Nondestructive Testing of Mechanical Parameters for Wood-based Materials

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Abstract

This article describes the national and international history, present situation and developing tendency in the research on nondestructive testing of mechanical parameters of Wood-based materials. It stressfully introduces foreign contributions in the field in order to provide some useful references to the researchers.

Keywords: Wood-based materials; Nondestructive testing; Mechanical parameters

1. Introduction

As a biological material, wood material has many characteristic properties. It is to be used widely in building, furniture, musical instrument, vehicle, ships and medical treatment apparatus. Research about the dynamic properties of wood material, chiefly can be divided into two following fields: (1) Sound insulation of the residence and acoustic property of musical instrument. (2) Nondestructive testing of mechanical parameters of wood-based materials by means of dynamic method.

Nondestructive testing of wood material will promote traditional test method to occur the ultimate revolution. Quality control of wood material will reach a new level. By means of the research of nondestructive testing and applying it to practice, the raw material will be saved and credibility of product can be ensured. Nondestructive testing is an important means to realize quality control, to raise work productivity, and to reach full automation.

2. Developments in the Research on Nondestructive testing of wood materials abroad

In the end of the 17th century, Bernoulli analyzed beam flection. In the beginning of the 18th century, Euler deduced elastic curve equation and flexural vibration equation. Bernoulli-Euler's beam theory was built. In 1921, Timoshenko has put forward the vibration equation including the influence of shear and rotatory inertia. In 1931, Goens deduced solutions of vibration equation of free-free beam including the influence of shear and rotatory inertia. In 1951, Mindlin expanded Timoshenko's theory. Leissa (1969) discussed the results of plates vibration. Hearmon (1948,1961) had carried out vibration experiment of plates according to the existing measure method of Young's modulus of wood. In addition, Hearmon (1958) discussed the rationality that vibration experiment of beam used to wood according to Timoshenko's theory [1-3].

In 1961, Kadita, Yamada and Suzuki studied the effect of moisture content on dynamic Young's modulus of wood. The results indicated that the maximum value of dynamic Young's modulus was observed at 4~5 percent moisture content in longitudinal direction, but not in the radial direction[4]. Matsumoto (1961) investigated that the different between the dynamic modulus and the logarithmic decrement of compression wood of soft wood and those of normal soft wood by vibration method. The following results were obtained: The dynamic modulus of normal wood is larger than that of compression wood. But the logarithmic decrement of normal wood is smaller than that of compression wood. In the normal wood, the dynamic modulus and the specific gravity is in linear correlation. In the compression wood, the dynamic moduli become smaller as the specific gravity becomes greater[5]. Suzuki, Nakato and Aikawa (1965) investigated that the frequency dependence of dynamic Young's modulus of wood and its relation to creep[6].

Since 1970's, with the progress of science and technology, very big progress had been gained in the research of nondestructive testing of wood material. In 1975, Nakayama studied nondestructive test of wooden beam by vibrational method[7]. Pellerin and Logan studied Transverse Vibration E-Computer, and gained American patent in 1977. E-computer has extensively been used by many wood production enterprises and scientific research organizations of America. The Young's modulus measured by E-computer is close to that measured by static bending test. Correlation coefficient is 0.96~0.99 [8]. In 1978, Paschalis studied the relationship between strength and texture of wood by vibration method and ultrasonic wave method. He indicated that vibration method and ultrasonic wave method had equal value to measure Young's modulus[9].

In 1980, Suzuki studied the relationship between specific gravity and decrement of dynamic Young's modulus with water. He indicated that dynamic Young's modulus considerably decreased as moisture content increased from 5 to about 35 percent and loss tangent increased with almost same moisture content range. In each of three structural axes, amount of decreased Young's modulus with water of certain moisture content increased with specific gravity in air dry of wood species. The decrement in radial direction was larger than in tangential direction[10]. Nakao, Okano and Asano studied the measurement of orthotropic shear modulus for wood by the high torsional vibration method[11]. Sobue investigated the instantaneous measurement for obtaining elastic constants using a FFT (Fast Fourier Transformation) spectrum analysis[12]. Sobue investigated that the simultaneous determination of Young's modulus and shear modulus of structural lumber. Complex vibrations of bending and twisting were produced by tapping a piece of lumber with a hard-rubber hammer. The isolation of the time-deflection signals of bending and twisting vibrations from the signal of a complex vibration was made by performing an addition to and a subtraction from the complex signals which were detected by a pair of vibration sensors installed at both edges of an end of a piece of lumber. The isolated signals were introduced to a Fast Fourier Transformation spectrum analyzer, and the resonance frequencies were identified instantaneously. This proposed method enabled a simultaneous determination of the Young's modulus and shear modulus of structural lumber. The results of the indirect estimations of shear modulus by the flexural vibration theory of Timoshenko's beam and by the regression analysis of shear modulus and Young's modulus proved that a twisting vibration method was indispensable for measuring the shear modulus of structural lumber[13].

After 1990's, with the rapid development of science and technology particularly electronics computer technology, the research about nondestructive testing of wood material reached a new stage. In 1990, Suzuki and Sasaki investigated the effect of grain angle on ultrasonic velocity of wood. The ultrasonic velocities of sugi and lauan were measured by the ultrasonic pulse-transmission technique. The effects of a specimen size and grain angle on the velocity of the longitudinal wave propagation were investigated. Experimental results were as follows: (1) For longitudinal waves traveling in the axial direction of a rod having a cross-section that was small compared to the wave length, the experimental ultrasonic velocities were nearly constant when the length of the rod was longer than 50mm. (2) The ultrasonic velocities decreased rapidly with increases of grain angles up to 45°, and in the range of 45°to 90°they decreased gradually with increasing grain angles. (3) Using the E_θ computed with the dynamic Young's moduli, E_L , E_R , and E_{45} obtained from the measured velocities of ultrasonic, calculated curves of sound velocities against grain angles agreed fairly well with the experimental results[14]. Yoshihara and Ohta (1993) measured the shear moduli in the tangential and radial planes of wood by torsion test. Sitka spruce was used for the specimens. The shear moduli obtained from the torsion test coincided well with the ones obtained from the compression test. Hence, it is proper to measure the shear modulus of wood by torsion test method[15].

Niemz, Kucera and Pohler studied sound velocities and dynamic Young's moduli of 13 kinds of Europe species and species abroad. The static Young's moduli were ascertained by measuring sound velocity and resonance frequency. The results indicated that there is correlation between the values and that measured by DIN52186[16]. In 2000, Kodama and Zhang used a wavelet transform method to evaluate wood quality[17]. Tonosaki, Saito, Hiramatsu (2001) studied the evaluation of non-homogeneity in wood by longitudinal and flexural vibration test[18]. Nagao, Washino, Kato and Tanaka (2003) studied the estimation of timber strength based on the distribution of MOE in the stem[19].

3. Developments in the Research on Nondestructive testing of wood-based panels abroad

When many scholars had studied dynamic properties of wood systemically, someone began to investigate those of wood-based panels whose application became more and more extensive.

In 1968, Matsumoto and Tsutsumi investigated the relationship between static Young's modulus and dynamic Young's modulus of plywood. The results of the studies are summarized as follows: (1) There is a very high correlation between static Young's modulus and dynamic Young's modulus of plywood. (2) Dynamic Young's modulus is greater than static Young's modulus. (3) The following approximate relations hold. $E_d^{90}/E_d^0 \approx E_s^{90}/E_s^0$, $E_d^{45}/E_d^0 \approx E_s^{45}/E_s^0$, $E_d^{45}/E_d^{90} \approx E_s^{45}/E_s^{90}$ [20]. Narayanamurti, Devarajan and Mohan (1977) studied nondestructive testing of 3-ply plywood. The following conclusions can be drawn: The correlation between the dynamic and static elastic moduli is high. The dynamic elastic modulus is greater than static elastic modulus[21]. In 1980, Dunlop measured the acoustic velocities of a wide range of particle boards from measurements of the transit times of wave packets through the materials. The velocities can be used to predict the properties of particle boards by means of the relationship the velocities and strength parameters[22]. Greubel (1989) investigated the propagation of sound perpendicular to board plane in industrial particleboards. There was a distinct correlation between tensile strength perpendicular to grain and sound velocity[23].

Dong (1992, 1994, 1995, 1996) studied the Young's modulus and shear modulus of particleboard and MDF from theoretical analysis and experiment verify. In 1994, Shyamasunder, Aswathanarayana and Venugopal studied the nondestructive evaluation of modulus of elasticity and modulus of rigidity of plywood by sonic methods. A high degree of correlation exits between dynamic and static MOE. The results obtained for G call for further investigation with a large number of samples[24-28]. In 1995, Greubul and Wissing investigated the modulus of elasticity and modulus of shear of one- and three-layered particle boards by bending vibrations[29]. In 1996, Niemz and Poblete studied the sound speed transmission in laboratory and industrial particleboards. A correlation between MOR and MOE with the speed of the sound transmission was calculated. An important effect of board density and amount of adhesive on the transmission was found[30]. In 2002, Nakao studied the prediction of strength of LVL by means of measuring of Young's modulus of veneer[31].

4. Developments in the Research on Nondestructive testing of wood-based Materials in China

In 1983, Shi, Yin and Ruan measured the sound velocities in wood using the sound pulse method. The mechanical strength test of wood samples was also made. Regression relations between sound velocities and compressive strength were secured. Factors affecting sound velocities in wood and the differences of sound velocities in the three main directions (longitudinal, radial and tangential) of wood were also determined. All this has been qualitatively described with the help of a tubular model[32]. In 1987, Dai, Liu, Ding and Pu checked the longitudinal and horizontal ultrasonic velocity and ultrasonic modulus of elasticity of four species of wood, they are Pinus koraiensis, larix dahurica, Faxinus mandshurica and Tilia amurensis, which are air dried. Correlativity between two ultrasonic parameter and the longitudinal compressive strength and bending strength of wood has been analyzed with monoacidic and dualistic regression[33]. In 1988, Zhao, Liu, Li and Zhu studied a new method to measure Young's modulus and shear modulus quickly by means of vibration theory, FFT analysis technology and computer technology. Results were summarized as: (1) Young's modulus and shear modulus of wood can be measured by means of FFT analysis technology and computer technology; (2) Compare to traditional method, this method is simple and quick; (3) There was strong correlation between dynamic Young's modulus and static Young's modulus; (4) This method was recommendable when it is difficult to measure shear modulus[34].

In 1995, Wang studied the measuring method of modulus of elasticity of MDF by non-destructive testing technology of stress wave. The research results indicated that the bending modulus of elasticity measured by non-destructive testing of stress wave was precise enough and it was possible to develop online quality control system of MDF according to mechanical properties and automatic control system of production line[35]. 2001-2005, Hu measured the dynamic Young's modulus and shear modulus of particleboard and MDF by flexural vibration, longitudinal transmission and longitudinal resonant vibration. The relationships among values measured by different tests were analyzed[36-39].

5. Conclusion

As indicated above, there are many reports on the research about nondestructive testing of wood. However, few investigations have been concerned with nondestructive testing of wood-based composites. With the wood resources going short gradually and manufacturing technology of wood-based composites improving continuously, wood-based composites will play more and more role in the coming production and the life. Therefore, it is necessary to study nondestructive testing of wood-based composites. In summary, the author thinks we should enhance research on the following aspects from now:

(1) Study on nondestructive testing mechanism of wood-based composites. Many countries of the world attached importance to the research of wood-based composites in recent years. Wood-based composites will play an important role in the coming the life of mankind. However, few investigations have been concerned with nondestructive testing mechanism of wood-based composites at present. We should explore nondestructive testing method that is suitable for wood-based composites by means of the research on nondestructive testing mechanism of wood-based composites.

(2) Study on the correlation of dynamic properties and static properties of wood-based composites. Dynamic nondestructive test have a lot of advantages, but according to the current national standard of China, the mechanical parameters of wood-based panels still be measured by using static damaged test method. Therefore, we must grasp the correlation of dynamic properties and static properties so that static properties can be calculated from dynamic properties.

(3) Study on the prediction of mechanical parameters of wood-based composites. Compare to traditional materials, the notable characteristic of composite materials is that they can be designed. So we must build the prediction model of mechanical parameters of wood-based composites. By means of material selection and matching, the expected purpose can be achieved farthest and to meet the use properties of engineering design.

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