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Changes in Anatomical Features, Air Permeability and Sound Absorption Capability of Wood Induced by Delignification Treatment

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To estimate the possibility of improving the sound absorption capability of wood by delignification treatment, the changes in anatomical features on the cross sectional surface, air permeability in the longitudinal direction and sound absorption capability of wood were evaluated. The intercellular substance gushed out and numerous small cracks were formed on the surface of the delignificated wood. Delignification treatment improved the air permeability of the wood in the longitudinal direction. The sound absorption coefficients of the delignificated wood were higher than those of normal wood over the entire frequency range studied and this trend increased with increasing frequency.

Keywords: sound absorption coefficient, delignification treatment, anatomical features, air permeability

INTRODUCTION

Fibers of glass or mineral materials have found many applications as building materials because of their dominance in the commercial market, good sound absorption capability and good thermal insulation property. The importance of wood and wood–based materials as a sound absorber and a renewable resource is increasing due to the growing concern for human health. However, few studies have investigated the sound absorption properties of wood and wood–based materials. It is recognized that the sound absorption capability of wood is mainly influenced by airflow resistance that varies according to the sound incident surface structure and pore characteristics (Wassilieff, 1996). Therefore, porous glass and mineral–fiber sound absorbers have been designed with optimum airflow resistance.

Although wood and wood–based materials has been used as construction materials because of their good hardness, resistance to weathering and relatively good appearances and elastic properties, wood has been considered as a sound reflecting material because of its low sound absorption coefficient. In construction fields, proper sound absorption coefficients of a component are necessary for successful structural design.

The three basic types of sound absorption are pore, membrane and resonator. In the former, when sound waves propagate into a capillary or continuous air bubble of a porous material, part of the sound energy is converted to thermal energy by internal friction or viscous resistance of the cavity wall, or by damping of micro fiber vibration. In this pore type, the absorption rate is positively correlated with the frequency range. In the membrane type, when sound waves radiate to an airtight surface such as thin veneer or canvas, part of the sound energy is decreased by plate vibration. This type shows a high absorption rate at a low frequency range, but the average absorption rates over the entire frequency range are not high. In the resonator type, the sound energy is decreased by the resonant vibration of air in the cavity that is built up naturally or artificially. The sound absorption characteristics of this type show a very high absorption rate but only within a very narrow frequency range. Sound absorption occurs as a combination of these three basic types. As a sound absorber, wood may be classified as a porous absorber as it has abundant pores due to its ecological structure. However, the sound absorption coefficient of wood is low because of its low ratio of continuous pores, which is one of the major favorable factors for porous absorption. If the abundant pores can be used for sound absorbing, the sound absorption capability of wood will be improved.

Two methods are available to estimate the sound absorption coefficient: reverberation room and impedance tube. The latter is quick and easy as it requires only small samples of the absorbing material. This method divided into two types: the standing wave method which measures the standing wave ratio, and the two microphone transfer function method. The latter method, which was described in ISO–10534–2, uses the transfer function measured between two microphones at two distinct positions in the impedance tube (Seybert and Ross, 1977; Chung and Blaser, 1980; Suzuki *et al.*, 1981).

Seybert and Ross (1977) reported that the two microphone method is about 40 times faster than the standing wave method in the measurement of normal incident sound absorption coefficients of materials and suggested that great care is needed mounting a sample in the impedance tube because of the possibility of error arising from

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the gap between the tube and the sample specimen. Haines and James (1989) reported obtaining excellent agreement between the standing wave and two microphone methods.

Recently, many researchers have investigated the possibility of using porous metals as a sound absorber because of their good sound absorption capability, good mechanical properties and adjustable manufacturing process for desired pore structure. The sound absorption coefficients have been reported to vary with the changing porosity of several kinds of porous metals such as copper, aluminum and magnesium (Guiping *et al.*, 2001; Xie *et al.*, 2004; Nakajima *et al.*, 2004; Hakamada *et al.*, 2006). Xie reported the relationship between airflow resistance and sound absorption coefficient. Sgard *et al.* suggested that perforations can improve the sound absorption capability of porous materials (2005). The sound absorption properties and the possibility as a sound absorber of wood and wood–based materials were assessed (Omran *et al.*, 1980; Wassilieff, 1996; Yang *et al.*, 2004).

In this study, to estimate the possibility of improving the sound absorption capability, the changes of air permeability and anatomical features of wood induced by delignification were evaluated. We adapted delignification treatment on the tree disk of *Larix kaempferi*, then observed the anatomical features of the cross sectional surfaces of normal and delignificated woods by stereoscope and scanning electron microscopy (SEM) observations, and gauged the density profile in the thickness direction of the delignificated wood by X–ray transmittance ratio apparatus. After investigating the air permeability of the control and delignificated side inlets from the same sample, we evaluated the sound absorption coefficients by the two microphone transfer function method. From these results, changes in the anatomical features, air permeability and sound absorption capability of wood induced by delignification treatment were evaluated.

MATERIALS AND METHODS

Sample specimens

Sample specimens were prepared from a tangential–radial plane board of *Larix kaempferi* by mill cutting. The mean of the specific gravity, the moisture content and the width of the growth ring were 0.60, 12% and 3.6mm, respectively. The mean of the specific gravity of the delignificated tree disk was 0.49. The dimensions of the tree disk for delignification treatment were about 100 mm(ø)×31 mm (thickness).

Cylindrical sample specimens of dimensions 29.8 mm (ø)×10 mm were prepared to estimate the air permeability and sound absorption coefficients by mill cutting and by cross cutting in the longitudinal direction after the delignification treatment. The cross cutting produced a cylindrical specimen with two different surfaces: one side is treated and the other counter side is the control surface. The same sample was used for the comparisons of sound absorption coefficient and air permeability between the control and delignificated wood. One surface and the other counter surface of a sample specimen were provided as the control and treated surfaces for both sound incidence and air permeability evaluation.

Delignification treatment

Tree disks of *Larix kaempferi* were treated with a mixed solution of alcohol and benzene for 48 hours to extract the extractive materials on wood. The ratio of alcohol to the benzene mixed solution was 1:2. After the delignification treatment was applied for 72 hours by Wise's method, the water–saturated sample specimens were dried to about 12% moisture content by a radio frequency–heated vacuum dryer to prevent severe drying stress.

Stereoscope and SEM observations

The stereoscope and SEM observations were made on the cross sectional surface of the wood and delignificated wood specimens by using a stereoscope and a scanning electron micrograph, respectively.

Estimating the sound absorption coefficients by the two microphone method

Fig. 1 presents a schematic diagram of the measuring apparatus for the two microphone transfer function method. The set–up consisted of a straight impedance tube with a loudspeaker connected to one end as an excitation source. In the tube, a broadband random wave was formed by the signal generator amplified by the power amplifier and then induced to the loudspeaker. At the other end, sample specimen was mounted to measure the sound absorption coefficient. Two microphones were mounted on the inner wall of the tube near the sample end of the tube. A multi–channel spectrum analyzer was used to obtain the transfer function between the microphones.

The reflection coefficient versus frequency of the material is determined from the transfer function, while the sound absorption coefficient can be determined from the reflection coefficient as a function of the frequency of the sample specimens. In this study, estimation frequency range was from 500 Hz to 6.4 kHz and the environmental conditions were atmospheric pressure, temperature, relative humidity, sound velocity and air density of 1008 hpa, 28 °C, 45%, 347.89 m/s and 1,164 kg/m^3, respectively.

Estimating the density profile

A square sample specimen of dimensions 5.0 cm(T)× 5.0 cm(R)×3.1 cm(L) was cut from a delignificated tree disk and used to measure the density profile. The density profile in the thickness direction of the delignificated sample specimens was measured by the ATR density slope measurement apparatus, which calculates the density of the continuous thickness direction from the X–ray transmission ratio of the material. This density slope measurement apparatus provided continuous density data in the thickness direction of the delignificated wood.

Air permeability

Air permeability in the longitudinal direction of wood was assessed by a PMI (Porous Materials Incorporated) capillary flow porometer which can estimate the bubble point, pore characteristics, and apparent liquid and air permeability (Akshaya and Krishna, 2002). In the PMI capillary flow porometer, a fully wetted sample is placed in the sample chamber which is then sealed. Gas is then allowed to flow into the sample specimen. The bubble point is determined as the pressure at which the gas is able to overcome the capillary action of the fluid within the largest pore. The bubble point results of wood are not included here.

After determining the bubble point, when the pressure was increased and all the sample pores were emptied, the sample was considered dry and the gas pressure and flow rates through the dry sample were measured. The gas permeability, k, was computed from the gas flow rate using Darcy's law, which states that the flow of fluids through porous media is proportional to the pressure gradient causing the flow. The proportionality constant is normally a function of the fluid's viscosity. Therefore, incorporating viscosity in the equation, Darcy's law becomes:

$$F=k\frac{A}{\mu L}(p_i-p_0)$$

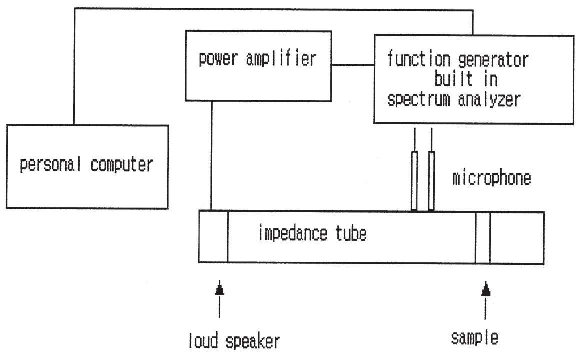

Fig. 1. Schematic diagram of the measuring apparatus for the sound absorption coefficients.

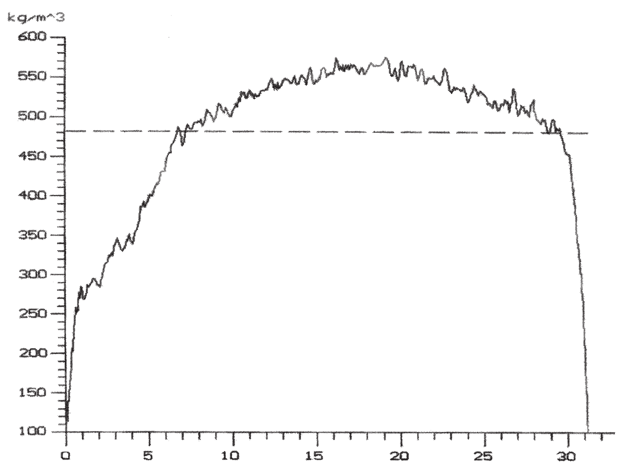

Fig. 2. Typical density profile of the delignificated wood.

where F is the volume flow rate at the average pressure per unit time, k the permeability, μ the viscosity of the fluid, A the cross–sectional area of the porous material, L the thickness of the porous material, p_i the inlet pressure and po the outlet pressure. The permeability can therefore be computed from the measured flow rates and differential pressures.

The gas permeability of the control surface and the treated surface inlet were determined by the PMI capillary flow porometer. Cylindrical specimens 2.90 cm in diameter and 1.0 cm long were cut from delignificated wood specimens with a thickness of 3.1 cm. The air permeability of the treated surface and the fresh counter surface were estimated under the same conditions from the same sample.

RESULTS AND DISCUSSION

Structural changes induced by delignification treatment

Upon delignification treatment, the color of the delignificated wood brightened and its air dry density decreased by about 19% as compared to normal wood. Numerous small cracks originated on the surface of the sample specimen, as shown in Fig. 3. Small cracks were not observed during the delignification process, but generated during drying of the delignificated woods. As described in 2.2, we dried the treated tree disk by a radio frequency–heated vacuum dryer to prevent severe drying stress over the drying period.

During the normal drying of the tree disk, big V–shaped cracks occurred on the weak surface by drying stress. During radio frequency–heated vacuum drying of the delignificated wood, numerous small cracks were formed uniformly on the whole surface of the delignificated tree disk of the sample, because the surface bonding strength among the cells was weakened by the delignification treatment. The small cracks were considered to have originated when the weakened cell walls separated before the drying stress reached the V–shape crack formation. These small cracks may behave as a sound–absorbing pore and contribute to the increased sound incidence. The density of the surface layer of the delignificated sample specimen was remarkably decreased as compared to that of the inner layer, as shown in Fig. 2, due to the occurrence of the small cracks and the increased porosity. The SEM observation of the microscopic structure showed that the intercellular substance gushed and the porosity increased, as shown in Fig. 4. These microscopic changes contributed to the increased porosity of the wood.

Air permeability

The air permeability of wood affects several physical properties of wood such as dimensional stability, drying stress, chemical impregnation capability and acoustical properties, etc. Many wood researchers have tried to improve the air permeability by changing the physical properties using various techniques such as freezing treatment, steam explosion and chemical treatment. In

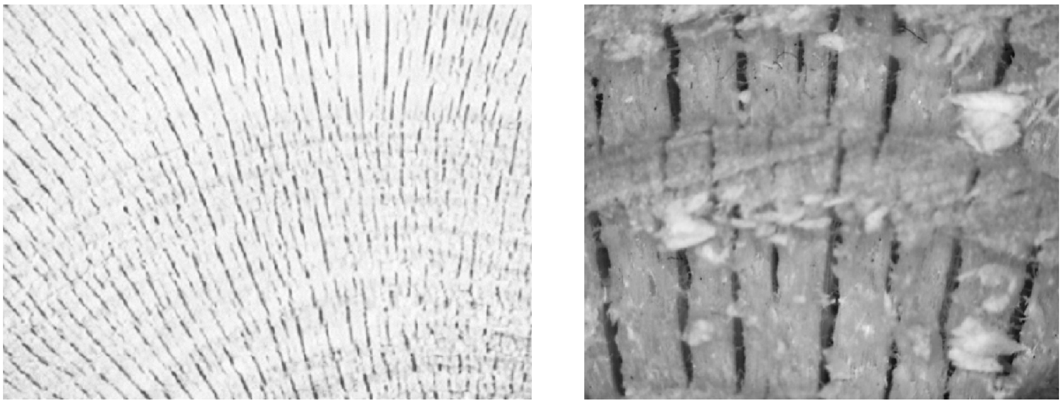

Fig. 3. Small cracks on the surface of the delignificated wood.

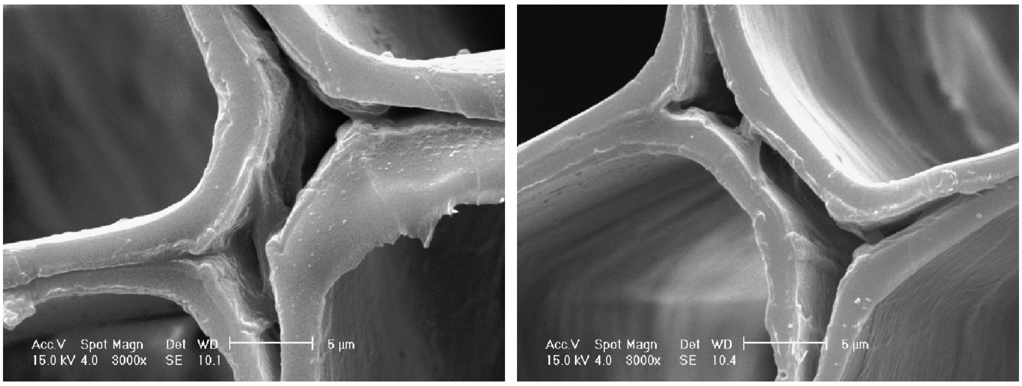

Fig. 4. Typical microscopic structural changes of the delignificated wood.

this study, we aimed to improve the air permeability of wood by the delignification treatment.

The test sample was cut from cylindrical, delignificated wood. The sample had both a treated surface and a control surface. The same sample specimen was tested under two conditions, where the control surface inlet and the reversed one were tested.

The average air permeability was increased by the delignification treatment, as shown in Figures 5 and 6 where one line represents the fluid rate of a sample specimen. The average air permeability of the control and delignificated side inlets was 0.147 and 0.292, respectively, which demonstrated that the air permeability was increased about two–fold by the delignification treatment. We surmised that this delignification–induced, air permeability increase was caused by the anatomical changes shown in Figs. 3 and 4.

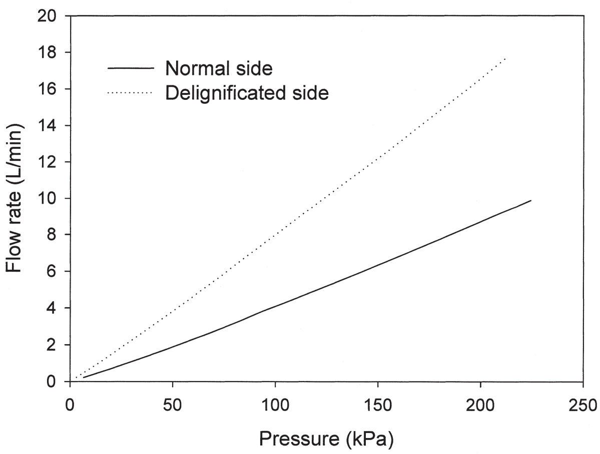

Fig. 5. Changes of flow rate through the normal and treated side of the delignificated tree disk as a function of differential pressure.

Change of sound absorption coefficients

The sound absorption coefficients of the control and delignificated wood were measured by the two microphone transfer function method to estimate the possibility of improving the absorbing capability by the delignification treatment. Great care was taken in preparing the sample specimens because a serious error can be introduced by even a very small gap between the impedance tube and the sample specimen.

The eight graphs in Fig. 6 represent the control and delignificated wood samples for each of the four tests. The sound absorption coefficient of the delignificated wood was higher than that of the normal wood and the trend increased with increasing frequency. In the frequency range of 2–6 kHz, the sound absorption coefficient of delignificated wood was about 20–30% higher than that of normal wood, which was attributed to the air permeability, as described above in section 3.2. The porosity of the cross sectional surface of the wood and the sound incidence surface were increased by the delignification treatment and the numerous small cracks generated by the drying stress acted as a sound absorbing pore.

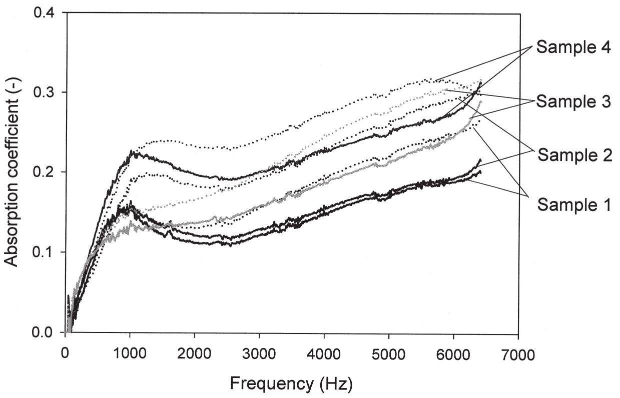

Fig. 6. Frequency versus sound absorption coefficients of control and delignificated wood. Solid line: control, dotted line: delignificated wood.

Although the sound absorption coefficients of normal wood and delignificated wood are lower than those of glass fiber, these values are higher than those of other construction materials such as concrete, steel, mortar and marble. Therefore, delignificated wood can be used as a construction material when more efficient absorption capability is required. To summarize, the delignification treatment was successfully used to improve the sound absorbing capability of wood. However, further investigation is required to determine the relationship among the pore structure, air permeability and sound absorption capability of wood.

CONCLUSIONS

The possibility of using delignification treatment to improve the sound absorption capability of a cross sectional surface of *Larix kaempferi* wood was estimated by comparing control and delignificated wood cross sections. After delignification treatment using Wise's method, the wood color brightened, the wood density decreased, the porosity of the treated wood increased, numerous small cracks were formed, the air permeability increased and the sound absorption coefficient of the delignificated wood was increased relative to that of normal wood. Although the structural and sound absorption properties were changed by the treatment, the mechanical properties of the delignificated tree disk were not severely affected because the changes were restricted to only the thin outer surface of the tree disk. These results suggested that the delignification treatment can be used to improve the sound absorption capability of wood.

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