Investigating the Sound Absorption Performance of Circular and Slotted Perforated Birch (*Betula platyphylla*) Plywood as Interior Building Materials

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The use of perforated plywood as an interior architectural sound-absorbing material has been increasing in popularity in Korea. This study investigated the sound absorption performance of marketed birch (*Betula platyphylla*) plywood with circular and slotted perforations using the sound absorption measurement method (KS F 2805) in a reverberation chamber with a 300 mm backspace. The results showed that unperforated birch plywood absorbed little sound. However, birch plywood with perforation levels of 1.77%, 5.77%, and 7.76% showed significant sound absorption. The noise reduction coefficient (NRC) of perforated birch plywood was 0.4 to 0.6. The results were 0.3 S to 0.5 S sound absorption grade by KS F 3503. The optimal perforation level was 5.77%. These findings can aid in expanding the wood sound absorption market.

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INTRODUCTION

Wood absorbs atmospheric carbon dioxide and stores it within its cellular architecture. This attribute confers wood a carbon-neutral character, because of which it can mitigate carbon emissions and reduce atmospheric CO_2 concentrations when it is used in construction (Gustavsson *et al.* 2006; Hepburn *et al.* 2019; Cordier *et al.* 2022).

In addition, wood is functionally favorable for interior construction. Its unobtrusive colors and textures create a comfortable indoor atmosphere, leading to psychological and physiological benefits such as stress reduction and lower blood pressure (Sakuragawa *et al.* 2005; Ikei *et al.* 2018). Untreated wood does not emit harmful chemicals and regulates water vapor in the air, making it an excellent natural insulator (Cetiner and Shea 2018; Pelliccia *et al.* 2020). Recently, it has been found that wood also has a sound-absorbing effect.

Sound-absorbing materials can be classified into two main types: porous and resonant. Porous sound absorbers work by causing sound waves to collide with the walls of the pores, converting their energy into heat and dissipating it. Generally, the effectiveness of sound absorption increases as the frequency of the sound wave increases (Cao *et al*. 2018; Jang 2023).

On the other hand, resonant sound absorbers utilize a different principle. They consist of panels with perforations and an air-filled cavity behind them, which creates a resonator. When sound waves enter the perforations, the air inside the neck of the perforation vibrates up and down, converting the sound energy into heat and dissipating it. This sound absorption method is particularly effective in attenuating noise at specific frequencies (Jin *et al*. 2022)

The pores of wood can absorb noise (Zhao *et al.* 2023). Diffuse-porous wood cross-sections have a favorable structure for absorbing noise (Jang and Kang 2021b,c, 2022c,e), and ring-porous wood cross-sections can be used as resonant sound absorbers when backspacing is applied (Jang 2022a; Jang and Kang 2022d). Thus, the authors proposed that wood cross-section boards could be used as sound-absorbing ceiling materials (Jang and Kang 2021c, 2022d).

Thin wood panels can also be utilized as a resonant sound absorber in the presence of drilled holes and backspace, which can be adjusted to achieve sound absorption in a specific frequency range (Song *et al.* 2016; Peng *et al.* 2018). While circular holes are commonly used to create resonant sound-absorbing materials (Kang *et al.* 2021), recent design developments have used slotted holes. This study examined the sound absorption capabilities of plywood with slotted holes. Given the increase in indoor noise exposure due to telecommuting and online classes resulting from the pandemic, the demand for sound-absorbing materials in indoor spaces has increased (Jang 2022b; Mimani and Nama 2022). By investigating the sound absorption capabilities of wood panels, the goal of this work is to contribute to the expansion of the market for wood sound-absorbing materials.

EXPERIMENTAL

Specimen Preparation

Figure 1 shows the birch (*Betula platyphylla*) plywood samples used in this study. They were supplied by Gaonwood (Jeonju, Korea) and originated in China. The dimensions of each plywood sample were 300(W) x 600(L) x 6(T) mm.

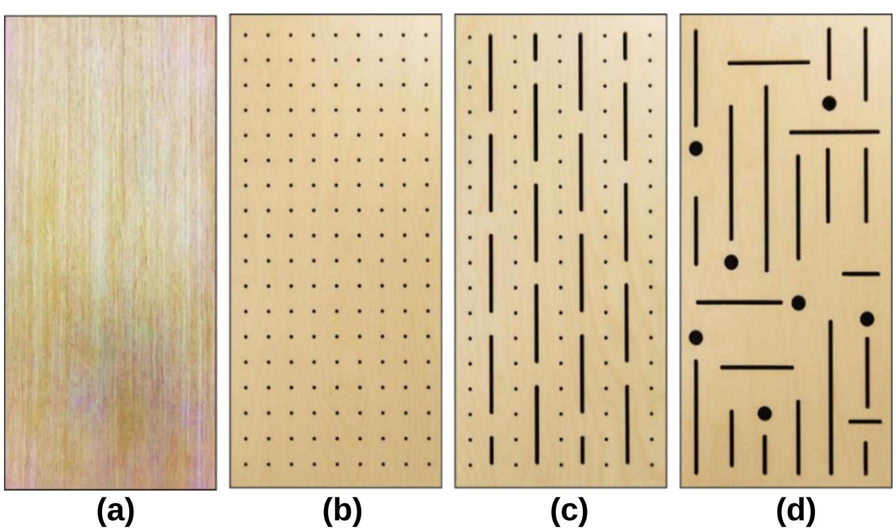

Fig. 1. Birch plywood samples with various perforation rates: (a) control, (b) 1.77%, (c) 5.77%, (d) 7.76%

The specific gravity of the plywood was 0.68, and their moisture content (MC) was 12%. This study used four plywood samples that varied in perforation rate and perforation type. Sample A is an unperforated plywood sample (control). Sample B is a circular perforated plywood sample with a 1.77% perforation level. Sample C is a circular, slotted plywood sample with a 5.77% perforation level. Finally, sample D is a circular, slotted plywood sample with a perforation level of 7.76%.

Measurement of Sound Absorption Coefficient Using the Reverberation Room Method

There are two methods for measuring the sound absorption coefficient: an impedance tube and a reverberation chamber (Zhang *et al.* 2017). Impedance tubes have the advantage of quickly measuring sound absorption coefficients with small samples, but they are limited to measurement of vertical incidence sound absorption (Jang and Kang 2021a). The reverberation chamber method requires a relatively larger sample size but provides a more realistic assessment of the material's acoustic characteristics as noise is incident from multiple directions. This study used the reverberation chamber method to investigate the sound absorption performance of the birch plywood samples. Figure 2 shows the sound absorption performance of perforated birch plywood using the reverberation chamber method.

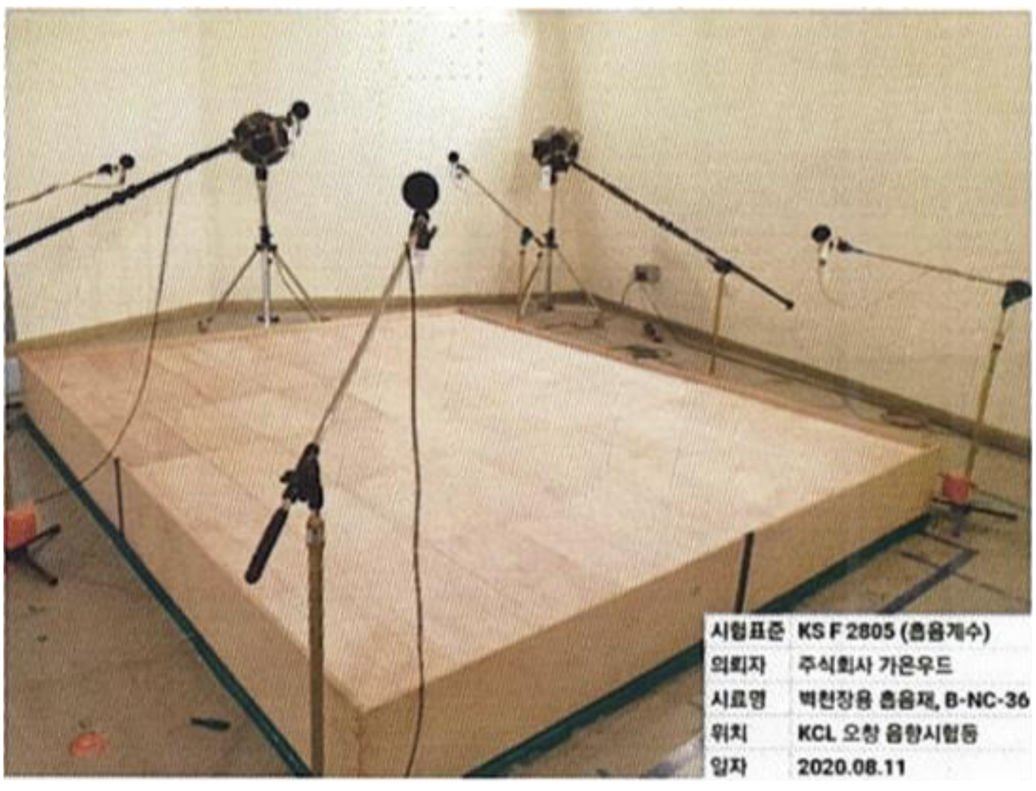

Fig. 2. Measurement of sound absorption performance using the reverberation room method

The measurement of sound absorption in a reverberation chamber was performed in accordance with KS F 2805 (2014). The reverberation time in the empty reverberation chamber and that after installing plywood were measured. The sound absorption coefficient (α) was calculated using Eqs. 1 and 2.

$$A_T = A_2 - A_1 = 55.3V(1/c_2T_2 - 1/c_1T_1) - 4V(m_2 - m_1) \quad (1)$$

$$\alpha = A_T/S \quad (2)$$

where A_2 is equivalent sound absorption area of the reverberation chamber with the specimen (m^2), A_1 is equivalent sound absorption area of the empty reverberation chamber (m^2), V is volume of the empty reverberation chamber (m^3), c_2 is sound velocity in the air in the reverberation chamber after the specimen is installed (m/s), c_1 is sound velocity in the air in the empty reverberation chamber (m/s), T_2 is reverberation time in the reverberation chamber after the specimen is installed (s), T_1 is reverberation time in the empty reverberation chamber (s), m_2 is power attenuation factor in the reverberation chamber with the specimen during the measurement (m^{-1}), m_2 is power attenuation factor in the empty reverberation chamber during the measurement (m^{-1}).

The area of the sample was 3000(W) x 3600(L) mm with a backspace of 300 mm. The frequency range of sound absorption performance measurement was 100 to 5000 Hz, and the noise reduction coefficient (NRC) was calculated by averaging the sound absorption coefficients at 250, 500, 1000, and 2000 Hz (Eq. 3).

$$\text{NRC} = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2500})/4 \quad (3)$$

RESULTS AND DISCUSSION

Sound Absorption Performance

Figure 3 provides the sound absorption performance of the four plywood samples. Unperforated birch plywood had a maximum sound absorption coefficient of 0.21 at 160 Hz and a sound absorption coefficient of 0.1 or less in most frequency ranges, showing little sound absorption. The sound absorption effect of unperforated wood can only be shown using a cross-section, and absorption in radial and tangential sections is low because there are few pores (Jang and Kang 2022a,b).

Perforated plywood, on the other hand, showed a tendency for the sound absorption coefficient to increase up to a certain frequency range and then decrease. The optimal sound absorption coefficient for Sample B was distributed from 0.35 to 0.59 at 125 to 400 Hz. The maximum sound absorption coefficient was 0.59 at 315 Hz. The optimum sound absorption coefficient of Sample C was 0.64 to 0.81 at 160 to 500 Hz, with the maximum sound absorption coefficient 0.81 at 250 Hz. The optimal sound absorption coefficient of Sample D was distributed in the range of 0.54 to 0.83 at 160 to 500 Hz, with the maximum sound absorption coefficient of 0.83 at 250 Hz.

The overall sound absorption frequency of the perforated plywood was distributed in the range of 125 to 500 Hz. The optimal sound absorption coefficient frequency of the perforated panel depends on the length of the backing space (Peng *et al.* 2018). In the present study, the length of the backing space was fixed at 300 mm, so the frequency range of the optimal sound absorption coefficient did not differ among samples.

However, the maximum sound absorption coefficient in the same frequency range increased with higher apertures. Sample B was about 2.81 times higher than the non-perforated panel, Sample C was 3.86 times higher, and Sample D was 3.95 times higher. However, the sound absorption performance did not differ between samples C and D.

The KS F 3503 (2012) standard categorizes the performance of sound absorbers into four levels based on their NRC in a reverberation chamber (0.3S: 0.21 to 0.40, 0.5S: 0.41 to 0.60, 0.7S: 0.61 to 0.80, and 0.9S: higher than 0.81).

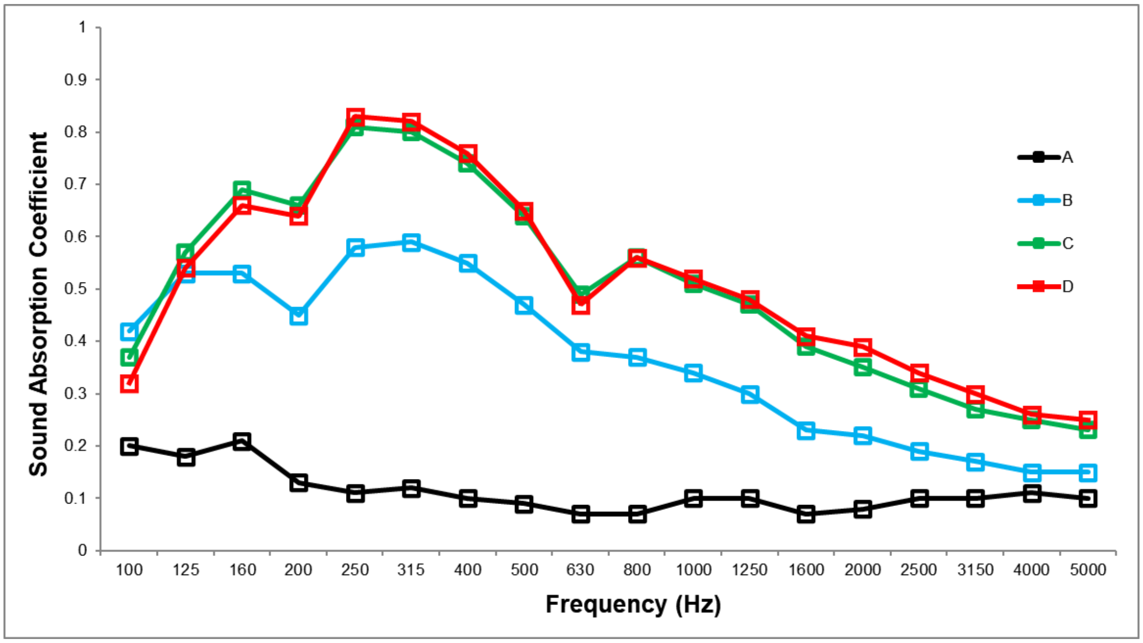

Fig. 3. The results of sound absorption performance of perforated birch plywood

Table 1 shows the sound absorption coefficients at 250, 500, 1000, and 2500 for the four plywood samples and their average calculated NRCs. The NRC of the unperforated plywood was 0.1, showing little sound absorption. On the other hand, the NRC of Sample B was about 4 times higher than that of perforated plywood, Sample C was about 5.8 times higher, and Sample D was about 6 times higher. As with the optimum sound absorption coefficient, the NRCs of samples C and D were not significantly different. The sound absorption performance of the perforated birch plywood samples based on KS F 3503 resulted in an ultimate classification of 0.3S for Sample B and 0.5S for Samples C and D.

Table 1. Sound Absorption Coefficient at 250, 500, 1000, 2000 Hz, and NRC

	Sound Absorption Coefficient			
Frequency (Hz)	A	B	C	D
250	0.11	0.58	0.81	0.83
500	0.09	0.47	0.64	0.65
1000	0.10	0.34	0.51	0.52
2000	0.08	0.22	0.35	0.39
NRC	0.10 (no grade)	0.40 (0.3S)	0.58 (0.5S)	0.60 (0.5S)

Note: Parentheses indicate the performance class of the sound absorbing material according to KS F 3503(2014).

Here, the optimal perforation ratio for circular and slotted perforated birch plywood with a 300 mm backspace was 5.77%. The results of this basic research will contribute to the utilization of wood as a sound-absorbing material based on various perforation methods that consider both design aspects and sound absorption.

The limitation of this study is that it did not consider the sound absorption characteristics based on the direction of slotted perforation (horizontal or vertical fiber direction). Depending on the direction of perforation, the exposure of the vessels in the wood varies.

The authors speculate that slotted perforation of the vertical direction of fibers can provide resonant sound absorption and a little porous sound absorption function. Therefore, our subsequent research will investigate the sound absorption performance according to the direction of the slotted perforation.

CONCLUSIONS

1. The round- and slotted-perforated birch plywood samples demonstrated a notable ability to absorb sound, with a proportional relationship between sound absorption and perforation rate.
2. The highest rating attained for perforated plywood in this study was 0.5S, and the optimal perforation was 5.77%.
3. The results of this study have implications for expansion of the market for perforated plywood as a sound absorber.

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AUTHORS' CONTRIBUTIONS

ES JANG: First author, Conceptualization, Methodology, Data analysis, Writing - original draft, and Writing - review & editing, SU JO: Experiment, Data analysis and Writing - review & editing, CW KANG: Conceptualization, Methodology and Writing - review & editing, HJ PARK: Corresponding author, Supervision and Writing - review & editing. All authors read and approved the final manuscript. All authors read and approved the final manuscript.

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