Experimental Research on Basical Mechanical Properties of Bamboo Plywood

Gan Tang$^{1,a}$, Zhexian Zhang$^{1,b}$, Ping Sun$^{2,c}$ and Tianli Jiang$^{1,d}$

$^1$Department of Civil Engineering and Airport Engineering, Nanjing University of Aeronautics and Astronautics, JiangJun Street 29, Nanjing, China
$^2$TUS-DESIGN Group Co., Ltd., XingHai Street 9, Sunzhou, China
*corresponding author email: tanggan@sina.com

Abstract. The objective of this study is to investigate the mechanical properties of bamboo plywood. Seeking more sustainable materials to reducing the carbon impact onto our environment has put bamboo on the map as an alternative building material, especially in the regions such as China, Southern Asia, and South America, where the bamboo is abundant. The basical mechanical properties of the bamboo plywood were carefully tested and recorded to provide a first-hand database on the parameters of the compressive strengths and shear strengths of such material. It can provide theoretical reference for the application of bamboo plywood in practical engineering.

1. Introduction

As a kind of plywood products, bamboo plywood is made of moso bamboo, which is rich in resources in China. It has the advantages of high strength and good toughness. Bamboo plywood has good mechanical properties, so it is widely used in building templates, carriage panels, container panels, etc., and it can also be used as structural members such as beams, columns, walls, and one-way slabs in building structures. At present, the research of plywood mainly focuses on the production technology and the application in building structure. There are few studies on the basic mechanical properties of bamboo plywood. This paper mainly investigates the mechanical properties of bamboo plywood. The bamboo plywood used in the experiment was produced in the "Hometown of Nanzhu"-Yiyang, Hunan. The dimension of bamboo plywood is 2440mm(length)×1220mm(width)×12mm(thickness).

2. Measurement of the Compressive Strengths

At present, the compressive strength test standard of bamboo plywood has not been determined in the world. This article consults the method of compressive strength test of bamboo in [1]. The dimension of the specimen is 15mm × 15mm × t mm (t is the thickness). Because the thickness of the bamboo plywood purchased in this article is 12mm, the dimension of the compressive strength of bamboo plywood is 15mm (length) × 15mm (width) × 12mm (thickness) as shown in Fig. 1. The specimens were saw-cut and polished with sander papers to the controlled precision. Three groups are designed to test the vertical direction (σx), horizontal direction (σy) and thickness direction (σz) compressive strength. The bamboo compressive strength performance is relatively stable, and the dispersion is small, so each group only has 3 specimens. The tests were carried out using a YES-1000 compression testing machine shown in Fig. 2. To draw the stress-strain curve, the displacement was collected by YHD-50 displacement sensor and the strain was collected by DH3818-2 static strain collector. The specimen was placed in the center of the base of the testing machine, and applied pressure at a uniform
speed. The rate of loading was 10MPa/min. We stopped loading when the specimen was damaged and the pressure dropped sharply.

The compressive strengths were calculated using the following equation (1):

\[ \sigma_i = \frac{F}{bl} (i = x, y, z) \]  

(1)

where: \( F \) is the ultimate loads from the tests, \( b \) and \( l \) are the width and length of the compressive area.

Figure 1. Specimen dimension
Figure 2. YES-1000 Pressure testing machine

After statistical analysis of the test results, the mean, standard deviation (SD) and variation coefficient (CV) of each group are shown in Table 1. The stress-strain curves of the three groups of test pieces are drawn based on the test data as shown in Figure 3, and the specimens after loading are shown in Figure 4.

Table 1. Compressive strengths of all specimens from the tests

| Strength | Specimen | Dimension(mm) | Area(mm²) | Ultimate loading(kN) | Strength (MPa) | Mean (MPa) | SD (MPa) | CV  |
|----------|----------|---------------|-----------|----------------------|---------------|------------|---------|-----|
| \[ \sigma_x \] | 1 | 15.6 | 11.38 | 177.53 | 10.26 | 57.79 | 60.02 | 2.25 | 3.76% |
| | 2 | 16.6 | 11.4 | 189.24 | 11.79 | 62.30 | 60.02 | 2.25 | 3.76% |
| | 3 | 15.2 | 10.4 | 158.08 | 9.48 | 59.97 | 60.02 | 2.25 | 3.76% |
| \[ \sigma_y \] | 1 | 14 | 11.1 | 155.4 | 8.97 | 57.72 | 55.11 | 3.33 | 6.05% |
| | 2 | 14.3 | 11.4 | 163.02 | 8.37 | 51.36 | 55.11 | 3.33 | 6.05% |
| | 3 | 14.8 | 11.44 | 169.31 | 9.52 | 56.24 | 55.11 | 3.33 | 6.05% |
| \[ \sigma_z \] | 1 | 16.6 | 16.8 | 278.88 | - | 30.82 | 32.06 | 2.98 | 10.02% |
| | 2 | 16.38 | 14.5 | 237.51 | - | 29.76 | 29.76 | 2.98 | 10.02% |
| | 3 | 14.14 | 16.8 | 276.86 | - | 26.39 | 29.76 | 2.98 | 10.02% |
According to Table 1 and figure 4:

1) The X and Y directions of compressive strengths were 60.02MPa and 55.11MPa respectively, and the variation coefficient were 3.76% and 6.05% respectively. The values of X and Y directions of compressive strengths are high, and have small dispersion;

2) The loading period went through the following three stages: first, the specimens went through the elastic stage, in which the adhesive of the specimens was well bonded with the bamboo curtain layer, and there was no crack inside; then, when the specimens entered the yield stage, cracks began to
appear inside the specimen accompanying clear tearing sound, and when the cracks continued to
develop to a certain scale, the specimens reached the ultimate loading. At last, the adhesive of the
specimens continued to expand, the bending deformation of the bamboo layer became obvious, and
the bearing capacity of the test piece decreased gradually;

(3) Bamboo plywoods were formed by orthogonal cementation of adjacent layers of bamboo
curtain, so its characteristics of X and Y directions were similar. The trend of stress-strain curve and
the maximum stress of X and Y directions was close;

(4) In Z direction, the specimens did not get the falling period, because the thickness of the
specimens were too small (12mm), and the specimens were flattened. Refer to China standard GB/T
8813-2008, the compressive strengths are taken as the compressive stress when the relative
deformation is 10%. Because the bamboo plywoods were cemented by multiple layers of bamboo
curtains. Because the deformation in thickness direction was relatively large, the critical value of
severe extrusion deformation of the specimen is near 20% relative deformation. In this paper, the
compressive strengths in thickness direction were selected when the relative deformation is 20%, and
compressive strengths of Z direction were 27.38MPa.

3. Measurement of the Shear Strengths
In order to determine the shear strengths of bamboo, two forces which were parallel and not in the
same straight line should be formed by a specific way of compression to make sure that the shear
surfaces of the specimens were pure shear failure. The loading method adopted in [2] is relatively
complex, and the specimens require high precision. This paper refers to the shear strength test method
in [3] and [4,5]. The specimens and test set up are shown in Figure 5. The set up was composed of
three parts: steel tank, steel cushion block and specimens. The specimens were divided into three
groups, and each group had three specimens to measure the shear strength in XY plane ($\tau_{xy}$), XZ plane
($\tau_{xz}$), and YZ plane($\tau_{yz}$).

![Figure 5. Specimen and test set up for shear strength testing.](image)

The shear strength was calculated as follows:

$$\tau_{ij} = \frac{F}{tL}(i,j = x,y,z)$$  \hspace{1cm} (2)

where: $F$ is the ultimate loads from the test and $t$ and $L$ are the width and length of the shear plane.

The results of the shear strengths from the tests are listed in Table 2 and the specimens after
loading are shown in Figure 6.
Table 2. Results of shear strengths

| Strength | Specimen | Dimension/mm | Area (mm²) | Ultimate loading (kN) | Strength (MPa) Mean (MPa) SD (MPa) CV |
|----------|----------|--------------|------------|----------------------|--------------------------------------|
| \( \tau_{xy} \) | 1        | 14.00        | 11.36      | 159.04               | 3.08                                | 19.37                          |
|          | 2        | 15.92        | 10.2       | 162.38               | 3.42                                | 21.06                          |
|          | 3        | 14.52        | 10.8       | 156.82               | 2.68                                | 17.09                          |
| \( \tau_{xz} \) | 1        | 14.22        | 12.1       | 172.06               | 0.92                                | 5.35                           |
|          | 2        | 16.28        | 13.34      | 217.18               | 0.71                                | 3.27                           |
|          | 3        | 15.6         | 13.8       | 215.28               | 0.96                                | 4.46                           |
| \( \tau_{yz} \) | 1        | 14.74        | 13.54      | 199.58               | 0.83                                | 4.16                           |
|          | 2        | 14.92        | 12.9       | 192.47               | 0.83                                | 4.31                           |
|          | 3        | 16.26        | 12.76      | 207.48               | 0.88                                | 4.24                           |

(a) XY plane shear failure  (b) XZ plane shear failure  (c) YZ plane shear failure

Figure 6. Shear failure specimens

According to the test results in table 2, the \( \tau_{xy} \) was 19.17MPa, \( \tau_{xz} \) and \( \tau_{yz} \) were followed by 4.36MPa and 4.24MPa respectively. Because the shear strength of bamboo fiber bundle was higher than the cementation between bamboo curtains, the shear strength of XY plane was higher than that of the other two planes. \( \tau_{xz} \) and \( \tau_{yz} \) were controlled by interlayer cementation, and almost the same value. The variation coefficient of the three groups of data was less than 25%, and the test results were relatively stable and reliable.

4. Summary
The experimental investigation focused on the mechanical properties of bamboo plywood. Based on this research, the following conclusions could be drawn:

(1) The experiment results showed that bamboo plywood had good mechanical properties, which can meet the requirements of building structure;

(2) Through compressive strength tests, the compressive strength of bamboo plywood in X, Y and Z directions were 60.02MPa, 55.11MPa and 27.38MPa respectively. The properties of in X and Y directions were similar, and they both had a degree of plastic deformation ability;

(3) Through shear strengths tests, shear strengths of bamboo plywood of XY plane, XZ plane and YZ plane were 19.17MPa, 4.36MPa and 4.24MPa respectively. Because the shear strengths of bamboo fiber bundle were higher than the bond strengths between bamboo curtains, the shear strengths of XY plane were significantly higher than that of the other two planes;

5. References
[1] Ministry of Construction of the People’s Republic of China 2007 Testing methods for physical and mechanical properties of bamboo used in building, JGT 199-2007.
[2] General Administration of Quality Supervision, Inspection and Quarantine of the People’s
Republic of China 2009 Method of testing in shearing strength parallel to grain of wood, GB/T1937-2009.

[3] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 1995 Testing methods for physical and mechanical properties of bamboos, GB/T 15780-1995.

[4] Cai J 2014 Study on Mechanical Behavior of Glued Laminated Timber.

[5] Zhou Q, Ren H, Li X, Lou W 2008 Research on Air-dried Density and Mechanical Properties of Moso Bamboo from Different Plantations, Chinese Forestry Science & Technology, ed Yun Y p 27-31.