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Strain method for synchronous dynamic measurement of elastic, shear modulus and Poisson's ratio of wood and wood composites

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HIGHLIGHTS

- The 0°–75° scheme can apply to synchronous dynamic test of *E*, *G* and μ for wood and wood composites.
- Pasting positions and directions of strain gauges in the 0°–75° scheme are provided.
- The results of μ from 0°–75° and 0°–90° schemes are identical.
- The method was validated by axial tension and static square-plate torsional tests.

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ABSTRACT

In this work, the principle and method for synchronous dynamic measurement of elasticity, shear modulus and Poisson's ratio of wood and wood composite with two strain gauges were studied and discussed. The experimental scheme, named 0°–75° scheme, was developed for synchronous dynamic measurement of elasticity (*E*), shear modulus (*G*) and Poisson's ratio (μ) with two strain gauges of 0° and 75°. The 75° strain gauge was not only used to measure Poisson's ratio together with the 0° strain gauge, but also to measure the first-order torsional frequency of cantilever plate. In addition, the principle of measuring elasticity and shear modulus by the 0°–75° scheme was described. Based on the stress and strain analysis of first-order bending and torsional modes of cantilever plates, the pasting position and orientation of strain gauges in the 0°–75° scheme were decided. Comparing the results of using two combinations of strain gauges, 0°–75° and 0°–90° schemes, the correspondence indicates that the 0°–75° scheme is feasible for dynamic measurement of Poisson's ratio. By transient excitation, the strain spectrums under 0° and 75° of Poplar's tangential section, Sitka spruce's radial section and medium density fiberboard (MDF) cantilever plate were measured. Thus, one-hammer-excitation synchronous measurement of elasticity, shear modulus and Poisson's ratio of materials was achieved. Its correctness was verified by axial tension and static square-plate torsion tests.

1. Introduction

Characterizing the elasticity, the elasticity constant is a vital mechanical property parameter of wood and reflects the resistance to deformation under external forces. With advantages of rapidness, simplicity and high reliability, the dynamic vibration method has been proved to be a successful method that is commonly used, obtaining the consistent results with traditional static method [1,2].

In engineering, strain gauges are commonly used to measure force, deformation, stress and principal stress at dangerous point in structural components, playing an important role in strength and stiffness design of components. Strain gauges receive signals as sensors. The signals are amplified and collected to obtain strain values, strain waveforms and frequency components of strain signals. In the work, it was aimed to measure amplitude and frequency of strain signals by two strain gauges pasted in different directions on cantilever plates as specimens so as to realize synchronous dynamic measurement of wood elasticity, shear modulus and Poisson's ratio. Different from accelerometer, the mass of a strain gage can be ignored. With certain mass, accelerometer could have effects on the measurement of frequency with additional mass on the system, resulting in lower frequency measured. Since strain gauges are necessary to measure Poisson's ratio of materials by strain method, a strain rosette which is a combination of crossed 0° and 90° strain gauges, was traditionally used to paste

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on the central line of the plate to measure only the elastic modulus and Poisson's ratio of materials. There are a plenty of work on the dynamic measurement of elastic modulus of wood and wood composites [3–5], whereas quite a few research focused on the dynamic measurement of shear modulus. The free-plate torsional mode method applies to test shear modulus of wood and isotropic materials. Based on the first-order torsional mode of free plate, the method has advantages of rapidness, simplicity, good repeatability and high precision [6–9]. However, free plate cannot be used as the specimen to measure Poisson's ratio. In dynamic test of E, G and μ of concrete, the free plate is used as specimen to measure E and G, while μ is measured by clamping free plate used in the measurement of E and G as cantilever plate [10]. The three parameters E, G and μ are measured in two steps but not synchronously. In 2014, dynamic measurement of wood Poisson's ratio was published on *Scientia Silvae Sinicae* [11]. In 2016, Wang Z. et al. made detailed theoretical analyses of pasting position of strain gauges in the dynamic test of Poisson's ratio in tangential, radial and cross sections of timber [12]. The equation of pasting position of strain gauges in the dynamic test of Poisson's ratio of wood was proposed and its correctness was verified by static tension and four-point bending tests. In 1983, Liu applied dynamic method of testing wood Poisson's ratio to isotropic materials successfully [14], but it still can only measure two parameters E and μ in one test.

In all work above, the strain rosette was pasted on the center line of cantilever plate surface, along the longitudinal and horizontal directions of the plate. Therefore, the strain spectrum did not reach peak value at the first-order torsional frequency of cantilever plate, thus the shear modulus cannot be measured. If the three parameters E, G and μ are expected to measure synchronously, a simple approach is to add an accelerometer to test first-order torsional frequency of cantilever plate. However, this experimental scheme is not demanded in the work. The purpose is to study how to use two strain gauges and two-channel acquisition to synchronously measure the three parameters E, G and μ in one test. In view of this, based on the first-order bending mode and the first-order torsional mode of cantilever plate, the principle and method for synchronous dynamic measurement of elasticity, shear modulus and Poisson's ratio of wood by two strain gauges were discussed in this work. Analysis of determining pasting location and direction was included. In other words, the two strain gauges are used to measure not only the first-order bending and torsional frequencies but also Poisson's ratio of the cantilever plate. In this case, a specific position should be selected to paste the two strain gauges in different directions on the cantilever plate as sensors so that the three parameters E, G and μ can be measured by only one excitation on the specimen.

2. Experiment

2.1. Specimens and equipment

2.1.1. Specimens

Tangential-section Poplar timber, with average air-dry density of 550 kg/m^3, moisture content of 12.2%, made to ε_x plates to get cantilever specimens of 450 mm × 100 mm × 10 mm with clamping length of 50 mm; Radial-section Sitka spruce timber, with average air-dry density of 354 kg/m^3, moisture content of 9.5%, made to *xy* plates to get cantilever specimens of 535 mm × 107 mm × 12.2 mm with clamping length of 65 mm; MDF, with average air-dry density of 715 kg/m^3 and moisture content of 11%, made to plates of 600 mm × 120 mm × 9 mm with clamping length of 60 mm.

2.1.2. Equipment and accessories

Type BX120-5AA strain gauges (resistance: 120Ω, sensitivity coefficient: 2.08 ± 1%; strain gauge grid length and width: 5 mm and 3 mm); Type YD-125 accelerometer of which the mass is 1.5 g; Type YD-28A dynamic strain gauge, made by Shanghai Huadong Electric Instrument Factory; Signal conditioning box, made by Nanjing Anzheng Software Company, to amplify and filter signals; AZ signal collection box, made by Nanjing Anzheng Software Company, to collect data; Signal analysis software named SsCras, made by Nanjing Anzheng Software Company.

2.2. Pasting position and direction of strain gauges

2.2.1. Pasting position of strain gauges

Pasting position of strain gauges x/l on cantilever plate should be calculated according to the material type and specimen size [13]. For Poplar tangential-section specimens, $x/l = 0.540$ by calculation; for Sitka Spruce radius-section specimens, $x/l = 0.499$ by calculation; for MDF specimens, $x/l = 0.426$ by calculation.

2.2.2. Pasting directions of strain gauges

The strain gauge of 0° was pasted along the central line on the upper or lower surface of cantilever plate.

The strain gauge of 75° was pasted close to the strain gauge of 0°, having a positive 75° angle with central line (or x direction) (see Fig. 1).

The requirements of pasting strain gauges are: (1) the longitudinal central line of 0-degree strain gauge grid coincides with the central line of cantilever plate surface; (2) The 75-degree strain gauge has an angle of 75° with the central line of cantilever plate; (3) The center points of 0-degree and 75-degree strain gauge grids are in a straight line. The distance between the line and fixed end is x/l.

2.2.3. Half-bridge connection method

There is difference between Poisson's ratios measured on the two surfaces of the plate due to timber anisotropy and growth characteristics. Therefore, the strain gauges were pasted on both surfaces of cantilever plate to measure Poisson's ratios according to the half-bridge method. The pasting positions were determined according to the equation given by Wang et al. in 2016. Fig. 2 shows the pasting directions of strain gauges on upper and lower surfaces.

The strain gauge in a certain direction on upper surface was connected to AB end of bridge box, then the strain gauge in the same direction on lower surface was connected to BC end of bridge box. Correction factor was set as (sensitivity factor of strain gauge/2) × 2. If the conditioning box was used for amplification, the correction factor should be multiplied by amplified factor set in the conditioning box.

2.3. Experimental scheme

If the strain gauges were pasted on two surfaces of cantilever plate according to Fig. 3(a) or (b), the strain spectrum would only

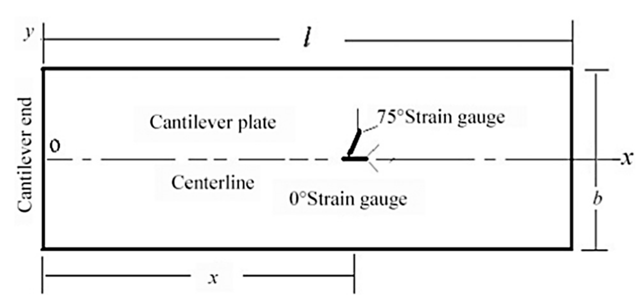

Fig. 1. Pasting positions and directions of 0° and 75° strain gauges.