Experimental Study on Integration Bamboo Elastic Modulus with Three-point Bending Nondestructive Testing Method

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Abstract. Integrated bamboo is widely used in daily life and industrial production. This paper explores and studies the determination method of its elastic modulus. In this paper, based on the elastic theory of the member, a three-point bending method is proposed. This method was used to carry out experimental design and experiment, and the results were analyzed and discussed. The conclusion is that the three-point bending method has simple experimental conditions, convenient operation and convenient application in practice.

1. Introduction
Integrated bamboo is widely used in daily life and industrial production. There are differences in different processes and batches, and the elastic modulus of the material is also different. Although the elastic modulus of integrated bamboo can be measured by tensile test, the process is cumbersome and the equipment volume is large, which is not convenient for field operation. In order to facilitate the sorting and selection of materials, it is particularly important to find a simple and effective experimental method and means to determine the elastic modulus of materials.

Based on the theory of mechanics and physics, the three-point bending method was used to test the integrated bamboo with different sizes and specifications, and the results were compared with the tensile method. The conclusion provides a certain experimental basis for the selection of experimental methods.

2. Theoretical basis of experiment
In this paper, the three-point bending method is used to measure the elastic modulus of materials, that is to fix the two ends of the specimen and apply the load step by step in the middle of the span to measure the elastic modulus of the material. The key of the experiment is how to measure the small deformation of larger bamboo accurately. Through the comparison and analysis of some measurement methods and literature, the loading amount and loading speed of each stage and the load reduction and speed should be strictly controlled in the experimental process.

The device of the three-point bending method can be simplified as a simply supported beam under the action of concentrated force F, as shown in Fig. 1.
When the concentrated force \( F \) acts on the middle of the span,

\[ a = b = \frac{l}{2} \]  

(1)

The maximum deflection is at the middle point of the span.

\[ \omega_{\text{max}} = \omega_{y/2} = -F/l^3 / 4EI \]  

(2)

All the specimens used in the experiment are rectangular, and the moment of inertia of the rectangle is:

\[ I_z = \frac{bh^3}{12} \]  

(3)

\[ E = \frac{\Delta F l^2}{(Ahb^3 \cdot \Delta w)} \]  

(4)

\( E \) - elastic modulus of the material (Pa);
\( \Delta F \) - average value of load increment (N);
\( \Delta w \) - the average value of deflection change (m).

3. Integrated bamboo elastic modulus testing with three point bending method

3.1. Experimental procedure of three-point bending method

The schematic diagram of the test device is shown in Figure 2.

- Select two fixed supports to fix the two ends of the test piece.

The materials used in this experiment are: laser rangefinder, 6 weights each of 0.319kg and 1.275kg, string, steel ruler, 8 integrated bamboo specimens. The dimensions of the specimens are shown in Table 1.

| Specimen number | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Length(mm)      | 1000| 1000| 1000| 1000| 1000| 1000| 1000| 1000|
| Width(mm)       | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  |
| Height(mm)      | 10  | 10  | 10  | 10  | 30  | 30  | 30  | 30  |

The specific experimental steps are as follows.
- Select two fixed supports to fix the two ends of the test piece.
- Connect the laser displacement detector, plug in the power supply, and adjust the position of the laser displacement detector so that the infrared point projected by the laser falls in the middle of the test piece.
- Load 1.275 kg weights on the test piece with size of 1000mm × 40mm × 30mm, and load the weights one by one. After the data on the test is stable, start reading and record. After the sixth reading is recorded, unload and record one by one; A test piece with a size of 1000mm × 40mm × 10mm is loaded with a weight of 0.319 kg, and the data is loaded and unloaded one by one.

### 3.2. Experimental data analysis

According to the above operation steps, the following data is obtained.

| Specimen number | size (mm)     | weight (kg) | xₒ (mm) | load 1 | load 2 | load 3 | load 4 | load 5 | load 6 |
|-----------------|---------------|-------------|---------|--------|--------|--------|--------|--------|--------|
|                 | 1000×40×10    | 0.319       | 7       | 5.75   | 4.45   | 3.17   | 1.88   | 0.66   | -0.61  |
| 2               | 1000×40×10    | 0.319       | 6.21    | 4.9    | 3.6    | 2.37   | 1.12   | -0.17  | -1.37  |
| 3               | 1000×40×10    | 0.319       | 6.96    | 5.77   | 4.6    | 3.39   | 2.2    | 1.01   | -0.21  |
| 4               | 1000×40×10    | 0.319       | 6.29    | 4.96   | 3.66   | 2.31   | 0.99   | -0.3   | -1.64  |
| 5               | 1000×40×30    | 1.275       | 29.94   | 29.73  | 29.53  | 29.32  | 29.1   | 28.88  | 28.67  |
| 6               | 1000×40×30    | 1.275       | 28.65   | 28.47  | 28.28  | 28.1   | 27.9   | 27.72  | 27.54  |
| 7               | 1000×40×30    | 1.275       | 29.83   | 29.64  | 29.48  | 29.32  | 29.14  | 28.97  | 28.79  |
| 8               | 1000×40×30    | 1.275       | 29.8    | 29.58  | 29.35  | 29.13  | 28.92  | 28.71  | 28.52  |

After sorting out the above data, two groups were selected for the following analysis.

| gravity (N)     | Rangefinder value (Loading process)(mm) | Deformation value (Loading process)(mm) | Rangefinder value (Load shedding)(mm) | Deformation value (Load shedding)(mm) |
|-----------------|----------------------------------------|----------------------------------------|--------------------------------------|--------------------------------------|
| 0               | 29.940                                 | 0.000                                   | 29.920                               | 0.000                                 |
| 12.495          | 29.730                                 | 0.210                                   | 29.710                               | 0.210                                 |
| 24.990          | 29.530                                 | 0.410                                   | 29.480                               | 0.440                                 |
| 37.485          | 29.320                                 | 0.620                                   | 29.270                               | 0.650                                 |
| 49.980          | 29.100                                 | 0.840                                   | 29.070                               | 0.850                                 |
| 62.475          | 28.880                                 | 1.060                                   | 28.860                               | 1.060                                 |
| 74.970          | 28.670                                 | 1.270                                   | 28.670                               | 1.250                                 |

From the data in Table 3, Figure 3 can be drawn.

| gravity (N)     | Rangefinder value (Loading process)(mm) | Deformation value (Loading process)(mm) | Rangefinder value (Load shedding)(mm) | Deformation value (Load shedding)(mm) |
|-----------------|----------------------------------------|----------------------------------------|--------------------------------------|--------------------------------------|
| 0               | 28.650                                 | 0.000                                   | 28.620                               | 0.000                                 |
| 12.495          | 28.470                                 | 0.180                                   | 28.440                               | 0.180                                 |
| 24.990          | 28.280                                 | 0.370                                   | 28.250                               | 0.370                                 |
| 37.485          | 28.100                                 | 0.550                                   | 28.070                               | 0.550                                 |
| 49.980          | 27.900                                 | 0.750                                   | 27.890                               | 0.730                                 |
| 62.475          | 27.720                                 | 0.930                                   | 27.710                               | 0.910                                 |
| 74.970          | 27.540                                 | 1.110                                   | 27.540                               | 1.080                                 |

From the data in Table 4, Figure 4 can be drawn.
Table 5. Data processing of specimen 1

| gravity(N) | Rangefinder value (Loading process)(mm) | Deformation value (Loading process)(mm) | Rangefinder value (Load shedding)(mm) | Deformation value (Loading shedding)(mm) |
|------------|----------------------------------------|----------------------------------------|--------------------------------------|----------------------------------------|
| 0          | 7.000                                  | 0.000                                  | 6.910                                | 0.000                                  |
| 3.1262     | 5.750                                  | 1.250                                  | 5.650                                | 1.260                                  |
| 6.2524     | 4.450                                  | 2.550                                  | 4.350                                | 2.560                                  |
| 9.3786     | 3.170                                  | 3.830                                  | 3.080                                | 3.830                                  |
| 12.5048    | 1.880                                  | 5.120                                  | 1.840                                | 5.070                                  |
| 15.631     | 0.660                                  | 6.340                                  | 0.620                                | 6.290                                  |
| 18.7572    | -0.610                                 | 7.610                                  | -0.610                               | 7.520                                  |

From the data in Table 5, Figure 5 can be drawn.

Table 6. Data processing of specimen 4

| gravity(N) | Rangefinder value (Loading process)(mm) | Deformation value (Loading process)(mm) | Rangefinder value (Load shedding)(mm) | Deformation value (Loading shedding)(mm) |
|------------|----------------------------------------|----------------------------------------|--------------------------------------|----------------------------------------|
| 0          | 6.290                                  | 0.000                                  | 6.250                                | 0.000                                  |
| 0.319      | 4.960                                  | 1.330                                  | 4.940                                | 1.310                                  |
| 0.638      | 3.660                                  | 2.630                                  | 3.600                                | 2.650                                  |
| 0.957      | 2.310                                  | 3.980                                  | 2.270                                | 3.980                                  |
| 1.276      | 0.990                                  | 5.300                                  | 0.950                                | 5.300                                  |
| 1.595      | -0.300                                 | 6.590                                  | -0.320                               | 6.570                                  |
| 1.914      | -1.640                                 | 7.930                                  | -1.640                               | 7.890                                  |

From the data in Table 6, Figure 6 can be drawn.

It can be seen from the correlation coefficient calculated from the above load and subtraction line graph that the correlation between force and vertical displacement is relatively high, and the correlation coefficient is almost close to 1, which verifies the linear relationship between stress and
strain in Hooke’s law, and also shows that the experiment Effectiveness. At the same time, it can be seen that bamboo has good restorability. After each loading and unloading, the laser projection point can almost be restored to the projection point of the previous level of loading, and almost return to the original point after all unloading, indicating that the material is experimented within the elastic range. Obtaining the slope from the loading and unloading line graph is to better establish the correlation between the elastic modulus and the slope, so as to better obtain the elastic modulus to improve the accuracy of the experiment.

Table 7. Deflection data processing table

| Specimen number | Size (mm) | Load difference value (mm) | \( \omega \) (m) |
|----------------|----------|--------------------------|-------|
| 1              | 1000×40×10 | 1.25 1.3 1.28 1.29 1.22 1.27 | 0.00761 |
| 2              | 1000×40×10 | 1.31 1.3 1.23 1.25 1.29 1.2 | 0.00758 |
| 3              | 1000×40×10 | 1.19 1.17 1.21 1.19 1.19 1.22 | 0.00717 |
| 4              | 1000×40×10 | 1.33 1.3 1.35 1.32 1.29 1.34 | 0.00793 |
| 5              | 1000×40×30 | 0.21 0.2 0.21 0.22 0.22 0.21 | 0.00127 |
| 6              | 1000×40×30 | 0.18 0.19 0.18 0.2 0.18 0.18 | 0.00111 |
| 7              | 1000×40×30 | 0.19 0.16 0.16 0.18 0.17 0.18 | 0.00104 |
| 8              | 1000×40×30 | 0.22 0.23 0.22 0.21 0.21 0.19 | 0.00128 |

According to the data in Table 7, substituting the deflection value into the calculation formula, the following table can be obtained.

Table 8. Modulus of elasticity measured by three-point bending method

| Specimen number | Size (mm) | \( \omega \) (m) | \( E \) (GPa) |
|----------------|----------|----------|----------|
| 1              | 1000×40×10 | 0.001268 | 11.609   |
| 2              | 1000×40×10 | 0.001263 | 11.655   |
| 3              | 1000×40×10 | 0.001195 | 12.321   |
| 4              | 1000×40×10 | 0.001322 | 11.14    |
| 5              | 1000×40×30 | 0.000212 | 10.297   |
| 6              | 1000×40×30 | 0.000185 | 11.782   |
| 7              | 1000×40×30 | 0.000173 | 12.575   |
| 8              | 1000×40×30 | 0.000213 | 10.217   |

The average modulus of elasticity with a size of 1000mm×40mm×10mm is:

\[
E = \left( (11.609 + 11.655 + 12.321 + 11.14) / 4 \right) = 11.681 \text{ (GPa)}
\]

The average modulus of elasticity with a size of 1000mm×40mm×30mm is:

\[
E = \left( (10.297 + 11.782 + 12.575 + 10.217) / 4 \right) = 11.218 \text{ (GPa)}
\]

The three-point bending method is to fix the two ends of the test piece and apply a load in the middle of the span to obtain the deflection and deformation, thereby obtaining the elastic modulus. This method is simple, convenient and easy to operate. From the above data, it can be seen:

- The larger the size of the test piece, the smaller the deflection and deformation.
- The radial size of the test piece is small, and the measured data dispersion is small. On the contrary, the radial size of the test piece is large, and the data dispersion is also large.
- Judging from the average number of specimens of different sizes, the elastic modulus of the material is related to the size, and more deeply, it is related to the density.
- Judging from the chart in the article, the integrated bamboo shows obvious resilience.
- Compared with the dynamic elastic modulus measured by the wave velocity method, the static elastic modulus measured by the three-point bending is slightly smaller, indicating that the test method is different, and the results will also have certain differences.
4. Comparative analysis of experimental results

Table 9. Comparison of elastic modulus of different test methods

| Specimen number | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Size            | 1000×40×10(mm) | 1000×40×30(mm) |
| Three-point bending method | 11.609 | 11.655 | 12.321 | 11.14 | 10.297 | 11.782 | 12.575 | 10.217 |
| Stretching method | 10.089 | 10.363 | 11.081 | 9.366 | —     | —     | —     | —     |
| average value   | Three-point bending method: 11.681(GPa) | Stretching method: 10.255(GPa) | Three-point bending method: 11.218(GPa) |

The above experiments are carried out reasonable and effective experiments in accordance with certain experimental procedures. The amount of influence in the experiment is reasonably controlled, and the material is always tested within the elastic range. The experimental data obtained is processed accurately, and the elastic modulus of the material after multiple experiments is finally obtained. The average value of the amount has achieved the purpose of experimental research.

5. Conclusion

In summary, there are the following conclusions:
- The wave velocity method nondestructive testing method is based on the vibration and propagation of the wave in the wood, so the specimen avoids shear and torsional inertia, but this is inevitable in the static bending experiment.
- Vascular bundle volume percentages in different bamboo specimens are different; the larger the vascular bundle volume percentage, the larger the elastic modulus value, and vice versa.
- The internal structure (such as porosity) of the specimen and the density of the specimen are different.
- Due to the sequence of experiments, the error may also be related to the moisture content of the specimen.
- The three-point method is used to determine the elastic modulus of integrated bamboo. The method is simple, the experimental conditions are easily met, and the results are relatively reliable.

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