Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 40, No. 2, pp. 90-98, June, 2024
https://doi.org/10.7747/JFES.2024.40.2.90

JFES
Journal of Forest and
Environmental Science

Sound Absorption Properties of Sound Absorption Materials Using *Zelkova serrata* Leaves

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Abstract

This study analyzes the characteristics of sound-absorbing materials made from forest by-products of the deciduous tree species *Zelkova serrata* (*Z. serrata*) by evaluating their sound absorption performance. Accordingly, sound-absorbing materials with varying sample thicknesses, leaf sizes, and drying conditions were fabricated. The sound absorption properties were measured using the impedance tube method via middle-type measurement tube (100 Hz-3,200 Hz). The sound absorption properties were evaluated using the average sound absorption coefficient (ASAC), which was calculated from the measured sound absorption coefficients at 250 Hz, 500 Hz, 1,000 Hz, and 2,000 Hz. The ASAC value significantly improved as the leaf size increased to 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2. The ASAC values under the two drying conditions were similar. There was no significant difference in ASAC according to the leaf size under the air-dried leaf condition, with a thickness of 2.50 cm. The highest ASAC value according to the sound-absorbing material thickness was 0.47 at a thickness of 2.50 cm and leaf size of 2.0×2.0 cm^2 under the air-dried leaf condition. In addition, the variation in ASAC was 0.23, indicating that the sound absorption performance according to leaf thickness was more significant than the difference in absorption properties according to leaf size. A sound absorption coefficient (SAC) of 0.4 or higher was observed across the measurable frequency band (100 Hz-3,200 Hz). Furthermore, the SAC values with respect to leaf size and thickness were close to 1 in the high-frequency range above 2,000 Hz. Therefore, it is considered that sound-absorbing materials using *Z. serrata* leaves are advantageous in the field of absorbing noise in a high-frequency band of 2,000 Hz or more, and it is better to manufacture a thickness of 2.50 and 2.0×2.0 cm^2.

Key Words: deciduous tree, impedance measure tube method, sound absorption coefficient, *Zelkova serrata*

Introduction

The expansion of cities and development of industries have brought many benefits to modern society; however, they have also led to various problems, such as air, water, soil, marine, and noise pollution. Among these, noise pollution is a multifaceted phenomenon, including loud noises from airplanes and large industrial machinery as well as sounds from next-door neighbors' music or the footsteps of a baby in the apartment above (Lee and Kim 2018). In

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Received: March 4, 2024. Revised: May 9, 2024. Accepted: May 13, 2024.

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densely populated urban areas, excessive noise generated by various factors, such as transportation, construction work, and industrial production activities, causes significant discomfort in the lives of modern individuals. Prolonged to exposure to excessive noise can have negative effects on the lives of both humans and animals, extending beyond mere discomfort to various health hazards including psychological and physiological effects (Han 2010). Methods such as modifying the structure or materials of noise sources to prevent noise generation or block and absorb noise can improve the acoustic environment of residential spaces; however, eliminating or attenuating noise sources can be challenging. Therefore, practical solutions often involve using sound-absorbing materials to absorb the generated noise (Kang et al. 2010). Sound absorption is the process of dissipating or reducing the energy produced by sound. These methods include absorption through friction in sound-absorbing materials with numerous air voids, absorption through panel vibration by installing thin panels with an air layer against the wall, and using single-resonator absorbers (Kang and Park 2001).

Glass and mineral wool are widely used as sound-absorbing materials because of their relatively high productivity, cost-effectiveness, and excellent sound absorption properties. However, due to the generation of particles through weathering, environmental constraints arise when particles are exposed to the atmosphere, which causes air pollution. Additionally, direct contact with these materials can cause irritation or itching, thereby posing health risks as well (Lee 2001). Furthermore, gypsum boards, commonly used in building ceilings, emit radon, which can lead to respiratory problems. In brief, they are harmful, have poor durability, and pose environmental pollution concerns during disposal. These problems restrict the use of non-eco-friendly materials. Therefore, alternative sound-absorbing materials that offer excellent acoustic performance, are safe for human health, economically viable, dimensionally stable, and possess good water resistance and thermal insulation properties need to be developed to replace gypsum boards (Kang et al. 2015). Thus, various sound-absorbing materials that are both environmentally friendly and offer high acoustic performance are being continuously studied. Research on using wood and wood-based materials as sound-absorbing materials is ongoing. Studies have evaluated the acoustic properties of thermally treated wood (Byeon et al. 2010) and thermally treated ash wood under ambient vacuum conditions, as well as the use of Korean pine wood boards (Kang and Park 2001) and carbonized medium-density fiberboard (Won et al. 2015) based on the carbonization treatment temperature. Furthermore, research on manufacturing sound-absorbing materials using forestry by-products includes evaluating the acoustic performance of materials made from *Dendropanax morbiferusa* (*D. morbifesusa*) and *Fatsia japonica* (*F. Japonica*) leaves (Jung et al. 2020), pineapple leaves (Putra et al. 2018), *Quercus glauca* (*Q. glauca*) leaves (Jung et al. 2023), *Chionanthus retusa* (*C. retusa*) leaves (Goh et al. 2023), spruce and larch bark (Tudor et al. 2020), and the leaves of nine hedge species (Oh et al. 2009). Studies on agricultural by-products have focused on materials such as rice hull mats (Kang et al. 2019), coconut coirs (Nor et al. 2004), and various grains regarding their acoustic properties (Min et al. 2005). Moreover, research on using recycled resources as sound-absorbing materials includes evaluating the acoustic properties of cellulose-based sound-absorbing materials extracted from paper (Yeon et al. 2013), sound-absorbing materials made from paper, cigarette filters, leaves (Lee 2001), and particleboards made from sawdust and orange peels (Kang et al. 2015). There are 5 species of *Zelkova serrata* (*Z. serrata*) trees distributed in East and West Asia. *Z. serrata* trees have straight trunks and display deep green leaves in the summer, turning into beautiful autumn foliage. This makes them valuable as ornamental and street trees. Large-scale plantings of *Z. serrata* as street trees provide various benefits, such as reducing urban heat island effects and serving as carbon sinks. The leaves of *Z. serrata* trees, which are considered forestry byproducts or industrial waste, can potentially be utilized as sound-absorbing materials, acting as new carbon sequestration sources.

Therefore, this study aims to evaluate the sound absorption performance of sound-absorbing materials made from domestic deciduous *Z. serrata* tree leaves, and to provide basic data to increase the value of forestry byproducts-based sound-absorbing materials.

Materials and Methods

Preparation of sound absorbing materials

To investigate the sound absorption properties of the domestic deciduous broad-leaved hardwood, the leaves of Korean *Z. serrata* were collected Gyeongsang National University in Gajwa-dong, Jinju-si, Gyeongsangnam-do. Leaves were collected naturally fallen and fresh leaves. The collected leaves were measured in thickness using a thickness measuring instrument (PDN-21, Peacock, Japan), and the area of the leaves was measured using a leaf area measuring instrument (Li-3000C, Licor). As shown in Fig. 1 to find out the change in sound absorption coefficient according to the size of the leaves, the three-unit sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2 were cut using a straw cutter in the same way as the previous study (Jung et al. 2023). For the absorption performance measurement, the thickness of the absorption material made by overlapping leaves was divided into 1.00 cm, 1.75 cm, and 2.50 cm, and it was manufactured with a pressure of 0.0256 kgf/cm^2. And to avoid the spring back effect, mesh-shaped plastic was placed on the surface and fixed using metal wire. The basic data of the leaves are shown in Table 1, the average moisture content of fresh leaves is 122.22% and the average moisture content of air-dried leaves is 12.66% after humidity drying for two weeks in a constant temperature and humidity room (20°C±1°C, 65±2%). And the basic data of weight and volume of each treatment factor are shown in Table 2.

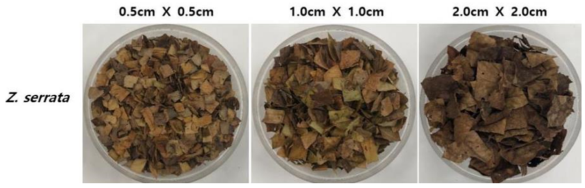


Fig. 1. Sample preparation by leaf specimen size of *Z. serrata* for sound absorption coefficient.

Sound absorption property measurement

The sound absorption properties of the leaves were measured by the transfer function method (Fig. 2), which measures with a impedance tube equipped with two microphones (Type 4206, B&K, Denmark) and a signal analyzer (Type 2035, B&K, Denmark). Human voice and music sound is mostly the frequency band range of 125-3,000 Hz (Tudor et al. 2020), a middle type of impedance measurement tube capable of measuring in the frequency band range of 100-3,200 Hz with a diameter of 63.5 mm was used for measuring the sound absorption coefficient. The

Table 1. The characteristics of the leaf of *Z. serrata* leaf

Classification	Leaf area (cm^2)	Length (cm)	Width (cm)	Thickness (mm)	Moisture content (%)	
					Fresh leaf	Air-dried leaf
Z. serrata	43.70	12.70	3.37	0.503	122.22	12.66

The obtained data is the average of three samples.

Table 2. The basic data of weight and volume of each treatment factor

Specimen type	Leaf layer thickness (cm)	Volume (cm^2)	Leaf specimen size		
			Weight (g)		
			0.5×0.5 (cm)	1.0×1.0 (cm)	2.0×2.0 (cm)
Fresh leaf	1	30.68	5.78	5.22	5.87
	1.75	53.69	12.08	9.89	9.14
	2.5	76.70	15.57	12.84	15.83
Air-dried leaf	1	30.68	2.79	2.03	1.77
	1.75	53.69	3.72	3.36	3.11
	2.5	70.70	5.1	4.95	4.76

measured sound absorption properties were presented as the frequency bands. The measurement of the sound absorption coefficient (SAC) for each sample was repeated 3 times, with 100 times each specimen, and the sound absorption coefficient measured in the entire frequency range was shown as the average sound absorption coefficient (ASAC) acquired for each test treatment according to formula (1) (Nandanwar et al. 2017) in Table 3.

$$Average\ sound\ absorption\ coefficient =$$

$$\frac{Sound\ absorption\ coefficient\ at\ 250\ Hz,\ 500\ Hz,\ 1{,}000\ Hz,\ 2{,}000\ Hz}{4} \cdots\cdots (1)$$

Results and Discussion

Sound absorption properties according to the leaf size

The sound-absorbing material created using *Z. serrata* leaves was processed under a pressure condition of 0.0256 kgf/cm^2, and the leaf samples were grouped into three sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2. For each size, the sound-absorbing materials manufactured using fresh and air-dried leaves were grouped into three thicknesses of 1.00 cm, 1.75 cm, and 2.50 cm.

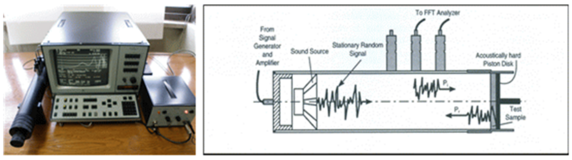


Fig. 2. Two-microphone impedance measurement tube (left side) and cut-away diagram of the impedance measurement tube (right side).

The average sound absorption coefficient (ASAC) at 250 Hz, 500 Hz, 1,000 Hz, and 2,000 Hz was determined from the sound absorption coefficient (SAC) of the sound-absorbing material manufactured using *Z. serrata* leaves. Accordingly, the graph of sound absorption coefficient variation within the total frequency band are shown in Fig. 3 for the 1.00 cm-thick material, Fig. 4 for the 1.75 cm-thick material, and Fig. 5 for the 2.50 cm-thick material.

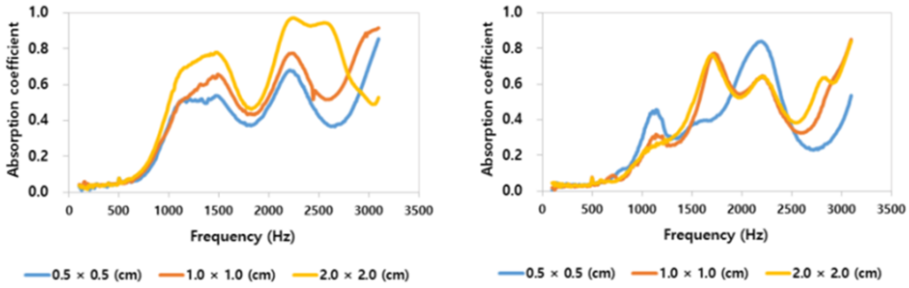
The ASAC was compared according to the leaf size used in the sound-absorbing material when the thickness of the sound-absorbing material was set to 1 cm (Fig. 3).

The ASAC for the fresh leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2 were 0.24, 0.25, and 0.32, respectively. This result demonstrated that the sound absorption performance increased as the leaf size increased. However, the ASAC for the air-dried leaf condition, with leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, were 0.27, 0.21, and 0.21, respectively, showing that contrary the former, the ASAC was highest with the smallest leaf size of 0.5×0.5 cm^2. In Fig. 4, the ASAC is compared according to the leaf size used in the sound-absorbing material when the thickness is set to 1.75 cm. At a thickness of 1.75 cm, the SAC of the sound-absorbing materials manufactured using fresh leaves were 0.39, 0.41, and 0.45 for leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, respectively. The ASAC results showed that the larger the leaf size was, the higher the absorption performance

Table 3. The average sound absorption properties and apparent density of *Z. serrata* leaves

Specimen type	Leaf layer thickness (cm)	Leaf specimen size					
		0.5×0.5 (cm)		1.0×1.0 (cm)		2.0×2.0 (cm)	
		ASAC	ρ (g/cm^3)	ASAC	ρ (g/cm^3)	ASAC	ρ (g/cm^3)
Fresh leaf	1.00	0.24±0.195	0.19	0.25±0.213	0.17	0.32±0.258	0.19
	1.75	0.39±0.333	0.22	0.41±0.343	0.18	0.45±0.389	0.17
	2.50	0.45±0.374	0.20	0.45±0.363	0.17	0.37±0.263	0.21
Air-dried leaf	1.00	0.27±0.268	0.07	0.21±0.202	0.07	0.21±0.194	0.04
	1.75	0.32±0.306	0.08	0.32±0.275	0.06	0.34±0.317	0.05
	2.50	0.46±0.485	0.07	0.45±0.363	0.06	0.47±0.381	0.05

ASAC, the average sound absorption coefficient for four points at 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz.



(a) Fresh leaf

(b) Air-dried leaf

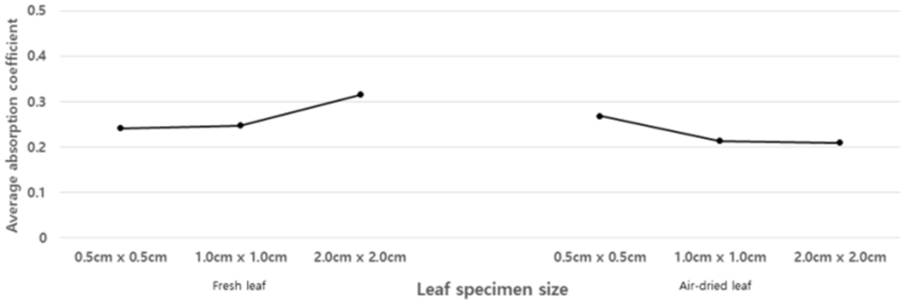
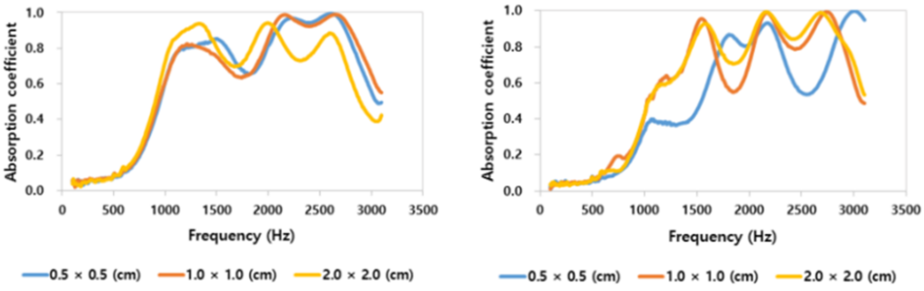


Fig. 3. Sound absorption properties by leaf specimen size of dry conditions with a leaf layer thickness of 1.00 cm.



(a) Fresh leaf

(b) Air-dried leaf

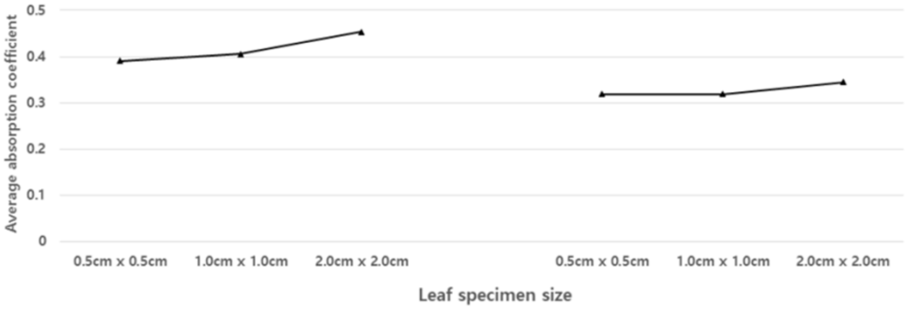
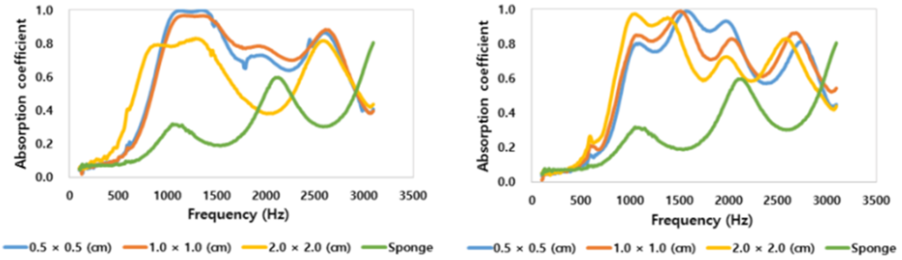


Fig. 4. Sound absorption properties by leaf specimen size of dry conditions with a leaf layer thickness of 1.75 cm.

became. The ASAC of the sound-absorbing materials manufactured using air-dried leaves were 0.32, 0.32, and 0.34 for leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, respectively, denoting an increase in the sound absorption coefficient as the leaf size increased, similar to the trend observed when using fresh leaves. Fig. 5 compares the sound absorption coefficients according to the leaf size at a thickness of 2.50 cm. The ASAC values observed when using fresh leaves were 0.45, 0.45, and 0.37 for leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, respectively.



(a) Fresh leaf (b) Air-dried leaf

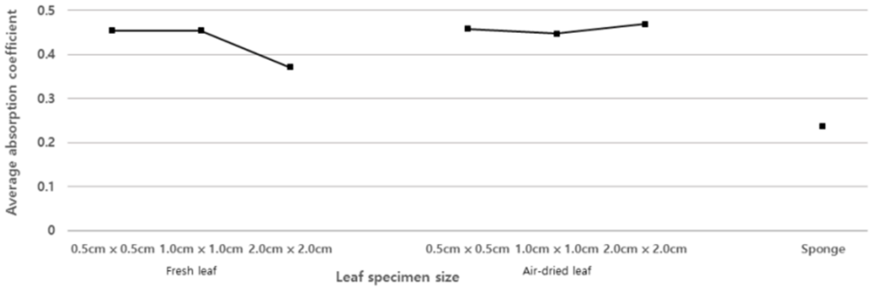


Fig. 5. Sound absorption properties by leaf specimen size of dry conditions with a leaf layer thickness of 2.50 cm.

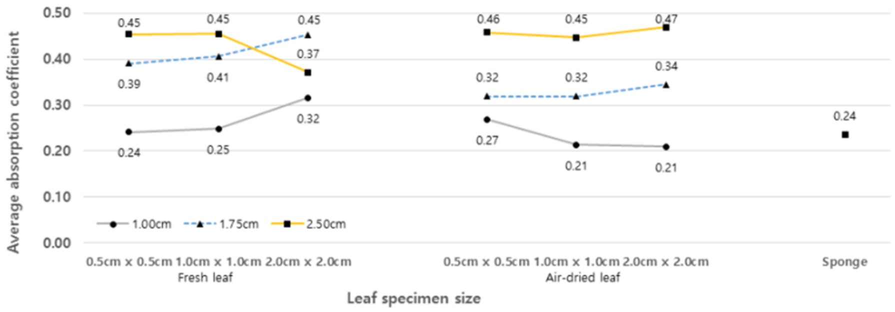


Fig. 6. Comparison of the average sound absorption performance by leaf specimen size between fresh and air-dried leaves composed of leaf layer thicknesses of 1.00 cm, 1.75 cm, and 2.50 cm.

Observe that the lowest ASAC value is attained with a leaf size of 2.0×2.0 cm^2. The ASAC values observed when using dried leaves were 0.46, 0.45, and 0.47 for leaf sizes of 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, respectively, showing no significant difference according to the leaf size. It is thought that with a thickness of 2.50 cm using dried leaves, the influence of thickness on the ASAC of the sound-absorbing material according to the leaf size is greater than the direct effect of leaf on the ASAC. The effect of leaf size constituting the sound-absorbing material on sound performance under a constant thickness generally indicated an increase with an increase in the leaf size, except for the sound absorption coefficient observed with air-dried leaves at thicknesses of 1.00 cm and 2.50 cm. Moreover, except for the ASAC observed with a leaf size of 0.5×0.5 cm^2 using air-dried leaves at a thickness of 1.00 cm and that observed with leaf sizes of 0.5×0.5 cm^2 and 2.0×2.0 cm^2 using air-dried leaves at a thickness of 2.50 cm, the ASAC values according to the leaf size under the same thickness was higher compared to those observed using fresh leaves. Observing higher sound absorption coefficients when using fresh leaves (Goh et al. 2023) was attributed to the difference in density due to moisture content. Accordingly, it is thought that there was a difference in the sound absorption coefficient between the two moisture content conditions considered in this study. Furthermore, not only the composition conditions of the sound-absorbing material under a certain pressure condition but also the effects of the anatomical structure of tissues depending on the type of leaves, tissue structure depending on the abaxial and adaxial sides of the leaves, and arrangement of components according to various pressure conditions on the sound characteristics require further research.

Sound absorbing properties according to the thickness

The sound absorption properties according to the thickness of the sound-absorbing material for each leaf size and ASAC for each condition are presented in Fig. 6. The ASAC of the sample with a thickness of 2.50 cm and size of 2.0×2.0 cm^2 observed using air-dried leaves was the highest at 0.47.

The increase in ASAC with respect to the leaf sizes was 0.01, indicating an insignificant effect. However, the amount of ASAC increase was 0.23 when the thickness increased from 1.00 cm to 2.50 cm. This result indicated to a significant effect on the ASAC value based on the leaf sizes. Furthermore, when comparing the sound absorption coefficients of the sound-absorbing materials manufactured using fresh leaves, the sound performance of the sound-absorbing material generally increases with an increase in thickness, except for the highest sound absorption coefficient (0.45 with a size of 2.0×2.0 cm^2 when the thickness was increased from 1.00 cm to 2.50 cm). Comparing the sound absorption coefficients at the same thickness between fresh and air-dried leaves, the ASAC values observed when using fresh leaves were generally higher than those observed when using air-dried leaves, except at a size of 0.5×0.5 cm^2 with thicknesses of 1.00 cm and 2.50 cm and at a size of 2.0×2.0 cm^2 with a thickness of 2.50 cm when using air-dried leaves. Because the sound insulating material manufactured using air-dried *Z. serrata* leaves are processed at the same pressure as the fresh leaves, the difference in ASAC due to the difference in density caused by the moisture content should be considered. Moreover, the main cause may be that the actual amount of pressure in the same area of the sound-absorbing material manufactured using air-dried leaves is less than that observed using fresh material due to the bending and twisting of the leaves caused during the drying process. According to the density of the sound-absorbing material with respect to the moisture conditions reported in Table 3, the density of the sound-absorbing material manufactured using fresh leaves was in the range of 0.17-0.22 ρ (g/cm^3), while that of the sound-absorbing material manufactured using air-dried leaves was formed in the range of 0.06-0.07 ρ (g/cm^3), indicating that sound-absorbing material manufactured using air-dried leaves has a relatively lower density. Accordingly, it is thought that the sound performance is higher when using fresh leaves. In a previous study, Koisumi et al. (2002) reported that as the density of bamboo-based sound-absorbing material increased, the sound absorption coefficient improved in the mid-frequency band from 500 Hz to 1 kHz, Moreover, the sound absorption coefficient showed a consistently increasing trend up to a specific wavelength or mid-frequency range. In this study, the density of fresh leaves was higher than that of air-dried leaves. Accordingly, the sound absorption coefficient according to the sound-absorbing material thickness generally exhibited higher values with fresh leaves, showing a trend similar to that reported in a previous study. In addition, Jung et al. (2023) implemented the same method as this study to analyze the trend of sound absorption for *Q. glauca* based on the thickness of the sound-absorbing material under the same moisture and pressure conditions. Consequently, they observed that the sound absorption coefficient tended to increase further as the thickness of the sound-absorbing material increased, up to a frequency range of 1.5 kHz. Goh et al. (2023) reported the sound absorption properties of *C. retusa* leaves as a sound-absorbing material. Accordingly, the sound absorption properties with a smaller size of leaves at a given thickness under the same moisture conditions showed a clearer trend. The increase in the ASAC according to thickness was higher with a size of 0.5×0.5 cm^2 compared to other leaf sizes and showed a similar trend to the sound absorption properties of the sound-absorbing material manufactured using *Z. serrata* leaves.

Sound characteristics according to frequency band

Figs. 3-5 compare the behavior of the sound-absorbing materials, in which the absorption coefficients are plotted for each leaf size condition at the thickness of 1.00 cm, 1.75 cm, and 2.00 cm, respectively, within a range of 100 Hz to 3,200 Hz. The frequency bands can be classified as below 500 Hz for low frequency, below 500-2,000 Hz for mid-frequency, and above 2,000 Hz for high frequency (Kim and Cha 1991).

Fig. 3a shows a sharp increase in the absorption coefficient after 500 Hz, peaking at approximately 1,500 Hz and decreasing until 2,000 Hz. In the high-frequency band of 2,000 Hz-2,500 Hz, the sound-absorbing material with a leaf size of 2.0×2.0 cm^2 attained the highest absorption coefficient, which sharply decreased between 2,500 Hz and 3,000 Hz. However, the SAC of the sound-absorbing materials constructed using the other two of leaf sizes decreased under 2,000 Hz-2,500 Hz, increased between 2,500 Hz and 3,000 Hz, and peaked above 3,000 Hz.

Fig. 3b shows a smaller increase in the slope compared to Fig. 3a and depicts an increase after a higher frequency (860 Hz). The sound-absorbing materials manufactured with leaf sizes of 0.5×0.5 cm^2 and 1.0×1.0 cm^2 peak around 1,000 Hz, and as the frequency increases to 2,000 Hz, the absorption coefficient increases. In the mid-frequency band, the absorption coefficients of the sound-absorbing materials with leaf sizes of 1.0×1.0 cm^2 and 2.0×2.0 cm^2 using air-dried leaves were higher that observed with a leaf size of 0.5×0.5 cm^2. This suggests that both fresh and air-dried leaves exhibit good sound performance in the high-frequency band above 2,000 Hz.

Fig. 4 show that the SAC based on the thickness conditions and leaf size conditions indicates to an absorption coefficient of over 0.4 in almost all frequency ranges. In addition, it shows a coefficient nearly equal to 1 in the high-frequency band above 2,000 Hz, suggesting that the sound-absorbing material can be used from the mid-to high-frequency bands.

Comparing the absorption coefficient behavior graphs depicted in Fig. 5, both moisture conditions show a sharp increase in the absorption coefficient from 500 Hz, exhibiting an absorption coefficient of over 0.4 across all frequency ranges. Unlike the results obtained with a leaf size of 2.0×2.0 cm^2 depicted in Fig. 5a, which showed the highest absorption coefficient in the high-frequency band, the other two leaf sizes showed the highest absorption coefficient in the mid-frequency band. These results showed similar sound absorption properties for each frequency band, as reported by Jung et al. (2020). In addition, the results were similar to the study that the sound absorption properties of *Q. glauca* by Jung et al. (2023) were higher in the band above the medium frequency band. It is thought that higher frequencies have shorter wavelengths and higher vibration frequencies, rendering them more linear; thus, when they pass through a medium, mainly reflection occurs rather than penetration. In other words, they are blocked on the surface, resulting in relatively lower sound performance (Choi and Kim 2021). As shown in Fig. 5, the absorption coefficient trend of the sponge was similar to that of the *Z. serrata* leaf sound-absorbing material, with an increasing absorption coefficient from 500 Hz to over 2,000 Hz. However, the absorption coefficient of *Z. serrata* sound-absorbing material was higher than that of sponge, suggesting that sound-absorbing materials made from forest by-products can demonstrate greater sound performance than artificial materials.

Conclusions

This study compared the sound absorption coefficients of air-dried leaves and fresh leaves for *Z. serrata* leaves, which are deciduous broad-leaved species. The size of the leaves constituted under the two drying conditions was 0.5×0.5 cm^2, 1.0×1.0 cm^2, and 2.0×2.0 cm^2, and the thickness of the sound-absorbing material was composed of 1.00 cm, 1.75 cm, and 2.50 cm. For all conditions, it was compared as the average of the sound absorption coefficient of 250 Hz, 500 Hz, 1,000 Hz, and 2,000 Hz.

(1) The sound absorption coefficient tended to increase as the size of the constituent leaves increased at the level of 1 cm and 1.75 cm in the thickness of the sound-absorbing material under the fresh leaf conditions. The sound absorption coefficient increased as the size of the constituent leaves increased at the level of 1.75 cm in the air-dried leaf condition, but there was no significant difference in the sound absorption coefficient at the level of 2.00 cm in thickness.

(2) In both drying conditions, as the thickness of the sound-absorbing material increased, the sound-absorbing performance tended to increase, and the difference in sound-absorbing performance was greater, especially in fresh leaf conditions.

(3) The average sound absorption coefficient under the 1.75 cm thickness condition shows a sound absorption performance of 0.4 or more and a sound absorption coefficient close to 1 in the high frequency range of 2,000 Hz or higher. In addition, the sound-absorbing material in the 2.0×2.0 cm^2 size condition showed the highest sound absorption coefficient in the medium frequency band under the 2.50 cm thickness condition. The sound-absorbing material under all size and thickness conditions showed high

sound absorption performance in the high frequency band of 2,000 Hz or higher.

(4) In terms of applying the sound-absorbing material to the noise space, the target frequency band showed high sound-absorbing performance in the high-frequency band of 2,000 Hz or higher. As a by-product or industrial waste, there is a possibility of using new resources of fixing carbon and improving living environments by using *Z. serrata* leaves, which are subject to disposal. However, in the future, research is needed to confirm the sound-absorbing performance by manufacturing a board using *Z. serrata* leaves.

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