Adhesion and Bonding Performance of Laminated Bamboo Lumber made from *Dendrocalamus sericeus*

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Abstract

The aim of this research was to determine the gluability and bonding properties of *Dendrocalamus sericeus*. These properties were analyzed in order to prove its suitability to be promoted as a raw material for the manufacture of Laminated Bamboo Lumber (LBL). The average value of pH and buffering capacity were 6.08 and 0.14 milliequivalents respectively. *D. sericeus* had high wettability compared to other commercial wood species. In addition, wettability of bamboo culm outer surface was found to be lower than inner part. The bonding strength of the bamboo strips was evaluated for MUF resin. It was observed that the layer structure glue appeared to be a significant variable for the bonding strength on LBL. Results indicate that LBL showed superior strength properties. The layer structure of bamboo strip had a significant effect on the modulus of rupture and elasticity, internal bond strength and thickness swelling.

Key words

Dendrocalamus sericeus, Laminated bamboo lumber, Adhesion, Bonding strength

Introduction

Bamboo belongs to the large woody grasses (Family Poaceae, Subfamily Bambusoideae) and encompasses about 1,200 species within 50 genera in the world (Chapman 1996; Qisheng et al. 2002). It is mostly distributed in the tropical and subtropical regions, covering an area of over 37 million hectares. Bamboo is a non-wood lignocellulosic material which has been widely used as a material for construction, furniture manufacture and daily household uses. In recent times, it has been used as a raw material for wood products manufactured in Asian factories, such as for pulp and paper, plywood, Medium Density Fiberboard (MDF), Particleboard (PB) and Oriented Strand Board (OSB), because of its high strength and properties. However, a change in raw material may affect on product properties and requires additional adjustment of some processing parameters, such as the adhesive system. Since the adhesive is a significant cost factor in board production, future development of bamboo-based composites will require an analysis of the bonding strength between bamboos and adhesives.

Laminated Bamboo Lumber (LBL) is a type of structural bamboo-based composite composed of several layers of bamboo lamellae which are placed parallel to each other bonded together with durable, moisture-resistant adhesives. According to Correal et al. (2009) and Pereira and Faria (2009) the manufacture of LBL can be summarized and present in figure 1. Correal et al. (2009) illustrates the mechanical properties of LBL made from *Guadua angustifolia* Kunt. Based on the this results, LBL due to the high density compared to wood has higher mechanical properties in bonding shear strength and bending strength compared to traditional timber species generally. In the point of view, the LBL can be suitable material for construction and design of thinner structural elements than those made of wood. It is used as vertical columns or horizontal beams, as well as curved configuration, arched shapes. Additionally, it is also applied in the panel form for truck floor and gang planks.

However, the product's weight is a disadvantage. Moreover, bamboo contains a waxy component with heavier and harder outer part of culm. It requires large quantity of resin and pressing time, thereby pushing up the production cost.

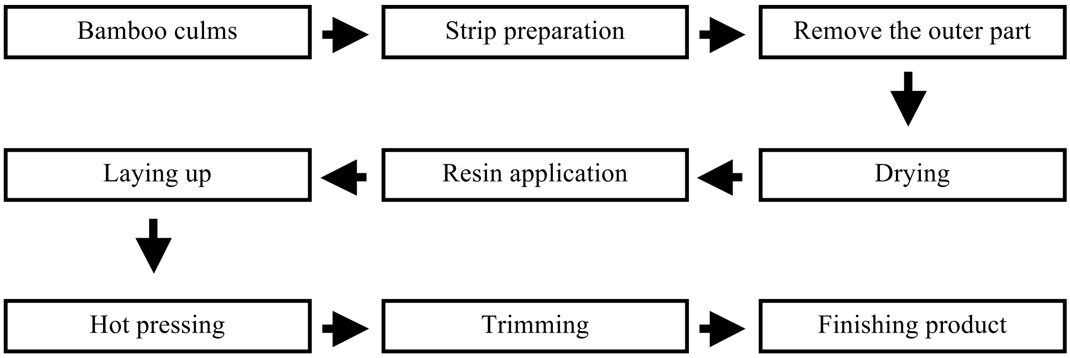

Figure 1 The flow chart of Laminated Bamboo Lumber production.

Therefore, the objectives of this study are to investigate the surface properties of *D. sericeus*. Additionally, the LBLs made from *D. sericeus* bonded with MUF resin were produced the lab-scale regarding to the combinations of the layer structure and their properties were investigated and compared to standard requirements and previous researches.

Materials and Methods

Material

In this study, the 1^{st} to 6^{h} internode taken from three years old of *D. sericeus* culms at the bottom part were collected from Maehia bamboo collection plot, Royal Project Foundation located in Chiang Mai, North of Thailand. These bamboos had an average culm diameter was about 7.35 cm. The average culm wall thickness was 2.62 cm. The average specific gravity at 12% moisture content was 0.608.

Table 1 presents the working properties of the commercial MUF resin (E1 type) used in this study. Ammonium sulfate was used as the catalyst for.

Table 1 The working properties of UF resin used in this study

Properties	**Results**
Appearance	White-colored liquid
Viscosity at 20°C *(*cps)	150
Solid content 3 hrs at 105°C (%)	62.20
pH at 20°C	9.86
Density at 20°C	1.27

pH Value and Buffer Capacity Measurements

Bamboo chips were ground into the small particles and then screened with a -40/+60 mesh sieve. Furnish remaining on the 60# mesh screen was used for the investigations.

The method for pH value measurement was modified from the TAPPI T 509 standard method. One gram of dry specimen was soaked with 70-ml distilled water. The solution was stirred during soaking for one hour at room temperature. A pH meter (Docu-pH+ meter Sartorius) was used to determine the pH value. The value was recorded when there was no more drift in the measurement for a period of 30 seconds.

The buffer capacity measurement procedure was adapted from the method described by Maloney and Borden Chemical Inc. (Maloney 1993). Thirty grams of dry specimen were soaked in

400-ml of distilled water at room temperature for 30 minutes. The mixture was stirred during the soaking. The mixture was filtered through the filter paper using a vacuum. One hundred-fifty grams of the liquid was titrated with 0.01 N Sulfuric acid. The liquid was mixed together by a magnetic stirrer and the pH value was measured after acid addition, until a pH of 3.5 was reached. The buffer capacity value was calculated form Normality and volume of acid needed to change the pH to 3.5.

Determination of Contact Angle (Wettability)

A contact angle meter (Kyowa DM 300 with Famas software) was used to determine the contact angle. Bamboo samples were prepared and removed the outer and inner layers. All specimens were conditioned at 20°C and 65% RH until the constant weight was reached. Each bamboo surface was sanded by 220-grid sandpaper immediately before 2 mg of distilled water was dropped onto the surface of the specimens. The angle made between the droplet and the bamboo surface was measured after 2 seconds. Comparisons between the bamboo culm surfaces (inner and outer surfaces) and culm parts (internode and node) were done.

LBL Production and Properties Testing

Bamboo culms were cross-cut to 30 cm length. They were cut into strips of 5 x30 x 3000 mm. Their outer nodes and the epidermal layer were removed by a knife. Two bamboo strips were bonded edge to edge using polyvinyl acetate (PVAc) resin until the width was 60 mm.

LBLs (four layers) with approximate dimensions of 16x60x350 mm were produced in the laboratory using MUF resin with a glue spread rate of 200 g/m^2. These strips were hand-made into mats and arranged with parallel orientation. The experimental design involved three combinations of the layered structure (outer-outer, outer-inner and inner-inner layers), as illustrated in figure 2. After forming, mats were then pressed into boards at a nominal thickness of 16 mm with a temperature of 160°C at a pressure setting of 20 kg/cm^2 for 10 minutes and were pressed.

All LBLs were cut into test specimens and placed in a conditioning room maintained at 65% RH and 20°C for 4 weeks until constant weight was attained. The physical and mechanical properties of specimens were determined in accordance with EN 300: 1997 and ASTM D 5456-99.

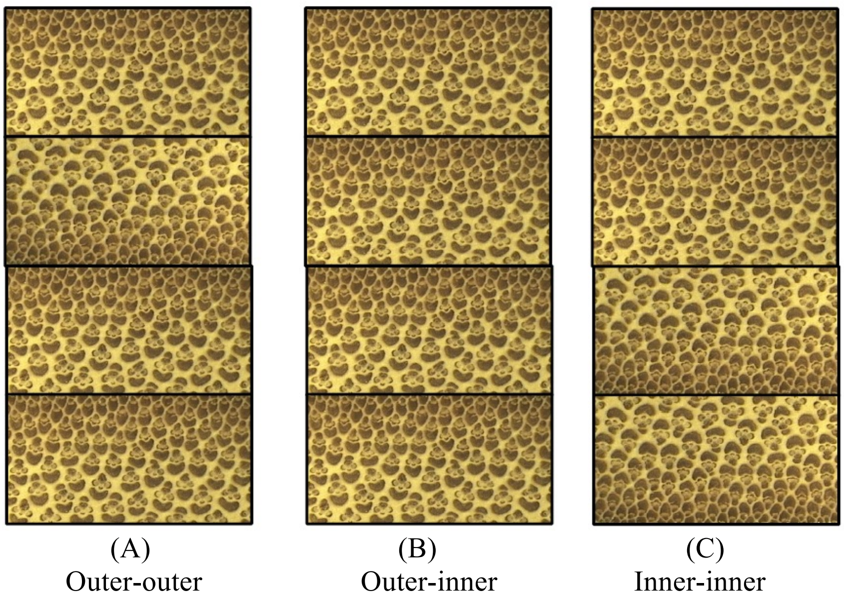

Figure 2 Combination of layered structure on laminated bamboo lumber; (A) outer-outer, (B) outer-inner and (C) inner-inner.

Results and Discussion

The mean pH value of *D. sericeus* is 6.08. Compared to wood species, the pH value of *D. sericeus* is slightly higher than those of some softwood and hardwood species commonly used as composite product which have value in the range of 4-6 (Fengel and Wegener 1984). The average buffer capacity of *D. sericeus* is 0.14 milliequivalents which is categorized as possessing high buffer capacity. From this result, it can be concluded that *D. sericeus* requires adding of a smaller amount of acid catalyst to reduce the pH to the optimum level which is required for a resin cure. The same technologies and practices may be applied to *D. sericeus* when manufacturing composites.

Table 2 Average value of contact angle on the surface of *D. sericeus*, separated by culm part and culm surface

Culm surface	**Culm part**	
	Internode	**Node**
Inner surface	45.05 (7.88)[1]	41.40 (7.79)
Outer surface	51.53 (4.56)	48.40 (9.82)

Note: [1] Number in parenthesis is associated to standard deviation

Table 2 presents the contact angle using distilled water at different culm part and surfaces. The average contact angle of *D. sericeus* is 46.60° which is quite similar to common wood species such as Aspen, Yellow-poplar and White Oak which have the contact angle of 38°, 51° and 50°, respectively (Freeman and Wangaard 1960). Comparison of contact angle was also made between the parts and surfaces in the culm. The result shows that the contact angle of outer surface is greater than that that of the inner surface. The larger angle at the outer surface implied that the outer surface is more difficult to be wetted than the inner surface. It could be explained by the density variation between the outer and inner part of bamboo culm Liese (1988). Moreover, the outer surface of bamboo culm is covered by wax that makes it hard for the adhesive to wet and penetrate to the cellular structure Liese (1988). Interestingly, the contact angle of nodes is significantly less than the internodes. An explanation for this phenomenon may be the different anatomical structure of the nodes and internode (Grosser and Liese 1971). Then, the wettability of nodes is found to be higher than internodes, which may impose some variability in adhesive bonding. The variation between internode and node is not desirable characteristics which have an effect on the wettability and penetration of liquid adhesive used for bonding the bamboo elements together.

From the practical point of view, the adhesive used for bamboo must be modified for the optimizing bonding process, such as increasing of the filler amount in the glue mixture, using the liquid which has the low surface tension as the solvent in glue mixture, or adding the surfactant into the glue mixture.

Table 3 Average physical and mechanical properties of four-ply laminated bamboo lumber made from *D. sericeus*

Type of layer	**SG**	**TS (%)**	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**
A	0.70 (0.03)[1]	22.6 (2.1)	47.64 (5.5)	5,604.16 (263)	0.29 (0.02)
B	0.71 (0.02)	12.2 (2.1)	57.78 (7.2)	7,977.78 (229)	0.42 (0.07)

C	0.70 (0.02)	10.8 (1.9)	58.69 (6.4)	9,863.60 (242)	0.45 (0.02)

Note: [1] Number in parenthesis is associated to standard deviation
SG = Specific gravity; TS = Thickness swelling; MOR = Modulus of rupture; MOE = Modulus of elasticity; IB = Internal bond strength

The physical and mechanical properties of LBL with different layered structures are shown in Table 3. The average specific gravity of LBL is 0.70 which is higher than the original specific gravity of *D. sericeus* because of the hot pressing process applied in LBL manufacture, which results in denser products. The result suggests that there is significant difference between types of layered structures. Type A shows the worse physical and mechanical properties than other types. This may be due to the center of specimen composed of the denser layer (outer-outer layer). As mentioned above, the outer surface of bamboo culm shows a high contact angle resulted in poor surface wettability and bonding strength of LBL. It can be confirmed by previous studies. Nugroho and Ando (2001) reported that the internal bond strength of bamboo zephyr board tended to decrease when bamboo zephyr strands were laid on outer-outer layer type. They explained that the outer surface of bamboo culm contains chemicals such as wax and silica, which has the seriously effect on the bonding strength of the glue line. Additionally, the outer surface of bamboo is denser than the inner layer, which can seriously affect the wettability and the penetration of resin. Furthermore, Anwar et al. (2005) reported that the shear strength property of Plybamboo was very low due to the low wettability of outer surface of bamboo culm. As the result, the best property occurred on the inner-inner layer. The getting higher in properties might be due to center of specimen composed of the lighter layer which is easier to be wetted by liquid adhesive resulted in better bonding strength.

Based on this finding, the bamboo strips should be laid in inner-inner layer type for LBL manufacturer.

Conclusions

Based on this study, the following conclusions can be drawn:

1. *D. sericeus* has the comparable pH value and buffer capacity to other commercial wood species.

2. The wettability of *D. sericeus* is quite similar to common wood species. In addition, wettability of bamboo culm outer surface is found to be lower than inner part. Moreover, the wettability of nodes was found to be higher than internodes.

3. The layered structure appears to be significant variable for the properties on four-ply LBL made from *D. sericeus*.

Acknowledgements

The authors gratefully acknowledge Royal Project Foundation and Centre of Excellence for Bamboos, Kasetsart University, Thailand for financial support. We would like also to express our thanks to Maehia bamboo collection plot and Research Center of Excellence on Wood Science and Engineering, Walailak University, Thailand for providing spaces and facilities for the experimental work.

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