

Preparation and Performance Evaluation of Bamboo Lumber Prepared by Assembly and Glue-Curing of Naturally Arc-Shaped Segments with Finger Joints

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Using bamboo to replace wood has great significance for the protection of forests. This work presents the concept of the reorganization of arc bamboo sheet to produce recombined arc-segment bamboo lumber (RABL). Several key preparation technology parameters were investigated. Results showed that when the phenol resin (PF) double-sided adhesive quantity was 250 g/m², unit pressure was 2.0 MPa, screen voltage was 4200 V, screen current was 1.5 A, and hot pressing time was 30 s/mm, the modulus of rupture (MOR) of the RABL was 105 MPa and the modulus of elasticity (MOE) was 5000 MPa. These parameters mean that RABL could be used as the structural material for load-bearing situations. If ignoring the machining allowance, the bamboo utilization rate of the RABL was 1.72 times that of the rectangular element recombinant bamboo and the adhesive level of the RABL was 0.6 times that of the rectangular element recombinant bamboo. When considering the machining allowance, the bamboo utilization rate of the RABL was 1.8 times that of the rectangular element recombinant bamboo, and the adhesive volume of the RABL was 0.56 times that of the rectangular element recombinant bamboo, so RABL has obvious advantages.

Keywords: Recombined arc-segment bamboo lumber; Preparation; Utilization rate; Adhesive volume; Rectangular element recombinant bamboo

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INTRODUCTION

With the decrease in wood resources, using wood efficiently and developing bamboo resources are becoming more and more important. China has the most abundant bamboo resources in the world. Using bamboo for replacing wood is a great measure to ease the use of wood resources and is also an effective measure to improve the ecological environment. The current applications of bamboo materials range from flooring, furniture, and decorative craft to structures in modern buildings (Zhang and Du 2007; Vogtlander *et al.* 2010; Li *et al.* 2011). In China, studies of bamboo mostly focus on bamboo plywood, bamboo reorganization, and bamboo integrated timber. Rectangular element recombinant bamboo has especially become a hot research topic for the replacement of wood. This type of bamboo is created by cutting bamboo tubes into equal lengths, splitting the tubes into consistent radian bamboo sections, and using a four-sided planer to cut the sections

into rectangular pieces. The pieces then undergo high-temperature heat treatment, drying, sizing glue application, and other processes, finally forming rectangular bamboo material for use instead of wood in products such as furniture and flooring. The bamboo utilization rate of rectangular bamboo, however, is low – usually only about 35%, and the machining process is quite complex; therefore, this work presents the concept of producing recombined arc-segment bamboo lumber (RABL).

RABL is made from arc bamboo sheet. These sheets are very smooth after the outer and inner parts of bamboo are removed. They are arranged to the direction of arc core, after applying adhesive. Several layers of material are stacked at the same direction. After the surface smoothing process, they are pressed into different thickness of material or lumber by adding adhesive; the inner and outer arc radius of arc bamboo are kept equal (Fei and Fu 2008). Domestic and foreign research related to bamboo recombination technology is neither based on the inherent characteristics of bamboo fiber nor the structure of the natural bamboo texture. Bamboo's arc structure, joints, hollow nature, and arrangement of cellulose are destroyed during recombination. Such a technology cannot reduce energy consumption, nor make full use of the excellent performance of the bamboo bionics, nor increase the functional index of the recombinant material.

The present study is based on utilizing the full inherent characteristics of bamboo fiber material, preserving the physical and mechanical properties of the bamboo, and maintaining the original natural bamboo texture to study the key process parameters of RABL: adhesive volume, high-frequency voltage, high-frequency current, pressure, and pressing time. The adhesive application level and bamboo utilization rate were also compared between the RABL and the currently used rectangular element recombinant bamboo.

EXPERIMENTAL

Materials

Bamboo (*Phyllostachys edulis*) was harvested from Xiangtan, Hunan province, China. A phenol resin (PF) (45% solids content) and an aqueous polymer isocyanate (API) with a purity of 99.6% were used as adhesives.

- PF: From Beijing Dynea Chemical Industry Co., Ltd. Viscosity (30 °C): 40.5 cps, solid content (2h/120 °C): 45.36%, pH (25 °C): 10.64, The multiple of water solubility: More than ten times.
- P-MDI: From Beijing Sheng Nuoya Technology Development Co., Ltd. Base: hardener=100:15. p-Nitrobenzoic acid (P-N-B) was used as a preservative.

Methods

Preparation of the arc restructuring unit

The production process of RABL is diagrammed in Fig. 1. A transverse circular saw machine was first used to cut the original bamboo into 1200-mm bamboo segments. According to the original bamboo taper and bending degree to confirm kerfs position and improve the utilization rate of bamboo, a mechanical breaking bamboo machine was used in the longitudinal direction to cut the bamboo into arc bamboo sheets with widths of approximately 40 mm. The required number of bamboo sheets is 500. (A set of related equipment is under development by the authors. The system can produce different size of bamboo sheet according to the different diameter of bamboo timber).

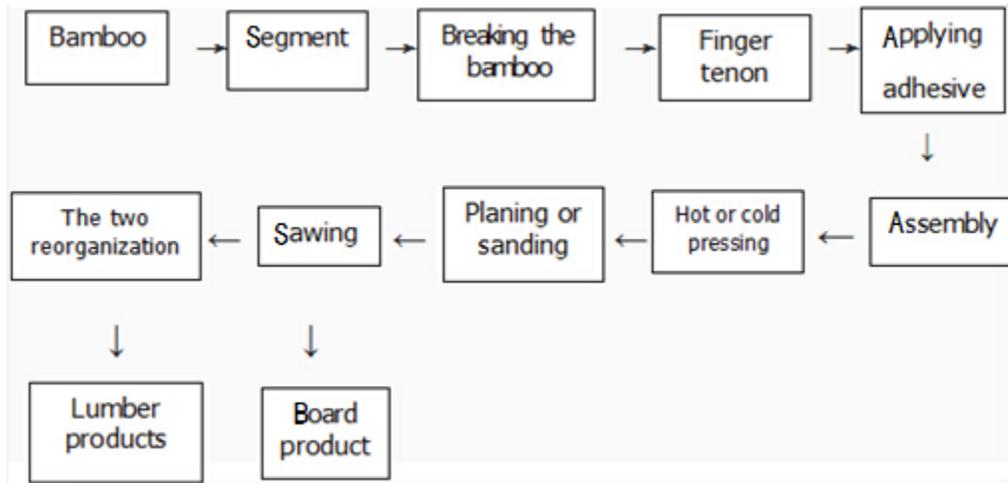


Fig. 1. Process flow diagram for the production of RABL

The sheets were removed from the bamboo interlayer, putting the arc bamboo sheet into a boiling 1.5% aqueous solution of P-N-B (bamboo sheet must be fully immersed). The bamboo was then heated with steam at a rate of approximately 2 °C/5 min to 60 to 70 °C and kept at this temperature for approximately 24 to 36 h. The arc bamboo sheet was then placed in a drying chamber at a temperature of 80 to 100 °C, drying to a moisture content of 5 to 10%. An arc shape and milling machine was used to remove the bamboo joints and the outer and inner part of bamboo, and it also cut the sheets to the required length. After the second milling, the cutting tool and clamping device were adjusted, and the bamboo sheets had a uniform width, an arc radius of 50 mm; the outer part and inner part of bamboo were removed, and the surface was smooth.



Fig. 2. Arc shape and milling machine



Fig. 3. Bamboo sheets without the outer part and inner part of bamboo

Applying adhesive and assembly

The bamboo sheets were divided into groups according to their length and width. In accordance with the bonding performance requirements of building structure materials, water proof adhesives with high bonding strengths and good anti-aging properties were selected: PF and API. The adhesive applications (two-sided) were performed at levels of 200, 250, or 300 g/m². After aging, the glued bamboo billets were assembled in the length

and width directions. The thickness of the material was the width of the bamboo billet, and the volume of the material was $1200 \times 1220 \times 35$ mm.

Hot pressing

A newly developed high-frequency hot pressing machine was used to produce RABL. This device was used to press the material in the vertical, lateral, and longitudinal directions at the same time. The highest voltage used was 6300 V, and the lowest was 4200 V, with all hot pressing conditions shown in Table 1.

Table 1. Hot Test Conditions for Recombined Arc-segment Bamboo Lumber

Test Level	Experimental Factors				
	Unit Pressure (MPa)	Glue	Adhesive Volume (g/m ²)	Hot pressing Time (s/mm)	Screen Voltage (V)
1	2.0	PF	300	15	6300
2	2.5	PF	300	30	4200
3	3.0	PF	300	30	4200
4	2.0	PF	200	30	4200
5	2.0	PF	250	15	6300
6	2.0	PF	300	15	6300
7	2.0	API	200	15	6300
8	2.0	API	250	15	6300
9	2.0	API	300	15	6300



Fig. 4. The finished product of RABL, which has good adhesion, beautiful lines, and good mechanical properties

RESULTS AND DISCUSSION

The Effects of Adhesive Type and Adhesive Volume on the Physical and Mechanical Properties of the Bamboo Material

For the sizing process, the primary investigation involved determining the changes in the material's physical and mechanical properties affected by the PF and API resins, with adhesive application levels of 200, 250, and 300 g/m². Figure 5 shows the influence of adhesive type and adhesive volume on the physical and mechanical properties of the material. With increasing PF adhesive application level, the bonding of the material increased; however, when the PF adhesive level was 300 g/m², the bonding strength of the material decreased. A similar trend was observed for MOR. The MOE increased with increasing adhesive application level; although there was fluctuation, the overall change was small. When the adhesive level was 250 g/m², the bonding strength was the highest, absorbent thickness expansion rate was the lowest, and the change of MOR was small.

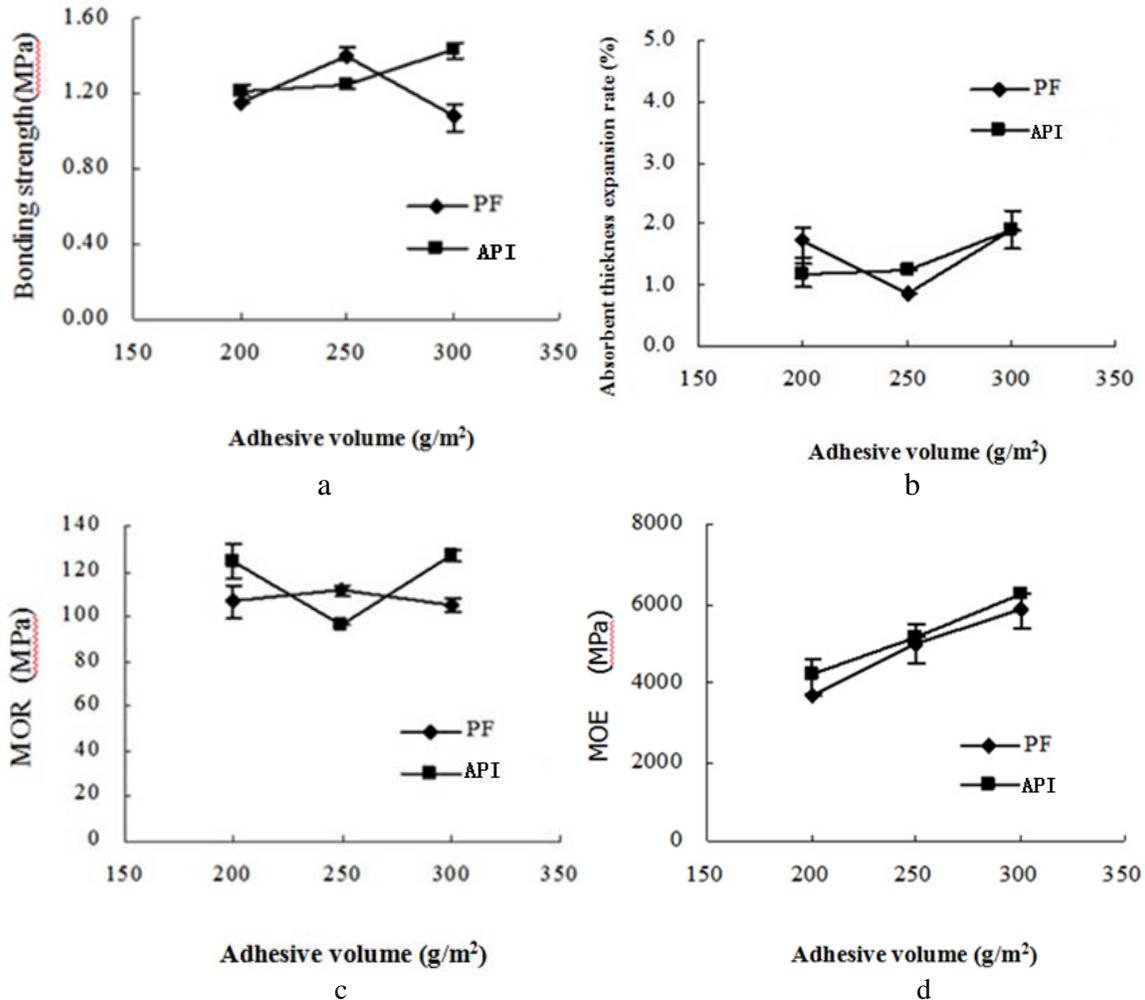


Fig. 5. The effect of adhesive type and adhesive volume on the physical and mechanical properties of material

For the bamboo sized with API, an increase in adhesive level enhanced the bonding strength, and the absorbent thickness expansion rate of the material was increased. At an application level of 250 g/m² the MOR of the material was the lowest. For the 200 and 300 g/m² adhesive levels, the difference in the material's MOR was small. With increasing adhesive level, the MOE increased.

From an overall perspective, the samples pressed with the API adhesive had a slightly higher MOR, MOE, and bonding strength than the material pressed with the PF adhesive. The absorbent thickness expansion rate is slightly lower for the material pressed with the PF adhesive. The reason is that the API has good liquidity, curing performance, and better permeability on the bamboo surface.

The Effect of Unit Pressure on the Physical and Mechanical Properties of the Bamboo Material

Figure 6 shows the effect of unit pressure on the material's physical and mechanical properties after hot pressing. Because the density of bamboo billet changes with species, age, diameter at breast height, stalk position, site conditions of the bamboo (Xu *et al.* 2003), and the fact that the bamboo sheets were collected from different locations, it is difficult to examine the influence of unit pressure on the material density, which therefore was not considered in this work.

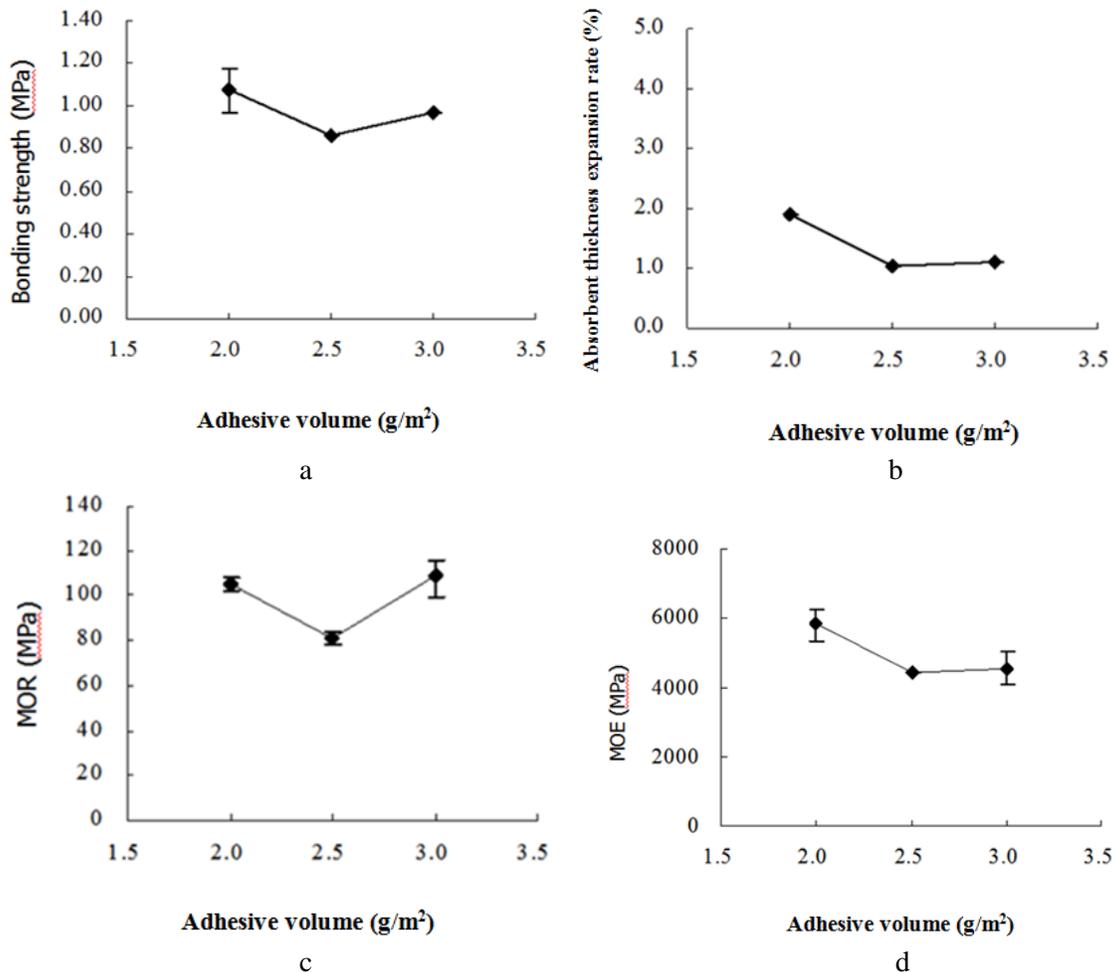


Fig. 6. The effect of unit pressure on the physical and mechanical properties of material
Note: Bamboo material used API as adhesive

Because bamboo has a high hardness, the influence of unit pressure on the material's moisture content, absorbent thickness expansion rate, and bonding strength was very small. As shown by Fig. 6, when the unit pressure was 2.5 MPa, the various properties of the material were low. When the unit pressure was 2.0 MPa, the bonding strengths of the materials was 1.08 MPa, the absorbent thickness expansion rates was 1.91%, the MORs was 105.0 MPa, and the MOEs was 5841 MPa. When the unit pressures were 3.0 MPa, the bonding strengths of the materials was 0.97 MPa, the absorbent thickness expansion rates was 1.12%, the MORs was 109.2 MPa, and the MOEs was 4531 MPa. Taking into account the cost reduction (the higher of the unit pressure, the more of the energy, the higher of production costs), the unit pressure of 2.0 MPa is considered the ideal pressure condition for low-cost production (Liu *et al.* 2009).

Effects of Various Experimental Conditions on the Mechanical Properties of the Bamboo Material

The primary mechanical performance index was calculated according to the National Standard of the People's Republic of China GB/T17657-1999 (Chen and Cao 1999). The test used the average value of the three parallel tests for the experimental results. The primary mechanical performance indices of materials pressed with different process conditions are shown in Table 2. The results of 2, 3, and 4 test levels from Tables 1 and 2 compared with other horizontal tests show that screen voltage and hot pressing time both influenced the MOR and MOE. When the screen voltage was 4200 V, the MOR ranged from 80.9 to 109.2 MPa and the MOE ranged from 3692 to 4530 MPa. When the screen voltage was 6300 V, the MOR ranged from 95.9 to 126.9 MPa and the MOE ranged from 4214 to 6240 MPa. Screen voltage and hot pressing time had no significant effect on the other indices. Because screen voltage is higher, the more heat energy produced by high-frequency hot pressing machine, it would be easier to promote permeation of adhesive into bamboo, so as to achieve better agglutination. As an overall result, RABL had better mechanical properties. Taking into account energy savings and cost reduction, a screen voltage of 4200 V and hot pressing time of 30 s/mm were selected for use.

Table 2. Physical and Mechanical Properties of Recombined Arc-segment Bamboo Lumber

Test Level	Density (g/cm ³)	Moisture Content (%)	Absorption Thickness Expansion Rate (%)	Bonding Strength (MPa)	MOR (MPa)	Elastic Modulus (MPa)
1	0.76	7.60	1.91	1.08	105.0	5841
2	0.70	8.70	0.41	0.86	80.9	4414
3	0.74	7.13	1.12	0.97	109.2	4530
4	0.73	7.95	1.72	1.15	107.0	3692
5	0.75	6.78	0.87	1.40	111.6	4997
6	0.76	7.60	1.91	1.08	105.0	5841
7	0.75	8.66	1.18	1.21	124.7	4214
8	0.71	6.34	1.24	1.24	95.9	5178
9	0.78	7.97	1.92	1.43	126.9	6240

Note: Bamboo material used API as adhesive

There is no standard for RABL, so the following standards were referenced: LVL standard (GB/T 20241-2006; Tang *et al.* 2006), structural bamboo and wood composite board standard (GB/T 21128-2007; Zhu *et al.* 2008), ply bamboo for concrete-form (LY/T 1574-2000; Zhang and Zhu 2000) to compare the mechanical properties of the materials.

Figure 7 shows a comparison of the MOR and MOE among RABL, laminated veneer lumber, structural bamboo, wood composite board, and ply bamboo for concrete-form. The results show that the MOR and MOE of RABL reached a 60E high-class product structure with laminated veneer lumber, a C level of bamboo wood composite board structure, and a B 50 type of bamboo plywood. RABL can thus be used as the structural material for load-bearing conditions.

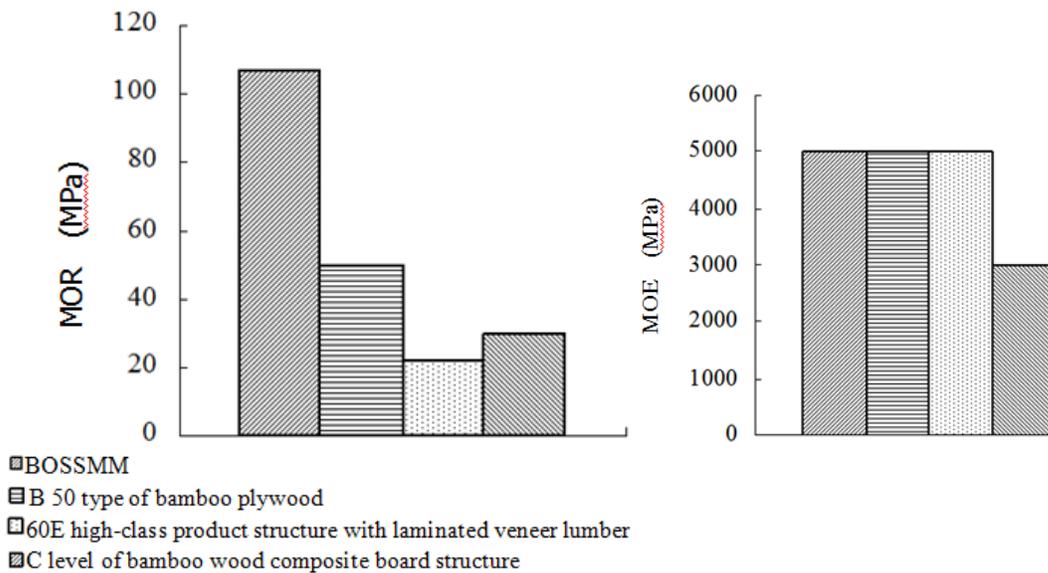


Fig. 7. Comparing the MOR and MOE of RABL and related materials.

Note: production conditions for RABL were double-sided PF adhesive, adhesive level of 250 g/m², and pressure of 2.5 MPa

Comparison of Bamboo Utilization Rate for RABL and Rectangular Element Recombinant Bamboo

Assuming that the original bamboo small end's outer radius is R , the inner radius is r , thickness is d , and cutting angle is 2θ , is cut into bamboo sections of length L . Each section of RABL volume formula can be calculated using Eq. 1 (Li *et al.* 2009).

$$V_{Arc} = S * L = L_{AB} * d * L \quad (1)$$

where S is the shaded part (dotted area) of the arc bamboo (as shown in Fig. 8). The volume of each rectangular section of bamboo can be calculated using Eq. 2 (Li *et al.* 2009),

$$V_{Rec} = S * L = L_{AB} * d_o * L \quad (2)$$

where S is the shaded part (line area) of the rectangular bamboo (as shown in Fig. 8). When ignoring the machining allowance of the bamboo, the length of the AB chord can be calculated using Eq. 3, and the height of the DC chord can be calculated using Eq. 4.

$$L_{AB} = 2r * \sin\theta \rightarrow V_{Arc} = d * L * 2r * \sin\theta \quad (3)$$

$$R - \sqrt{R^2 - (r \sin \theta)^2} \rightarrow d_o = d + \sqrt{R^2 - (r \sin \theta)^2} - R \quad (4)$$

The rectangle height must be greater than 0. Otherwise it will not produce rectangular bamboo unit, so $d_o > 0$, $\theta < \arcsin(\sqrt{2 * R * d - d^2} / r)$

$$V_{Rec} = L * 2r * \sin \theta * [d + \sqrt{R^2 - (r \sin \theta)^2} - R] \quad (5)$$

The ratio of the bamboo utilization rate of arc bamboo to that of rectangular bamboo is β :

$$\begin{aligned} \beta = V_{Arc} / V_{Rec} &= 2 * d * L * r * \sin \theta / L * 2 * r * \sin \theta * [d + \sqrt{R^2 - (r \sin \theta)^2} - R] \quad (6) \\ &= d / (d + \sqrt{R^2 - (r \sin \theta)^2} - R) \end{aligned}$$

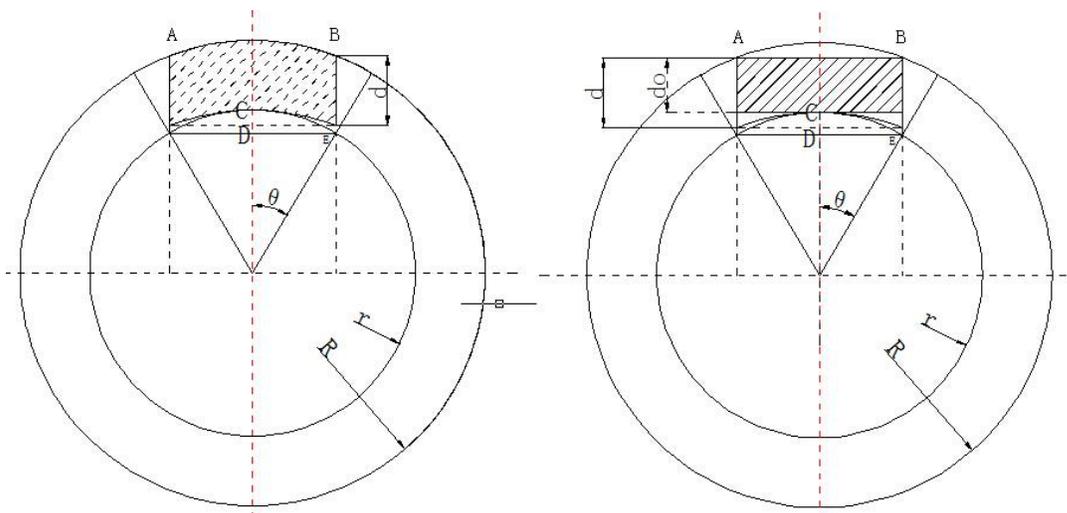


Fig. 8. Bamboo small end section coordinate diagram when ignoring the machining allowance

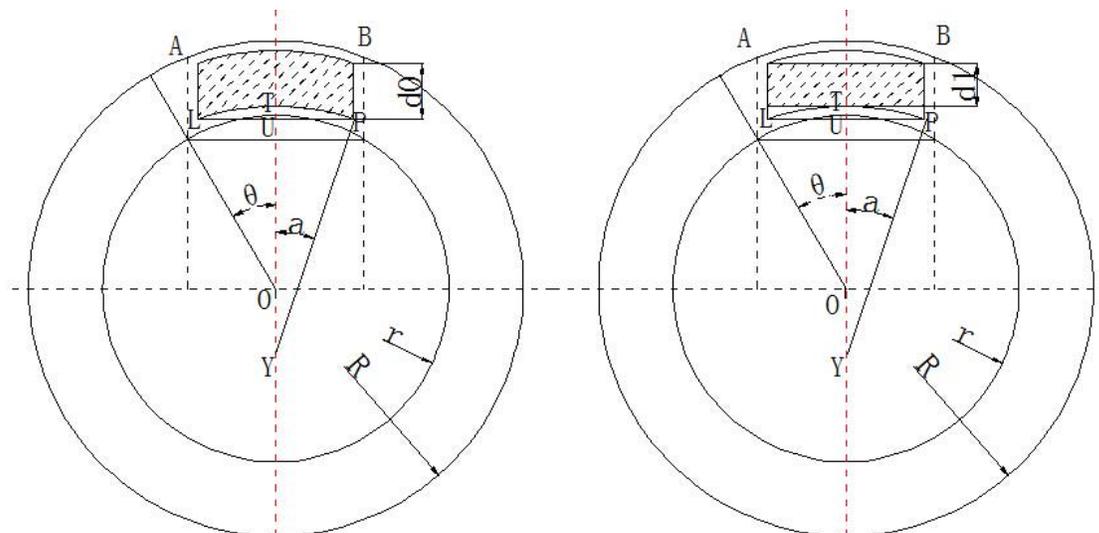


Fig. 9. Bamboo small end section coordinate diagram when considering the machining allowance

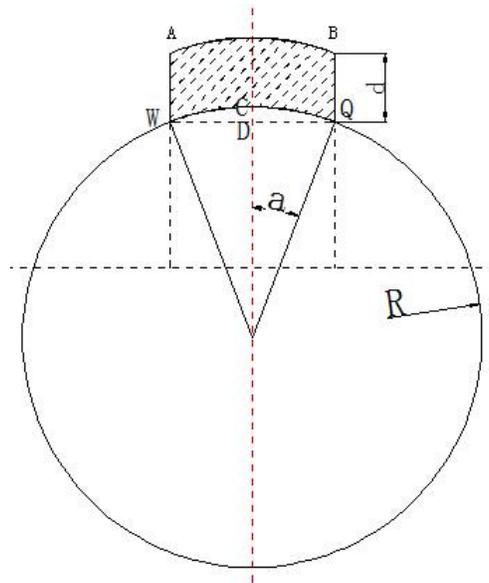


Fig. 10. Schematic diagram of arc bamboo small end section coordinates

When considering the machining allowance and assuming the machining allowance is 1 mm, the chord length $LP = 2r \cdot \sin\theta - 2$, $d_0 = d - 2$, so $V_{Arc} = L \cdot (d - 2) \cdot (2r \cdot \sin\theta - 2)$,

$$UP = r \cdot \sin\theta - 1, YU = \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} \tag{7}$$

$$UT = R - \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} \tag{8}$$

$$d_l = d + \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} - 2 - R \tag{9}$$

To ensure $d_l > 0$, $\theta < \arcsin[(\sqrt{2R \cdot d + 4d - 4 - 4R - d^2} + 1)/r]$. Therefore:

$$V_{Rec} = L \cdot (d + \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} - 2 - R) \cdot (2r \cdot \sin\theta - 2) \tag{10}$$

The ratio of the bamboo utilization rate of arc bamboo to that of rectangular bamboo is β :

$$\beta = V_{Arc}/V_{Rec} = L \cdot (d - 2) \cdot (2r \cdot \sin\theta - 2) / L \cdot (d + \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} - 2 - R) \cdot (2r \cdot \sin\theta - 2) = (d - 2) / (d + \sqrt{R^2 - (r \cdot \sin\theta - 1)^2} - 2 - R) \tag{11}$$

Comparison of RABL and Rectangular Element Recombinant Bamboo for Applying Adhesive Quantity

The amount of adhesive applied is an important factor in reducing the cost of production and reducing the release of harmful substances. This work compared the amount of adhesive required for RABL and rectangular recombined bamboo.

When ignoring the machining allowance of bamboo, it can be seen from Fig. 8:

$$\begin{aligned} \sin a &= r \cdot \sin\theta / R \quad \rightarrow \quad a = \arcsin(r \cdot \sin\theta / R) \quad \rightarrow \\ \text{Arc length WQ} &= 2a \cdot R = 2R \cdot \arcsin(r \cdot \sin\theta / R) \end{aligned} \tag{12}$$

Therefore, the medial area of the arc material is,

$$S_{Arc} = 2R * \arcsin(r * \sin\theta / R) * L \quad (13)$$

and the medial area of the rectangle material is:

$$S_{Rec} = 2r * \sin\theta * L \quad (14)$$

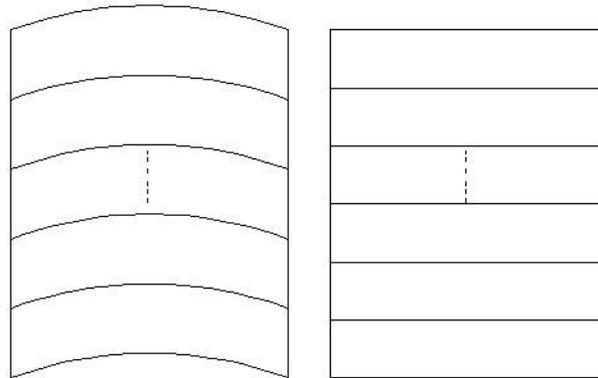


Fig. 11. Schematic diagram of material product

When using the same specifications as the original bamboo, producing P ($P = V_{Arc} * V_{Rec}$) cubic meters of material goods, the V_{Rec} arc restructuring unit or V_{Arc} rectangular restructuring unit is needed.

If each square meter of the adhesive was Z , with double-sided adhesive, the adhesive volume of that arc material needs to be:

$$\begin{aligned} H_{Arc} &= 2 * Z * 2R * \arcsin(r * \sin\theta / R) * L * \{L * 2 * r * \sin\theta * [d + \sqrt{R^2 - (r * \sin\theta)^2} - R] - 1\} \\ &= 4Z * R * L * \arcsin(r * \sin\theta / R) * \{L * 2 * r * \sin\theta * [d + \sqrt{R^2 - (r * \sin\theta)^2} - R] - 1\} \end{aligned} \quad (15)$$

The adhesive volume of the rectangular bamboo needs to be:

$$H_{Rec} = 2 * Z * 2r * L * \sin\theta * (2d * L * r * \sin\theta - 1) = 4Z * r * L * \sin\theta * (2d * L * r * \sin\theta - 1) \quad (16)$$

The adhesive volume required to produce P cubic arc material and rectangular material is determined by the ratio:

$$\begin{aligned} \eta &= H_{Arc} / H_{Rec} = 4Z * R * L * \arcsin(r * \sin\theta / R) * \{L * 2 * r * \sin\theta * [d + \sqrt{R^2 - (r * \sin\theta)^2} - R] - 1\} \\ &\quad / 4Z * r * L * \sin\theta * (2d * L * r * \sin\theta - 1) \\ &= R * \arcsin(r * \sin\theta / R) * \{L * 2 * r * \sin\theta * [d + \sqrt{R^2 - (r * \sin\theta)^2} - R] - 1\} \\ &\quad / r * \sin\theta * (2d * L * r * \sin\theta - 1) \end{aligned} \quad (17)$$

When considering the machining allowance of bamboo:

$$\begin{aligned} \sin a &= (r * \sin\theta - 1) / R \quad \rightarrow \quad a = \arcsin[(r * \sin\theta - 1) / R] \\ \rightarrow \quad \text{Arc length LP} &= 2 \arcsin[(r * \sin\theta - 1) / R] * R \end{aligned} \quad (18)$$

The medial area of the arc material is given by,

$$S_{Arc} = 2r \arcsin[(r \sin \theta - 1) / R] * R * L \quad (19)$$

whereas the medial area of the rectangular material is given by:

$$S_{Rec} = (2r \sin \theta - 2) * L \quad (20)$$

When using the same specifications as the original bamboo, producing P ($P = V_{Arc} * V_{Rec}$) cubic meters of material goods, either the V_{Rec} arc restructuring unit or V_{Arc} rectangular restructuring unit is required.

If each square meter of the adhesive application is Z , with double-sided adhesive, the adhesive volume of the arc material needs to be:

$$H_{Arc} = 2Z * 2r \arcsin[(r \sin \theta - 1) / R] * R * L * (V_{Rec} - 1) \quad (21)$$

and the adhesive volume of the rectangular bamboo needs to be:

$$H_{Rec} = 2Z * (2r \sin \theta - 2) * L * (V_{Arc} - 1) \quad (22)$$

The ratio of adhesive volume that produces P cubic arc material and rectangular material required is:

$$\eta = H_{Arc} / H_{Rec} = 2r \arcsin[(r \sin \theta - 1) / R] * R * (V_{Rec} - 1) / (2r \sin \theta - 2) * (V_{Arc} - 1) \quad (23)$$

According to the relationship between the bamboo small end diameter, wall thickness, and taper from Table 3, and using the average value of each section of the small end diameter (97, 110, 120, 130, and 140 mm), the radii are 48.5, 55, 60, 65, and 70 mm, respectively; this is with a common cutting angle $\pi/3$ and a cutting length L of 1200 mm. These values were used to determine the bamboo utilization rate (β) and the ratio of adhesive volume producing P cubic arc material and rectangular material (η), and the calculated results are shown in Table 4.

Table 3. The Relationships among Bamboo Small End Diameter, Wall Thickness, and Taper

External Diameter of Small End (mm)	Wall Thickness of Small End (mm)	Outer Taper	Inner Taper	Taper Difference
90 to 104	10	0.002	0.002	0
106 to 114	11	0.003	0.002	0.001
116 to 124	12	0.004	0.003	0.001
126 to 134	13	0.006	0.005	0.001
136 to 145	14	0.007	0.005	0.002

As shown in Table 4, when ignoring the machining allowance of bamboo, the utilization rate for the RABL is 1.72 times that of rectangular element recombinant bamboo; however, the adhesive volume is 0.6 times that of rectangular element recombinant bamboo. When considering the machining allowance of bamboo, the RABL utilization rate is 1.8 times that of rectangular element recombinant bamboo, and the adhesive volume is 0.56 times that of rectangular element recombinant bamboo.

Table 4. The Relationships among the External Diameter of Small End, β , and η

External Diameter of Small End (mm)	Value of β when ignoring the machining allowance of bamboo	Value of η when ignoring the machining allowance of bamboo	Value of β when considering the machining allowance	Value of η when considering the machining allowance
97	1.66	0.85	1.62	0.63
110	1.72	0.6	1.86	0.55
120	1.72	0.6	1.85	0.55
130	1.72	0.6	1.83	0.56
140	1.72	0.6	1.82	0.56

CONCLUSIONS

1. This work presents the concept of arc bamboo strip recombination, and it also produces RABL. This production process is a technological innovation of rectangular element recombinant bamboo.
2. The performance of RABL with a PF adhesive is slightly lower than RABL with an API adhesive. Taking into account the cost of production, it is suitable to use a PF adhesive in industrial production; the amount of PF double-sided adhesive is 250 g/m², and the performance of the material is good.
3. In hot pressing, the unit pressures are 2.0 and 3.0 MPa and the properties of the material are good, with little difference. Considering the energy saving and cost reduction, the unit pressure of 2.0 MPa is the ideal pressure condition. The hot pressing process selected used a screen voltage of 4200 V, a screen current of 1.5 A, and a hot pressing time of 30 s/mm. The MOR and MOE of the RABL pressed by this process reached 60 E high-class product structure with laminated veneer lumber, C level of bamboo wood composite board structure, and B 50 type of bamboo plywood, which can be used as structural material for load-bearing situations.
4. When ignoring the machining allowance of the bamboo, the utilization rate of RABL was 1.72 times that of the rectangular element recombinant bamboo; however, the sizing quantity was 0.6 times that of the rectangular element recombinant bamboo. When considering the machining allowance of the bamboo, the utilization rate for the RABL was 1.8 times that of the rectangular element recombinant bamboo, and the sizing quantity was 0.56 times that of the rectangular element recombinant bamboo. Compared with the current rectangular element recombinant bamboo, RABL has obvious advantages of high utilization rate of bamboo timber, low glue consumption, and being environmentally friendly.

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