Acoustic absorption properties of perforated gypsum foams

Bart Van Damme, Aurèle Goetz, Gwenael Hannema, Armin Zemp, Cong Truc Nguyen, Camille Perrot

ACOUSTIC ABSORPTION PROPERTIES OF PERFORATED GYPSUM FOAMS

Bart Van Damme[1] **Aurèle Goetz**[1] **Gwenael Hannema**[1]
Armin Zemp[1] **Cong Truc Nguyen**[2] **Camille Perrot**[2]
[1] Laboratory for Acoustics/Noise Control, Empa, Switzerland
[2] Univ Gustave Eiffel, CNRS UMR 8208, Univ Paris Est Creteil, F-77454 Marne-la-Vallée, France

ABSTRACT

Mineral foams with high porosity, large cells and thin cell walls are perforated to achieve high sound absorption. Impedance tube measurements show that a thin layer of the perforated foam can reach an absorption coefficient higher than 90% for frequencies below 1000 Hz. Numerical models, leading to the identification of the JCAL homogenized properties, confirm and accurately predict the functionality. Differing the perforation diameter and distance effectively changes the absorptive properties over a wide range, which can lead to practical applications.

1. MATERIAL PROPERTIES AND SAMPLE PREPARATION

Mineral foams with a gypsum of cement matrix can be manufactured in large volumes with accurate control over the porosity and cell size, much like standard synthetic foams. Their unique features are a high temperature resistance, and the rigidity of the cell walls. The gypsum foam manufactured by DeCavis (https://decavis.com/) has a total porosity of up to 97%, with a mainly closed cell configuration. Cell sizes up to 5 mm and a wall thickness around 0.1 mm are available as shown in Fig. 1(a). Due to the closed pore structure, the raw material has a low acoustic absorption coefficient, the inherent microporosity is responsible for values up to 25% at 1600 Hz.

It has been reported that perforated closed-cell foams can be used as efficient acoustic absorbers [1]. For this purpose, microperforations were made by needles of 0.25 mm and 0.45 mm through a material sample with thickness 25 mm. The distance between two perforations is 10 mm, in a square pattern. The same samples are then perforated again leading to a pattern with 5 mm distance. This leads to 4 different samples, on top of the 2 unperforated ones.

The quality of the perforations can be inspected from scanning electron microscope images as shown in Fig. 1(b). The perforations are not perfectly circular due to the brittleness of the walls, and there are deviations to a perfectly square pattern.

2. IMPEDANCE TUBE MEASUREMENTS

The absorption coefficients of all samples were measured in an impedance tube (Brüel & Kjaer type 4206) of 100 mm diameter according to standard ISO 10534-2. The foam samples were cast in a solid gypsum ring which was sealed to the impedance tube by means of vaseline to avoid leakage.

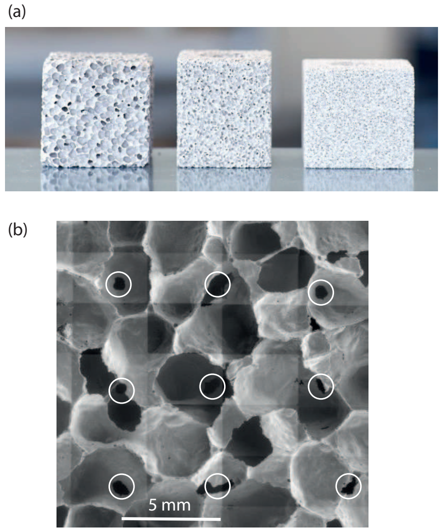

Figure 1. Gypsum foam samples with varying porosities (a) and scanning electron microscope image of perforated foam surface (b). The white circles show the positions of 9 perforations in a 5 mm grid.

The results are presented in Fig. 2. As expected, the perforated samples show a peak of high acoustic absorption at fairly low frequencies, after which the absorption coefficient drops again. The 0.25 mm perforations lead to higher absorption values than the 0.45 mm samples. A higher perforation rate increases the absorption coefficient, but the central frequency shifts to higher values.

3. NUMERICAL DETERMINATION OF THE JCAL PARAMETERS

The acoustic properties (impedance, sound speed, wave number) of porous and perforated media can be described by means of an equivalent fluid with frequency-dependent, complex material properties. The viscous and thermal losses that are responsible for sound absorption can be described by a set of non-acoustic parameters for use in a series of models with various levels of complexity. Most fibrous materials only require one single value to predict its acoustic behavior over the entire frequency range: the

10.48465/fa.2020.0445

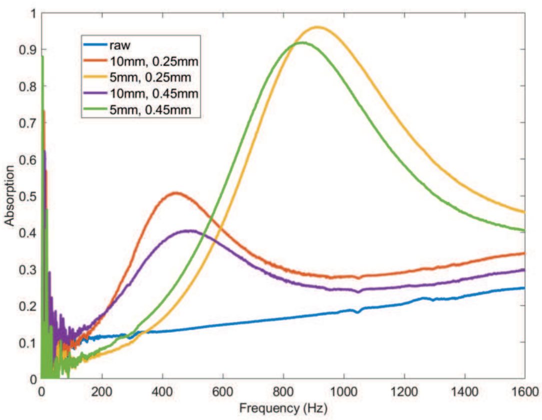

Figure 2. Absorption coefficient of 25 mm thick perforated gypsum foam samples with different perforation patterns.

flow resistivity. Porous materials with intricate paths of sound propagation and a large range of geometric scales affecting the overall behavior demand up to 6 parameters to achieve good agreement between model and reality. An advanced model is the one by Johnson-Champoux-Allard-Lafarge (JCAL) [2].

Estimated JCAL input parameters (open porosity, flow resistivity, high-frequency tortuosity, thermal and viscous lengths, and thermal permeability) can be measured for existing materials. However, they also offer the possibility to predict properties of engineered materials. In this case, the free choice of the perforation pattern introduces a certain tunability of the absorption. Perforating and experimentally investigating many samples would be too time consuming and expensive, and only offers limited insight in the underlying processes. A numerical predictive model allows us to investigate many more cases.

A validated scheme to retrieve these parameters numerically has been presented in [3, 4]. The complex cell structure can be replaced by a periodic packing of Kelvin cells, using the averaged cell size and wall thickness of the material. The numerical model can then be constructed on a unit cell, which reduces the calculation time significantly. Three different models are necessary: viscous static flow to predict the flow resistivity, an electric conduction equivalent of inviscid flow for tortuosity and viscous length, and a thermal diffusion model for thermal permeability. The two remaining parameters can be derived from the geometry and require no numerical models.

4. CONCLUSION

Thanks to the advantageous geometrical properties of mineral foams (large cells and thin cell walls), microperforated samples show very high sound absorption for thin layers. The absorbed frequencies are much lower than for commercially available open-cell synthetic foams with the same thickness. Numerical models can assist to define a well chosen perforation pattern in order to tune the acoustic properties of the material.

(a)

(b)

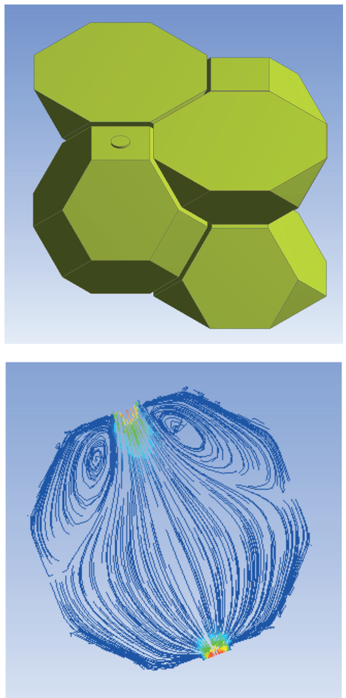

Figure 3. Modeled air cavities in an assembly of Kelvin cells with an inner diameter of 3 mm and showing a perforation with diameter 0.4 mm (a). Air flow lines due to a pressure difference between inlet and outlet to determine the flow resistivity (b).

5. ACKNOWLEDGMENTS

The short term scientific mission at the basis of the collaboration was funded by COST Action DENORMS (CA 15125). The materials were manufactured and provided by DeCavis.

6. REFERENCES

[1] 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.

[2] J. Allard and N. Atalla, *Propagation of sound in porous media: modelling sound absorbing materials 2e*. John Wiley & Sons, 2009.

[3] C. Perrot, F. Chevillotte, and R. Panneton, "Bottom-up approach for microstructure optimization of sound absorbing materials," *The Journal of the Acoustical Society of America*, vol. 124, no. 2, pp. 940–948, 2008.

[4] C. Perrot, F. Chevillotte, M. Tan Hoang, G. Bonnet, F.-X. Bécot, L. Gautron, and A. Duval, "Microstructure, transport, and acoustic properties of open-cell foam samples: Experiments and three-dimensional numerical simulations," *Journal of Applied Physics*, vol. 111, no. 1, p. 014911, 2012.