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Sound Absorption Property of Heat-Treated Wood at A Low Temperature and Vacuum Conditions*1

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ABSTRACT

Heat treatment was performed to improve sound absorption properties for four tree species; Tulip tree, Korean Paulownia, Red pine and Costata birch, at temperature of 175°C and 200°C under vacuum condition. Sound absorption properties of two kinds of boards, which were in radial and tangential sections, were measured under a frequency range of 100 to 3200 Hz by the two microphone transfer function method. It was found that sound absorption properties were increased by heat treatment and the efficiency was higher at 200°C than that at 175°C. Even Costata birch had a little effect on low temperature of 175°C, 200°C heat treatment for sound absorption property, the efficiencies of sound absorption were 14, 19%, respectively. The efficiencies of sound absorption ranged 22 to 120% for heat-treated Tulip tree, Korean Paulownia.

Keywords : sound absorption property, heat treatment, low temperature and vacuum

1. INTRODUCTION

Wood and/or wood-based materials such a laminated wood, plywood, particleboard, fiberboard etc. have been used as furniture and construction materials for a long time because they have many good properties. Recently, sound absorbing materials with advanced noises reduction are requested for construction and interiors. The glass or rock wool and foamed aluminum with closed pores are used most frequently as sound absorbing materials. In most cases, these materials have a low strength and are not environmentally-friendly and are sometimes prevented from using for a good circumstances.

The development of sound absorbing materials with comprehensive characteristics such as being lightweight, eco-friendly and with good sound absorption property is desirable.

The acoustic property of wood and/or wood-based materials was investigated by Watanabe

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(1967), Hong (1989, 1991), Kang (2001, 2005) etc. Hong (1989) reported that acoustic absorption coefficient by standing wave method according to solid wood section was higher in the cross section than that in radial or tangential section and the acoustic absorption coefficient was the highest in the frequency range from 400 Hz to 600 Hz. Hong (1996) reported that the acoustic absorption coefficient of lauan plywood recorded by standing wave apparatus increased with plywood thickness and backing air gap. Kang (2005) suggested that the sound absorption coefficient of fiberboard can be estimated in a short time by the two microphone transfer function method.

Perforation and delignification method were employed to increase sound absorbing properties by Kang (2001, 2005). Kang (2005) reported that the sound absorption coefficient of delignificated wood was higher than that of solid wood.

The development of sound absorbent materials by using textiles and recycled materials was achieved by Suh (2004), Yang (2003, 2004) and Yoon (2005).

The sound absorption capability of oak mushroom bed log was also realized by Kang *et al.* (2008).

In this study, heat-treatment was performed to improve the sound absorption properties of four kinds of species at maximum temperatures of 175°C and 200°C under vacuum condition. After heat treatment, the sound absorption properties of the four kinds of species were investigated.

2. MATERIALS and METHODS

2.1. Specimen Preparation

Tulip tree (*Liriodendron tulipifera*), Korean Paulownia (*Paulownia coreana*), Red pine (*Pinus densiflora*) and Costata birch (*Betula costata*) were used in radial and tangential sections. Solid wood (control) specimens for testing absorption properties were cut into circular plates a thickness of 11mm and diameter of 60.8(∅) mm. Heat treatment specimens for testing absorption properties were also cut into circular plates with a thickness of 11mm and diameter of 65(∅) mm. The size of the diameter of heat-treated specimen was cut to 60.8(∅) mm after heat treatment. However, the size of thickness for heat-treated specimens slightly decreased because of their shrinkage.

2.2. The Methods of Heat Treatment and Absorption Property Measurement.

The specimens of solid wood were maintained at a room temperature of 20 ± 1°C and relative humidity of 65 ± 2% for 2 weeks. The specimens of heat-treated wood were also maintained at a room temperature of 20 ± 1°C and relative humidity of 65 ± 2% for 2 weeks and were dried for 6 hours at 120 ± 2°C in a drying oven. Two types of heat-treated board were manufactured in a vacuum sinitering furnace (KOVACO KSF-100 Type). The conditions were 700 mmHg, heating rate of 10°C/min, decreasing rate 5°C/min and duration of 3 minutes at maximum temperatures of 175°C or 200°C. The heat-treated specimens for measuring absorption properties were also maintained at a room temperature of 20 ± 1°C and relative humidity of 65 ± 2% for 2 weeks.

The absorption properties test apparatus for the two microphone method consisted of an impedance measurement tube (Type 4206A), a signal analyzer unit (Type 2035), a power amplifier (Type 2706) and two microphones (Type 2670), as shown in the left side of Fig. 1. The range of the frequency measurement was 100

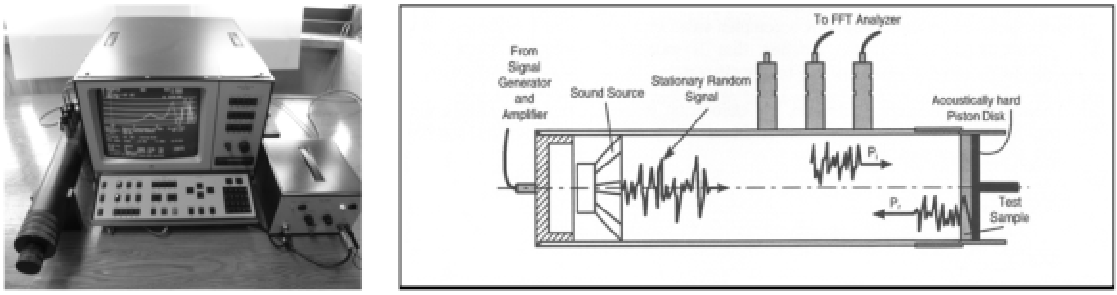

Fig. 1. Two-microphone impedance measurement tube (left side) and cut-away diagram of the impedance measurement tube (right side).

Hz～3.2 kHz in a middle type impedance measurement tube. The absorption coefficient was measured 200 times on both the radial and tangential planes after calibration by a sponge and the mean values were accepted. Four replications were adopted for one condition. India rubber band was used for a accurate setting. The two-microphone method of measuring the acoustic absorption coefficient involves the decomposition of a broadband stationary random signal into its incident (P_i) and reflected (P_r) components. The signal is generated by a sound source, and the incident and reflected components are determined from the relationship between the acoustic pressure measured by microphones at two locations on the wall of the tube (in the right side of Fig. 1).

From the incident the reflected components of the sound pressure at the two microphone positions, three frequency response functions are calculated: H_l, the frequency response function; H_i, the frequency response function associated with the incident component; and H_r, the frequency response function associated with the reflected component. Using these values, the complex reflection coefficient (R) is calculated from the following equation:

$$R = \left(\frac{H_l - H_i}{H_r - H_l}\right)e^{j2k(l+s)} \qquad (1)$$

where k is the wave number, l is the distance between the first microphone location and the front of the sample and s is the spacing between the microphones.

Using this value for the reflection coefficient, the sound absorption coefficient (α) can be calculated from the following equation:

$$\alpha = 1 - |R|^2 \qquad (2)$$

The increased ratio of sound absorption properties was calculated by the following equation:

Increased ratio of sound absorption properties $= (\alpha_H - \alpha_S)/\alpha_S \times 100(\%)$ (3)

where α_S, α_H are sound absorption coefficients obtained from solid and heat-treated woods, respectively.

3. RESULTS and DISCUSSION

3.1. Absorption Properties of Solid and Heat Treated Woods at Temperature of 175°C

Table 1 shows the physical and sound absorption properties of solid and heat-treated woods at both temperatures of 175°C and 200°C. The

Table 1. Physical and sound absorption properties of solid and heat-treated woods.

Species	Heat treatment condition	Weight loss (%)		Density (cm^3)		SAC		Increase ratio of SAC (%)	
		175°C	200°C	175°C	200°C	175°C	200°C	175°C	200°C
Sponge						31.02 (0.13)	31.02 (0.13)	0%	0%
Pinus densiflora	solid wood			0.52	0.57	5.90 (0.66)	5.90 (0.66)		
	heat-treated wood	13.57	28.09	0.50	0.45	6.33 (0.40)	7.93 (0.64)	7.29%	34.41%
Paulownia coreana	solid wood			0.30	0.31	5.52 (0.38)	5.52 (0.38)		
	heat-treated wood	19.52	34.73	0.22	0.19	8.18 (0.52)	9.79 (0.96)	48.19%	77.36%
Betula costata	solid wood			0.69	0.70	5.53 (0.38)	5.53 (0.38)		
	heat-treated wood	12.80	31.71	0.65	0.57	6.57 (0.70)	6.30 (0.68)	18.81%	13.92%
Liriodendron tulipifera	solid wood			0.54	0.55	5.59 (0.47)	5.59 (0.47)		
	heat-treated wood	21.24	39.24	0.44	0.37	12.31 (2.76)	6.80 (0.73)	120.22%	21.65%

Notes; SAC: Sound absorption coefficient, data are average values from 6 replications without differentiating radial or tangential sections, parenthesis is standard deviation.

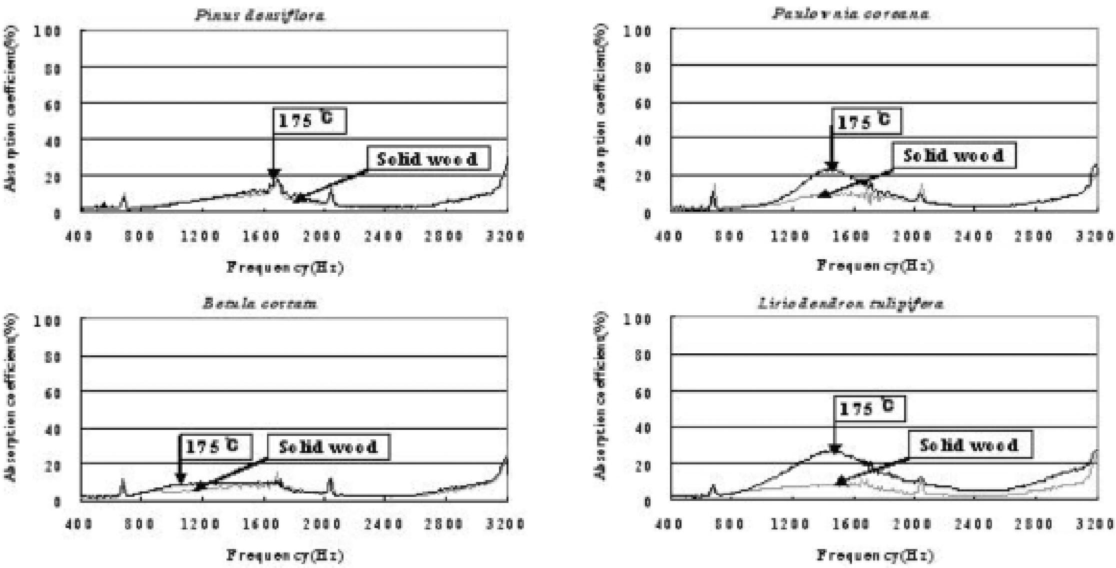

Fig. 2. Absorption properties of heat-treated woods at a temperature of 175°C.

average data was adopted without differentiating between radial or tangential section because the data in the radial sections were close to those in the tangential sections. Fig. 2 shows absorption properties of heat-treated woods at temperature of 175°C. The data is an average value without differentiating between radial or tangential sections. The weight loss ranged from 12.8% to 21.2% for the four kinds of species. The percentages of sound absorption coefficient (SAC) were 5.9, 5.5, 5.5, 5.6% for solid red pine, korean paulownia, costata birch and tulip tree,

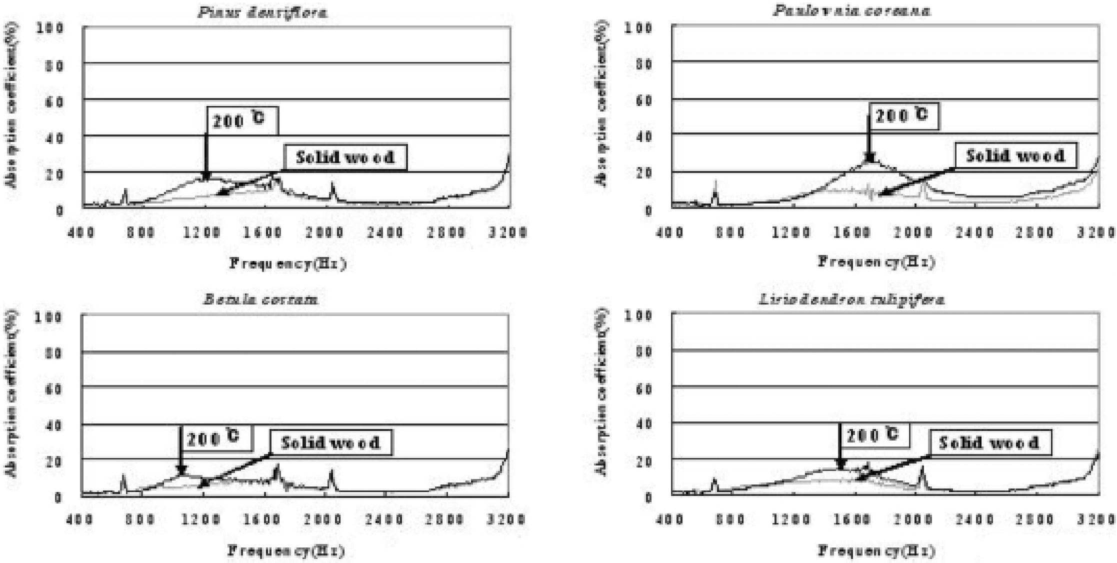

Fig. 3. Absorption properties of heat-treated woods at a temperature of 200°C.

respectively. The SACs for four species had a narrow range of values, 5.5～5.9%.

Even though the SAC for the control specimens of the four species showed very similar values, as the SAC of the wood specimens after treatment of 175°C were 6.3, 8.2, 6.6, 12.31%, the increase ratios of SAC were 7.3, 48.2, 18.8, 120.2% for red pine, korean paulownia, costata birch and tulip tree, respectively. The SACs increased by heat treatment. There was a higher increase of SACs at the frequency of around 1400 Hz in the korean paulownia and the tulip tree.

The acoustic absorption coefficient according to wood section was higher in the cross section than in radial or tangential sections and the acoustic absorption coefficient was highest in the frequency range from 400 Hz to 600 Hz (Hong, 1989). A higher acoustic absorption coefficient appeared in the frequency of around 600Hz. However, the highest one was shown in the frequency of 1200～1800 Hz. Sound absorption coefficients of oak mushroom bed log were 2～3 times higher than those of solid wood (Kang *et al.*, 2008). Kang (2001) reported that sound absorption coefficients of wood specimens simply perforated and perforated with stair were higher than that of normal specimens and stair type perforation was about 50～60% higher than that of normal specimen. Kang (2005) also reported that the sound absorption coefficient of delignificated wood was higher than that of solid wood.

The SAC value of the tulip tree was very high and standard deviation was also high. The result needs to be studied more. However, it is concluded that heat treatment improves the sound absorption properties of wood.

3.2. Absorption Properties of Heat-treated Woods at Temperature of 200°C

Fig. 3 shows absorption properties of heat-treated woods at temperature of 200°C. The weight loss ranged from 28.1% to 39.2% for

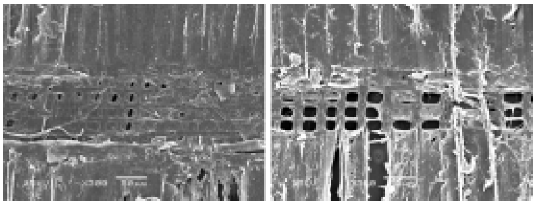

Fig. 4. Microphotographs of radial sections to solid wood (left side) and heat-treated wood (right side) of *Pinus densiflora* by scanning electronic microscope.

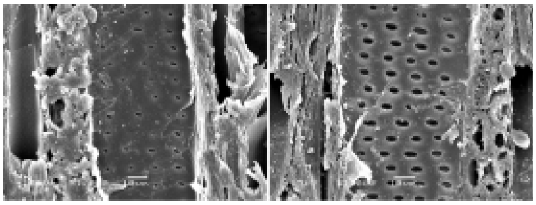

Fig. 5. Microphotographs of tangential sections to solid (left side) and heat-treated wood (right side) of *Lidiodendron tulipifera*.

the four kinds of species. The SACs were 7.9, 9.8, 6.3, 6.8% and the increased ratio of SACs were 34.4, 77.4, 13.9, 21.7% for red pine, korean paulownia, costata birch and tulip tree, respectively, at treatment temperatures of 200°C.

The SACs after heat treatment of 200°C for red pine and korean paulownia were higher than those after heat treatment of 175°C. The SACs after heat treatment of 200°C for costata birch and tulip tree were slightly lower than those at heat treatment of 175°C. Therefore, the heat treatment temperature of 175°C is more effective for red pine and korean paulownia and the heat treatment temperature of 200°C is more effective for costata birch and tulip tree. Finally, it can be concluded that heat treatment at a low temperature improves the sound absorption properties of wood.

3.3. The Micro-anatomic Observation of Heat-treated Woods

Fig. 4 shows the typical microphotographs of radial sections to solid wood (left side) and heat-treated wood (right side) of *Pinus densiflora* by scanning electronic microscopy. The more spacious cross-field pits are shown in the cross-fields of the right side photograph of which heat-treated wood. It is considered that the wider spaces were developed by heat treatment. Fig. 5 shows the typical microphotographs of tangential sections to solid (left side) and heat-treated woods (right side) of *Lidiodendron tulipifera.* The bigger pits are shown in the vessel of the right side photograph of which heat-treated wood. It is also considered that the bigger pits were developed by heat treatment. Kang (2004) reported that delignification treatment made wood more spacious and improved sound absorption property.

4. CONCLUSIONS

Heat treatment was performed to improve absorption properties for four tree species; Tulip tree, Korean Paulownia, Red pine and Costata birch, at temperature of 175°C and 200°C under vacuum condition. The results were as follows:

The weight loss ranged from 12.8% to 21.2% at temperature of 175°C and 28.1% to 39.2% at temperature of 200°C.

The percentages of sound absorption coefficient had a range of values, 5.5～5.9% for solid wood.

The increase ratios of sound absorption coefficient ranged 7.3 to 120% by heat treatment at a low temperature and vacuum conditions.

The more spacious cross-field pits and bigger pits were observed in heat-treated woods.

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