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Investigation of sound absorption capability of pine (*Pinus densiflora*) cone particles

Eun-Suk Jang[1,3] and Chun-Won Kang[1,2*]

Abstract

In this study, the sound absorption capability of pine (*Pinus densiflora*) cone particles was investigated as an alternative and eco-friendly, sound-absorbing material. The sound absorption coefficient of pine cone particles was examined after filling impedance tubes with 4, 6, 8, and 10 cm of particles. The sound absorption capability of 4 cm and 6 cm thickness was categorized as 0.5 M class, and that of 8 cm and 10 cm thickness was classed as 0.8 M class according to the KS F 3503 sound-absorbing capability classification of sound-absorbing materials. In particular, 10 cm pine cone particles demonstrated exceptional sound absorption capability in the range of 250–6400 Hz, with an average sound absorption coefficient of 0.6 or greater. In conclusion, pine cone particles were found to have excellent sound absorption capability. Thus, this work suggests that pine cone particles may be useful as an eco-friendly, sound-absorbing material.

Keywords Pine cone, Pine cone particles, Eco-friendly, Sound-absorbing material, Sound absorption coefficient

Introduction

As concerns about global warming increase, carbon emission reduction has become an important task facing mankind [1, 2]. In 2015, The Paris Agreement was reached at the United Nations Framework Convention Climate Change (UNFCCC) in Paris, hosted by UN Secretary-General Ban Ki-moon. The Paris Agreement proposes maintaining the average global temperature rise below 2 °C and strives to not exceed 1.5 °C [3].

In line with this, the Korean government announced that it would move forward to become 'carbon neutral' by 2050. As an interim goal for carbon neutrality in 2050, Korea submitted its Nationally Determined Contribution (NDC) to the UNFCC, aiming to reduce greenhouse gas emissions 40% by 2030 compared to 2018. [3].

*Correspondence:
Chun-Won Kang
kcwon@jbnu.ac.kr
[1] Research Institute of Human Ecology, College of Human Ecology, Jeonbuk National University, Jeonju 54896, South Korea
[2] Department of Housing Environmental Design, College of Human Ecology, Jeonbuk National University, Jeonju 54896, South Korea
[3] Sambo Scientific Co. Ltd, R&D Center, Seoul 07258, South Korea

Expanding the use of wood is a crucial task in moving toward carbon neutrality. Wood requires low energy to manufacture and process, and discarded wood can be used as an energy source. Thus, wood is a sustainable, cyclical resource that can be used indefinitely [4, 5] and has been a popular eco-friendly material in construction, furniture, and musical instruments from the past to the present [6–11].

Recently, noise pollution has haunted as a weighty environmental problem. Raising recognition of the health effects of noise has accelerated the widespread interest in sound-absorbing materials [12, 13].

Among the various uses of wood resources, there are various studies on the use of solid wood and wood by-products as sound-absorbing materials. Thin wood panels have a plate vibration-type sound absorption effect [14]. Perforated wood paneling acts as a resonant sound absorber. It is possible to absorb sound according to the noise frequency by adjusting the diameter and frequency of the perforations and the size of the air back cavity [15, 16].

Also, wood cross-sections can be used as porous sound-absorbing materials. Sound absorption effects are better in a broadleaf tree cross-section with developed vessels than in a conifer cross-section made of tracheids [17]. As for the effect of pore structure on sound absorption, diffuse-porous wood with high through-pore porosity without large pore size is more advantageous than ring-porous wood [12, 18, 19]. Depending on the area, sapwood has better sound absorption than heartwood. The reason is that heartwood has developed tyloses, which interfere with the absorption of sound waves [17, 20–22].

Ring-porous wood also has sound-absorbing effects. A cross-section of ring-porous wood is not a very good sound-absorbing material; however, it can be used as a resonance sound-absorbing material if used concurrently with a backside air back cavity. The longer the distance of the air back cavity, the better the sound absorption capability at low frequencies [23, 24].

Forest by-products, such as tree bark, wood chips with sawdust, and bark panels, can be excellent sound-absorbing materials. In addition, many researchers have recently studied the sound absorption capabilities of natural cellulose materials, such as kenaf, coconut, hemp, straw, granular cork, broom fibers, and date palm waste [25–27]. Among them, this study focuses on forest by-products as eco-friendly, sound-absorbing materials.

Kang et al. [28] investigated the sound absorption capabilities of wood bark particles with different thicknesses and densities by crushing wood bark from five types of conifers and 1 type of broadleaf tree. It was shown that the sound absorption coefficient increased as the thickness of the impedance tube containing the wood bark particles increased. The most effective sound absorber was made of Hinoki (*Chamaecyparis obtusa* (Siebold & Zucc.) Endl.) bark particles (100 mm thickness) and had an average sound absorption coefficient of 0.90 at 100–6400 Hz.

Boubel et al. [29] reported the sound absorption capabilities of wood chips and sawdust depending on the particle size. The results showed relatively better absorption coefficients at 1.25–2.5 mm, 0.63–1.25 mm, and 0.31–0.63 mm, whereas 5–8 mm and above and 0.16–0.315 mm grades had the lowest sound absorption efficiencies. Redwood particles sized 1.25–2.5 mm showed the best sound absorption capability.

Tudor et al. [30] manufactured larch bark panels by adjusting density, particle size, and particle orientation (perpendicular and parallel) parameters and investigated their sound absorption capabilities. The noise reduction coefficients (NRCs) of the larch bark panels were 0.1–0.3 (for 30 mm particle thickness) and 0.15–0.5 (for 60 mm thickness).

Jang [31] examined the sound absorption capability of pine (*Pinus densiflora*) pollen corns using ISO 10534-based impedance tubes. Their optimum sound absorption coefficient was 0.586 at 740 Hz, found at 12 cm particle thickness. Their NRC reached 0.305 at 6 cm thickness and 0.517 at 12 cm thickness.

Pine cones are the fruit of a pine tree and are the shell after the pine tree seeds have been blown away. Recently, there have been various studies to utilize them, such as using them as flocculants for water purification [32], biocarbon [33], and anti-inflammatory agents [34]. However, there are few studies on the use of pine cones as sound-absorbing materials. This study may outline a new approach to utilizing pine cone particles as an eco-friendly sound-absorbing material.

So, this study investigated the sound absorption capability of pine cone particles. In order to contribute to the creation of high added value forest by-products, this study intends to propose pine cones as one of the candidates for eco-friendly, sound-absorbing materials.

Materials and methods

Sample preparation

Figure 1 shows the preparation of the pine cone particle samples used in this study. Pine cones were obtained from Korean red pine (*Pinus densiflora*) trees in front of Jeonbuk National University, College of Human Ecology (Jeonju, Korea). Pine cones were granulated through a crusher for this study, and pine cone particles smaller than 10 mm were collected.

Scanning electron microscopy image analysis

This study used Scanning Electron Microscopy (SEM: Genesis-1000, Emcraft, Korea) to observe the surface traits of the pine cone samples. They were dried at 40 °C for 10 h in a laboratory air dryer, then mounted on the sample die of SEM and observed at 500 × and 1000 × magnifications in high vacuum mode.

Sound absorption capability of pine cone particles

There are two methods to evaluate the sound-absorbing capacity of sound-absorbing materials, divided into a reverberation chamber method and a transfer function method [35]. This study investigated the sound absorption capability of pine cone particles using the transfer function method and an impedance tube conforming to ISO 10534-2 [36].

The transfer function method has the advantage of measuring the sound absorption coefficient in a short time (within 10 s) with a small-sized sample (2.9 mm or 9.9 mm) [37]. This is widely used as a simple way to evaluate sound absorption capabilities in a laboratory [12, 28, 38]. The sound absorption coefficient measuring device used in this study was impedance tube type 4206 (Brüel & Kjær, Denmark).

Fig. 1 Preparation of pine cone particle samples

As shown in Fig. 2, large impedance tubes and small impedance tubes were filled with pine cone particles to heights of 4, 6, 8, and 10 cm. This study did not use a frame to measure the sound absorption capability of pure pine cone particles alone. Usually, an impedance tube is used in the horizontal direction. However, this study used vertically oriented impedance tubes to prevent the sample from flowing down. The sound absorption coefficient was measured at both 100–1600 Hz for the large impedance tube (99 mm inner diameter) and 500–6400 Hz for the small impedance tube (29 mm inner diameter).

Since the sound absorption coefficient changes depending on the frequency, the sound absorption capability of the sound absorption material is evaluated as a single index using NRC in the industrial field [31, 39–42]. NRC is calculated as described by Eq. (1).

$$\mathrm{NRC} = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4}, \quad (1)$$

where α_{250} is the sound absorption coefficient at 250 Hz, α_{500} is the sound absorption coefficient at 500 Hz, α_{1000} is the sound absorption coefficient at 1000 Hz, and α_{2000} is the sound absorption coefficient at 2000 Hz.

In addition, this study calculated the average of the sound absorption coefficient depending on four frequency sections (250–500 Hz, 500–1000 Hz, 1000–2000 Hz, and 2000–6400 Hz). Sound absorption coefficients measured at up to 1000 Hz were measured using large impedance tubes, and sound absorption coefficients measured above 1000 Hz were measured in small impedance tubes.

Results and discussion

SEM images

Figure 3 shows SEM images of the pine cone particles. The image of the pine cone particles observed at 500 × magnification (Fig. 3a) was irregular and rough. The image at 1000 × magnification (Fig. 3b) shows that undulation of the surface of the pine cone particles was observed. It can also be seen that fine powder is attached to the pine cone particles, a valuable structure for scattering incident sound waves.

Sound absorption capability

Figure 4 represents the results of the absorption coefficient curve, and Table 1 depicts the NRC and average sound absorption coefficient at four frequency ranges (250–500, 500–1000, 1000–2000, and 2000–6400 Hz).

Figure 4a shows a graph of the absorption coefficient measured in a large impedance tube. The maximum sound absorption coefficients of the pine cone particle sound-absorbers were 0.994 at 1100 Hz for 4 cm thickness, 0.982 at 802 Hz for 6 cm thickness, 0.998 at 530 Hz for 8 cm thickness, and 0.992 at 384 Hz for 10 cm thickness. As the filling thickness of the pine cone particles increased from 4 to 10 cm, the maximum sound absorption coefficient shifted toward lower frequencies.

Figure 4b shows a graph of the absorption coefficient of pine cone particles measured in a small impedance tube. There were three sound absorption peaks at 4 cm thickness and six peaks at 10 cm thickness, and each time the thickness of the pine cone particles increased from 4-to-2 cm, the number of sound absorption peaks increased by one. This phenomenon is typical of natural fibro-granular, sound-absorbing materials [13, 42].

The NRC of the pine cone particle, sound-absorbing material was 0.540 at 4 cm thickness and increased to 0.755 at 10 cm thickness. According to the KS F 3503 [43], the sound absorption capability of a sound-absorbing

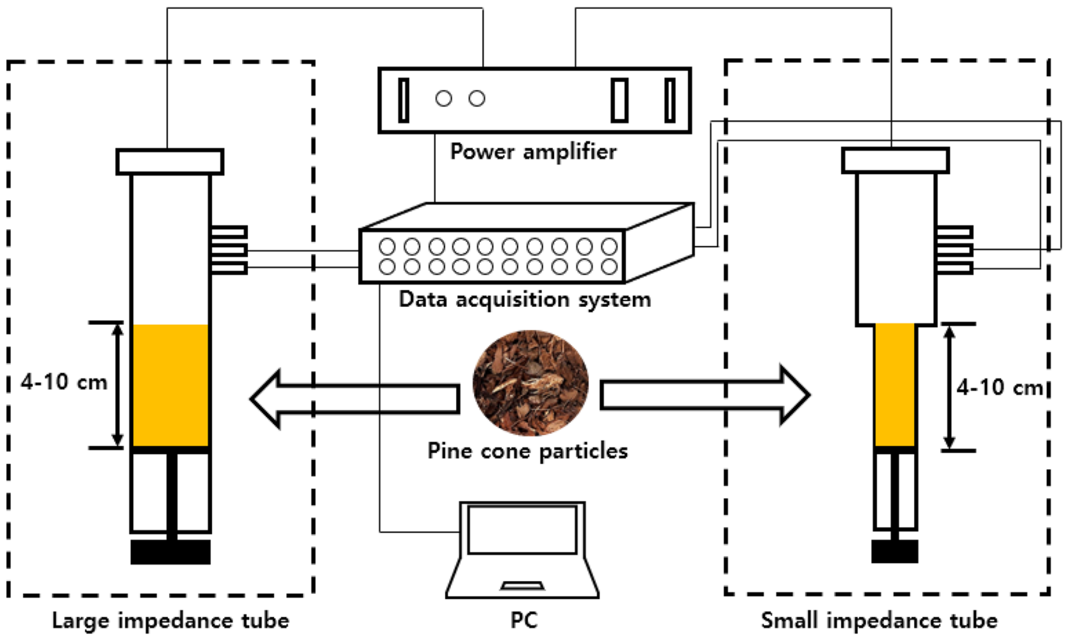


Fig. 2 Schematic of large and small impedance tubes for sound absorption coefficient measurement

material can be divided into four classes based on NRC (0.9 M grade: above 0.81, 0.7 M grade: 0.61–0.80, 0.5 M grade: 0.41–0.60, and 0.3 M grade: 0.21–0.40).

From this classification, pine cone particle sound-absorbers with 4 cm and 6 cm thicknesses were classified as 0.5 M class, and those with 8 cm and 10 cm thicknesses were classified as 0.8 M class. In particular, the 10 cm-thick pine cone particle sound-absorber showed an excellent sound absorption capability with an average sound absorption coefficient of 0.6 or more across all four frequency ranges. This means that it can absorb more than 60% of most of the noise of daily life, which suggests its promising use as a commercial sound-absorbing material.

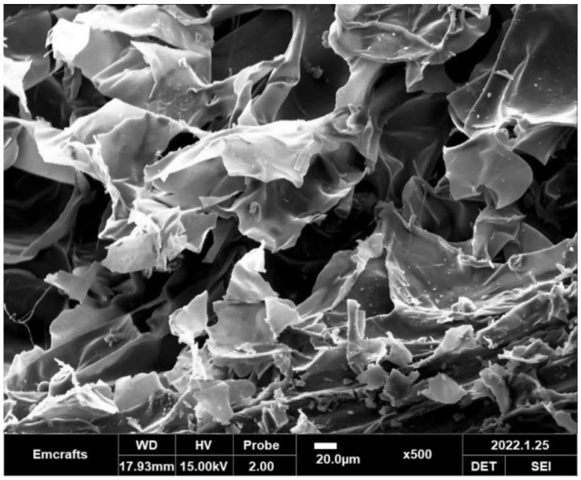
It is known that the frequency range where humans are most sensitive to noise is 1000–4000 Hz [44]. In particular, noise in this frequency range is detected frequently in a wood processing factory where various cutting machines operate [45]. As a result of this study, the pine cone particle, sound-absorbing material has a noise absorption effect of 60% at 1000–4000 Hz. So it would be helpful in these wood processing factories.

Figure 5 compares sound absorption capabilities between the sound-absorbing materials manufactured from forest by-products investigated in the previous study and the pine cone particles investigated in this study. The sound absorption capability of pine cone particles showed a comparative advantage compared to other forest by-product sound absorption materials. It is thought that the rough surface and irregular size of the pine cone particles compared to other forest by-products contributed to the excellent sound absorption performance.

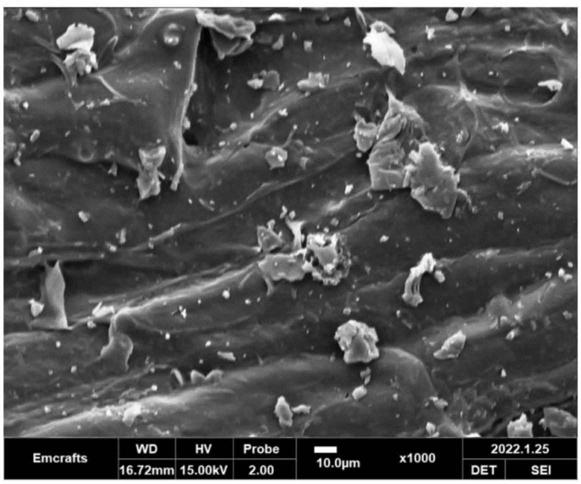
The author proposes to use the pine cone particle sound absorber in the form of a mat. If an adhesive is used to make it into a board shape, the porosity is significantly reduced because the adhesives block the empty void between the pine cone particles. This may lead to a decrease in sound absorption capability [11]. As a result, the pine cone particles' sound-absorber can be used as an attractive eco-friendly, sound-absorbing material.

Conclusions

This study investigated the sound absorption capability of pine cone particles. As the thickness of the layer of pine cone particles in the sound-absorber increased from 4 to 10 cm, the maximum sound absorption coefficient shifted towards the low-frequency direction from 0.994 at 1100 Hz to 0.992 at 384 Hz. According to the capability classification of sound-absorbing materials described by KS F 3503 [43], the sound absorption capability of 4 cm- and 6 cm-thick sound absorbers was classified as 0.5 M class, and that of 8 cm and 10 cm thicknesses was classified as 0.8 M class. In particular, the sound-absorber made with 10 cm of pine cone

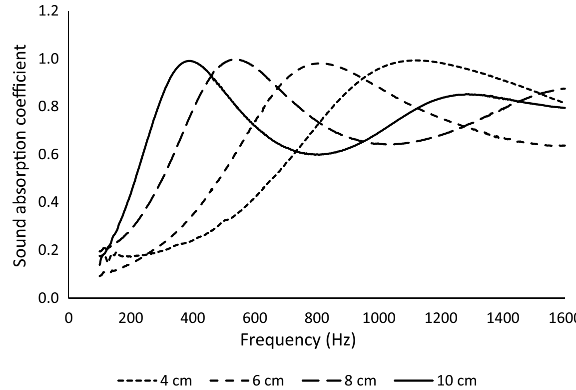


(a) 500×

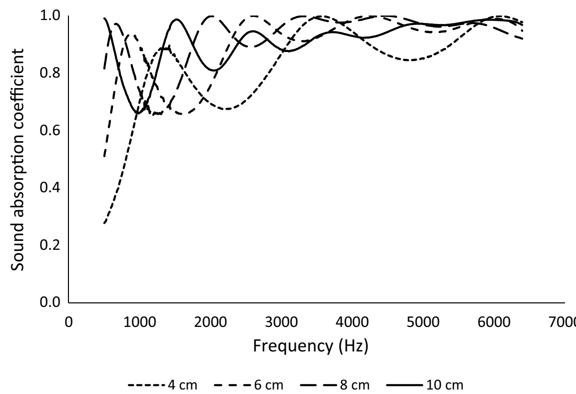


(b) 1000×

Fig. 3 SEM images of pine cone particles



(a) Large tube



(b) Small tube

Fig. 4 Sound absorption curves of pine cone particle sound absorbers depending on thickness

particles showed excellent sound absorption capability, with an average sound absorption coefficient of 0.6 or more in the range of 250–6400 Hz. This result was a performance that was comparable to a commercial

Table 1 The average sound absorption coefficient at four frequency sections and NRCs of pine cone particle sound absorbers

Thickness (cm)	Average sound absorption coefficient				NRC
	250–500 Hz	500–1000 Hz	1000–2000 Hz	2000–6400 Hz	
4	0.183	0.323	0.959	0.695	0.540
6	0.182	0.526	0.881	0.755	0.586
8	0.377	0.982	0.646	0.998	0.751
10	0.645	0.868	0.693	0.812	0.755

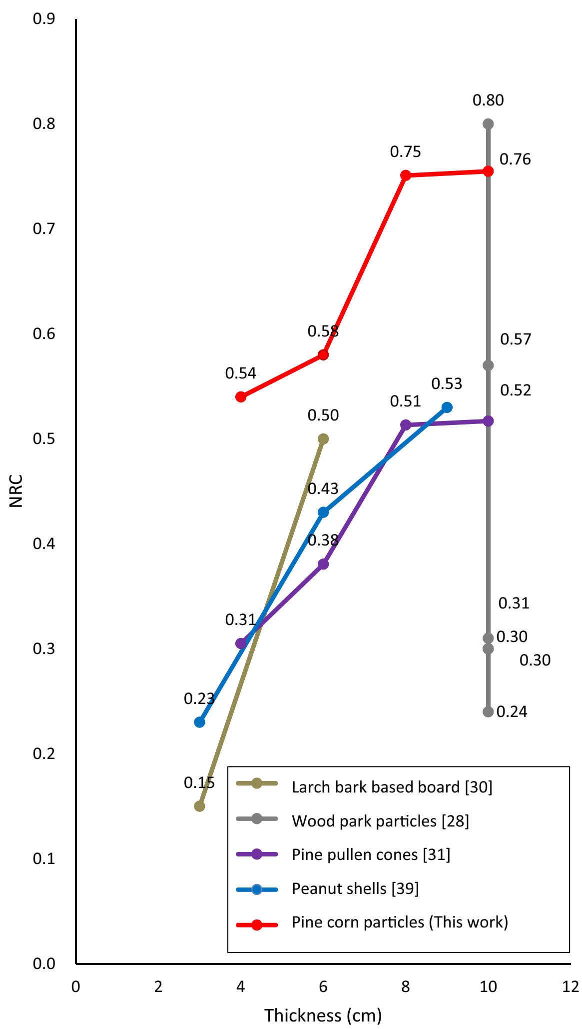


Fig. 5 Comparison of sound-absorbing capabilities between sound-absorbing materials manufactured from forest by-products investigated in previous studies

sound-absorbing material. In conclusion, this investigation implies that these sound-absorbing properties may add value to pine cone particles.

Abbreviations

NDC	Nationally determined contribution
UNFCCC	United Nations Framework Convention Climate Change
NRC	Noise reduction coefficients
SEM	Scanning electron microscopy

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Author contributions

ES JANG: First author, Conceptualization, Methodology, Experiment, Data analysis, Writing—original draft, and Writing—review and editing. CW KANG: Corresponding author, Supervision and Writing—review and editing. Both authors read and approved the final manuscript.

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Declarations

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Competing interests

The authors have no competing interests.

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