ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 22, No. 1. 2016

Utilization of Bamboo as Lightweight Sandwich Panels

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crossref http://dx.doi.org/10.5755/j01.ms.22.1.8887

Received 10 December 2014; accepted 11 April 2015

Lightweight sandwich panels from bamboo faces and oil palm trunk core were manufactured using melamine urea formaldehyde with the resin content of 250 g/m^2 (solid basis). The parameters examined were node and density of bamboo faces. Physical (board density, thickness swelling and water absorption) and mechanical (modulus of elasticity and modulus of rupture) properties of the sandwich board obtained were investigated and compared with other bamboo products and commercial wood based products. Result showed that this panel had better dimensional stability than those of other bamboo products but lower bending strength. Node of bamboo had no significant effect on any board properties examined. Most of board properties were influenced by bamboo face density. Comparing the properties to commercial wood based products, this panel could be used as wall/floor applications.

Keywords: bamboo face, bamboo density, node of bamboo, physical and mechanical properties, lightweight panels.

1. INTRODUCTION

Bamboo, which are widely known as non-wood forest resources, can be found in worldwide. In Thailand, there are about 60 bamboo species and *Dendrocalamus asper* is the most important species planted in more than 60 provinces [1]. Bamboo is a fast growing species. It can be harvested at the age of approximately 3 – 4 years from the time of cultivation [1]. The utilization of bamboo especially for structural uses has been limited by its tubular shape when the flat plane is required. To eliminate this restriction, laminated bamboo lumber (LBL) [2 – 5], oriented bamboo strand lumber (OSL) [6, 7] and oriented bamboo strand board (OSB) [8 – 10] have been developed. Although, their mechanical properties are appropriate for structural uses, however, their densities were as high as approximately 720 – 1000 kg/m^3 [5, 6, 8]. This might cause to increase the cost and difficulties in uses.

Bamboo comprises mainly of vascular bundles embedded in parenchymatouse tissue [1]. The number of vascular bundles increases from the inner to the outer of cross section and from the bottom to the top of the culm's height [1, 5]. The density and mechanical properties of bamboo vary with the volume fraction of vascular bundles [5]. Bamboo has a dominant mechanical property in tensile resistance [1]. It has been reported that the tensile strength in longitudinal direction at the top part of bamboo (*Dendrocalamus asper*) culm was as high as 314 MPa [11] greater than that of rubberwood approximately 3 times [12].

Nowadays, lightweight sandwich structures become the most alternative products used in any applications [13, 14, 15]. Their structures consist typically of three main layers including two stiff faces and a low density core [16, 17]. Generally, these structures are used for resisting bending and buckling loads [16]. The strong faces mostly carry the tensile stress and the low density core carries the shear stress [16]. Products based on the sandwich structure give a high stiffness and strength with a low weight [16, 17]. With regarding to tensile resistance property of bamboo, it should be used as alternative raw materials for facing of the lightweight sandwich structures.

The main objective of this study was to evaluate the feasibility of using *Dendrocalamus asper* Backer bamboo as facing of lightweight sandwich structures for structural uses. Low density oil palm trunk, available in large amounts in Thailand, was selected to use as a lightweight core. The effects of density and node of bamboo on the physical (board density, thickness swelling and water absorption) and mechanical (modulus of rupture and modulus of elasticity) properties of the sandwich boards were investigated. The board properties obtained were compared with other bamboo products and commercial wood based products.

2. MATERIALS AND METHODS

2.1. Face material preparation

Sweet-Bamboo (*Dendrocalamus asper* Backer) culms older than 5 years old in a private plantation area from Krasaesin district, Songkhla province, Thailand were collected. The bamboo culms were dried with the laboratory kiln (Eurasia, Singapore) at the Research Center of Excellence on Wood Science and Engineering, Walailak University, Thailand to the final moisture content of 12 %. Bamboo culms were then converted into three types of slats with respect to culm's height level and node; slats with node (BN specimen) and without node (BWN specimen) from the bottom part and slats without node from the top part (TWN specimen) (Fig. 1). The node of BN specimens located on the center point of the slat's length (Fig. 1 a). Each slat had dimensions of 20 mm (tangential)×520 mm (longitudinal)×4 mm (radial). These slats were planed on both flat plane sides using planar plate with the 40 grits rough sandpaper to achieve

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the final thickness of 3.4 ± 0.1 mm (radial) and kept in conditioning room at temperature of 20 °C and humidity of 65 % until the final moisture content reach to 12 %. At this moisture content, average density of slats from the bottom (BN and BWN specimens) and the top (TWN specimens) parts were 618 ± 43 kg/m^3 and 893 ± 42 kg/m^3, respectively. Ten same type slats were bonded side to side with polyvinyl acetate (PVA) to form a face at the dimensions of 200 mm (width)×520 mm (length)×3.4 mm (thickness). The faces prepared from BN, BWN and TWN specimens were named as BN, BWN and TWN faces, respectively.

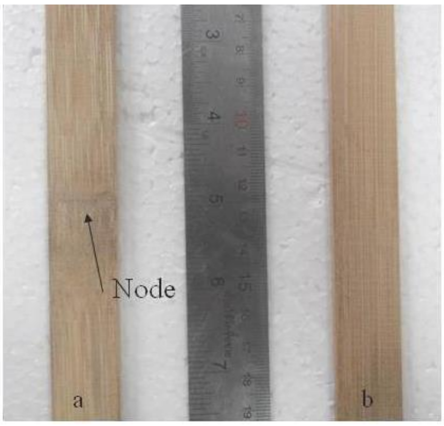

Fig. 1. a – slat with node; b – slat without node

2.2. Core material preparation

The 25 years old oil palm trees in the plantation area of Surat Thani province, Thailand were cut down and transported to dry with the laboratory kiln (Eurasia, Singapore) at the Research Center of Excellence on Wood Science and Engineering, Walailak University, Thailand to the final moisture content of 12 %. The oil palm trunk specimens with the dimensions of 100 mm (tangential)×260 mm (longitudinal)×20 mm (radial) were then prepared. These specimens were sanded on both flat plane sides using planar plate with the 40 grits rough sandpaper to achieve the required thickness of 13.2 mm. These oil palm pieces were kept in conditioning room at temperature of 20 °C and humidity of 65 % at least 1 month. The final moisture content of oil palm trunk specimens was 12 %. The average density of oil palm trunk specimens at this moisture content was 176 ± 20 kg/m^3. Four oil palm trunk specimens were bonded edge to edge and end to end to form a rectangular core section at the dimensions of 200 mm (width)×520 mm (length)×13.2 mm (thickness). The grain directions of oil palm trunk specimens were oriented in longitudinal direction to the board's length.

2.3. Adhesive

Melamine urea formaldehyde (MUF) adhesive supplied by AICA Co., Ltd., Hatyai district, Songkhla province, Thailand, was selected to bond between the face and core layers in this experiment. The MUF adhesive at 30 °C has a viscosity of 155 cps, solid content of 53.4 %, pH level of 9.18, density of 1.198 and gel time of 198 second.

2.4. Board manufacturing

The MUF adhesive with the resin content of 250 g/m^2 (solid basis) was spread onto the surface of the prepared faces. The glued faces were then put on the bottom and top surfaces of the prepared oil palm core so that the grain direction of bamboo faces and oil palm core were oriented in parallel direction to the board's length (Fig. 2). The assembled mats were then placed on the placing space of a single-opening hydraulic lab hot press (600 × 600 mm^2 Wabash MPI, USA). Two steel bars with the dimensions of 20 mm (width)×20 mm (thickness)×600 mm (length) were put on both sides of the assembled mat to control the final thickness of board during pressing. The boards were pressed with temperature of 160 °C at 2 MPa for 5 minutes.

The board produced had the thickness of 20 mm. A total of 9 boards (three boards for each type of faces) were produced in this study.

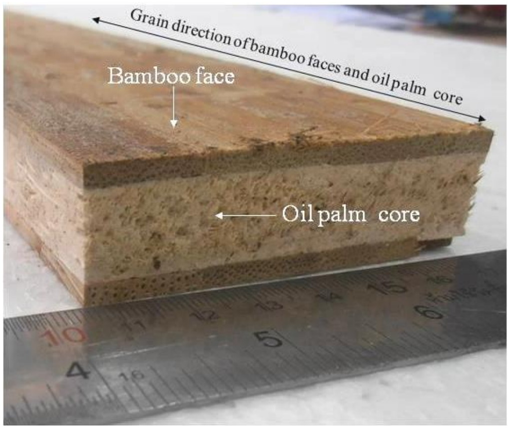

Fig. 2. The sandwich board consisting of bamboo faces and oil palm core

2.5. Property testing

The obtained boards were cut into test specimens and then kept in the conditioning room at a temperature of 20° C and humidity at 65 % until a constant weight was reached. Below are the examined board's properties:

– board density was determined using specimens with the dimensions of 50 mm (width)×50 mm (length)×20 mm (thickness) according to EN 323: 1993 [18];
– thickness swelling and water absorption were performed on specimens with the dimensions of 50 mm (width)×50 mm (length)×20 mm (thickness) by water immersion at 20 °C for 24 hours in accordance with EN 317:1993-08 [19] and ASTM D 1037-12 [20], respectively;
– modulus of elasticity and modulus of rupture were evaluated by three-point static bending test. The test specimens with the dimensions of 50 mm (width)×500 mm (length parallel to the grain direction of slats)×20 mm (thickness) were prepared in accordance with EN 310: 1993 [21]. Three-point static bending test was conducted using a 150 kN universal testing machine (Lloyd, UK). The test span length (L) was 400 mm.

Duncan's range tests were conducted to determine significant differences between mean values.

3. RESULTS AND DISCUSSION

The average values of the physical and mechanical properties of the sandwich boards obtained are shown in Table 1.

Table 1. Some physical and mechanical properties of the sandwich boards produced from various types of bamboo faces and oil palm trunk core

Types of faces	Properties of the sandwich boards (Oil palm core density = 176 ± 20 kg/m^3)				
	ρ, kg/m^3	*TS*, %	*WA*, %	*MOR*, MPa	*MOE*, MPa
BN faces Density = 618 ± 43 kg/m^3	329^b (5)	3.3^a (0.5)	114^a (6)	34.3^b (0.6)	6,496^b (323)
BWN faces Density = 618 ± 43 kg/m^3	342^b (13)	3.4^a (0.2)	113^a (10)	33.6^b (0.4)	6,415^b (169)
TWN faces Density = 893 ± 42 kg/m^3)	448^a (9)	3.4^a (0.1)	68^b (8)	42.8^a (0.9)	11,019^a (439)

– ρ – board density, *TS* – thickness swelling, *WA* – water absorption, *MOR* – modulus of rupture, *MOE* – modulus of elasticity;
– groups with same letters in column indicate that there is no statistical difference between the samples according to Duncan's multiply range test;
– the values in parentheses are standard deviations

3.1. Board density (ρ)

Density values of the sandwich boards produced are shown in Table 1. It ranged from 325 to 458 kg/m^3. The result showed that the densities of the sandwich boards with BN faces were not difference from those of BWN faces. Density of the sandwich board having the same density face (BN and BWN faces) was not dependent on node of bamboo. This result was further confirmed by statistical analysis showing that node of bamboo had no significant effect on this value (Table 1). But the position of bamboo face along the culm's height affected on this value significantly. As the result shown in Table 1, the sandwich boards with bamboo faces from the top part (TWN faces) showed higher board density than those of bamboo faces from the bottom part (BN and BWN faces). It should also be noted that the density of the TWN faces was greater than those of BN and BWN faces. Basically, density of sandwich structures can be described using the rule of mixtures. It depends on density of the face and the core, volume fraction occupied by the face and amount of adhesive. Thus, the density of sandwich board having the same oil palm core density and thickness, resin content and face thickness depends solely on face density. It increases with increasing face density.

Notably, the obtained sandwich board densities were lower than 500 kg/m^3. It can be classified as lightweight panel according to USDA specification. When compared with other bamboo products which have been successfully developed for structural uses, it showed that the density of the sandwich board was about 1.9, 1.6 and 1.5 times lower than laminated bamboo lumber (LBL) with density of 890 kg/m^3 [22], oriented bamboo strand lumber (OSL) with density of 720 kg/m^3 [6] and oriented bamboo strand board (OSB) with density of 700 kg/m^3 [8], respectively.

3.2. Thickness swelling and water absorption

The thickness swelling (*TS*) values after being water-soaked at 20 °C for 24 hours are shown in Table 1. The *TS* values of this panel ranged from 2.7 – 3.7 %. As statistical analysis, node and position of bamboo faces along the culm's height had no significant effect on *TS* value. The average *TS* value of this type of the sandwich board was about 3.4 ± 0.3 %. This value is much lower than those of laminated bamboo lumber (*TS* = 12.4 %) [23], oriented bamboo strand lumber (*TS* = 26.4 %) [6] and oriented bamboo strand board (*TS* = 12.9 %) [8]. In addition, the *TS* value of this panel is about 6 times lower than that of OSB type 2 (*TS* = 20 %) according to European standard requirement for wall application [24].

Water absorption (*WA*) values of the sandwich boards after being soaked in water for 24 hours are also shown in Table 1. The *WA* values of the sandwich boards ranged from 66 % to 120 %. Statistical analysis revealed that node of bamboo had no significant effect on *WA* value. The *WA* value depended on the position of bamboo face along the culm's height. As shown in Table 1, the *WA* value of the sandwich board with bamboo face from the top part (TWN faces) was about 1.5 times lower than those of bamboo faces from the bottom part (BN and BWN faces). It should be noticed that the density of the sandwich board with TWN faces was higher than those of BN and BWN faces due to have higher face density. In general, water absorption of wood increase with porosity of the wood cell which is proportional to the reciprocal of wood density [25].

When compared with other bamboo products, the sandwich board showed higher WA value than those of laminated bamboo lumber (board density = 740 kg/m^3) with *WA* value of 26.1 % [23], oriented bamboo strand lumber (board density = 720 kg/m^3) with *WA* value of 40.5 % [6] and oriented bamboo strand board (board density = 700 kg/m^3) with *WA* value of 47.8 % [8]. It should be also noticed that the density of the sandwich board is lowest.

3.3. Modulus of rupture and modulus of elasticity

The modulus of rupture (*MOR*) and modulus of elasticity (*MOE*) of the sandwich boards produced are shown in Table 1. No bonding failure between the face and the core layer as well as along end surface glue line of oil palm core specimens was observed during bending test. So, the effects of delamination failure and end surface glue lines between the oil palm core specimens on bending strength of the sandwich board can be ignored. It was observed that the sandwich beams with TWN and BWN faces failed by core shear (Fig. 3 a) due to the shear stress in the core exceeded the allowable shear strength of the oil palm core. While the sandwich beams with BN faces failed by bottom face fracture around the nodes (Fig. 3 b) due to the tensile stress in the bottom face exceeded the tensile strength of bamboo face. This kind of failure mode might be affected by the node structure of bamboo. The vertical alignment of vascular bundles has slightly bent in the node area [1, 26]. In addition, some vascular bundles which lay in transverse direction have also been observed in node section [26]. This discontinuity of vascular bundles which are formed as complicated net around the nodes could lower the tensile resistance of bamboo [26, 27]. On the other hand, vascular bundles in internode area of BWN and TWN faces are strongly oriented in longitudinal direction [1, 26]. This caused higher tensile resistance to be obtained for the bamboo face without node.

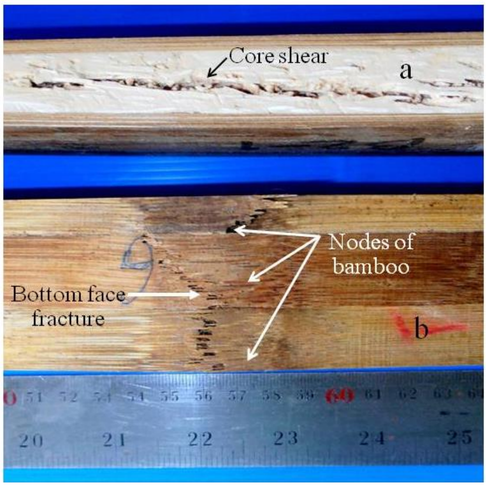

Fig. 3. Failure mode of the sandwich beams: a – core shear and b – bottom face fracture around the nodes

As statistical analysis shown in Table 1, node of bamboo had no significant effect on *MOE* and *MOR* values. The average *MOE* and *MOR* values of the sandwich board with BN and BWN faces which had the same density were 6,495 ± 235 MPa and 34.0 ± 0.6 MPa, respectively. The *MOE* and *MOR* values of the sandwich board were influenced by the position of bamboo faces along the culm's height (Table 1). The sandwich board with bamboo face from the top part (TWN faces) showed higher *MOE* and *MOR* values than those of bamboo faces from the bottom part (BWN and BN faces). The different density of the faces and the variation of oil palm core density should be responsible for the different *MOE* and *MOR* values of the sandwich board obtained. The face and oil palm core density of the sandwich board with TWN face were slightly higher than those of BWN and BN faces. The *MOE* and *MOR* values of the sandwich board with TWN faces (*MOE* = 11,019 ± 439 MPa and *MOR* = 42.9 ± 0.9 MPa) were greater than those of BWN and BN faces about 1.7 and 1.3 times, respectively. In addition, the density of the sandwich board with TWN faces was also higher than those of BN and BWN faces. Generally, Higher board density shows higher *MOE* and *MOR* values [28].

When compared with other structural wood based composites products made from bamboo such as laminated bamboo lumber (LBL) with density of 890 kg/m^3 (*MOR* = 128 MPa, *MOE* = 15 GPa) [22], oriented bamboo strand lumber (OSL) with density of 720 kg/m^3 (*MOR* = 65 MPa, *MOE* = 11 GPa) [6] and oriented bamboo strand board (OSB) with density of 700 kg/m^3 (*MOR* = 58 MPa, *MOE* = 9 GPa) [8], the *MOR* value of the sandwich board was lower than those of others. While the *MOE* value was lower than that of LBL but comparable with OSL and OSB. However, the *MOR* and *MOE* values of this panel are higher than that of OSB type 2 used for wall applications in accordance with European standard requirement [24].

In order to use as structural components, strength to weight ratio must be considered. The specific *MOR* (*MOR* value/board density) and *MOE* (*MOE* value/board density) values of the sandwich board produced were compared with those of other bamboo products developed for structural uses and OSB type 2 (EN 300) as shown in Fig. 4. It showed that the specific *MOR* value of the sandwich board (SB) was lower than that of laminated bamboo lumber (LBL) [21] but higher than those of oriented bamboo strand lumber (OSL) [6], oriented bamboo strand board (OSB) [8] and OSB type 2 [24]. While the specific *MOE* of this type of panel was highest.

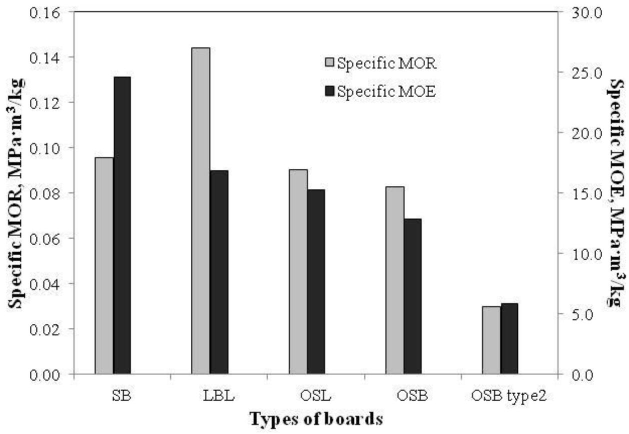

Fig. 4. Specific *MOR* and *MOE* values of the sandwich board (SB) compared with laminated bamboo lumber (LBL) [21], oriented bamboo strand lumber (OSL) [6], oriented bamboo strand board (OSB) [8] and OSB type 2 [24]

4. CONCLUSIONS

Bamboo could be effectively used as facing materials for lightweight sandwich structures having density lower than 500 kg/m^3 using oil palm trunk as a core. Node of bamboo did not affect on any board properties examined but affected to different of failure modes of the sandwich board under bending load. Most of board properties examined mainly influenced by face density excepted the thickness swelling value. The obtained panel had a better dimensional stability and lighter than those of other bamboo products and commercial wood based product. Lightweight sandwich panel made from bamboo faces and oil palm trunk core could be potentially used as wall/floor applications.

Acknowledgements

The author gratefully acknowledges the Research Center of Excellence on Wood Science and Engineering, Walailak University, Thailand for the financial support and AICA Co., Ltd., Songkhla, Thailand for providing MUF adhesives used within this work.

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