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Nondestructive Testing of Wood Defects based on Stress Wave Technology

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Abstract

The wood samples were tested by the technique of stress wave, and the testing results were analyzed by using the statistic software of SPSS. The results showed that the length, density and knots of wood, the sizes of holes and numbers of holes have significant influence on propagation parameters and dynamic modulus of elasticity. Under the same specifications, the propagation time of the stress wave was longer in the wood with holes than the perfect wood samples, and the time become longer with the increasing the sizes and numbers of holes. The studying results of this paper will provide a sound background for the application of stress-wave technique in detecting the inner defects of wood products and other wooden structures.

Keywords: *wood samples, defect, stress wave, non-destructive testing*

1. Introduction

How to increase timber production and improve the quality of wood is one of the main problems for forestry enterprises. The contradiction can be solved from two aspects. On one hand, reasonable forest harvesting should be applied to mutually coordinate the relationship between harvesting and planting and excessive cutting should be avoided. On the other hand, the limited forest resources should be rationally used and wood utilization rate should be improved. Wood quality detection is a very important method to improve the rate of wood utilization. The purpose of this paper is to use an effective non-destructive testing method to accurately and quickly judge the inner information of wood products including all kinds of defects in order to ensure the reasonable selection and scientific utilization of timber products, improve wood utilization rate, effectively conserve timber resources, and ensure the sustainable development of forest ecological environment.

Wood non-destructive testing technology is a new and comprehensive detection method. It can detect and evaluate the physical properties of wood, growth characteristics, mechanical properties, and wood defects without destroying the final value of the wood. Since 1950s, wood non-destructive testing technique has been widely applied from standing trees to lumber and artificial board, from moisture content to mechanical properties, and from external to internal wood defects. Current non-detructive methods include X radiographic testing, RF detection, infrared detection, ultrasonic testing, mechanical stress testing, vibration detection, impact stress wave detection, acoustic emission testing, nuclear magnetic resonance spectroscopy, and so on [1-3]. When compared to other nondestructive testing techniques such as CT, X ray, the stress wave detection technology has its advantages including low cost and easy to carry, and it is not limited by the shape and size of the measured wood. It does not damage the measured wood, and no coupling agent is used between the sensor and the measured wood. Therefore, stress wave detection technology has been widely applied in the field of wood products industry, and many gratifying results have been achieved [4-11]. In this paper, the stress wave technique was used to test the impacts of wood defects of Korean pine wood samples. The research results can help save the timber resource, improve the wood utilization rate and wood production quality, and provide necessary conditions for the process control and automation during timber production, which will bring great economic benefits and social benefits to the forest industry.

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2. Testing Method

2.1. Testing Principle

The basic principle of stress wave testing method is to generate stress wave inside of the wood sample by hitting the end of the wood sample, and then determine the properties of wood (such as modulus of elasticity and defects) by measuring the change of stress wave propagation time and velocity. Based on the relationship among elastic modulus *E*, stress wave velocity *u*, and wood density *D*: $E=u^2D/g$, the wood elastic modulus can be measured. The judgment of wood defects is usually based on the change of propagation time and velocity. If there is a defect (such as hole or decay) along the propagation path of stress wave, the propagation velocity would decrease, and the propagation time would increase accordingly. The principle of stress wave detection of wood defects is shown in Figure 1.

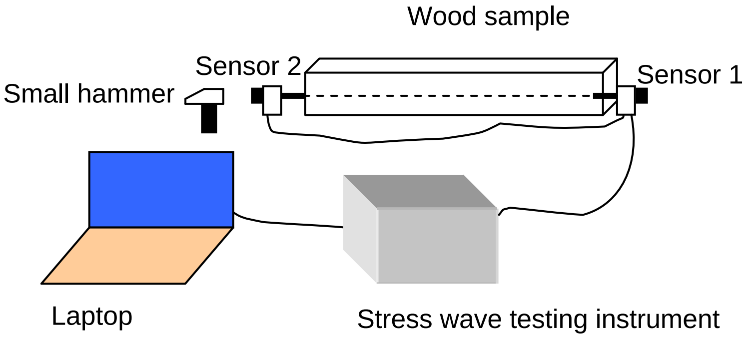

Figure 1. Principle of Testing Wood Defects using Stress Wave Technology

2.2. Testing Method

The impact stress wave method was used in the paper. Two probes were nailed on both ends of the wood sample, and sensors were hanged on the probes (Figure 1). When hitting the sensor by using a small hammer, stress wave was generated in the interior of the wood, and two sensors was used to induct the change of wave, and the propagation data was shown on the screen of the laptop. Based on the propagation time and velocity, the wood properties (such as modulus of elasticity and defects) were determined.

2.3. Testing System

The stress wave detector ARBOTOM imported from Germany was used in the experiment. The ARBOTOM detector is mainly used to measure the internal situation of wood. The propagation velocity of stress wave and wood density is highly correlated, so the ARBOTOM can be used to collect the information of wood internal defects. Before testing, some parameter values should be input, such as the number of sensors, the distance of all sensors, the unit of distance, the height of sensors above ground, the PC port, filtering mode, the name of tree species, and so on.

2.4. Wood Samples

The Korean pine wood samples were prepared in three dimensions, namely 200mm×50mm×50mm (type I, 27), 250mm×50mm×50mm (type II, 15), and 300mm×50mm×50mm (type III, 19). The text in the brackets contains the abbreviation of the dimension and the number of wood samples herein. In type I, the wood samples include the intact samples, samples with taper hole at one end, and the samples with single hole, two holes, and three holes evenly distributed along the axis. In type II, the wood samples include the intact samples, samples with taper hole, and samples with orthogonal localized double holes. In type III, the wood samples include intact samples and samples with a taper hole or a cylindrical hole at one end. The locations of the holes are illustrated in Figure 2. Six kinds of diameters of the holes along the axis are considered, including 5.2mm, 10mm, 15mm, 22.5mm, 30mm, and 35mm (depth is 50mm). The specifications (diameter (mm)×depth (mm)) of the taper hole include 5.2×35, 5.2×60, 10×50, 10×100, 15×50, 15×100, 25×50, 25×100, 25×60, 25×80, 25×90, 25×100, 30×30, 30×60, 30×100, and 30×110. The density of the wood samples is measured using weighting method and the moisture content is tested by KLORTNER-50 before machining the holes. The moisture content of the wood samples is around 9% due to the long time stored after being processed.

a. Single hole along the axis b. Double holes along the axis

c. Three holes along the axis d. Double holes at orthogonal

e. Taper hole at one end f. Cylindrical hole at one end

Figure 2. Location of Holes

3. Results and Analysis

3.1. Testing Results for the Clear Wood Samples

(1) Testing results

In this study, the moisture content of wood is 9. If the moisture content of wood is low, its physical changes are small. Therefore, the influence of stress wave on the wood detection is mainly affected by the wood density, wood length, and other physical characteristics. The wood density ranges from 0.4 to 0.5g/cm^3, and the length of wood samples is 200mm, 250mm, and 300mm, respectively. As the increase of the length of Korean pine wood samples, the propagation time was prolonged and the velocity decreased. As wood density increased, the propagation time tended to decrease and the velocity increased. However, the change was not significant. The testing results are shown in Table1.

Table 1. Testing Results for Clear Korean Pine Wood Samples with Same Moisture Content

No.	Length (mm)	Density(g/cm^3)	Transit time (μs)	Velocity (m/s)	MOE (Pa)
1	200	0.476	78.5	2578.5	3.165E+09
2	200	0.508	77	2598	3.429E+09
3	200	0.465	79	2532	2.981E+09
4	200	0.474	80	2500	2.963E+09
5	200	0.506	79	2532	3.244E+09
6	200	0.463	78	2564	3.044E+09
7	250	0.436	81	3070	4.110E+09
8	250	0.472	87	2874	3.899E+09
9	250	0.474	83	2992	4.243E+09
10	250	0.434	82	3049	4.035E+09
11	250	0.470	86	2907	3.972E+09
12	250	0.472	83.5	2994	4.231E+09
13	300	0.469	98	3062	4.397E+09
14	300	0.467	99.5	3015	4.245E+09

(2) Statistical analysis

The length of Korean pine wood samples has significant impacts on the propagation parameter and dynamic elastic modulus. As shown in Figure 3 (In order to show the variation of propagation time, velocity, and elastic modulus, the unit of velocity is set as 100m/s, the unit for elastic modulus is 10^8Pa), the propagation time (*T*), velocity (*V*), and elastic modulus (*E*) are all positively related to the length of the wood samples (*L*). A regression model was derived by using SPSS software. The correlation coefficients are 0.914, 0.896, and 0.912, respectively. The corresponding regression models are: T=41.938+0.177L, V=14.355+0.05809L, E=5.067+0.136L.

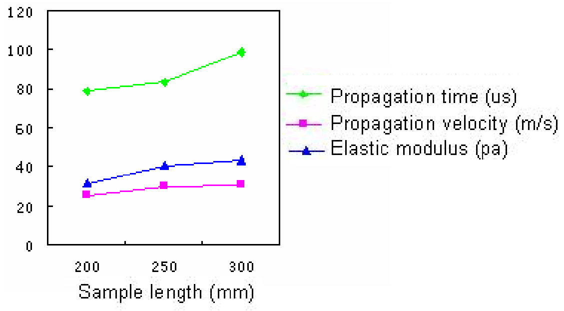

Figure 3. Effects of Sample Length

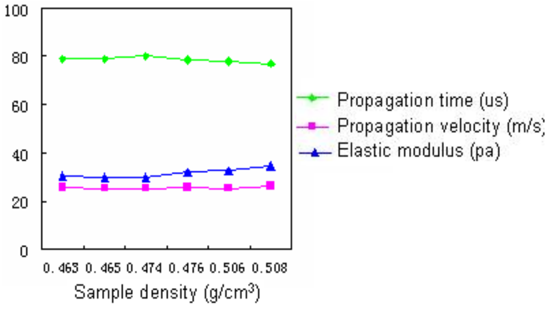

Figure 4. Effects of Sample Density

Wood density (ρ) has a certain impact on the propagation parameters and the dynamic elastic modulus for the samples with length of 200mm. As shown in Figure 4, the propagation time is negatively correlated to wood density, and the velocity and elastic modulus are all positively correlated to wood density. The correlation coefficients for the three parameters are 0.409, 0.328, and 0.891, respectively. The corresponding regression models are: T=89.031-21.646ρ, V=22.56+6.107ρ, E=-8.588+82.8ρ.

3.2. Testing Results for Natural Knot

Stress wave may without passing through the wood knot region during the vertical detection, which causes some effects on the testing results. Therefore, in order to find the effects of the knot on stress wave propagation parameters, lateral testing was used on the Korean pine wood samples with one natural knot. The results showed that the natural knot has significant impact on the propagation parameters. By comparison, the propagation time of stress wave in wood samples is shorter than that in wood samples with similar moisture content and density and the velocity increases. As the size of knot increases, the propagation time decreased and the velocity increased. For example, when the knot size increased from 0mm to 30mm, the propagation time decreased from 74μs to 61μs. As shown in Figure 5 (the unit for velocity (*V*) is 10m/s and the unit for elastic modulus (*E*) is 10^7Pa), the size of knot (*d*) is negatively correlated to the propagation time and positively correlated to velocity and elastic modulus. The correlation coefficients for the three parameters are 0.953, 0.947, and 0.962, respectively. The regression models are: T=74.712-0.426d, V=66.769+0.435d, E=21.386+0.295d. Therefore, the propagation parameters have better correlation relationship with the size of knot.

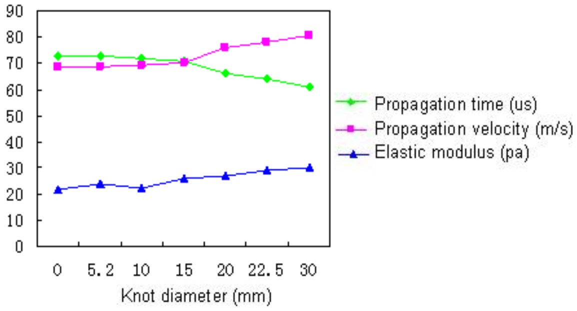

Figure 5. Lateral Testing of Knots using Stress Wave Technology

3.3. Testing Results for the Wood Samples with Holes

(1) Testing results

In type I wood samples, the size of the holes ranges from 5.2mm to 35mm. The testing results for the samples with single hole located in the middle of the axis showed that the propagation time increased from 75μs to 82.5μs and the velocity decreased from 2667m/s to 2439 m/s. The testing results for double holes evenly distributed along the axis showed that the propagation time increased from 80μs to 91μs and the velocity decreased from 2500m/s to 2198 m/s. The testing results for three holes evenly distributed along the axis showed that the propagation time increased from 51.5μs to 60μs and the velocity decreased from 2439.5m/s to 2128 m/s.

In type II wood samples, double holes are orthogonally and evenly distributed along the axis. As the size of the holes increased from 15mm to 35mm, the propagation time increased from 88μs to 98μs. In type III wood samples, the propagation time increased from 108.5μs to 112μs as the size of holes (taper holes with depth of 100mm) increased from 25mm to 35mm. Therefore, the size of taper holes has no obvious effect on the propagation parameters. This is probably due to stress wave may without passing through the hole, and the changes are caused by the samples' physical properties.

(2) Statistical analysis

The testing results on the type I wood samples with single hole evenly distributed along the axis showed that the size of the hole (*d*) has significant impact on the propagation parameters and dynamic elastic modulus (Figure 6). The diameter of the hole is positively correlated to the propagation time and negatively correlated to the velocity and dynamic elastic modulus. The regression analysis showed that the correlation coefficients for the parameters are 0.748, 0.734, and 0.835, respectively. The regression models are: $T= 72.034+0.529d$, $V = 27.534–0.162d$, $E = 3.8-0.0515d$.

For the wood samples with hole size of 15mm, the number of holes along the axis (n) has significant effect on the propagation parameters and dynamic elastic modulus. The number of holes is positively correlated to the propagation time and negatively correlated to the velocity and elastic modulus (Figure 7). The regression analysis results showed that the correlation coefficients are 0.991, 0.968, and 0.857, respectively. The regression models are: $T= 69+6.5n$, $V= 28.343-0.197n$, $E= 3.29-0.245n$.

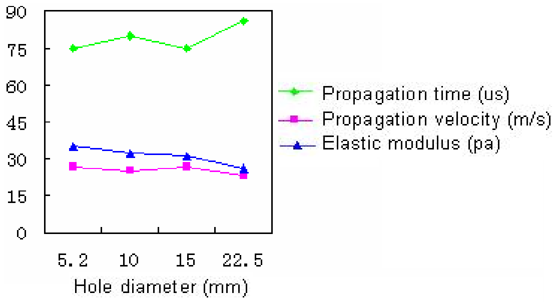

Figure 6. Effects of Hole Size

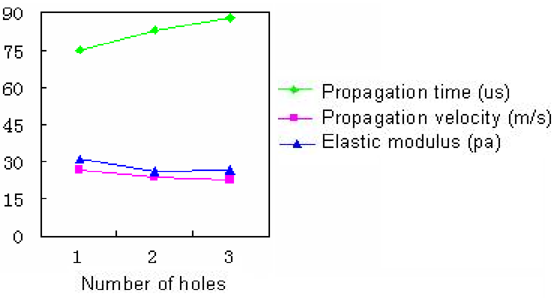

Figure 7. Effects of Number of Holes

4. Conclusion

By applying stress wave testing technology in the testing of Korean pine wood samples, the following conclusions can be drawn: (1) The length of wood samples has significant impact on the propagation parameters and dynamic elastic modulus and is positively correlated to propagation time, velocity, and elastic modulus. (2) Wood density and knots have a certain effect on the parameters and elastic modulus. The wood density and knot size are negatively correlated to propagation time, while they are positively correlated to velocity and elastic modulus. (3) The size of hole along the axis has great impact on the parameters and elastic modulus, which is positively correlated to propagation time and negatively correlated to velocity and elastic modulus. (4) The hole size at one end of the wood samples has no significant impact on the parameters and elastic modulus. This is probably due to stress wave may without passing through the hole.

Even though a series of testing were carried out based on different factors, such as sample length, knots, and holes at different size and locations, there are still some limitations in this study. Due to the limited number of wood samples tested, there may be some derivations in the statistical analysis. Therefore, it is recommended that multiple tree species and different wood defects can be considered in the future study. Meanwhile, the testing on actual wood defects such as knot, cracks, and decay should be conducted. In addition, because the impact force is not the same when using the mall hammer to hit the sensors, so there is a great influence on the accuracy for the stress wave detection. In order to reduce the error, the instrument itself should be able to transmit and receive signal during the testing process, which will reduce the influence of human factors.

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