Laminated Panel Manufacture of Two Kinds of Bamboo for Architecture Material and Property Comparison

Zheng Wang Wenjing Guo
(Research Institute of Wood Industry, Chinese Academy of Forestry Research, Beijing, 100091)

Abstract: The manufacture technologies of two kinds of bamboo laminated panel and their physical-mechanical properties have been studied in this paper. The species of bamboo are the *D. yunnanicus hsueh* produced from Yunnan province and *P. heterocycla var. Heterocycla pubescens* produced Zhejiang province. The data are offered in order to characterise architectural panels made by bamboo materials. The results have shown as follows: laminated bamboo panels can be produced by the splitting and regluing, and the mechanical properties reached or even exceeded some pine used in architecture. Comparing the physical-mechanical properties of laminated panel made of two bamboo species, it can be seen that properties of laminated *Yunnanicus Hsueh* panel were higher than those of laminated *Heterocycla pubescens* panel, but dimensional stability was worse than the latter. In the comparison of laminated directions, it can be seen that parallel panel had better mechanical properties than crossed panel, and can be used for bearing parts in building such as I-beam and column, while the laminated panel with orthogonal direction can be used as less or non bearing components such as wall, roofing and flooring boards. Comparing with the *Heterocycla pubescens* panel, the aging characteristic of the *Yunnanicus Hsueh* laminated panel was the worse. It showed that physical-mechanical properties of laminated *Heterocycla pubescens* panel were more stable.

Key words: Bamboo, Laminated board, Architecture material, Physical- mechanical property.

Introduction:

Bamboo is one of the most important forestry resources in our country. It is one of a kind of rapid-growing biologically-based materials which can be utilized long-term by reasonable management. In recent years, because of the implementation of the "Natural Forest Conversation Program" and increase of GDP, wood resources become increasingly out of stock. Under this situation, to take bamboo as raw material and make use of advanced reconstituted technology to produce laminated panel for structural-used architecture materials not only can release the strained situation between supply and demand, but also play an important role in developing bamboo usages and improving people's living standard in these districts. This study took two kinds of big bamboo—*D. yunnaicus Yunnanicus Hsueh et D. Z. Li* and *P. heterocyclavar. Heterocycla pubescens ohwi* as basic materials then discussed basic process and key variables of reconstituted technology to produce structural-use boards. At the same time, influences that bamboo species would make on product's properties were studied. It brought forward basic proof to bamboo architecture technology.

1. Materials and experiment methods

1.1 Bamboo materials

In this study, the common big bamboo species—*D. yunnaicus Yunnanicus Hsueh et D. Z. Li* and *P. heterocyclavar. Heterocycla pubescens ohwi* were studied. *D. yunnaicus Yunnanicus Hsueh et D.Z.Li* is a kind of sympodial bamboo, diameter is 110~180 mm, culms can be 25 meters high and wall can be more than 10 mm. *P. heterocyclavar. Heterocycla pubescens ohwi* is also one of commonly used big bamboo species, it is a kind of monopoial bamboo, diameter is 180 mm and culms can be 20 meters high. The area of *Heterocycla pubescens* takes more than 2/3 of total areas in China. It is the most widely scattered economic bamboo species and can be used for flooring, furniture, bamboo-weaved products and bamboo cement formwork.

1.2 Equipments and assistant materials

The following equipments were used: impregnation tank, hot press, cold press, universal physical-mechanical testing apparatus, cold-water vessel, hot-water vessel and oven. In order to guarantee the properties of structural-use bamboo materials and weathering resistance, PF adhesive was taken into consideration.

1.3 Experiment methods

The following is technological process that produces laminated bamboo panel:

rip *trim* *dipping* *dry*

Bamboo culms ⟶ *bamboo pieces* ⟶ *bamboo strips* ⟶ *saturated bamboo* ⟶

lay up *hot/cold-pressing*

oven-dried saturated bamboo ⟶ *mat* ⟶ *laminated bamboo panel*

In this process, bamboo culms were cut into long pieces at longitudinal directions first, then trimmed as strips 0.5~0.8 mm thick and 20~30 mm wide, at the same time exterior layer was wiped off. When bamboo strips were air dried to 10~12% moisture content (m.c.), they were dropped into 37% PF adhesive. After surface of bamboo strips had adhesive, they were fished out and excessive adhesive was wiped off. After these saturated strips were dried to 16% m. c., they were laid up according to requirements and hot and cold pressed to products.

In this study, processing variables were as follows: adhesive adding content was 8%, suppose bamboo strips were 12~16% m.c.; hot pressing temperature was 140 ; hot pressing time was 1~1.5 min/mm (decided by m.c.); hot pressing pressure was 5 MPa, density of panel was 0.95~1.00 g/cm^3; cold pressing pressure was 1.5 MPa and time was 0.5 min/mm.

Bamboo strips were laminated with different directions, one was along the grain, which strips were laid up at the same direction; the other was crossed laminated, laid one layer or more than one layers together with adjacent layers crossed.

1.4 Physical-mechanical property testing of the laminated bamboo panel

The physical-mechanical properties of laminated bamboo panels were determined as follows: modulus of rupture (*MOR*), modulus of elasticity (*MOE*), density, thickness swelling content (*TS*) after saturated in cold-water for 24 hours and in boiling-water for 2 hours. To testify its weathering resistance, property changes should be tested after accelerated aging. Two methods were adopted to test the aging property: one was the standard ASTM D3434 in America, the method was: to put laminated panel into 100 boiling water for 10 minutes and air-dry test pieces for 4 minutes at room temperature, then treat it in 107 oven for 1 hour, we call it a cycle. In this study, data of residual *MOR* and *MOE* were tested after 20 cycles. The other method was: to put laminated panel into boiling water for 2 hours, then at the temperature of 107 , oven-dry it for 17 hours, test residual *MOR* and *MOE.*

2. Results and Discussion

2.1 The appearances of the laminated panels and their molding structure component samples

The appearances of the laminated panels with different laying up directions have been shown in the fig.1. The small samples of the molding structure component that are made from the laminated panels have been seen in the fig.2.

Fig. 1 the panels laminated along the grain and cross grain, as well as the bamboo flake board for architecture wall material

fig.2. The samples of the molding structure component, box-beam and splint-column made from bamboo laminated panels

2.2 Physical properties of two kinds of bamboo laminated panels

Table 1 showed physical-mechanical properties of two kinds of bamboo panel laid up at different directions.

Tab. 1 Physical-mechanical properties of two laminated bamboo panel

Species	Directions	Density /(g/cm^3)	*TS* (%)		*MOR* /MPa	*MOE* /GPa	Compressive strength parallel to grain
			24 hours in cold water	2 hours in boiling water			
Heterocycla pubescens	Parallel	0.96	2.4	17.8	174.70	13.68	85.47
	Crossed	1.00	2.5	17.1	135.78	10.50	71.99
Yunnanicus Hsueh	Parallel	0.88	3.5	23.5	210.23	23.48	89.42
	Crossed	1.03	3.6	26.7	194.96	19.72	82.42

From the data of table 1, we can see that parallel and crossed *Yunnanicus Hsueh* panel's mechanical properties were higher than those of *Heterocycla pubescens*. *MOR* of Laminated *Yunnanicus Hsueh* panel parallel to grain had reached 210.23 MPa, MOR of crossed laminated panel was 194.96 MPa. Made by the same process, Laminated *Heterocycla pubescens* panel were 174.70 MPa and 135.78 MPa. There was trend in the test of MOE: MOE of Laminated *Yunnanicus Hsueh* panel were 23.48 and 18.37 GPa diversely, which were higher than those of Laminated *Heterocycla pubescens* panel 8~10 GPa. Also the same rule was happened on CS, but the difference was less than MOE (it was mainly accorded to the amount of layers laid up). There was something to do with its' own strength. Table 2 showed comparison between Yunnan *Yunnanicus Hsueh* and *Heterocycla pubescens*'s physical-mechanical properties.

Tab. 2 Comparison between physical-mechanical properties of two kinds of bamboo

Species	Contra variant strength/MPa	*MOE*/GPa	Compressive strength parallel to grain
Heterocycla pubescens	140~165	11.7~12.5	65~79
Yunnanicus Hsueh	175.00	15.30	71.10

Attention: 1. Data of *Heterocycla pubescens* were come from *Physical-mechanical properties of seven kinds of bamboo in China*, Li Yuanzhe *etc*.

2. Range in data of *Heterocycla pubescens* were caused by bamboo age (range from 2~6 years, 2 years is the lowest)
3. Data of 4 years' *Yunnanicus Hsueh* were tested directly.

It can be seen from table 2 that one of important factors that affect mechanical properties was *Yunnanicus Hsueh*' s own strength was higher than *Heterocycla pubescens*.
In manufacture, because of the higher strength of *Yunnanicus Hsueh*, more energy are needed in its' panel manufacture. Considering that *Yunnanicus Hsueh* is an important sympodial bamboo in South China an has not yet been utilized well, it is good to develop it as structural-use panel.

2.3 Dimensional stability of two laminated bamboo panel

There are data about panel's TS that was dropped in cold-water for 24 hours and boiling-water for 2 hours in table 1. Table 1 showed that TS of *Yunnanicus Hsueh* panel were higher than TS of *Heterocycla pubescens* panel after above treatments. Parallel panel and crossed *Yunnanicus Hsueh* panel after cold-water's immersion were 3.5% and 3.6% separately, while data of *Heterocycla pubescens* panel were 2.4% and 2.5%. After 2 hours' boiling, TS of two kinds of bamboo were increased to a great extent, TS of crossed *Yunnanicus Hsueh* panel was the highest, the next was parallel *Yunnanicus Hsueh* panel.
TS of the two laminated *Heterocycla pubescens* panel after 2 hours' boiling were lower than those of *Yunnanicus Hsueh* panel, and difference directions caused was not distinguishable. It was indicated that dimensional stability of *Heterocycla pubescens* panel was better than that of *Yunnanicus Hsueh* panel, factors that influence dimensional stability of laminated bamboo panel were not simple, such as their own properties of swelling-shrinkage, thickness and variability, properties of adhesive, process conditions and sum of laminated layers and density that would influence more or less. Deep studies should been taken on this respect.

2.4 Aging resistance of two kinds of laminated bamboo panels

Used as structural-use material, aging resistance or aging resistance during use is an important factor worth noticing. This study was according to standard ASTM D3434 in America to examine adhesive's aging resistance outside, which was: after 20 cycles of boiled in water and conditioned in hot wind, to test residual rate of those mechanical properties. They were compared with the results that after once aging treatment (boiled 2 hours and dried 17 hours). The results are showed in table 3 and table 4.

Tab. 3 Change of *MOR* of two kinds of laminated bamboo panel after aging

Species	Assembly style	Untreated /MPa	Aging 1 /MPa	Aging 2 /MPa	Residual *MOR*/%	
					Aging 1	Aging 2
Heterocycla pubescens	Parallel	174.70	174.46	166.25	99.9	95.2
	Crossed	135.78	132.74	120.10	97.8	88.5
Yunnanicus Hsueh	Parallel	210.23	143.2	131.72	68.1	62.7
	Crossed	194.96	155.32	174.12	79.7	89.3

Data of aging 1: According to ASTM D3434 standard after 20 cycles
Data of aging 2: After 2 hours boiling and 17 hours at 107 in oven.

Tab. 4 Change of *MOE* of two kinds of laminated bamboo panel after aging

Species	Assembly style	Untreated /GPa	Aging 1 /GPa	Aging 2 /GPa	Residual *MOE*/%	
					Aging 1	Aging 2
Heterocycla pubescens	Parallel	13.68	13.66	13.37	99.9	97.9
	Crossed	10.50	10.31	10.42	98.2	99.2
Yunnanicus Hsueh	Parallel	23.48	20.23	18.37	86.2	78.2
	Crossed	19.72	19.14	18.07	97.1	91.6

It can be seen from table 3 and table 4 that compared with laminated *Heterocycla pubescens* panel, mechanical strength of laminated *Yunnanicus Hsueh* panel decreased more than that of laminated *Heterocycla pubescens* panel, and parallel panel decreased more than crossed panel. After 20 cycles' aging treatments according to ASTM standard, residual *MOE* was 68% of before; while residual *MOE* was 62% after the second aging treatments. After the two aging methods *MOE* of the two crossed panel remained 79.7% and 89.3% separately.
In this study, there was a phenomenon worth watching, that *Yunnanicus Hsueh* panel of two different

directions decreased differently after two aging treatments, parallel *Yunnanicus Hsueh* panel decreased more after the first aging treatment, converse was the crossed panel.

MOR of laminated *Yunnanicus Hsueh* panel met the same situation after two aging treatments, and showed the following characters:

1. The extent that laminated *Yunnanicus Hsueh* panel decreased was bigger than laminated *Heterocycla pubescens* panel;
2. Parallel laminated panel decreased more than crossed laminated panel;
3. Between the two aging treatments, the second made parallel panel and crossed panel decreased more than the first, this was different with crossed laminated *Yunnanicus Hsueh* panel.

Aging resistance of laminated *Heterocycla pubescens* panel was better than laminated *Yunnanicus Hsueh* panel. Residual *MOR* of parallel *Heterocycla pubescens* bamboo after two aging treatments was 99.9% and 95.2% separately. It can be safely concluded that according to ASTM standard, almost no change happened on parallel *Heterocycla pubescens* panel after 20 cycles, even under the more severe conditions where boiled for 2 hours and dried at high temperature for 17 hours made it decreased 4.8%. It showed good properties of aging resistance.

Strength of crossed laminated *Heterocycla pubescens* panel decreased more than that of parallel panel after aging treatment. Residual strength after the first treatment was 97.8%, and the second was 88.5%.

MOE of laminated *Heterocycla pubescens* panel after aging decreased still little. *MOE* of parallel *Heterocycla pubescens* panel remained 99.9% and 97.9% separately and the crossed panel was 98.2% and 99.2% separately. The extent decreased was very trivial. We should notice that when *MOR* of crossed panel decreased a little more (residual rate was 89.3%), *MOE* of it decreased much less (residual rate was 99.2%). To find the reason more research was needed.

3. Conclusion

This article was mainly studied on the manufacture method of laminated panel made of *D. yunnaicus hsueh et D. Z. Li* and *P. heterocyclavar. Heterocycla pubescens ohwi*. This article also compared their physical-mechanical properties in order to provide proof to produce architectural panel made by bamboo materials. Conclusions are as follows through this study:

1. Laminated bamboo panel can be produced by adding adhesive and hot pressing. Mechanical properties reached or even exceeded pine properties used in architecture.
2. Comparison between physical-mechanical properties of laminated panel made of two kinds of bamboo we can see that properties of laminated *Yunnanicus Hsueh* panel were higher than those of laminated *Heterocycla pubescens* panel, but dimensional stability was worse.
3. From comparison between properties of laminated panel laid up at different directions can see that parallel panel had better mechanical properties than crossed panel, so it can used as I-beam bearing girder and straddle, while crossed laminated panel can be used as I-beam web or other complex components like wall board need not bearing.
4. Aging resistance of laminated *Yunnanicus Hsueh* panel was the worse. Parallel laminated *Yunnanicus Hsueh* panel after aging decreased much more while laminated *Heterocycla pubescens* panel decreased little. It showed that physical-mechanical properties of laminated *Heterocycla pubescens* panel were more stable.

Acknowledgement

This research work was carried out with the collaboration and assistance of the International Network for Bamboo and Rattan.

Reference

Jules Janssen; Designing and Building with Bamboo; 2000 INBAR Technical Report No 20

P. M. Ganapathy Zhu Huanming S. Zoolagud etc.; Bamboo Panel Boards---a State of the Art Review; 1999 INBAR Technical Report No12

Divid S. Gromala, 1996 Manual for engineered wood construction, Load and resistance factor design pp150,

ASTM D3434-00, Standard, Test Method for Multiple-Cycle Accelerated Aging Test for Exterior Wet Use Wood Adhesives 2000, p232

ASTM D3043-87, Standard, Methods of Testing Structural Panels in Flexure. Philadelphia, 1987 PA.

GB/T15780-1995, Testing methods for physical and mechanical properties of bamboo