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Influence of Resin-Infiltrated Time on Wood Natural Materials Using Conventional/Air-Coupled Ultrasound Waves

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Abstract Composite wood materials are very sensitive to water and inspection without any coupling medium of a liquid is really needed to wood materials due to the permeation of coupling medium such as water. However, air-coupled ultrasound has obvious advantages over water-coupled experimentation compared with conventional C-scanner. In this work, it is desirable to perform contact-less nondestructive evaluation to assess wood material homogeneity. A wood material was nondestructively characterized with non-contact and contact modes to measure ultrasonic velocity using automated data acquisition software. We have utilized a proposed peak-delay measurement method. Also through transmission mode was performed because of the main limitation for air-coupled transducers, which is the acoustic impedance mismatch between most materials and air. The variation of ultrasonic velocity was found to be somewhat difference due to air-coupled limitations over conventional scan images. However, conventional C-scan images are well agreed with increasing the resin-infiltrated time as expected. Finally, we have developed a measurement system of an ultrasonic velocity based on data acquisition software for obtaining ultrasonic quantitative data for correlation with C-scan images.

Keywords: Air-Coupled Ultrasound, Wood Material, Ultrasonic Velocity

1. Introduction

Owing to the advantages of environmental control and recycling, wood materials are attractive for a wide range of applications in the areas of furniture, household goods, architecture structures, engineering parts, etc. In particular, the wood products modified with a chemical substance are one of the few engineering materials that are suitable for engineering parts, building structures, etc. Usually wood is treated with a chemical substance to prevent moisture absorption and to improve mechanical properties. Treated wood is not only more resistive against water soaking but also has much improved mechanical properties, particularly its strength (Im et al., 2002).

To ensure a chemically treated wood quality and structural integrity, nondestructive evaluation (NDE) methods are needed for inspecting wood product integrity (Hsu et al., 1994). Various techniques have been tested for their suitability as NDE tools for wood product. Henrique, kyziol and Rybiki (1986) investigated the possibility of

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acousto ultrasonic method through the measurement and calculations of wood fiber and board. Patten-Mallory, Anderson and DeGroot (1986) showed an acousto ultrasonic method for evaluating decayed wood. Kowalski, Kyziol and Rybiki (2002) demonstrated the development and characterization of a composite material consisting of woody skeleton and polymerized methacrylate.

In this work, through-transmission C-scan of wood samples was conducted, which sealed in polyester film in an immersion setup based on both the amplitude and time-of-flight. A couple of ultrasonic NDE techniques were carried out for qualitative assessment of the material homogeneity in the wood samples of treated wood samples. Immersion and air-coupled ultrasonic testing were conducted to obtain C-scan images of the wood samples. A NDE test technique (a peak-delay measurement method) was proposed to get an ultrasonic velocity based on through-transmission mode. Also, we have developed an ultrasonic measurement system based on data acquisition software for correlation with C-scan images and ultrasonic velocity with obtand could obtain quantitative data. Finally we have compared results of C-scan images based on Peak-to-peak amplitude and time-of-flight (TOF).

2. Experimental Approach

2.1 Sample Configuration

In this test, wood sample (Douglas fir provided by a Certain Company in Korea) were prepared by using an automatic planer and dried in a laboratory drier. The specimens were infiltrated by antiseptic solution (Kunos from Korea) as an insect repellant for a period of 0 min, 10 min and 2hr respectively. Polyester film tapes (853, 3M Co.) were used to seal on both sides of specimens in order to scan in water. Thickness of the tapes is 0.05mm. Test specimens were prepared with dimensions about 100x100 (width x length) and 3, 8, 12 and 16 mm in thickness respectively (see Table 1). Here allowable error of thickness for specimens is +/- 0.5 mm. Firstly, the utilized system is called Sonda 007CX Airscan (Sonda), which is commercially available from Quality Materials Inspection, Inc. (QMI). The transducer used was piezo-ceramic and a pair 400 kHz focused probes with 25.4 mm in diameter. Also, the air-coupled system form QMI is adapted to an already existing motorized scanner from Sonix, Inc. (see Fig. 1) Also for the conventional way, the through-transmission ultrasonic C-scanner was conducted in an immersion tank using a Sonix scanning system. A pair of 1 MHz, 25.4 mm diameter, focused transducers were aligned perpendicular to the wood and driven by a Panametrics 5073 pulser/receiver.

Fig. 1 QMI piezoceramic transducers

Table 1 Thickness and infiltrated time for samples

Spec. \ No.	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Thickness	3	3	3	8	8	8	12	12	12	18	18	18
Infiltrated time(min)	0	10	120	0	10	120	0	10	120	0	10	120

2.2 NDE Techniques

The ultrasonic velocity in the wood samples was measured in the thickness direction at several points on the sample using dry-coupling ultrasonics (KD50-1, Ultran Lab.) as shown in Fig. 2. All measurements were made with narrow bandwidth ultrasonic transducers which have high penetration power and sensitivity. Because the inhomogenous nature of the wood samples that makes the ultrasonic transmission difficult, the data were obtained in the time domain. And contact and planar transducers of dry-coupling were used. To obtain a quantitative, accurate value of the ultrasonic velocity, a pulse-overlap method with dry-coupling transducers was used (Hsu, 1992). These transducers contain an elastomer face layer and can be coupled by applying pressure. To obtain the ultrasonic transit time through the sample, the difference in transmit time between two ultrasonic pulses was measured. The first pulse was transmitted through the reference piece but without the sample in place and the second pulse was transmitted through the reference piece plus the sample. Thin rubber sheets were used in both cases to provide dry-coupling between the reference piece and the sample and to ensure that its own transit time was canceled out (Hsu, 1992). These two pulses were stored in the memory of a LeCroy 9400 digital oscilloscope and their difference was obtained by shifting one pulse to overlap and match with the other pulse as shown in Fig. 2.

2.3 Velocity Measurement

The velocity was simply the sample thickness divided by the transit time through the sample. To improve the reproducibility of ultrasonic velocity measurement, a digital force gauge system (I=SV-2s, Imada) was employed as shown in Fig. 3. To confirm the above velocity data, an immersion experimentation were made to measure the ultrasonic velocity at the local point in the wood materials. An immersion configuration was plotted for measuring the velocity and thickness measurement (see Fig. 4). Here the time of flight t_w and t_m refer, respectively, to the wave propagation time in water only (for example, specimen removed from between the transducers) and the propagation time through the material of unknown thickness d and unknown group velocity V. Time of flight t_1 and t_2 are the propagation times of the various pulse-echo and through-transmission signals as shown in Fig. 4. We have the following

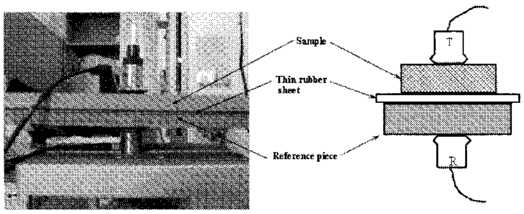


Fig 2 Experimental setup for overlap method to obtain ultrasonic velocity

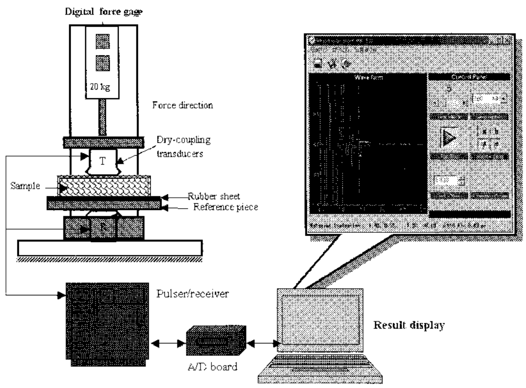


Fig 3 Digital force gauge system used in ultrasonic velocity measurement

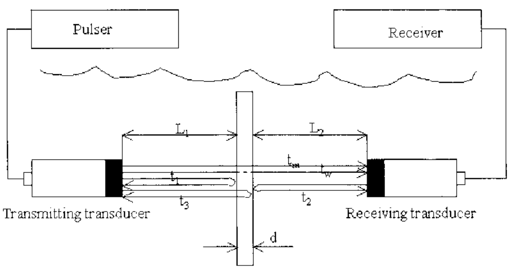


Fig 4 Experimental setup for ultrasonic velocity (through-transmission mode)

expressions (eqn. 1) to obtain velocity of wood (Hsu, 1992).

$$V = V_w \left(\frac{2(t_w - t_m)}{t_3 - t_1} + 1 \right) \quad (1)$$

The data acquisition mechanism was kept as simple as possible to allow for the easy adaptability into an experimentation environment. A digital force gauge could simply be used to keep up uniform coupling on the sample.

This prototype was built with a industrial computer and Visual Basic based data acquisition system for measuring the ultrasonic velocity. Fig. 5 shows a screen shot of the data acquisition software. Here we have developed a technique to measure ultrasonic velocity by using a peak-delay measurement method.

We have compared the results with the data from a pulse-overlap method. In a pulse-overlap method these two pulses are stored in the memory of a digital oscilloscope and their difference is obtained by shifting one pulse to overlap and match with the other pulse. The velocity was simply the sample thickness divided by the transit time through the sample. So the velocity is easily obtained in this manner. However, it involves time-consuming and tedious manual steps to get the ultrasonic velocity. In a peak-delay method based on peak amplitude, these two pulses are stored in the memory of a digital oscilloscope and their time difference is obtained by comparing peak amplitude difference as shown in Fig. 5. First, a gate is placed over a pulse and then a gate is placed on the other pulse; their time difference is automatically measured based on highest amplitude of each pulse.

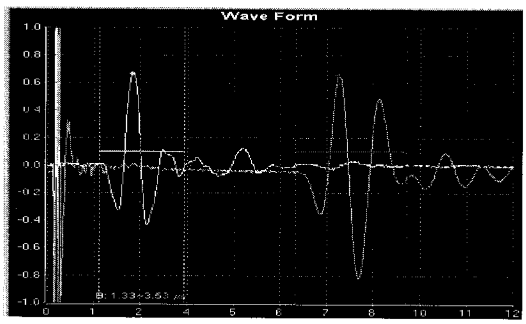
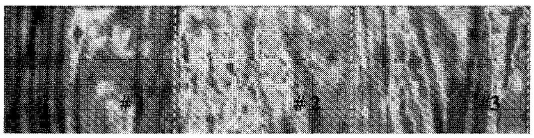


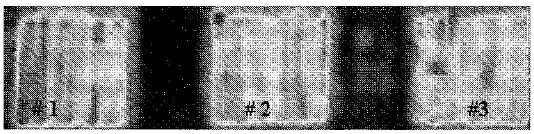
Fig 5 Screen shot of the data acquisition software

3. Test Result and Examination

Figs. 6-9 show C-scan images between conventional and air-coupled C-scanner based on the mode of through-transmission for # 1, # 2, # 3, # 4, # 5, # 6, # 7, # 8, # 9, # 10, # 11 and # 12 specimens respectively. Fig.6 shows C-scan images of through-transmission mode for # 1, # 2 and # 3 specimens respectively. These specimens are 3mm in thickness. In case of # 1 specimen with no infiltration, peak-to-peak amplitude value is much lower over the entire area. In case of # 2 and # 3 specimens, peak-to-peak amplitudes increased as infiltration time increased. However there is little difference on the peak-to-peak amplitude for # 1, # 2 and # 3 specimens. Especially as shown in Fig. 7, the attenuation was higher and the velocity was lower at one location. These results were also consistent with the expectation of density variation. In case of # 4 specimen with no infiltration, peak-to-peak amplitude value is lower over the entire area. It is found that there is somewhat agreed with the peak-to-peak amplitude for # 4, # 5 and # 6 specimens in Fig 7.



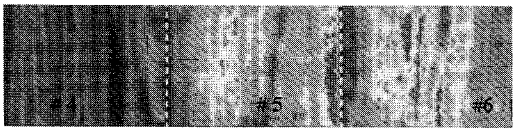
(a) Conventional



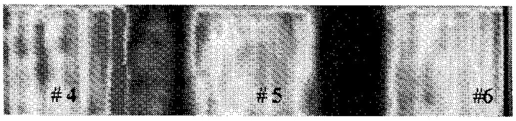
(b) Air-coupled

Fig 6 C-scan image comparison between (a) conventional and (b) air-coupled ultrasonic testings based on the through-transmission for # 1, # 2, and # 3 specimens(3 mm)

There are similar consistency as Fig. 7 for Figs. 8-9 respectively. Here, there are somewhat differences between conventional and air-coupled images due to air-coupled limitations (frequency, parameter, etc.). In terms of the time-of-flight (TOF), the TOF C-scan images of the through transmission scan are obtained. It is found that the c-scan images for # 1, # 2 and # 3 specimens correspond to infiltration time of antiseptic solution (Kunos) for a period of 0 min, 10 min and 2 hr respectively. The images were plotted based on time-of-flight. In case of specimen #1 with no infiltration, peak-to-peak amplitude of C-scan image is lower and time-of-flight value is shorter in the left area. In case of specimens # 2 and #3 , peak-to-peak amplitude values were increased as the infiltration time became longer and the time-of-flight value seemed to increase too. The amplitude images of # 2 and # 3 specimens showed that the transmitted signals had no significant difference even through the infiltration time of # 3 specimen was longer. Peak-to-peak amplitude value of # 3 specimen appears lower than of # 2 specimen due to their different contents of wood year rings and some deformation during seasoning wood. However the behavior of the ultrasonic transmission through the wood of # 1 specimen was consistent with changes in ultrasonic attenuation and velocity caused by density variation (Jeong, 1992). As shown in Fig. 6, the attenuation was higher and the velocity was lower at the left location. These results were also consistent with the expectation of density variation.

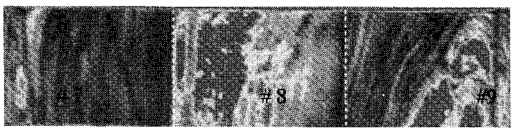


(a) Conventional

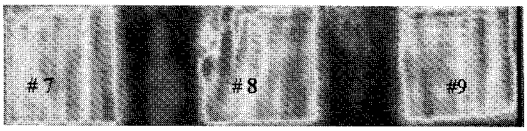


(b) Air-coupled

Fig 7 C-scan image comparison between (a) conventional and (b) air-coupled ultrasonic testings based on the through-transmission for # 4, # 5, and # 6 specimens(8 mm)



(a) Conventional

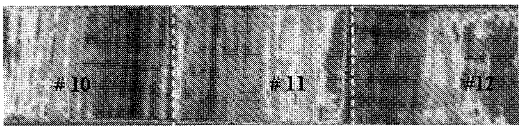


(b) Air-coupled

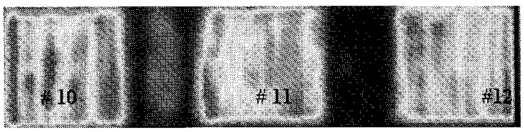
Fig 8 C-scan image comparison between (a) conventional and (b) air-coupled ultrasonic testings based on the through-transmission for # 7, # 8, and # 9 specimens(12 mm)

Fig. 10 shows a through-transmission peak amplitude and TOF of # 1, # 2, # 3, # 4, # 5, and # 6 specimens. Fig. 10 (a) shows peak amplitude of C-scan image. Two arrows show higher amplitude area compared to the rest area which means higher density. Also Fig. 10(b) shows time-of-flight of C-scan image. Two arrows show lower time-of-flight area which means higher ultrasonic velocity.

Figs. 11-14 show relationship of ultrasonic variation according to the infiltration time and also a comparison based on the peak-delay measurement method for # 1, # 2, # 3, # 4, # 5, # 6, # 7, # 8, # 9, # 10, # 11 and # 12 specimens respectively. There is a trend on

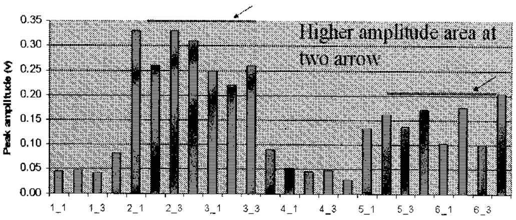


(a) Conventional

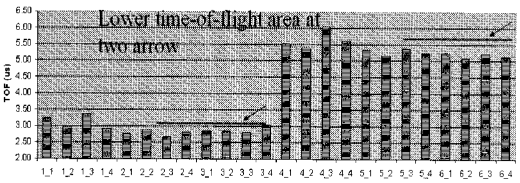


(b) Air-coupled

Fig 9 C-scan image comparison between (a) conventional and (b) air-coupled ultrasonic testings based on the through-transmission for # 10, # 11, and # 12 specimens(16 mm)



(a) Peak amplitude of C-scan image



(b) Time-of-flight of C-scan image

Fig 10 Through-transmission peak amplitude and TOF of # 1, 2, 3, 4, 5, and 6 specimens

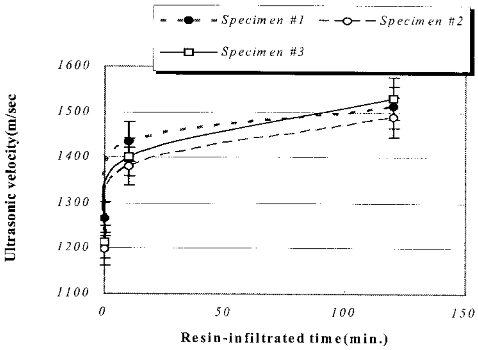


Fig 11 Relation between infiltration time and ultrasonic velocity for # 1, # 2 and # 3 specimens

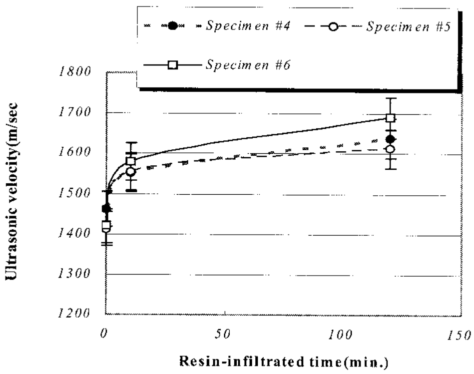


Fig 12 Relation between infiltration time and ultrasonic velocity for # 4, # 5and # 6 specimens

effect of resin-infiltrated time on Figs. 11-14. It is found that the ultrasonic velocity depends on the resin-infiltrated time. However, there are some difference as shown in Fig. 13 due to the wood homogeneity.

Also, the velocity data measured with dry-coupling transducers provided strong evidence

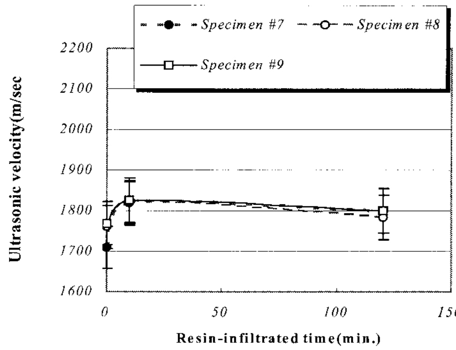


Fig 13 Relation between infiltration time and ultrasonic velocity for # 7, # 8and # 9 specimens

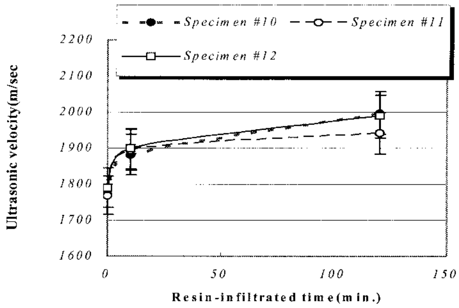


Fig 14 Relation between infiltration time and ultrasonic velocity for # 10, # 11 and # 12 specimens

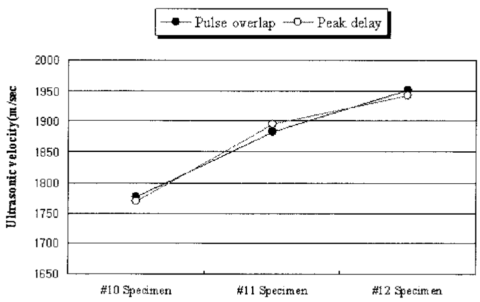


Fig 15 Relation between infiltration time and ultrasonic velocity for # 10, # 11 and # 12 specimens

of a consistently material property nonuniformity with the increase of resin- infiltrated time in the thickness direction as shown in Fig. 15. It is found that good results were obtained for both through-transmission, a pulse overlap method and a peak-delay measurement method. Therefore it is possible that the proposed peak-delay measurement method was effective to obtain ultrasonic velocity using developed software.

4. Summary and Conclusions

In this work, nondestructive test techniques have been conducted with wood samples about evaluating material property nonuniformity of wood samples, the following conclusions have been obtained.

1) An ultrasonic system was developed for ultrasonic velocity measurement based on data acquisition software.
2) It has been found that the immersion ultrasonic and air-coupled C-scan images could be obtained for the wood samples. However, there are somewhat differences between conventional and air-coupled images due to air-coupled characteristics.
3) The good correlation was observed between through-transmission conventional C-scan images and dry-coupling ultrasonic results using a NDE test technique (a peak-delay measurement method) based on through-transmission mode.
4) Ultrasonic velocity in the thickness direction seemed to be affected somewhat by the resin-infiltrated time, however, it seemed to be affected more by the relatively contents of year rings and density.

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