DOI: 10.61782/fa.2025.0268

DEMONSTRATING THE EFFECTIVENESS OF A MULTI-LAYER THIN MINERAL SOUND ABSORBER FOR COURTYARD NOISE REDUCTION

Bart Van Damme[1*] **Jean-Marc Wunderli**[1] **Liviu Zambila**[1]
Théo Cavalieri[1,2]
[1] Laboratory for Acoustics/Noise Control, Empa, Ueberlandstrasse 129, 8600 Dübendorf, Switzerland
[2] L-Acoustics, 13 rue Levacher Cintrat, 91460 Marcoussis, France

ABSTRACT

Reducing traffic noise in urban environments has a proven positive effect on the wellbeing. It is known that sound absorbing façades can improve the noise level in streets and courtyards, but practical large-scale surface treatments are scarce. Porous absorbers are typically bulky, and resonant absorbers too expensive for this kind of application. We have shown previously that perforated mineral foams (PMFs) yield high sound absorption levels over a relatively wide frequency range, while requiring only a fraction of the thickness of open-pore absorbers. In this work, a multi-layer PMF absorber is demonstrated. In a first step, the optimal configuration of four PMF layers with a total thickness of 55 mm is shown to yield high diffuse-field sound absorption in the 500-1000 Hz range. Based on this result, a 12 m^2 surface is manufactured and its absorption coefficient measured in a reverberation room. Finally, the demonstrator is tested in realistic conditions, and shows a significant reduction of broadband noise transmission through a courtyard entrance. The controlled measurements are supported by finite element simulations to improve their effectiveness by optimal placement considerations.

Keywords: *sound absorption, demonstrator, acoustic optimization*

**Corresponding author: bart.vandamme@empa.ch.*

1. INTRODUCTION

Acoustic absorbers are crucial in creating a pleasant environment. By reducing reflections and reverberation time, the overall noise level can be lowered, the intellegibility improved, or the musical quality enhanced [1]. Acoustic absorbers also play a crucial role in reducing engine, turbine, and ventilation noise. This paper presents a method to achieve high diffuse acoustic absorption in a chosen broad frequency range. Using an optimized layering of perforated mineral foams, the absorber can be devised considerably thinner than when conventional porous media are used. The effectiveness is illustrated with a large-scale demonstrator, designed to reduce street noise transmission through a courtyard entrance.

2. ACOUSTIC ABSORPTION BY PERFORATED FOAMS

2.1 Homogenization of the acoustic properties

The use of perforated rigid foams for low-frequency sound absorption was shown in previous studies [2, 3]. By combining foam properties (pore size and wall thickness) with an appropriate perforation pattern (diameter and spacing), the absorption spectrum can be tuned to a desired frequency range. The modelling is done in two steps. First, a numerical simulation of a representative volume element of the perforated foams allows us to calculate homogenized fluid properties, i.e. complex valued bulk modulus and mass density, based on the Johnson-Champoux-Allard description of viscous and thermal losses [4]. In a second step, a combination of the four foam parameters is chosen to achieve the desired absorption spectrum.

In our previous work, we showed that the tortuosity of such structures is considerably higher than for open-pore foams [3, 5]. However, high tortuosity typically comes at the cost of higher flow resistivity. Therefore, a compromise between absorption amplitude and the frequency of maximum absorption has to be found. It is practically possible to achieve absorption levels higher than 0.8 for a layer thickness equal to or smaller than 1/15 of the wavelength in air. This is similar to several advanced absorber designs based on coiled or resonant structures.

2.2 Optimization of layered sound absorbers

The homogenization step allows to generate a library of acoustic materials with various sound propagation properties. In collaboration with a foam manufacturing company, de Cavis AG, gypsum foams with pore sizes varying between 1 and 3 mm, and a constant wall thickness between 0.1 and 0.3 mm, can be reliably produced in batches of 1 m^3. Due to advanced stabilizers, a total porosity higher than 90% can be achieved, yielding a mass density below 150 kg/m^3 for the lightest materials. The foams are cut to the desired thickness, and can be perforated by needle punching or water jet cutting.

It is known that layered sound absorbers can outperform homogeneous porous media in terms of thickness and band width [6,7]. For our application, we aim for high sound absorption in the range between 400 and 1000 Hz. To achieve this, we can use three foam types, combined with several perforation patterns. The perforations can be either 0.5 or 1 mm in diameter, and 5 or 10 mm apart in a rectangular pattern. In total, ten combinations have desirable acoustic properties and are considered useful for the absorber design.

The optimization process aims to achieve a minimal absorption level within prescribed frequency bounds, by finding a suitable stack of materials with optimized thickness and order. Limitations such as total thickness, minimal layer thickness, and maximum amount of layers can be easily introduced. The absorption of the rigidly backed stack is calculated by a transfer matrix approach, and the optimization is done by a particle swarm optimization. To further improve the design space, air is allowed as one of the layers.

3. LARGE ABSORBER DEMONSTRATOR

3.1 Optimized absorber layout and construction

For a practical implementation, we aim for absorption levels higher than 0.8 starting at 400 Hz and up to 1000 Hz. The absorber stack should not be thicker than 55 mm, which is thinner than 1/15 of a wave length in air and thus considerably thinner than traditional porous absorbers. In order to reduce fragility, the layers should not be thinner than 10 mm and the amount of layers cannot be higher than 4.

Figure 1. Top: layered setup of the opimized absorber panel. Bottom: Placement of the absorber panels in the courtyard entrance.

Several combination of layers yield a suitable absorption spectrum, and further practical considerations can be taken into account for the final choice. In this case, it turns out that only one foam type is necessary: a lightweight gypsum foam with 3 mm pore size and 0.1 mm wall thickness. Combining one type of perforated and one non-perforated layer, in which case only the inherent microporosity is considered, the prescribed absorption can be achieved. The layers are cut to size and placed in wooden frames for easy transportation and placement. In total, 72 panels of 40×40 cm^2 are made, yielding a 12 m^2 surface. Each panel weighs less than 1.5 kg and has a total thickness of 57 mm, making it ideal for treating walls without increasing the demands on bearing capacity, or taking too much space. the structure of the panels is shown in Fig. 1.

3.2 Reverberation room measurement

In order to validate the optimization and the models, the diffuse sound absorption is measured according to EN ISO 354. The entire sample is placed on the floor of a reverberation room, including the beams that will be used for installation in situ (see Fig. 2). This slightly increases the total surface, and therefore reduces the diffuse absorption coefficient. Despite this small difference, it can be seen in Fig. 2 that the absorption reaches a peak value of 1.1 at 400 Hz. At frequencies higher than 1200 Hz the absorption is reduced, since the stack was not optimized in this range. This is however not necessarily negative. In many real situation, the higher frequency range is sufficiently absorbed by other effects, and additional absorption might reduce intellegibility and could make the room sound too dry.

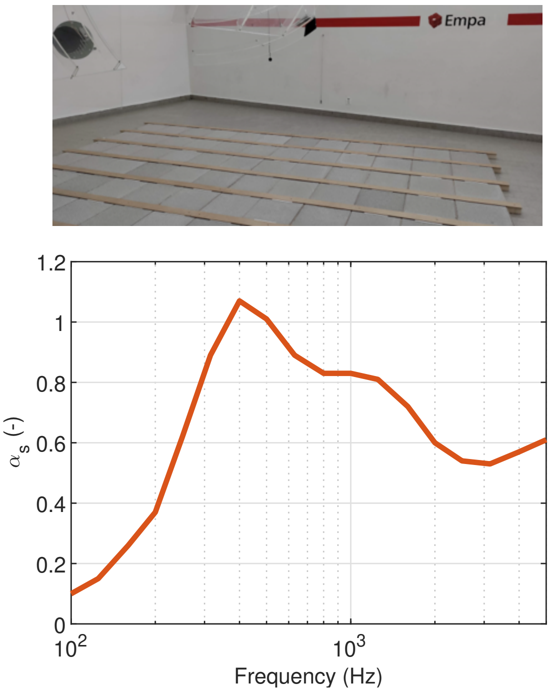

Figure 2. Diffuse absorption coefficient measurement according to EN ISO 354. Top: experimental setup in the Empa reverberation room. Bottom: measured absorption curve.

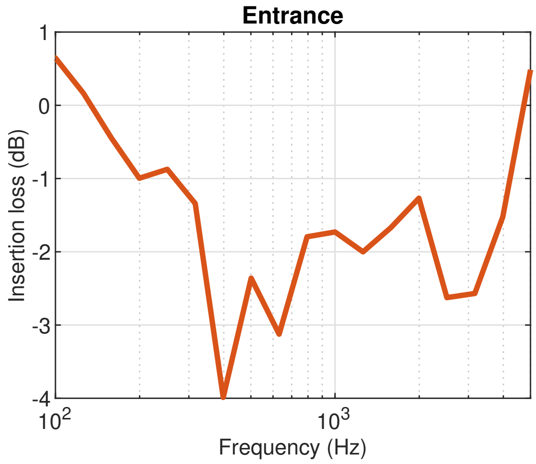

Figure 3. Measured insertion loss comparing the sound transmission through the entrance with and without absorber panels.

3.3 Noise transmission reduction in a courtyard entrance

The efficiency of the absorber panels to reduce street noise transmission is tested in a passage to a courtyard with dimensions $3 \times 3 \times 12$ m^3. The panels are placed on both side walls in a symmetric way, close to the street side entrance, in a 3×12 panel arrangement. This way, 1.2×4.8 m^2 of each wall is covered, which is around 1/6 of the walls' surface. The final setup is shown in the bottom image of Fig. 1.

Pink noise is generated by an omnidirectional loudspeaker, placed 3 m away from the entrance, and measured by microphones placed at the entrance and exit of the passage. To mimic a car pass-by, the loudspeaker is moved parallel to the street, starting in the middle of the passage and spanning 6 positions with 0.5 m steps. The sound transmission loss is calculated as the transfer function between the entrance and exit in third octave bands for each loudspeaker position, for the situation with and without absorbing panels. Finally, the insertion loss is calculated as the difference between the situations with and without absorbers of the mean SPL.

The correlation between the insertion loss and the diffuse sound absorption spectrum is clearly seen in Fig. 3. At the frequency of maximum absorption, an insertion loss of 4 dB can be measured. At very low (¡200 Hz) and at very high (¿4000 Hz) frequencies, the insertion loss is minimal.

4. CONCLUSION

Layered sound absorbers consisting of perforated mineral foams can be optimized to achieve broadband high absorption, while only needing a fraction of the thickness of conventional porous absorbers. Since the base material is a mineral foam, their application is similar to standard absorbing materials, and they can be fabricated in bulk. Moreover, mineral foams offer unique properties, e.g. external use (in case of cement foams), or high-temperature environments (in case of ceramic foams). A large demonstrator of 12 m^2 allowed us to confirm the validity of the optimization by standardized absorption testing. Moreover, it was possible to measure a 4 dB sound transmission reduction in realistic conditions, showing that effective acoustic treatments can be realized with thin structures.

5. ACKNOWLEDGMENTS

This work was funded by Innosuisse project IP-EE 56633.1 and by the City of Zurich, Environmental and Health Protection Department. We gratefully acknowledge the support of de Cavis AG.

6. REFERENCES

[1] T. Cox and P. d'Antonio, *Acoustic absorbers and diffusers: theory, design and application*. CRC press, 2016.

[2] F. Chevillotte, C. Perrot, and R. Panneton, "Microstructure based model for sound absorption predictions of perforated closed-cell metallic foams," *The Journal of the Acoustical Society of America*, vol. 128, no. 4, pp. 1766–1776, 2010.

[3] B. Van Damme, T. Cavalieri, C.-T. Nguyen, and C. Perrot, "Enhancement of the sound absorption of closed-cell mineral foams by perforations: Manufacturing process and model-supported adaptation," *Materials & Design*, vol. 249, p. 113540, 2025.

[4] C. Perrot, R. Panneton, and X. Olny, "Linking microstructure and acoustic properties of open-cell foams," *The Journal of the Acoustical Society of America*, vol. 120, no. 5_Supplement, pp. 3145–3145, 2006.

[5] T. Cavalieri and B. Van Damme, "Sound pressure-dependent acoustic absorption by perforated rigid-frame porous materials," *Acta Acustica*, vol. 8, p. 79, 2024.

[6] M. D. Guild, V. M. García-Chocano, W. Kan, and J. Sánchez-Dehesa, "Acoustic metamaterial absorbers based on multilayered sonic crystals," *Journal of Applied Physics*, vol. 117, no. 11, 2015.

[7] J. Boulvert, T. Cavalieri, J. Costa-Baptista, L. Schwan, V. Romero-García, G. Gabard, E. R. Fotsing, A. Ross, J. Mardjono, and J.-P. Groby, "Optimally graded porous material for broadband perfect absorption of sound," *Journal of Applied Physics*, vol. 126, no. 17, 2019.