Experimental Study on Integration Bamboo Elastic Modulus with Wave Velocity Nondestructive Testing Method

Liuchuang Wei1*, Ping Wei2, Yong Yang2

1Faculty of Mechanical and Electrical Engineering, Kunming University, Yunnan Kunming 650214, China
2Faculty of Architectural Engineering, Kunming University, Yunnan Kunming 650214, China
*Corresponding author’s e-mail: weiliuchuang@126.com

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 wave propagation principle, the wave velocity method is proposed. This was used to carry out experimental design and experiment, and the results were compared, analyzed and discussed.

1. Introduction
Integrated bamboo is widely used in daily life and industrial production, and there are differences between different processes and different batches, and the elastic modulus of materials is also quite different. Using the method of tensile test, although the elastic modulus of the integrated bamboo can be measured, the process is cumbersome, the equipment is large, and it is not convenient for on-site operation. In order to facilitate the sorting of materials and the convenience of material selection, seeking a simple and effective experimental method and means to measure its elastic modulus is particularly important for the improvement of production efficiency.

Combining relevant mechanics and physical theories, the author conducts experiments on integrated bamboo with different sizes and specifications, and the wave velocity method, and compares and analyzes the experimental results. The conclusions obtained provide a certain experimental basis for the choice of experimental methods.

2. Theoretical basis of test method
The principle of measuring the elastic modulus of materials by the wave velocity method is the principle of wave propagation in one-dimensional elastic rods. The derivation process of the wave velocity method to calculate the elastic modulus formula is as follows.

The horizontal size of the materials made in this article is much smaller than the vertical size. Due to the small lateral size, its influence is negligible, so it is assumed that the wave propagation in the bamboo used is one-dimensional, moving only in the axial direction, and only acting in the axial direction.
Because the particle velocity and strain are the reciprocal of displacement to X and t respectively, the continuous equation of the particle velocity and strain can be obtained according to the single continuous condition of displacement.

\[
\frac{\partial v}{\partial X} = \frac{\partial \varepsilon}{\partial t} \tag{1}
\]

As shown in the figure above, assuming that the force of section A is \( F(X,t) \), then the force of section B is \( F(X+dx,t) \), then:

\[
F(X + dx, t) = F(X, t) + \frac{\partial F(X, t)}{\partial X} dX \tag{2}
\]

According to Newton's second law:

\[
\frac{\partial A}{\partial X} \frac{\partial V}{\partial t} = F(X + dx, t) - F(X, t) = \frac{\partial F(X, t)}{\partial X} dX \tag{3}
\]

Thus:

\[
\frac{\partial^2 u}{\partial t^2} dX \rho A = \frac{\partial \sigma}{\partial X} dXA \tag{4}
\]

Where:
- \( A \) — the cross-sectional area of the material;
- \( \sigma \) — axial stress;
- \( \rho \) — material density.

From the above formula and the concept of strain:

\[
\rho \frac{\partial^2 u}{\partial t^2} = E \frac{\partial^2 u}{\partial x^2} \tag{5}
\]

And because:

\[
c = \sqrt{\frac{E}{\rho}} \tag{6}
\]

So:

\[
\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2} \tag{7}
\]

The solution of the equation is:

\[
u(x, t) = f(x - ct) + g(x + ct) \tag{8}
\]

After time \( dt \), we can get:
\[ u(x,t) = f((x - c \cdot dt - ct) + g(x + c \cdot dt + ct) \] (9)

After time \( dt \), the displacement at \( x \) is the sum of \( f \) at time \( t \) and \( g \) at time \( t \), so the wave velocity is only related to the elastic modulus and density of the medium, and has nothing to do with Poisson’s ratio.

We get the theoretical calculation formula for measuring the elastic modulus of materials by the wave velocity method:

\[ E = \rho c^2 \] (10)

Where:
- \( E \) — The elastic modulus of the medium;
- \( \rho \) — The density of the medium;
- \( c \) — Wave speed.

3. Using wave velocity method to measure elastic modulus of integrated bamboo

3.1. Experimental materials and instruments

The material used in this experiment is integrated bamboo made from moso bamboo. In this experimental study, 8 specimens were used for the experiment, as shown in Table 1. The materials come from the same batch of products from the same manufacturer, and the density and water content are relatively stable.

The experimental instrument uses the ZBL-U520 series non-metall ic ultrasonic detector produced by Beijing Zhibolian Technology Co., Ltd. as the ultrasonic instrument. The detector can set parameters, signal acquisition, and signal storage. Waveform diagram, wave amplitude, propagation speed, propagation time, etc. can be displayed on the screen of the detector. In addition, this experiment also used electronic scales, steel tape measure and petroleum jelly.

| 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  |

3.2. Experimental steps

This experiment is carried out according to the following steps:
- Plug in the electronic scale, adjust the zero, weigh and record the quality of the tested parts;
- Calculate the density of the test piece;
- Connect the non-metal detector, open and adjust the parameters;
- Apply an appropriate amount of petroleum jelly (coulplant) on both ends of the test piece, place the two ultrasonic sensors on both ends of the test piece, and gently press to make the test piece and the sensor fully coupled;
- Click the "Sampling" button to read and record the propagation velocity of the wave;
- After testing, calculate the elastic modulus according to formula (10).

It is worth noting that in order to improve the accuracy of the data, during the inspection process of the test piece, foam should be cushioned at both ends to avoid the interference of the base.

The schematic diagram of the experiment is shown in Figure 2.
3.3. Data analysis

Through the above steps and the calculation of Formula 9, the following data are obtained.

Table 2. Dynamic elastic modulus data sheet

| Specimen number | Size(mm) | Mass (kg) | Density(kg/m³) | Wave speed (m/s) | E(GPa) |
|-----------------|----------|-----------|-----------------|-----------------|--------|
| 1               | 1000×40×10 | 0.292     | 730.000         | 4131            | 12.458 |
| 2               | 1000×40×10 | 0.304     | 760.000         | 4372            | 14.527 |
| 3               | 1000×40×10 | 0.293     | 732.500         | 4436            | 14.414 |
| 4               | 1000×40×10 | 0.290     | 725.000         | 4469            | 14.480 |
| 5               | 1000×40×30 | 0.888     | 740.000         | 4420            | 14.457 |
| 6               | 1000×40×30 | 0.876     | 730.000         | 4301            | 13.504 |
| 7               | 1000×40×30 | 0.873     | 727.500         | 4263            | 13.221 |
| 8               | 1000×40×30 | 0.896     | 746.667         | 4380            | 14.324 |

The average elastic modulus of integrated bamboo with a size of 1000 mm×40mm×10mm is:

\[ E = \frac{12.458 + 14.527 + 14.414 + 14.48}{4} = 13.970 \text{ (GPa)} \]

The average elastic modulus of integrated bamboo with a size of 1000mm×40mm×30mm is:

\[ E = \frac{14.457 + 13.504 + 13.221 + 14.324}{4} = 13.877 \text{ (GPa)} \]

It can be seen from the above data:

- The length and width of the test piece are the same, but the height is different. Although the measured data are close, there are still differences. It is preliminary that the elastic modulus of the test piece is related to the size.
- Because of the different sizes, the internal structure of the specimens is also different. They are all integrated bamboo materials. Due to the processing technology, it is difficult to control the porosity of the specimens.

4. Experimental comparative analysis

The elastic modulus of the test piece measured by the results of different experimental methods is compared and analyzed.

The experimental data list is as follows:

Table 3. Elastic modulus data sheet

| Specimen size | 1000×40×10(mm) | 1000×40×30(mm) |
|---------------|-----------------|-----------------|
| Specimen      | 1 2 3 4 5 6 7 8 | 1 2 3 4 5 6 7 8 |
| number | Stretching method | Three-point bending method | Wave speed method |
|--------|------------------|---------------------------|------------------|
|        | 10.089 10.363 11.081 9.366 | 11.609 11.655 12.321 11.14 10.297 11.782 12.575 10.217 | 12.458 14.527 14.414 14.48 14.457 13.504 13.221 14.324 |
| average value | Stretching method: 10.255(GPa) | Three-point bending method: 11.681(GPa) | Wave speed method: 13.97(GPa) |

The above three 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 material after multiple experiments is finally obtained. The average value of elastic modulus achieves the purpose of experimental research.

The results of dynamic elastic modulus and static elastic modulus measured by wave velocity method and three-point bending method are shown in Figure 16. It can be seen from the figure that the elastic modulus measured by the two methods does not have obvious linear correlation and may be related to the experiment. The number of repetitions is related. It can be seen from Table 12 that the bamboo elastic modulus values measured by the wave velocity method are almost all greater than the elastic modulus values measured by the three-point bending method and the stretching method, and even the three-point bending method and the stretching method both measure the static elasticity. Modulus, the data obtained is also different.

![Figure 3. The relationship between dynamic elastic modulus and static elastic modulus](image)

**5. Conclusion**

In summary, there are the following conclusions:

- The test principles used by different test methods are different. Bamboo is not a complete elastomer. When the static elastic modulus method is used for the experiment, there are some viscous strain components, and the mechanical properties and strain rates shown by the material related. The test time of dynamic elastic modulus is very short, and the vibration speed of the particle unit is fast, which is almost a pure elastic phenomenon. In the wave velocity method experiment, petroleum jelly
was used as the coupling agent, and the amount of coupling agent applied would also have a certain impact on the experimental results.

- The wave velocity method nondestructive testing method is based on the vibration and propagation of the wave in the wood, so the specimen avoids the shear and torsional inertia, but this is inevitable in the static bending experiment.
- 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.
- Due to the viscous strain of integrated bamboo, the dynamic elastic modulus is slightly larger than the static elastic modulus, and the dynamic elastic modulus cannot be regarded as its static elastic modulus.

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