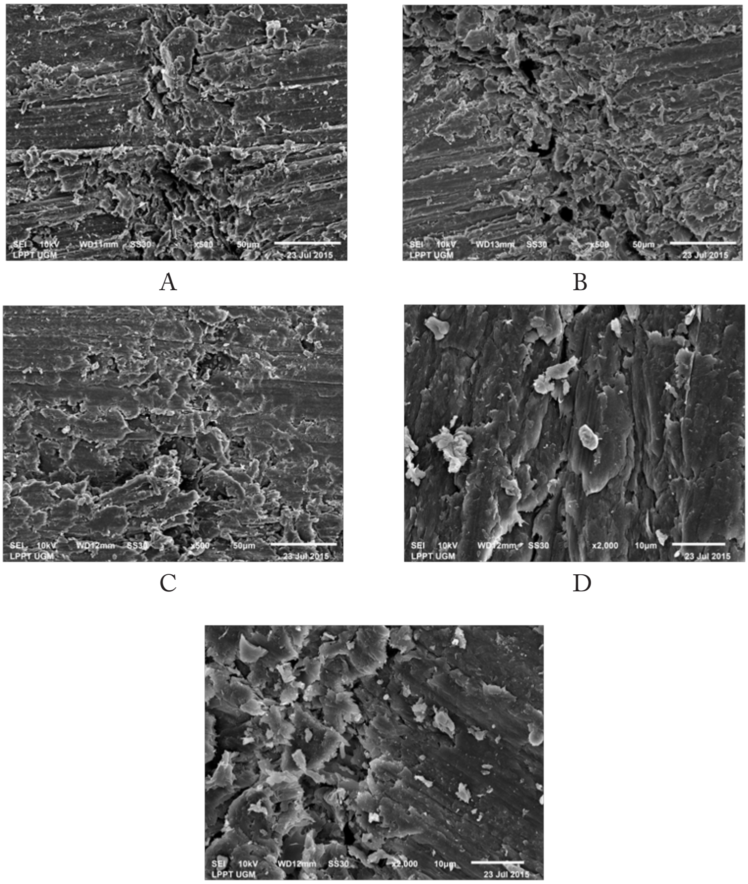
Fig. 1: Scanning electron micrograph of the transverse section of fiberboards made of five bamboo species: (A) Dendrocalamus asper; (B) Bambusa vulgaris; (C) Gigantochloa atroviolacea; (D) Gigantochloa apus; (E) Gigantochloa atter.

The resistance of the fibreboard to termite attack.

In this study, the strength of the fiberboard of five bamboo species to termite attack was tested by following the method of JIS K. 1571- 2004. The results of the bamboo fiberboard bioassays and challenge test against termites are presented in Fig. 2 and Tab. 2. The surface texture of the fiberboard before assay and after assay differed. This result reinforces a previous study by Subekti et al. (2015) that reported weight losses in bamboo fiber after 3 weeks of termite attack (subterranean termites *Coptotermes formosanus* and *Incisitermes minor*). Our current results show that the bamboo fiber with the most significant loss of weight was *G. atter*, followed by *G. atroviolacea*, *B. vulgaris*, *G. apus*, and *D. asper*. However, these results do not reflect the correlation between lignin content in bamboo fiber and the ability of the termites to digest the fiber. In fact, termites themselves cannot degrade the lignin content in fiber; microorganisms accomplish this action in the digestive tract of the termites. Although the lignin concentration in bamboo fiber is high, the microorganisms can still with stand it (Donovan et al. 2001, Ohkuma and Brune 2011, Ni and Tokuda 2013).

Tab. 2: The weight loss of bamboo after termite attack.

No	Bamboo species	Weight loss percentage (%)	Criteria
1	*Gigantochloa atter*	9	Low resistance
2	*Bambusa vulgaris*	9	Low resistance
3	*Gigantochloa atroviolacea*	8	Medium resistance
4	*Dendrocalamus asper*	7	Medium resistance
5	*Gigantochloa apus*	8	Medium resistance



A B

C D

E

Fig. 2: Scanning electron micrograph of the transverse section of five bamboo fiberboard after termites' attack: (A) Dendrocalamus asper; (B) Bambusa vulgaris; (C) Gigantochloa atroviolacea; (D) Gigantochloa apus; (E) Gigantohloa atter.

D. asperis a popular bamboo species in Indonesia which is usually utilized as housing materials. The popular name of *D. asperis bamboo betung*. Also, it has been explored and expanded for high value-added products such as composites and laminated products. In fact, the properties of bamboo are almost similar to certain timbers. Bamboo has an advantage of its longer fibers to support its application as hardboard (Ashaari et al. 2010, Azmy and Abd. Razak (2000). The result of this study shows that *D. asper* has the fiber which is difficult to be digested by termites. The age of the bamboo is also important in affecting the fiberboard properties. It is in line with the study results by Kasim et al. (2001). They study the fiberboard properties made from bamboo *Gigantochloa scortechinii*, and the results show that the age of bamboo gave significant affects the fiberboard properties.

CONCLUSIONS

Based on the examination of the anatomical characteristics and properties of the five bamboo species as well as their resistance to termite attack, *Dendrocalamus asper* fiber appears to be the best alternative for building materials. It shows the lowest weight loss (7%) among five bamboo species. Moreover, the lignin content in bamboo has the weak correlation with the fiberboard strength. The use of waste trunk fiber from *D. asper* was effective in prohibiting the degradation by termites. Therefore, aside from the usefulness as a renewable, environmentally friendly, and safe material for construction, *D. asper* is also a likely choice in the context of declining wood supply.

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