A Dry–Wet Process to Manufacture Sliced Bamboo Veneer

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Abstract

The processes and properties of sliced bamboo veneer are discussed in this article. The results show that using a dry–wet process in the assembly of wet laminated bamboo lumber is the key technology for improving the yield of sliced bamboo veneer. Use of the dry–wet process increases the moisture absorption of laminated bamboo lumber, which results in the improvement of heat transfer and makes it possible to solve the problems of bamboo damage caused by uneven softening. The yield of sliced bamboo veneer is 66 percent by the dry–wet process, which is significantly higher than the previous dry process (20%). The final moisture content and appearance quality of sliced bamboo veneer in the dry–wet process are improved compared with the previous dry or wet processes.

Bamboo is a promising raw material for the manufacture of decorative products because of its remarkable growth rate, uniquely straight texture, elegant color, and its physical and mechanical properties compared with some commercial wood species (Jain et al. 1992, Kumar and Dobriyal 1992, Lee et al. 1996). The feasibility of using bamboo in different composite panels has been studied in many countries, especially in Asia, where bamboo is widely used in housing, light bridges, and furniture (Janssen 1988; Chen et al. 1989; Zhang 1995; Kim et al. 1998; Nugroho and Ando 2000, 2001; Zhang and Jiang 2003).

The small-diameter, thin-walled cells, and hollow structure of bamboo, however, require complicated manufacturing processes and result in low yield and high cost for bamboo-based products. Sliced bamboo veneer is a new type of high-grade decorative material, which was adopted due to the rising prices of raw materials and increasingly intense market competition (Li et al. 2003, Liu et al. 2003). The bamboo veneer, as a value-added product, provides new opportunities for furniture and other related industries.

In our previous research, two methods, a dry process (Li et al. 2003, Liu et al. 2003) and a wet process (Huang 2003), were studied in the manufacture of sliced bamboo veneer. A typical dry manufacturing process of bamboo veneer from harvesting bamboo to a finished product includes the following series of steps: *raw bamboo* → cross-cutting → splitting → primary planing → steaming with chemicals → drying → smoothing and planning → *final strip* → glue application → assembly → hot pressing → *bamboo board* → sanding → glue application → assembly → cold pressing → *laminated bamboo lumber* → steaming and softening → slicing → wetting sliced bamboo veneer → drying → crosswise jointing, lengthening → binding with nonwoven fabric (paper) → edging → remedial treatment → sanding → *final product*. Figure 1 demonstrates how raw bamboo is transformed into veneer. In this dry process, the knots and water-resistant glue lines in laminated bamboo lumber result in difficulties transmitting moisture and heat into laminated bamboo lumber and require long treatment times and high energy during the softening process. The quality of the sliced bamboo veneer was extremely low as a result of nonuniform moisture and temperature distribution. To solve these issues, a modified process called the wet process was developed. In this wet process, bamboo strips were kept wet without drying and cold pressed into wet bamboo boards and wet bamboo lumber. The wet process significantly improved softening and, thus, veneer quality. During the industrial trial, however, it created a new problem. It took only 5 days for the wet bamboo strips and boards to grow

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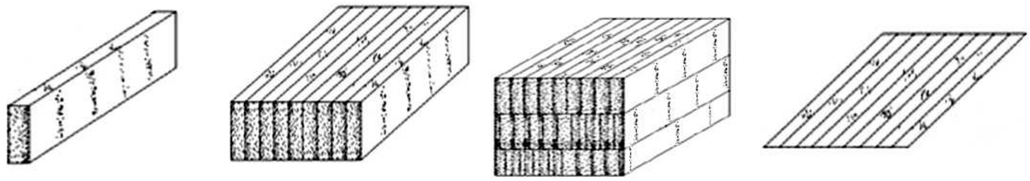

(a) (b) (c) (d)

Figure 1.—Schematic diagram of (a) bamboo strip, (b) bamboo board, (c) laminated bamboo lumber, and (d) sliced veneer.

mold and display color changes during the wet storage. The quality of the sliced bamboo veneer was also poor, and it easily changed color. Both methods did not achieve the requirements for high productivity, rate of qualified products, and good quality of industrial production.

The objective of this research was to develop a new dry–wet process to fabricate laminated bamboo lumber for veneer production in order to solve the technical issues related to the existing dry process and wet process. The moisture content of bamboo board for different conditioning pressures and times was investigated. And the quality and properties of bamboo sliced veneer manufactured by three techniques were also evaluated and compared.

Materials and Methods

Materials

Raw bamboo (*Phyllostachys edulis* (Carr.) H. De Lehaie) of 5 to 6 years of age and more than 10 cm in diameter was taken from a bamboo plantation located in Linan District, Hangzhou, China. The melamine-modified urea-formaldehyde resin (MUF), water-based polymer isocyanate (API), urea-formaldehyde resin (UF), and polyvinyl acetate emulsion (PVAc) were used as the adhesives in different processes. The mixture of UF and PVAc was used to glue a nonwoven fabric (paper) to the final product.

Yield of sliced bamboo veneer

The yield of sliced bamboo veneer was the ratio between the number of full-sized sliced bamboo veneers and the total number of the theory-sliced thin bamboo veneers per cubic meter.

This was calculated as follows:

$$X = \frac{A}{B} \times 100\% \quad (1)$$

where X is the yield, A is the number of full-sized sliced bamboo veneers per cubic meter, and B is the total number of the theory-sliced thin bamboo veneers per cubic meter, which is equal to bamboo lumber thickness divided by bamboo veneer thickness.

Producing bamboo strip and board

Three thousand bamboo strips (shown in Fig. 1a) with fixed width were made through processes such as sawing, cross-cutting, splitting, primary planing, steam treatment, drying, and dimensional planing. Some of the strips for the wet process did not go through the drying step before dimensional planing. The tolerance of width and thickness of bamboo strips was controlled within ±0.1 mm. The strips with severe warps, blunt edges, decay, wormy areas, or blue and yellow fungus stain were removed, which improved the grade of sliced veneer. The final size of the bamboo strips was 2,650 (length [L]) by 20 (width [W]) by 6 to 8 (thickness [T]) mm, with a moisture content of 8 to 10 percent for both the dry process and the dry–wet process. The process parameters of bamboo boards and laminated bamboo lumber produced in three different processes are summarized in Table 1. The bamboo strips were assembled side-by-side and edge-glued using MUF for both the dry process and the dry–wet process; API was used for the wet process. Cold pressing was used to manufacture the bamboo boards (Fig. 1b) for the wet process, and hot pressing was used for both the dry process and the dry–wet process. The final size of bamboo boards consisting of 40 to 54 strips was 2,650 (L) by 320 (W) by 20 (T) mm.

Producing laminated bamboo lumber

Laminated bamboo lumber was produced by assembling several layers of bamboo board with the grain in parallel directions. The MUF and hot pressing were used for the dry process. The API and cold pressing were used for both the dry–wet process and the wet process (shown in Table 1). For the dry–wet process, the bamboo boards were submerged under water at 0.4 to 1.0 MPa pressure and room temperature for 1 to 5 hours (listed in Table 2) prior to bamboo lumber fabrication. After pressing, the lumber was conditioned at room temperature for 24 hours and then immersed in water to further increase water absorption.

Slicing and evaluation

All laminated bamboo lumber was stored under water at room temperature for at least 2 days and then conditioned under hot water at 60°C for 2 to 3 days prior to slicing. The target thicknesses of sliced veneers were 0.3 to 0.8 mm, which were the same as the references of Li et al. (2003).

Results and Discussion

Bamboo board moisture content

To increase the moisture content of the bamboo boards, preconditioning was done at atmospheric condition or in a pressured tank. Because knots and adhesive layers of bamboo resist water transfer, the bamboo boards took 1.5 days for the moisture content to rise from 10 to 40 percent under atmospheric condition. For laminated bamboo lumber, increasing the moisture content was even more difficult. It could not meet the requirements of industrial production. Therefore, in actual production, speeding up the conditioning cycle of the bamboo boards by pressurized immersion greatly increased the efficiency of production. Table 2 shows the moisture content change of bamboo boards for different pressures and conditioning times. Between 0.4 and 1.0 MPa, the moisture content of bamboo

Table 1.—Process parameters of bamboo boards and lumber produced in different processes.

Process	Sample	Adhesive[a]	Pressing parameters			
			Adhesive spread (g/m^2)	Pressure (MPa)	Temp (°C)	Time (min)
Dry	Bamboo board	MUF	130	2.5	95	15
	Laminated bamboo lumber	MUF	150	2.0	Room	180
Wet	Bamboo board	API	180	2.5	Room	180
	Laminated bamboo lumber	API	180	1.5	Room	180
Dry–wet	Bamboo board	MUF	130	2.5	95	15
	Laminated bamboo lumber	API	180	1.5	Room	180

[a] MUF = melamine-modified urea-formaldehyde; API = water-based polymer isocyanate.

boards increased with pressure or time. Because bamboo is a porous material, there are many different sizes of cells and voids on the surface of bamboo; it has the permeability of a porous solid surface (Zhang 1995). Pressure forces the water to penetrate the voids and forms high pressure both inside and outside of the bamboo cells, which allows water molecules to flow into the bamboo. The greater the pressure, the quicker water transfers. Selecting the appropriate conditioning process parameters in the production process should be based on production equipment. The treated bamboo boards should be stored in a wet condition to increase water absorption.

The differences of shrinkage and swelling of bamboo are distinct because its density and vascular distribution of cells is different from wood. The density of bamboo in the cross-section varies along its thickness. The density of bamboo in the outer surface region is much higher than the density in the inner surface region due to distinct differences between the fiber and vascular cell distribution. This makes it easy for bamboo to warp and difficult to slice (Zhang 1995). In the dry process, when dry bamboo board was directly glued into laminated bamboo lumber, the existence of water-resistant bond lines and the structure of bamboo made it difficult for water and heat to penetrate during the conditioning processes, resulting in uneven softening and delamination. These problems usually occurred when the moisture content of bamboo lumber was less than the fiber saturation point, which would decline with increasing moisture content. In the wet process, when the moisture content of laminated bamboo lumber exceeded the fiber saturation point, additional moisture could not cause laminated bamboo lumber swelling and delamination. The sliced bamboo veneer was relatively smooth and flat. But during the storage, a lot of wet bamboo strips and boards molded and discolored, which negatively affected the quality of sliced bamboo veneer. Moreover, the use of the wet–cold press processes to manufacture both bamboo boards and laminated bamboo lumber required long pressing cycles, which resulted in the lower efficiency of production. The new dry–wet process allows bamboo strips to be fabricated into bamboo boards by hot pressing with a short pressing cycle, and the moisture content of bamboo boards can be increased to more than 30 percent within a few hours (Table 2). Both bamboo strips and boards can be stored in the dry condition, which eliminates potential mold and color change issues. The bamboo boards were then cold-glued into wet laminated bamboo lumber. Owing to the higher moisture content, heating the laminated bamboo lumber was easily achieved.

Table 2.—Moisture content (%) of bamboo boards for different conditioning pressures and times.

Conditioning time (h)	Pressure (MPa)			
	0.4	0.6	0.8	1
1	28.80	29.95	35.60	39.15
2	35.36	36.52	42.97	47.76
3	39.33	40.94	49.80	53.43
4	41.91	45.43	54.71	58.12
5	47.19	49.24	57.85	62.14

Quality of sliced bamboo veneer

Softening of laminated bamboo lumber is key to manufacturing high-quality sliced bamboo veneer, which could reduce knife wearing and cutting resistance. Laminated bamboo lumber is quite different from solid wood lumber because it contains more nodes and glue lines. Conventional wood lumber conditioning parameters, typically submerging the lumber in 70°C to 90°C water, could not be used to soften laminated bamboo lumber because it could easily result in delamination of the laminated bamboo lumber. Therefore, a lower temperature of about 60°C with a slow heating rate is required to condition the bamboo lumber. A mill trial showed that the initial high moisture content of the wet laminated bamboo lumber produced by the dry–wet process significantly improved heat transfer, temperature distribution, and plasticity, which helped achieve smooth slicing of laminated bamboo lumber. The suitable parameters to condition the laminated bamboo lumber in the water were a heating speed of 1.5°C/h, a final water temperature of 60°C ± 3°C, and a conditioning time of 2 to 3 days.

The conditioned laminated bamboo lumber was sliced into bamboo veneer using conventional equipment, such as a horizontal or hang slicer as shown in Figure 2. Table 3 summarizes the quality of sliced bamboo veneer produced in different processes. The slicer results showed that the conditioned laminated bamboo lumber could be sliced easily and smoothly. The yield of full-sized sliced bamboo veneer was 66 percent by the dry–wet process, which was significantly higher than the dry process (20%) as measured by Equation 1. As discussed in the previous section, uneven softening and delamination usually occurred in the laminated bamboo lumber made by the dry process and consequently resulted in lower yield of full-sized sliced bamboo veneer. The slice blade should be tilted in the direction of bamboo fiber orientation and have a certain degree of angle with the bamboo lumber. Blade sharpening was particularly critical. The blade should be straight and have no defects

Figure 2.—(Top) A horizontal slicer and (bottom) a hang slicer.

(i.e., chips); otherwise the surface of the veneer might have small defects from the blade. The suitable slicing parameters were as follows: posterior horn of slicing was 1° to 2°, cutting angle was 18° ± 1°, and the inclination of the tool cutting edge was 5°.

Table 3.—Evaluation of sliced bamboo veneer produced in different processes.

	Moisture content (%)			
Process	Bamboo strip	Bamboo board	Laminated bamboo lumber	Evaluation
Dry	7–10	7–10	7–10	Thin bamboo veneer yield is 20%
Wet	≥30	≥30	≥30	Wet bamboo strips were easy to mold, discolored, low veneer productivity
Dry–wet	7–10	Dry, 7–10; wet, ≥30	≥30	Thin bamboo veneer yield is 66%, product quality is better with high efficiency; it is easy to achieve industrial production

It can be seen from Table 4 that the moisture content and appearance of thinly sliced bamboo were improved with the dry–wet process and now meet the requirements of industrial production. The thickness of sliced bamboo veneer was generally 0.3 to 0.8 mm. Because the sliced bamboo veneer was easily damaged owing to its low tensile strength perpendicular to the grain, a mixture of UF and PVAc resins was used to bond a nonwoven fabric (paper) to protect the sliced bamboo veneer. In the industrial trial, a stainless veneer roller dryer was used to dry bamboo veneer; the drying temperature was about 80°C to 90°C, and the drying time increased with increasing veneer thickness. The moisture content was reduced to about 8 to 12 percent for the final products. Sliced bamboo veneer can be made into

Table 4.—Thickness properties of sliced bamboo veneer produced by dry–wet process and dry process.

Process	Thickness (mm) ± SE	Moisture content (%)
Dry–wet	0.8 ± 0.05	9.3
	0.6 ± 0.05	8.9
	0.4 ± 0.03	7.8
Dry	0.8 ± 0.07	9.5
	0.6 ± 0.06	9.0
	0.4 ± 0.04	7.7

many products, such as large size bamboo veneer, bamboo veneer cover material, bamboo veneer plywood, and so on.

Productivity

In the dry–wet process, a hot pressing schedule was used to fabricate the bamboo boards, and the pressing cycle was 15 minutes. The overall veneer productivity was significantly improved. At present, sliced bamboo veneer has widely been used as a decorative veneer and interior decoration material for wood-based panels, furniture, flooring, and so on. Sliced bamboo veneer can be edge-jointed to manufacture standard 4 by 8-foot sheets, which can be overlaid to plywood, medium-density fiberboard, particleboard, and other wood-based panels using conventional overlay presses.

Conclusions

The yield of sliced bamboo veneer was 66 percent by the new dry–wet process, which was significantly higher than the dry process (20%). When compared with the wet process, the efficiency of producing sliced bamboo veneer with the dry–wet process increased substantially, and the properties of mold growth and discoloration in the surface of sliced bamboo veneer greatly improved. Therefore, the final moisture content and appearance of sliced bamboo veneer in the dry–wet process were improved.

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