Iranian Society of Acoustics and Vibration
The 14th ISAV2024 International Conference on Acoustics and Vibration
11-12 Dec 2024 Karaj - Iran
Kharazmi University

Acoustic properties of eco-friendly Micro-Perforated Panel (MPP) incorporating animal fibers

Ali Khavanin [a], Mohammad Hosein Beheshti[b*], Ali Safari Varyani[c], Musli Nizam Bin Yahya[d], Ali Alami[e], Farahnaz Khajenasiri[f]

[a] full Professor, Department of Occupational Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[b] Assistant Professor, Department of Occupational Health Engineering, School of Public Health; Social Determinants of Health Research Center, Gonabad University of Medical Sciences, Gonabad, Iran
Corresponding author e-mail: beheshtihasan8@gmail.com
[c] Associate Professor, Department of Occupational Health, School of Health, Qazvin University of Medical Sciences, Tehran, Iran
[d] full Professor, Faculty of Mechanical and Manufacturing Engineering, Tun Hussein Onn University of Malaysia (UTHM), Batu Pahat, Malaysia
[e] Associate Professor, Department of Epidemiology and Biostatistics, School of Public Health; Social Determinants of Health Research Center, Gonabad University of Medical Sciences, Gonabad, Iran
[f] Associate Professor, Department of Community Medicine, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran

Abstract

Micro-perforated panels (MPPs) are innovative alternatives to traditional sound-absorbing materials, though they exhibit limitations in efficiency at high frequencies, rendering them unsuitable for interior wall finishes. Enhancing their performance involves incorporating porous materials into the air gap. Natural materials, like sheep, goat, and camel wool, are emerging as sustainable substitutes for synthetic sound insulators. This study assessed the sound absorption coefficients of wool-based insulating materials and analyzed MPPs backed by wool composites of varying thickness using an impedance tube per ISO 10534-2. The impact of pore shape, perforated plate thickness, and wool composites in the air gap were investigated. Results revealed that camel wool demonstrated the highest sound absorption performance, achieving a maximum absorption coefficient of 0.95 at frequencies above 1000 Hz. The maximum sound absorption coefficient of MPPs generally occurs in the medium frequency range (800–1500 Hz), shifting to lower frequencies with increased panel thickness without altering the absorption bandwidth. Similarly, sugarcane fiber composites with varying thicknesses showed that a 1 cm-thick wool composite reached a peak SAC of 95% at 3500 Hz, shifting to lower frequencies as thickness increased. Importantly, the pore shape and porosity did not significantly affect SAC, highlighting the limited impact of these factors. The incorporation of wool composites in the air gap notably enhanced SAC and broadened the absorption bandwidth, particularly at lower frequencies. However, this enhancement came at the cost of reduced SAC at higher frequencies, making MPPs with wool composites unsuitable for managing sounds above 3000 Hz. Nonetheless, MPPs backed by wool composites provide an environmentally responsible option for low-frequency sound management. Their reduced ecological footprint and improved acoustic performance at lower frequencies underscore their potential for sustainable acoustic solutions This study highlights the viability of integrating natural materials like wool into acoustic designs, achieving both superior sound absorption and sustainability. By focusing on lower-frequency sound control, MPPs with natural backing materials emerge as a promising alternative in the field of eco-friendly acoustic engineering.

Keywords: Micro-Perforated Panel, MPP, noise, adsorption

1. Introduction

Micro-perforated panels (MPPs) are considered one of the most promising next-generation alternatives to traditional porous materials. Over the past decade, they have gained considerable attention for their noise control applications in various fields, including construction.[1], building acoustics [2-3], aircraft [4], environmental settings [5], automobiles [6-7], electrical distribution transformers [8], and even medical devices [9], this can be attributed to their durability, sensitivity, recyclability, flexible design, and high sound absorption characteristics [10]. Unlike traditional sound-absorbent materials, MPPs do not emit powdered fibers and pose no adverse health effects. Therefore, MPPs are considered the most promising green sound-absorbing material of the 21st century [11]. The theoretical foundation and design principles of MPPs were initially introduced by Maa in 1975 [12]. An MPP consists of a thin film or panel, which can be made from materials such as plastic or metal, featuring low thickness, sub-millimeter pores, and a porosity ratio of less than 1%. These panels are designed with an air gap and a rigid wall at the back [13]. MPPs offer numerous advantages over traditional sound-absorbing materials and overcome many of the limitations associated with both natural and artificial absorbers. Despite these benefits, MPPs are known to have a lower sound absorption coefficient at low frequencies [14]. Researchers have investigated the performance of MPPs extensively [15-18]. Some studies have explored various strategies to enhance the sound absorption coefficient of MPPs. These include using MPPs backed by irregularly shaped cavities [19], employing multilayer sound absorbers with 3D-printed MPPs [18], and arranging elastic micro-perforated plates in parallel [20], Implementing MPPs according to the designs proposed in these studies can be challenging and complex. Key issues include the manufacturing costs and the technological requirements associated with these designs. One of the simpler approaches to enhance the sound absorption of MPPs is to incorporate porous materials within their air gap [11].

Acoustic chamber absorbers are typically made from porous synthetic materials such as rock wool, glass wool, polyurethane, or polyester. These materials are costly to produce, mainly derived from petrochemicals, and have significant environmental impacts [21]. Recently, increasing environmental awareness has driven a shift toward more eco-friendly materials. Natural materials offer several advantages, including low density, excellent mechanical properties, ease of production, high stability, minimal health effects, widespread availability, affordability, and minimal environmental impact. Additionally, incorporating natural materials in buildings can positively influence human health. Based on their microscopic structure, porous absorbent materials are classified into three groups: cellular, fibrous, and granular [22]. Generally, fibrous materials contain tunnel-like pores created by gaps within the fibres. Fibres are divided into two categories: synthetic and natural. Natural fibres can be plant-based (e.g., hemp, jute, wood), animal-based (e.g., wool, fur), or mineral-based (e.g., asbestos). In contrast to synthetic absorbers, natural materials offer various advantages such as low density, excellent mechanical properties, ease of production, high stability, minimal health effects, wide availability, low cost, and reduced environmental impact. Additionally, using natural materials in buildings can positively affect human health .Natural materials help regulate indoor air humidity and their distinct scent can have a beneficial effect on human well-being. Experimental results from a straw bale house in Germany, where several important features were systematically measured, demonstrated positive outcomes for healthy living conditions. Organic materials are generally permeable to water vapour and can absorb moisture through air adsorption.

Wool is a natural fiber sourced from animals like sheep, goats, and camels. It is renowned for its excellent insulation properties and low flammability [23]. Wool fibers are mainly sourced from Australia, New Zealand, China, the UK, South Africa, and parts of Europe and Asia. Short wool fibers, which are collected during shearing, are not suitable for clothing and are often discarded as waste. These fibers are also obtained from animals raised for meat production, known as waste wool. Wool fibers are widely available but often with little added value. Environmentally, wool requires less energy for use and disposal compared to other natural materials. Sheep wool is renewable, recyclable, and eco-friendly, consisting of approximately 60% animal protein, 15% moisture, 10% fat, 10% sweat, and 5% impurities [24]. The aim of this paper is to introduce a novel micro-perforated panel that combines pore morphology, panel design, and animal wool composites to provide both sound and thermal insulation. The panels developed in this study offer effective insulation under various conditions. This absorber contributes to the development of green buildings by utilizing recyclable and biodegradable materials, and it helps reduce carbon emissions during the disposal of the panels at the end of their lifecycle.

2. METHOD

2.1 Preparation of Wool Samples

In this study, camel, goat, and sheep wool were collected from farms in eastern regions for producing natural acoustic insulation materials. The wool was manually cleaned to remove impurities, including natural substances like lanolin, sweat, and urine, as well as environmental contaminants such as dust, plant debris, straw, and dyes. Cleaning involved washing with water and soap, followed by carbonization and chlorination. During carbonization, the wool was treated with sulphuric and hydrochloric acids to convert impurities into charcoal through high-temperature hydrolysis. The wool was then dried at 70–90°C and briefly exposed to 110°C to complete the removal of fats and cellulose. Neutralization with diluted ammonia ensured safety and stability. In the chlorination stage, sodium hypochlorite was used to reduce felting and shrinking properties, enhance surface transparency, and improve dye absorption. The processed wool was prepared for testing with specialized equipment, such as pressing machines and impedance tubes, ensuring it met the required specifications for acoustic applications.

2.2 Design and Fabrication of Single Leaf Micro-Perforated Panel

These panels represent the most basic form of Micro-Perforated Panels (MPPs), consisting of a perforated plate with sub-millimetre pores and a thick rear wall, which creates an air gap between the perforated plate and the back wall. A schematic of single-leaf micro-perforated panel is shown below.

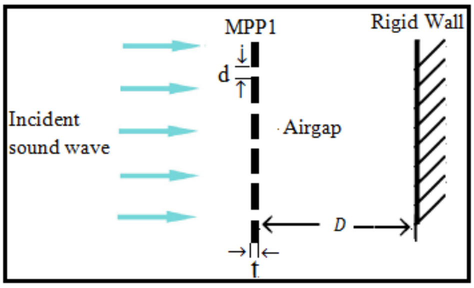

Figure 1. Schematic of a single-leaf Micro-Perforated Panel

Studies suggest that a 1% porosity ratio and 0.5 mm pore diameter are optimal for MPPs. Based on this, the panels in this study were designed with these parameters. Circular specimens of 3 cm and 10 cm diameters were prepared for sound absorption tests using an impedance tube. The study investigated three variables: perforated plate thickness (2, 4, 6, 8, and 10 mm), pore shape (circular, triangular, and square), and air gap. A schematic of the fabricated samples is provided below.

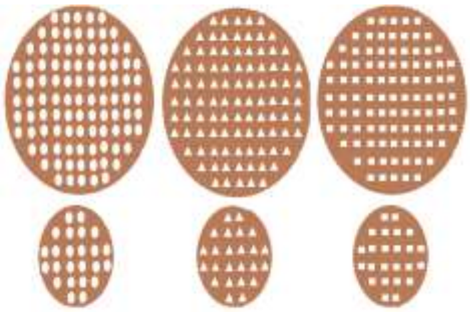

Figure 2. Schematic of microporous plates made with circular, triangular and square pores

The physical parameters of the perforated plate are detailed in Tables 1.

Table 1. Physical parameters of perforated plate

Sample group.	Radius of perforated plate (mm)	pore diameter (mm)	Pore shape	Thickness of perforated plate (mm)	Perforation ratio (%)
1	30	0.5	Circular triangular square	2, 4, 6, 8, 10	1
2	100	0.5	Circular triangular square	2, 4, 6, 8, 10	1

2.3 Micro-perforated panels backed by porous absorbent

This study examined the effect of incorporating wool waste composites (density: 150, thickness: 1–5 cm) on the sound absorption performance of MPPs. The schematic of a single-leaf MPP with sound-absorbing material in the air gap is shown below.

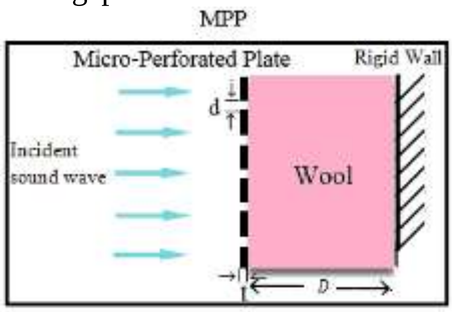

Figure 3. Schematic diagram of MPP with the sound-absorbing material (Wool) in the air gap

2.4 Measurement of SAC using impedance tube

The Sound Absorption Coefficient (SAC) was measured using an impedance tube device, adhering to ISO 10534-2 standards. A 10 cm diameter tube was used for low frequencies (100-1600 Hz), and a 3 cm diameter tube was used for high frequencies (1600-6300 Hz). The device components and sample positioning are shown in the figure.

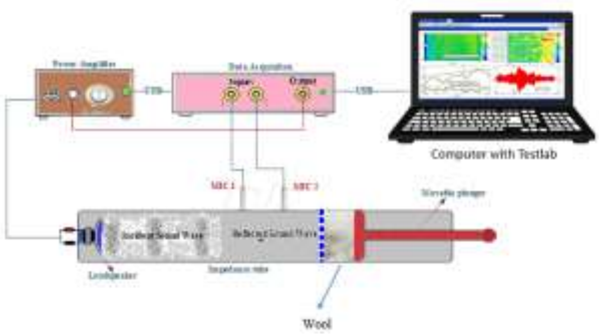

Figure 4. Diagram of measuring the sound absorption coefficient of MPP containing wool in the air gap.

Experiments for the low, mid, and high-frequency bands were conducted separately, and the average Sound Absorption Coefficient (SAC) was calculated for each frequency range.

3 Results

3.1 sound absorption coefficient of wool

The sound absorption coefficient analysis for 5 cm thick samples made from goat wool, sheep wool, and camel wool at different frequencies is shown in Figure …...

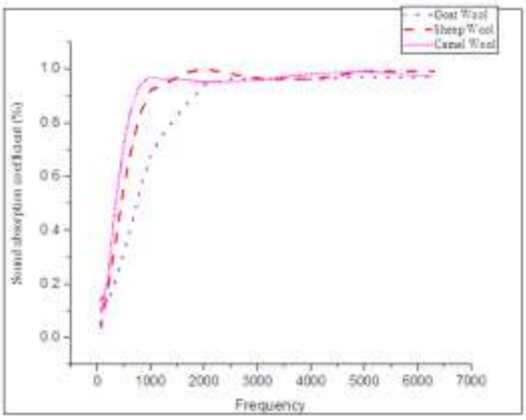

Figure 5. Sound Absorption Coefficient of Sheep, Camel, and Goat Wool at 5 cm Thickness

The study measured the sound absorption coefficients of animal fibers (goat, sheep, and camel wool) across frequencies from 63 to 6300 Hz. The results showed that the sound absorption of the samples increased with higher frequencies. The peak coefficients were 0.99 for goat wool at 5000-6300 Hz, 1.00 for sheep wool at 2000 Hz, and 0.99 for camel wool at 5000 Hz. Camel wool had the highest absorption at frequencies below 500 Hz, while goat wool had the lowest at conversational frequencies. Above 2000 Hz, all three fibers exhibited similar absorption coefficients.

3.2 sound absorption coefficient of MPP

3.2.1 Effect of Panel Thickness

Fig. 6 presents the effect of panel thickness on the SAC of MPP with the same cavity depth.

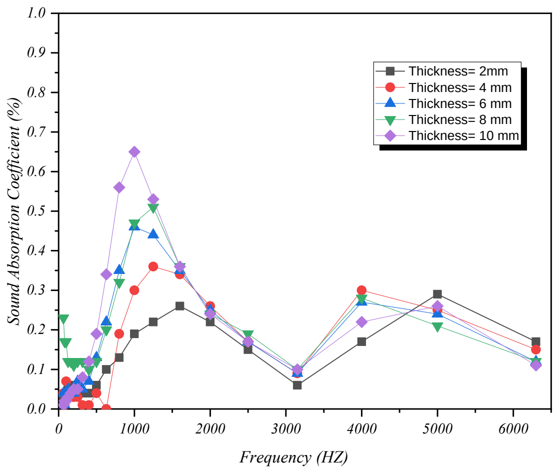

Figure 6. The sound absorption coefficient (SAC) for different panel thickness t with air cavity depth D=50 mm

The study found that as the thickness of the micro-perforated panels (MPPs) increased, the peak frequency shifted to lower frequencies, while the absorption bandwidth remained unchanged. This is because the increased thickness raises the acoustic mass of the MPPs without affecting their resistance. The stiffness of the resonator system stays the same, causing the peak frequency to shift lower. The results also showed that Plexiglass MPPs exhibited two peaks in sound absorption, with the highest absorption occurring between 800 and 1500 Hz. As the thickness increased, the absorption coefficient also increased, particularly at higher frequencies, while significant changes at lower frequencies required a greater thickness increase.

3.2.2 Effect of Pore Shape

The results of the sound insulation analysis of the MPP with a perforated plate having circular, triangular, and square-shaped holes are shown in Figure 9.

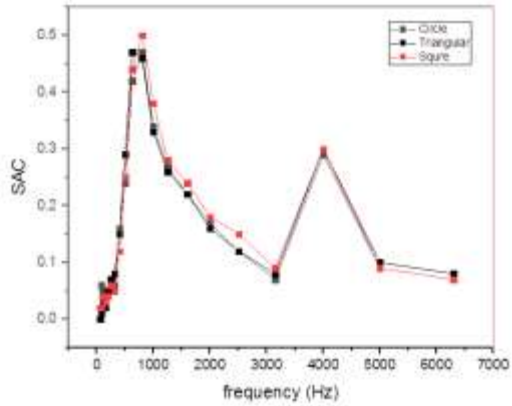

Figure 7. Effect of Pore Shape on sound absorption coefficient (SAC) of MPP

Figure 9 shows that the shape of the pores does not significantly affect the sound absorption coefficient (SAC), and porosity has no impact on the SAC.

3.2.3 Effect of wool waste composite in air gap

The normal sound absorption coefficient of the MPP backed by wool waste composite in different thicknesses was measured in an impedance tube in accordance with ISO 10354-2. The measured results are shown in fig 10.

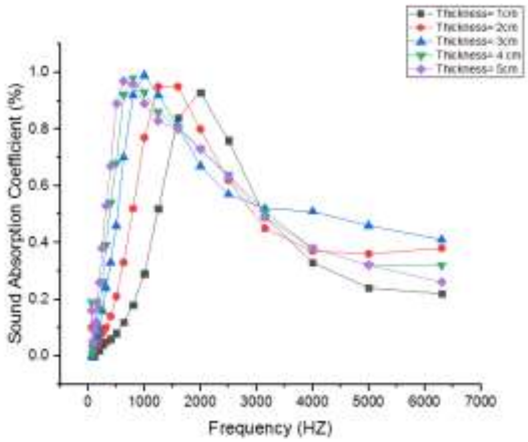

Figure 8. The effect of using camel wool (with a density of 75) in the air gap of microporous panels made of Plexiglas with a thickness of 10 mm

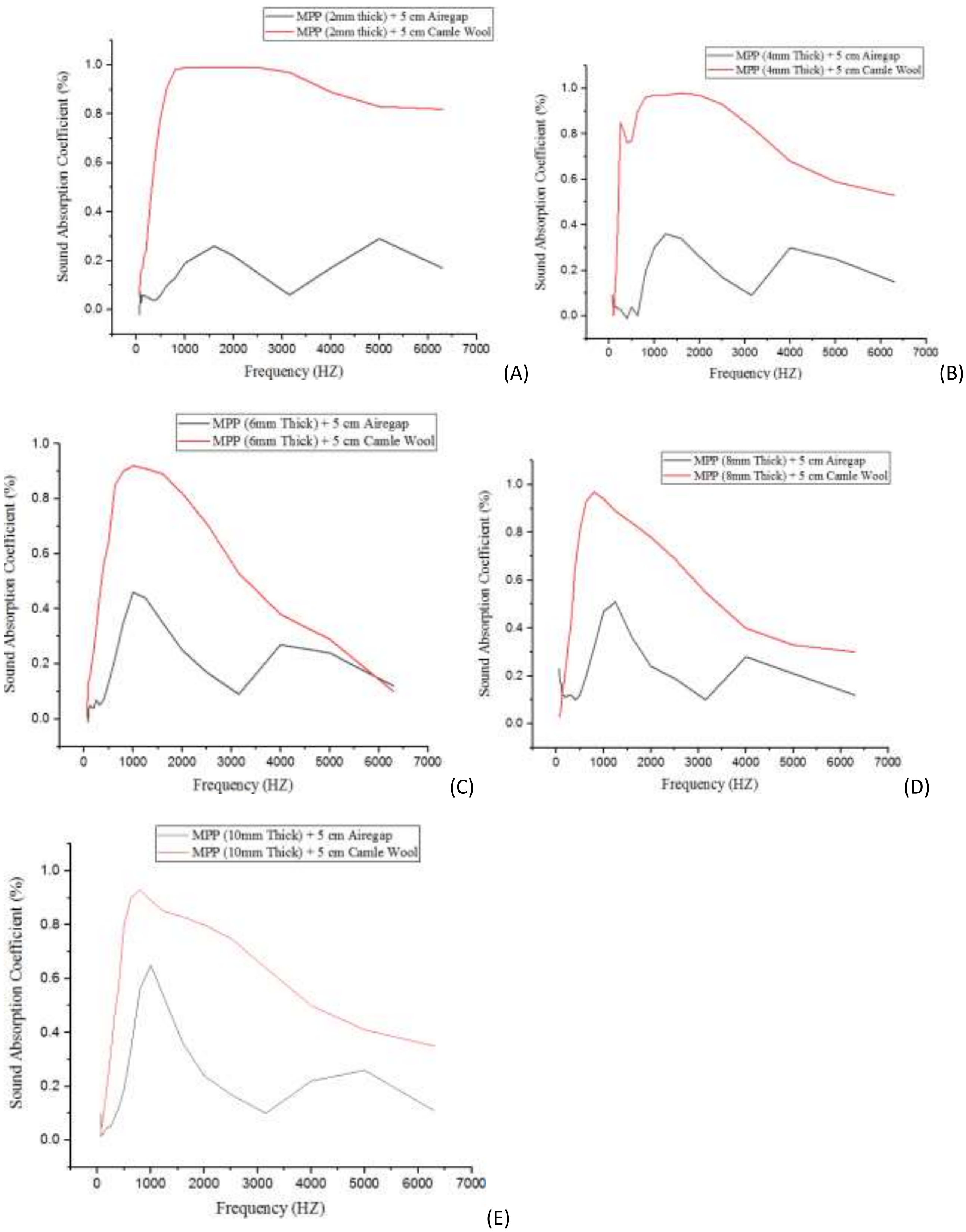

Figure 9. Result of the measured normal absorption coefficients of different thick MPP backed by wool waste composite in different thicknesses. All wool waste composite is 150 density and composite thicknesses are: A=2mm, B=4mm, C=6mm, D=8mm, E= 10m.

Fig. 11 shows that incorporating wool waste composite in the air gap shifts the peak frequency to lower values (3500 to 1500 Hz) as the panel thickness increases from 0 to 10 mm. However, this also leads to a decrease in the maximum absorption coefficient and absorption bandwidth.

4. Discussion

This study investigated the sound absorption coefficients of samples made from goat wool, sheep wool, and camel wool, measured across low (63-1600 Hz) and high (1600-6300 Hz) frequency ranges. The results showed that these natural fibers performed well, with goat wool achieving a peak SAC of 0.99 at 5000 and 6300 Hz, sheep wool at 2000 Hz (1.00), and camel wool at 5000 Hz (0.99). The absorption increased with frequency, demonstrating higher performance at mid to high frequencies. The combination of natural absorbers and Micro-Perforated Panels (MPPs) enhanced low-frequency absorption, with factors like material thickness, number of MPP layers, and choice of absorbers being key influences. Natural materials, unlike synthetic ones, offer advantages such as low cost, high availability, and reduced environmental impact. Previous studies have shown that wool can perform similarly to mineral wool and synthetic foams as sound absorbers. For MPPs, increasing thickness shifts the peak frequency to lower values, but it may reduce SAC at higher frequencies. For frequencies over 3000 Hz, MPPs are not recommended; instead, wool waste composites should be used for better performance. The study concludes that for optimal sound absorption across different frequency ranges, the choice of material and panel thickness should be carefully selected based on the desired SAC and bandwidth.

Conclusion

This study shows that Micro-Perforated Panels (MPPs) backed by wool composites perform well in absorbing low-frequency sounds (below 1000 Hz). The addition of wool enhances sound absorption at these frequencies, making wool-backed MPPs effective for controlling low-frequency noise. Increasing the thickness of the perforated plate shifts the peak absorption to lower frequencies. These panels are particularly useful in environments like recording studios and industrial settings where bass frequencies need to be controlled. Additionally, wool-backed MPPs offer an eco-friendly and sustainable acoustic solution, combining high performance with reduced environmental impact.

4. Acknowledgments:

This study is part of a Ph.D. dissertation (ethics code: IR.MODARES.REC.1398.115) registered at the Research Department of Medical Sciences, Tarbiat Modares University, Tehran, Iran. The authors thank the Deputy of Research and Technology at Tarbiat Modares University for providing the necessary laboratory facilities.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Data will not be shared because of Data confidentiality.

Conflict of interest

The authors report there are no competing interests to declare.

Funding

The Funding is provided by Gonabad University of Medical Sciences, Iran.

Authors' contributions

All of authors contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Reference:

1. D. K. Agarwalla, A. R. Mohanty. "Low-Frequency Wideband Sound Absorption Properties of Composite Layer Micro-perforated Panel Absorber." *Journal of Vibration Engineering & Technologies* 12, (4), 6251-6271 (2024)
2. M/Cingolani, F. Giulia, B. Luca, D. Dario, H. Brian, G. Massimo. "A trial acoustic improvement in a lecture Hall with MPP sound absorbers and FDTD acoustic simulations." *Applied Sciences* 11, . 6 (2021)
3. I. Prasetiyo, S. Indra, S. Joko, S. Anugrah. "Natural ventilation system with thin microperforated panel (MPP) component for wideband sound insulation." *Applied Acoustics* 210 (2023).
4. C. Li, L. Yang, L. Chunbo, W. Yang. "Noise reduction in helicopter cabins using microperforated panel composite sound absorption structures." *Applied Sciences* 13, no. 14 (2023)
5. E. Fasllija, Y. Semiha. "Investigating the potential of transparent parallel-arranged micro-perforated panels (MPPs) as sound absorbers in classrooms." *International Journal of Environmental Research and Public Health* 20, no. 2 (2023)
6. W. Lee, K. Jae-chul, m. Hee."Application of a micro-perforated panel absorber to reduce the curve squeal noise of railways." *Noise Control Engineering Journal* 69, no. 6 , 507-517. (2021)
7. L. Yuvaraj, S. Jeyanthi. "Acoustic performance of countersunk micro-perforated panel in multilayer porous material." *Building Acoustics* 27, no. 1. 3-20. (2020)
8. Z. Hashemi, A. Nasrin, M. Sadeghian, A. Putra, S. Ahmadi, M. Alidosti, M. J. SheikhMozafari. "Optimization and Comparative Analysis of micro-perforated panel sound absorbers: A study on structures and performance enhancement." *Measurement* 236 .115123. (2024):
9. W. Yang, C. Yatsze, L. Ying. "Acoustical performance of a wavy micro-perforated panel absorber." *Mechanical Systems and Signal Processing* 185. 109766. (2023):
10. T.Okuzono, K. Sakagami. "A finite-element formulation for room acoustics simulation with microperforated panel sound absorbing structures: Verification with electro-acoustical equivalent circuit theory and wave theory" *Appl. Acoust*. 95, 20–26 (2015). https://doi.org/10.1016/j.apacoust.2015.02.012
11. M. H. Beheshti, A. Khavanin, A. Safari Varyani, M. N. Bin Yahya, A. Alami, F. Khajenasiri, R.Talebitooti. "Improving the sound absorption of natural waste material-based sound absorbers using micro-perforated plates." *Journal of Natural Fibers* 19, no. 13. 5199-5210. (2022)
12. D. A. H. Maa, "Theory and design of microperforated panel sound-absorbing constructions." (1975).
13. K.Sakagami, T. Nakamori, M Morimoto, M.Yairi "Double-leaf microperforated panel space absorbers: A revised theory and detailed analysis". *Appl. Acoust*. 70, 703–709 (2009). https://doi.org/10.1016/j.apacoust.2008.09.004
14. X.d. Zhao, X. Wang, Y. Yu. " Enhancing low-frequency sound absorption of micro-perforated panel absorbers by combining parallel mechanical impedance". *Applied Acoustics*. 2018;130:300-4.

15. Z. Zhu, M. Lifeng, L. Chunxiao, X.Xiaolong, and Jiajia Hu. "Design and Optimization of One Special Microperforated Plate-Labyrinth Coupled Structure (MPPS-LS): From the View of Numerical Simulation." *International Journal of Acoustics & Vibration* 29, no. 2 (2024).
16. Chiang Y, Choy Y. Acoustic behaviors of the microperforated panel absorber array in nonlinear regime under moderate acoustic pressure excitation. The Journal of the Acoustical Society of America. 2018;143(1):538-49.
17. J. Carbajo, S-H. Nam, N. X. Fang. "Fabrication of Micro-Perforated Panel (MPP) sound absorbers using Digital Light Processing (DLP) 3D printing technology." Applied Acoustics 216 (2024): 109788.

18. Z. Liu, J. Zhan, M. Fard, JL. Davy. Acoustic properties of multilayer sound absorbers with a 3D printed micro-perforated panel. *Applied Acoustics*. 121:25-32. (2017)
19. C. Wang, L. Cheng, J. Pan, G. Yu. Sound absorption of a micro-perforated panel backed by an irregular-shaped cavity. *The Journal of the Acoustical Society of America*. 127(1):238-46. 2010
20. H-S. Kim, P-S. Ma, B-K. Kim, S-R. Kim, S-H. Lee. Low-frequency sound absorption of elastic micro-perforated plates in a parallel arrangement. *Journal of Sound and Vibration*. 460:114884.(2019)
21. E. Taban, A. Tajpoor, M. Faridan, S.E. Samaei, M.H. Beheshti. "Acoustic absorption characterization and prediction of natural coir fibers." *Acoustics Australia* 47. 67-77. (2019)
22. U. Berardi, G. Iannace. "Predicting the sound absorption of natural materials: Best-fit inverse laws for the acoustic impedance and the propagation constant". *Applied Acoustics*;115:131-8.(2017)
23. M.H. Beheshti, A. Firoozi, M. Jafarizaveh, A. Tabrizi. "Acoustical and Thermal Characterization of Insulating Materials Made from Wool and Sugarcane Bagasse." *Journal of Natural Fibers* 20, no. 2 . (2023):
24. J. Zach, A. Korjenic, V. Petránek, J. Hroudová, T. Bednar. "Performance evaluation and research of alternative thermal insulations based on sheep wool". *Energy and Buildings* 246..53- 49. (2012)
25. R. Del Rey, A. Uris, J. Alba, P. Candelas. "Characterization of sheep wool as a sustainable material for acoustic applications". *Materials*.;10(11).(2017)
26. D. Tămaş-Gavrea, T.Dénes . "Mechanical, Thermal and Acoustical Properties of an Innovative Lime-Wool Composite". *Procedia Manufacturing*. 402. (2020)