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Use of Pine (*Pinus densiflora*) Pollen Cones as an Environmentally Friendly Sound-Absorbing Material

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ABSTRACT

This study examined the utility of pine (*Pinus densiflora*) pollen cones as an environmentally friendly material with sound-absorbing properties. Pine pollen cone samples with widths of 0.8–1.2 cm and lengths of 3.5–4.5 cm were prepared. After filling impedance tubes to heights of 6, 8, 10, or 12 cm with the pine pollen cones, the sound absorption coefficient of the pine pollen cones was investigated. The peak sound absorption frequency of the samples with a thickness of 6 cm was reached at 1,512 Hz; however, this value shifted to 740 Hz in samples with a thickness of 12 cm. Therefore, the sound-absorbing performance of pine pollen cones at low frequencies improved as the material thickness increased. According to KS F 3503 (Korean Standards Association), the sound absorption grade of pine pollen cones ranges from 0.3 to 0.5 M, depending on the material thickness of the pine pollen cones. In conclusion, the pine pollen cones demonstrated good sound absorption properties. They, thus, may be considered an environmentally friendly sound-absorbing material.

Keywords: pine pollen cones, eco-friendly sound-absorbing material, sound absorption coefficient, sound-absorbing properties

1. INTRODUCTION

Noise pollution is regarded as one of the most threatening environmental pollutions to humankind, second only to air and water pollution (Patel *et al*., 2021). Long-term exposure to noise pollution can lead to chronic diseases such as hearing damage, stress, sleep disturbances, high blood pressure, and heart problems (Yang, 2020).

Since the COVID-19 pandemic, the time spent indoors has increased. As the use of online education, telecommunication, and video conferencing increases, the demand for improving the acoustic environment at home or in the office also increases (Andargie *et al.*, 2021). The number of households raising dogs in apartments also increases exponentially in Korea (Park *et al*., 2021) and family dogs make indoor noise at times and cause disputes between neighbors (O'Brien, 2020).

To overcome noise pollution and associated problems, sound-absorbing materials such as urethane foam, synthetic fiber, and mineral fiber have been introduced. These sound-absorbing materials have been widely used as they are cost-effective, easy to mold, and demonstrate excellent sound-absorbing performance (Arenas and

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Crocker, 2010).

Recycling these commercially available materials is, however, difficult and may adversely affect human health. In particular, studies have shown an increased risk of respiratory cancer among workers who produce or discard mineral fiber (Gualtieri, 2021; Metintas *et al*., 2019). In addition, employees exposed to styrene may have a cancer risk in the petrochemical industry (Moshiran *et al*., 2021).

Various types of natural fibrous materials derived mostly from agricultural industry have been researched as an alternative to commercially available sound-absorbing materials. These materials are, for example, coir fiber (Nor *et al*., 2010), kenaf fiber (Taban *et al.*, 2020), and kapok fiber (Xiang *et al*., 2013), and rice by-products (Kang *et al.*, 2019b). Natural fibrous materials exhibit a sound absorption coefficient (the frequency range between 200 and 2,000 Hz) comparable to that of commercially available sound-absorbing materials (Iannace, 2017).

Research has demonstrated that the highest value of the sound absorption coefficient has shifted to the lower frequency as the thickness of the experimented materials has increased. The sound absorption coefficient value also increases as the thickness of the materials increases (Kang *et al.*, 2019b; Taban *et al.*, 2020).

Wood is familiar and sustainable resources as a building material from prehistoric times to the present (Ghani and Lee, 2021; Hadi *et al*., 2022; Jamaludin *et al*., 2020; Kim and Kim, 2020). Wood has been also widely researched as a sound absorbing material. Plywood can be used as a resonance type sound absorber by adjusting the hole size and air back cavity (Peng *et al*., 2018). Cross-sections of hardwoods also can be used as a porous sound absorber and their high through pore porosity is found to be advantageous for sound absorption (Jang and Kang, 2021a, 2021b, 2021c; Jang and Kang, 2022).

Wood bark particles can be used as a granular type sound absorber (Kang *et al.*, 2019a; Tudor *et al.*, 2020) while evergreen tree leaves used as sound-absorbing materials (Jung *et al.*, 2020). Wood pellets also has sound absorption effect (Jang, 2022). This previous study indicates that not only solid wood but also its by-products can be used as sound-absorbing materials.

Pine (*Pinus densiflora*) pollen has various nutrients and physiologically active ingredients, widely used as food and herbal medicine (Hou *et al.*, 2017). However, the pine pollen cone was known to be a useless by-product. This study focused on using pine pollen cones as a sound-absorbing material. The pine pollen cone has a low density, its granules can absorb noise using their hollow space, and their rough surfaces can scatter sound waves. This study investigated the sound absorption properties of pine pollen cones using impedance tubes. This study is the new approach that proposes pine pollen cones as an alternative for an eco-friendly sound-absorbing material.

2. MATERIALS and METHODS

2.1. Sample preparation

Pine pollen cone samples shown in Fig. 1 were collected in the front yard of College of Education at Jeonbuk National University (Jeonju, Korea). These pine pollen cone samples had an abscissa length of approximately 0.8–1.2 cm and an ordinate length of approximately 3.5–4.5 cm.

2.2. Scanning electron microscopy (SEM) image analysis

One pine pollen cone sample was dried in a laboratory oven at 40℃ for 5 hours. The sample was then loaded into an ion coater (SCM, Emcrafts, Korea) and coated with gold. The SEM (Genesis-1000, Emcrafts, Korea) was used to examine a sample at 100× and 500× magnification in high-vacuum mode (7.5×10^{-5} mmHg).

Fig. 1. Sample preparation of pine pollen cones.

2.3. Measurement of sound absorption coefficient of pine pollens

Fig. 2 shows the schematic diagram of the impedance tubes (type 4206, Brüel & Kjaer, Denmark) to measure the sound absorption coefficient. The impedance tubes consist of a large impedance tube (99 mm diameter) and a small (29 mm diameter) tube. The pine pollens with a height of 6 to 12 cm were loaded to large and small impedance tubes. Their apparent density in the impedance tubes was kept at 0.085 g/cm^3.

A large impedance tube was used to measure the absorption coefficient in the frequency range of 100–1,600 Hz, while a small impedance tube was used to evaluate the absorption coefficient in the frequency range of 500–6,400 Hz. The range of the sound absorption coefficient is from 0 to 1.

Environmental condition during measurement of the sound absorption coefficient was as follows; an atmospheric pressure was 1,018.00 hPa, a temperature was 10.10℃, a relative humidity was 31.50%, the velocity of sound was 337.39 m/s, the density of air was 1.251 kg/m^3, and the characteristic impedance of air was 421.7 Pa/(m/s).

3. RESULTS and DISCUSSION

3.1. Scanning electron microscopy (SEM) images

Fig. 3(a) shows SEM images of the pine pollen cones at 100 magnification, and Fig. 3(b) and Fig. 3(c) show SEM images at 500 magnification. The pine pollen cone has a form of overlapping broad, thin scale-like shapes,

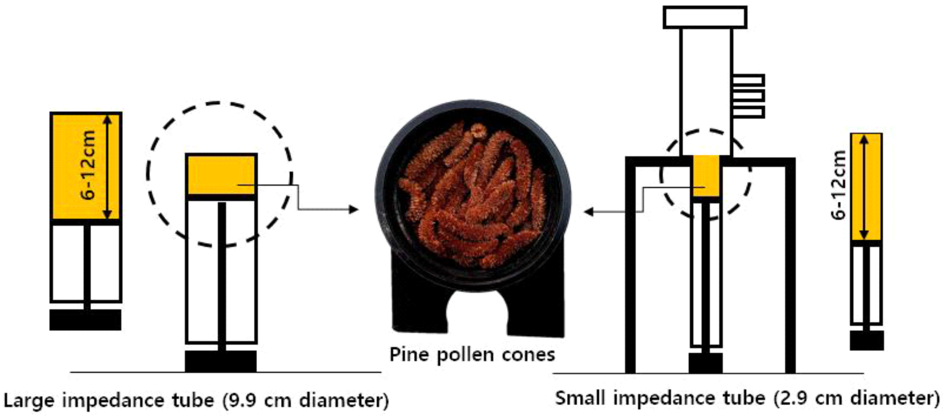


Fig. 2. Schematic diagram of impedance tubes.

and curved and rough surfaces. When the incident sound waves encounter these structures, they can be diffracted or scattered, and advantageous for sound absorption.

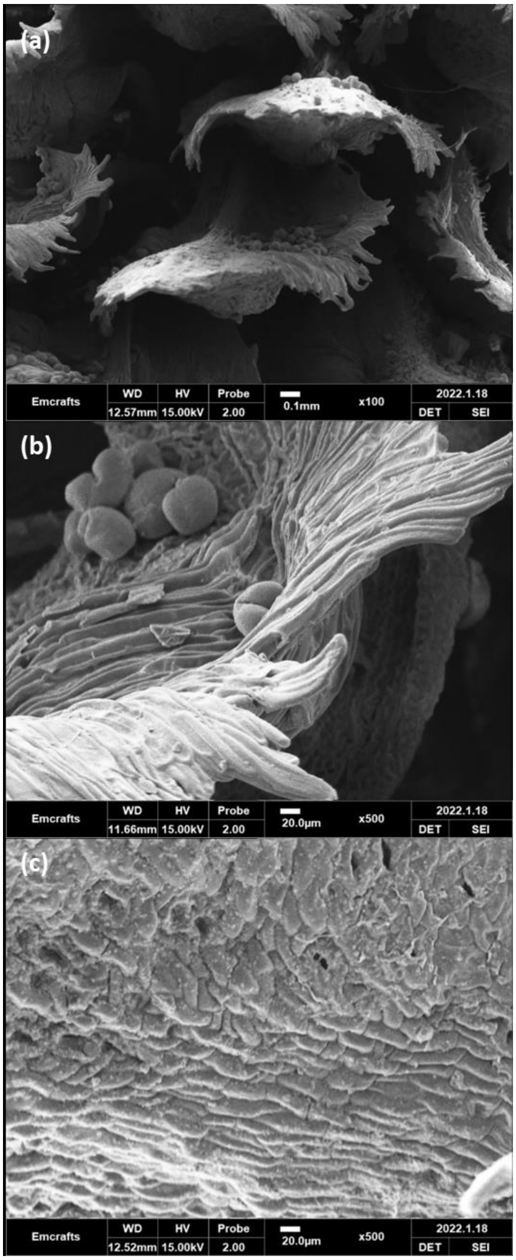


Fig. 3. SEM images of the pine pollen cone. SEM: scanning electron microscopy.

3.2. Sound-absorbing properties

Fig. 4 shows the frequency of pine pollen cones' acoustic absorption curves. Fig. 4(a) demonstrates the results from the large impedance tubes, and Fig. 4(b) the results from the small impedance tubes.

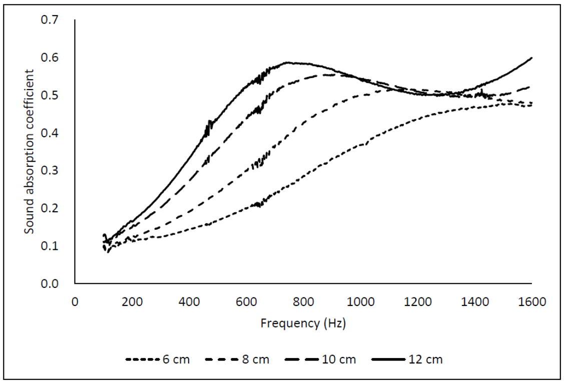
As the thickness of the pine pollen cones filled in the impedance tubes increased, the sound absorption coefficient at low frequencies also increased. The maximum sound absorption coefficient at 6 cm thickness was 0.477 at 1,512 Hz, 0.515 at 1,122 Hz for 8 cm thickness, and 0.555 at 910 Hz for 10 cm thickness, 0.586 at 740 Hz for 12 cm thickness [Fig. 4(a)].

At high frequencies above 1,000 Hz, the number of sound absorption peaks increased as the thickness of the pine pollen cones increased. At 6 cm thickness, 3 sound absorption peaks appeared, 8 cm showed 4, 10 cm demonstrated 5, and 12 cm identified 6 peaks. For every 2 cm thickness increases, the sound absorption peak increased by 1. At a thickness of 12 cm, the sound absorption coefficient was close to unity above approximately 1,500 Hz. Pine pollen cones are, therefore, should be considered a very useful material for high-frequency sound absorption.

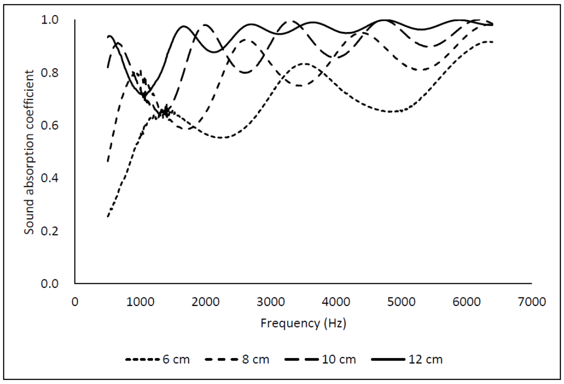
The dominant frequency range of family dog barks is between 160 and 2,630 Hz (Pongrácz *et al*., 2010). The results of this study identified 12 cm thickness pine pollens used as a sound-absorbing material can cover a significant portion of this frequency range, which may help reduce barking noise.

Table 1 summarizes the sound absorption coefficients (250, 500, 1,000, and 2,000 Hz) and the NRC (Noise Reduction Coefficient). When the thickness was doubled from 6 cm to 12 cm, the sound absorption coefficient increased by 1.7 times at 250 Hz, 2.6 times at 500 Hz, 1.5 times at 1,000 Hz, and 1.6 times at 2,000 Hz. As a result, the NRC was 1.7 times increased.

Kang *et al*. (2019a) reported the sound absorption performance of sound absorbers made of wood bark



(a)



(b)

Fig. 4. Sound absorption curves of pine pollen cones. (a) Large impedance tube, (b) small impedance tube.

Table 1. The sound absorption coefficient at 250, 500, 1,000, and 2,000 Hz and NRC

Thickness (cm)	Sound absorption coefficient @ Frequency (Hz)				NRC
	250	500	1,000	2,000	
6	0.118	0.167	0.368	0.567	0.305
8	0.136	0.241	0.498	0.647	0.381
10	0.174	0.356	0.543	0.980	0.513
12	0.198	0.438	0.541	0.891	0.517

NRC: noise reduction coefficient.

particles. Their NRC (10 cm thickness) was 0.24 for Radiata pine, 0.30 for Hemlock, 0.30 for Elm, 0.31 for Douglas-fir, 0.57 for Larch, and 0.80 for Hinoki. The sound absorption properties of the pine pollen cones at the same thickness were equivalent to or higher than that of the wood particles. This is thought to be because the surface of pine pollen is rough, and many scale-like curves facilitate sound wave scattering.

The Korean Industrial Standard KS F 3503 (KSA, 2012) classifies the sound-absorbing properties into four grades (0.3 M grade: 0.21–0.40, 0.5 M grade: 0.41–0.60, 0.7 M grade: 0.61–0.80, and 0.9 M grade: above 0.81) depending on the NRC of the sound absorption materials. This study found that pine pollen cones had a sound absorption grade of 0.3 M (NRC: 0.305) in 6 cm, 0.3 M (0.481) in 8 cm, and 0.5 M (NRC: 0.513) in 10 cm, and 0.5 M (0.517) in 12 cm.

The sound-absorbing performance of pine pollen cones was sufficient to be considered an alternative to commercially available synthetic sound-absorbing materials. Pine pollen cones once were a useless resource for which no one cared. However, this study demonstrated that pine pollen cones have utility value as an eco-friendly sound-absorbing material.

4. CONCLUSIONS

The sound absorption properties of pine pollen cones were investigated in this work. As the thickness of pine pollen cones increases, the sound absorption ability improves. Pine pollen cones had a sound absorption grade of 0.3 M to 0.5 M (KS F 3503) depending on their filling thickness. Pine pollen is a valuable resource widely used as food and herbal medicine, but pine cones were a wasted resource. Conclusively, this study proposes using pine pollen cones as an environmentally friendly sound-absorbing material.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

Not applicable.

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