The Change of Ultrasonic Transmission Velocity by Wood Decay¹

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ABSTRACT

The deterioration in wood by the brown-rot fungus (*Fomitopsis palustris*) and the white-rot fungus (*Trametes versicolor*) were measured using ultrasonic velocity. Those were used for the decay exposure and 4 wood species of wood as the test specimens, *Pinus densiflora*, *Larix kaempferi*, *Pinus koraiensis* and *Pinus rigida*, were chosen with both the brown- and white-rot culture petridish during 12 weeks. After 12 weeks, the decrease rate of ultrasonic velocity was measured at 10 ~ 15%. In both brown- and white-rot exposure experiments, *P. rigida* showed significant decrease in ultrasonic velocity (20%), *L. kaempferi* on the other hand did not show decrease in ultrasonic velocity. After the fungal exposure experiment, the inside of specimens was investigated by computer tomography (C/T). After C/T investigation, bending tests were performed.

Keywords : Brown-rot fungus, White-rot fungus, Ultrasonic velocity, Computer tomography, Deterioration

1. INTRODUCTION

There are many problems affecting wood in timber architecture and in wooden cultural properties. These are caused by deterioration so that the performance is reduced due to the biological and non-biological factors. The study on timber architecture and historic timber architecture and deterioration is in progress. Kim *et al.* (2007) suggested that a pillar of historic timber architecture tends to be susceptible to deterioration and there are many examples of decay of various types of wooden parts in the environment around us. Kim *et al.* (2003) reported that

in deterioration evaluation of column members of ancient architecture through non-destructive inspection, deterioration of pillars at the section adjacent to the land and at the top of the upper part. Son *et al.* (2004) estimated the extent of decay of a Korean palace by nondestructive evaluation (NDE). Deterioration of the wood threatens a building's durability and internal stability.

Before assessing soundness of wood before it is used consideration of the systematic and historical importance of the wood is required and the method of measuring its internal state with avoiding direct destruction of wood is necessary. Following these requirements among the methods of evaluating wood soundness, the study of

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NDE using ultrasonic velocity in wood is being developed.

Lee *et al.* (2003), who investigated ultrasonic transmission route in wood, if ultrasonic cannot directly be transmitted by a defect in wood, it may be delivered by the primary reflection in the opposite side.

Park *et al.* (2008) tried to detect artificial flaws in wood using ultrasonic passing time. It is reported that there is a relationship between a location of the ultrasonic detector and the direction of fracture. Furthermore, to detect internal deterioration of wood, an artificial defect is made and ultrasonic velocity is measured. The result showed that the larger the size of a defect, the less the ultrasonic velocity (Saeed K. *et al.*, 2009).

Lee *et al.* (2008) investigated on how brown-rot fungus in wood is develops through measurement of mass loss rate, mechanical property and ultrasonic velocity with samples that have been exposed to brown-rot fungus in the wood. The current study investigated the change in ultrasonic transmission velocity caused by the decay period and the change in ultrasonic transmission velocity in decayed specimens using ultrasonic transmission velocity about the absence of decay that is artificially produced through ultrasonic measuring instrument, Wood Pole Tester.

2. MATERIALS AND METHOD

2.1. Fungal Culture

Fomitopsis palustris and *Trametes versicolor* were a specimen size of is $2 \times 2 \times 30$ (cm). The test specimens were *Pinus densiflora*, *Larix leptolepis*, *Pinus koraiensis* and *Pinus rigida*. By taking heartwood and sapwood samples from each species

Fig. 1. The type of specimens.

of trees, a total of eight test specimens was used in this study. A Wood Pole Tester (PROCEQ, CH/PILODYN, 6J), (77 kHz) was employed to measure the velocity of propagation of ultrasonic waves (Fig. 1). Computed tomography was undertaken using a TSX-0001A, (TOSHIBA corp), located in Korean Forest Research Institute (KFRI), where it is employed to measure bending test of wood.

2.2. Experiment Method

2.2.1. Preparation of Test Specimens

To find out the change in velocity of transmission of ultrasonic waves through wood caused by wood rot-fungus each test specimen ($2 \times 2 \times 30$ (cm)) was taken from the heartwood and sapwood of the different wood species (Fig. 1). The first condition is to make the space where it is both right and left side off 1cm from the center of the length direction of test specimens. It is to protect the space from penetrating decaying rot-fungi when epoxy resin is sealed in the marked space (HT1, ST1). For the second condition, the method inoculating decaying rot-fungi without epoxy resin sealed in the test specimens were employed (HT2, ST2). Finally, a control group of wood specimens which had not been inoculated with wood rot fungi was included.

Fig. 2. Wood Pole tester.

2.2.2. Measuring the Velocity of Propagation of Ultra Sonic Waves

Measuring the velocity of propagation of ultrasonic waves was conducted by measuring the change in the velocity of propagation of ultrasonic waves by rot-fungi inside wood at every 7 days from a week when the wood rot-fungi were infected by the Wood Pole Tester (77 kHz) (Fig. 2).

2.2.3. Experimental Construction

After pouring and solidifying 2% agar (which is without nutrition) with pressurization and sterilization in schale with 90~100 diameter and 15 mm height, MRS agar is made including glucose 2.5%, peptone 0.5%, malt extract 1.0%, potassium dehydrogen phosphate 0.3% and magnesium sulfate 0.2%.

By positioning in the schale centre of the length direction of a specimen, a mycelium was allowed to grow from the specimen's centre. Sterile water was added to the specimen as required. To protect the specimen from exterior fungi, test specimens were cultivated for 12 weeks in the sealed plastic bags, at a temperature of $26 \pm 2^\circ\text{C}$ and relative humidity greater than 70% (Fig. 3).

Fig. 3. Specimens under fungal exposure test.

2.2.4. Computed Tomography

After the experiment on decay exposure, to investigate the internal shape of wood was computed tomography by a TSX-0001A with X-Rays for 5 seconds at 120 kV, 110 mA and set at 10 mm for intervals.

3. RESULTS AND DISCUSSION

3.1. Change in Ultrasonic Velocity

3.1.1. Influence of *F. palustris*

In the case of *P. densiflora*, ultrasonic velocity in wood at the early stage was 4881.65 (m/s) for the heartwood and 4609.43 (m/s) for the sapwood and after 12 weeks it was recorded at 4026.50 (m/s) for the mean of heartwood and 4286.15 (m/s) for that of sapwood, respectively. From this result, heartwood of *P. densiflora* decreased by 17.51% and sapwood by 7.01%.

For *P. koraiensis*, ultrasonic velocity in wood at the early stage was measured 4369.89 (m/s) for the heartwood and 4466.01 (m/s) for the sapwood and after 12 weeks it became 3891.82 (m/s) for the mean of heartwood and 4047.77 (m/s) for that of sapwood, indicating a decrease in 10.94% for heartwood and 9.36% for sap-

Fig. 4. Computed tomography.

wood compared with both means at the early stage, respectively (Fig. 4). Therefore the change in ultrasonic velocity in decayed heartwood changed more than for sapwood.

3.1.2. Impact of *T. versicolor*

Fig. 5 shows the relationship between *F. pal-*

ustris exposure time and ultrasonic velocity.

Fig. 5 indicating the change in ultrasonic velocity in wood caused by *T.versicolor*. One week after inoculation, for *P.densiflora*, the average of the heartwood's ultrasonic velocity was 4459.57 (m/s) and that of sapwood's was 5137.58 (m/s). After 12 weeks, the mean recordings for heartwood and sapwood average were 3880.31 (m/s) and 4766.70 (m/s) respectively.

In *L.kaempferi*, one week after inoculation, the heartwood mean of ultrasonic velocity was 4670.53 (m/s) and the sapwood mean of that was 5057.41 (m/s). After 12 weeks, the each average of heartwood and sapwood was 4018.61 (m/s) and 4690.55 (m/s).

In the case of *P.koraiensis*, while mean ultrasonic velocity in wood at the early stage was 4812.75 (m/s) for the heartwood average and 5147.29 (m/s) for the sapwood average, after 12 weeks mean ultrasonic velocity in wood for the

Fig. 5. Relationship between fungal exposure time and ultrasonic velocity (*F.palustris*).

Fig. 6. Relationship between fungal exposure time and ultrasonic velocity (*T.versicolor*).

heartwood and sapwood mean was 4444.44 (m/s) and 4737.10 (m/s).

In *P.rigida*, one week after inoculation, the heartwood was 4839.98 (m/s) and the sapwood 4614.77 (m/s) and after 12 weeks, both were measured in 3919.90 (m/s) and 3248.20 (m/s), respectively (Fig. 6).

3.1.3. Change Rate of Ultrasonic Velocity

Following exposure to the brown-rot fungus exposure comparison of ultrasonic velocity for two different periods (before and after inoculation), the change rate of ultrasonic velocity for each specimen indicated a decrease of 19.19% (*P.densiflora*'s sapwood), 8.27% (*L.kaempferi*'s sapwood), 13.95% (*P.koraiensis*'s sapwood) and 21.11% (*P.rigida*'s sapwood). Among 4 specimens, the rate of change in ultrasonic velocity for *P.rigida*'s sapwood was the most significant.

For *T.versicolor* the ultrasonic velocity for the two different periods the rate of change in ultrasonic velocity for each specimen was 12.98% (*P.densiflora*'s sapwood), 13.95% (*L.kaempferi*'s sapwood), 7.65% (*P.koraiensis*'s sapwood) and 19% (*P.rigida*'s sapwood). Therefore for the 4 specimens, the rate of change for *P.rigida*'s sapwood was again the most significant (Fig. 7).

Following decay *F.palustris* and *T.versicolor* over 12 weeks, computer tomography (C/T) was conducted. Fig. 7 shows the result of C/T following decay exposure experiment. It is classified by positioning that Type 2 was put above Type 1 and plastic plate is set in the middle.

Son *et al.* (2004) found that in the decay test the larger decrease in wood mass caused by the decay then the slower the ultrasonic velocity. Furthermore the longer the wood exposure times the slower the ultrasonic velocity and there is a

Fig. 7. Relationship between fungal exposure time and decreased rate of ultrasonic velocity (A: *F. palustris*, B: *T. versicolor*).

difference in the extent of the decay and the rate of change in the ultrasonic velocity depending on the properties of each specimen property. Lee *et al.* (2008) reported on loss rate of mass and ultrasonic velocity through the test specimen ($10 \times 3 \times 10$) that had been decayed by 2 types of brown-rot fungus. It was reported that at the early stage, the decay detection by measurement of ultrasonic velocity was possible and whereas qualitative evaluation was possible quantitative evaluation was unsatisfactory. Furthermore during 8 weeks of decay activity intensity capacity fell 80% and ultrasonic velocity decreased by around 30%. Compared with the findings of Lee *et al.* (2008), the current experimental procedure used larger test specimens ($2 \times 2 \times 30$) and a longer incubation period (12

weeks). Considering the size of the test specimens and the difference between types of wood, the results of decrease in the rate of ultrasonic velocity were similar to those published by Lee *et al.* (2008).

3.2. Computer Tomography (C/T)

After the test specimens had been exposed to the decay fungi during 12 weeks period the internal conditions of the wood samples were investigated using computer tomography. In the test specimen of constant thickness and high density the decrease in X-ray energy was higher than that of the test specimen with low density. Therefore, the brightness of a film is high due to decreasing the sensitivity of the X-ray film.

Fig. 8. CT images of specimens after fungal exposure test (A: *P.densiflora* B: *P.koraiensis* C: *P.densiflora* D: *P.koraiensis*) (A, B : decayed by *F. palustris* C,D : decayed by *T. versicolor*).

The greater the extent of the decay is, the lower the brightness is in the test specimen performed by C/T (Fig. 8). As Kim *et al.* (2006) reported that the brightness in the edge of the test specimen is strongly observed and it is thought that the phenomenon results from higher the X-ray intensity reaching a film and the higher X-ray intensity the greater the brightness of a film.

4. CONCLUSION

This study using 4 different wood types which were separated into heartwood and sapwood was undertaken to assess the extent of deterioration and the change in ultrasonic velocity in the inside of wood following the decay period from brown-rot and white-rot fungi.

The result showed that there is a significant decrease in ultrasonic velocity at the early stage of decay. Results for the 4 types of wood used indicated that the deterioration caused by the

brown-rot fungus in *P.rigida* (heartwood 21.11%, sapwood 18.09%) resulted in the largest change-*L.kaempferi*, the least change in ultrasonic velocity. Moreover, comparing heartwood and sapwood, heartwood decrease rate was higher than for sapwood.

Deterioration caused by the white-rot fungus was greatest in *P.rigida* (heartwood 19.00%, sapwood 29.61%). Like the brown-rot fungus the least change in the decrease in ultrasonic velocity was found to be for *L.kaempferi*. Except for *P.rigida* the remainder of the test specimens decrease in ultrasonic velocity was higher in heartwood was higher than in sapwood.

From this study, in artificially produced decay, qualitative evaluation is proved to be possible but additional research for quantitative evaluation is required

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