3D printed folded porous material for sub-wavelength absorption of sound

J. Boulvert[1,2,3], J. Costa-Baptista[2], E. R. Fotsing[2], T. Cavalieri[1,3], V. Romero-García[1], G. Gabard[1], A. Ross[2], J. Mardjono[3] and J.-P. Groby[2]

[1] Laboratoire d'Acoustique de l'Université du Mans, LAUM - UMR CNRS 6613, Le Mans Université, Avenue Olivier Messiaen, 72085 Le Mans Cedex 9, France
[2] Laboratoire d'Analyse Vibratoire et Acoustique, LAVA, Mechanical engineering, Polytechnique Montréal, Montréal, Québec, Canada
[3] Safran Aircraft Engines, Villaroche, Rond Point René Ravaud - Réau, 77550 Moisy-Cramayel Cedex,France

Open-cell acoustic materials are widely employed for broadband noise absorption of medium and high frequencies. However, due to their intrinsic loss mechanisms, porous materials suffer from a lack of efficiency in their sub-wavelength regime defined by $\lambda < 4L$ *where* λ *is the wavelength in air and* L *the thickness of the treatment. A slab of porous material presents low absorption below its so called "quarter wavelength resonance frequency", which is related to the thickness of the slab. Increasing the thickness of a porous treatment can enhance its low frequencies absorption but makes it bulkier and heavier which is problematic in many practical applications. In this work, a metaporous surface is introduced. Its is a treatment made of folded porous materials having an acoustic effective thickness greater than the thickness of the treatment itself. The metaporous surface is optimized, 3D printed and tested experimentally. The mean value of the measured absorption coefficient is 0.98 for frequencies corresponding to a wavelength in air* λ *such that* $5.3L < \lambda < 9.9L$*, where* L *is the thickness of the treatment.*

1 Presentation of the Metaporous Surface

A metaporous surface (MpS) composed of folded porous materials (FPMs) is designed, optimized for sub-wavelength and broadband absorption of sound, and tested experimentally as reported in [1].

A MpS usually consists in inclusions embedded in a porous material slab [3]. The inclusions increase the density of state in the sub-wavelength regime of the porous slab. The opposite approach is used in this work: folded quarter wavelength resonators are filled by a porous material. The FPMs consist in cavities folded in helical shape and filled with a structured porous medium. Folded cavities have an higher acoustic effective thickness than their actual height. A parallel assembly of several FPMs, each one tuned at a distinct frequency, generates the MpS, see Fig. 1(a).

2 Modeling and optimization

The normal incidence acoustic behavior of the treatment is predicted analytically by a mode matching model [2] and numerically by a Finite Element Method (FEM) model. The mode matching model is used during the treatment optimization and is coupled to a Nelder-Mead optimization algorithm [4] while the FEM model confirms the validity of the analytic predictions.

The effective thickness and the intrinsic losses of the MpS are controlled separately by tunning the pitch of the cavities and the pore size of the filling porous medium. The optimization of the pitch and of the pore size enables to achieve perfect absorption at frequencies much lower than the quarter wavelength frequency of the treatment.

3 Results

A 30 mm thick MpS is optimized to maximize its absorption coefficient in normal incidence and with a rigid backing in $[1150; 2000]$ Hz. It is 3D printed by means of Fused Deposition Modeling technique and tested in an impedance tube. The corresponding absorption coefficients computed analytically and

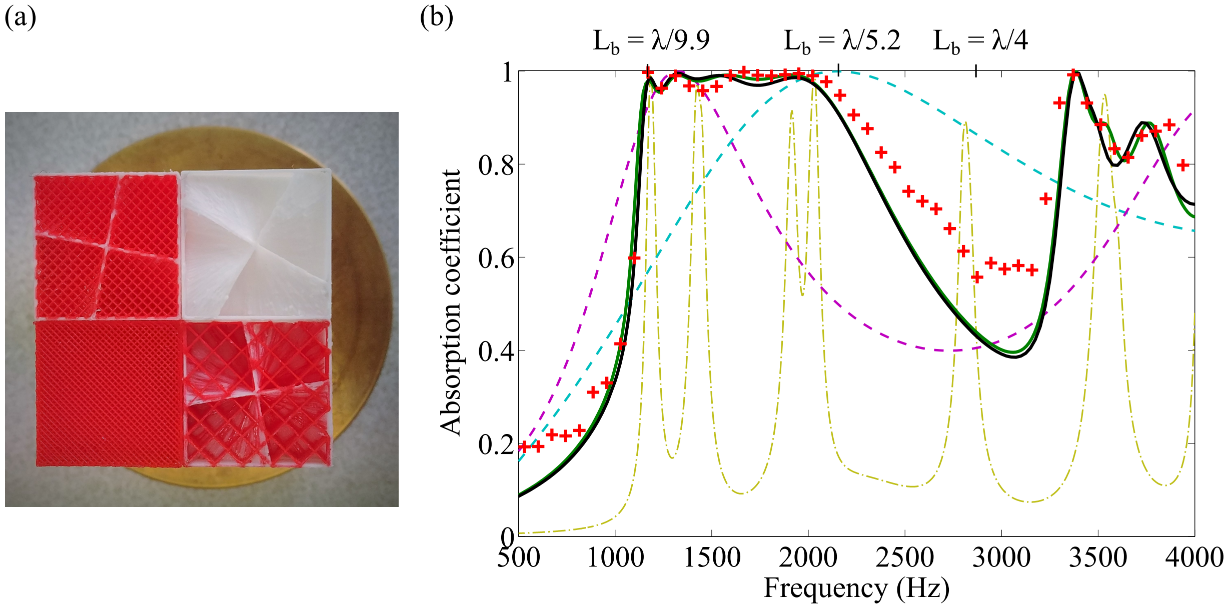

Figure 1: (a) Picture of optimized and 3D printed MpS placed on the rigid termination of the impedance tube.
(b) Absorption coefficient of $L_b = 30$ mm thick materials in normal incidence with rigid backing. Critically coupled: homogeneous porous material (dashed blue line) and single FPM (dashed purple line). Simulation of the optimized MpS: analytical model (solid green line), FEM model (solid black line). Measurement of optimized MpS (red crosses). Analytical simulation of the optimized MpS replacing the porous material by air (dash-doted green line).

numerically and measured experimentally are presented in Fig. 1(b). Simultaneous sub-wavelength and large band absorption are observed: the mean value of the measured absorption coefficient is 0.98 for frequencies corresponding to a wavelength in air λ such that $5.3L < \lambda < 9.9L$, where L is the thickness of the treatment.

Comparison of the MpS absorption to that of (1) straight porous material (blue dashed line), (2) single FpM (purple dashed line) and (3) MpS replacing the filling porous medium by air (yellow dashed line) highlights that (1) folding the cavities allows to reach perfect absorption at lower frequencies, (2) that combining several FpMs tuned at different frequencies allows to broaden the absorption plateau and (3) that the filling porous material controls the losses of the folded cavities leading to the critical coupling condition [5] and decreases the modes quality factor.

References

[1] J. Boulvert, J. Costa-Baptista, T. Cavalieri, V. Romero-García, G. Gabard, E. R. Fotsing, A. Ross, M. Perna, J. Mardjono, and J.-P. Groby. Folded metaporous material for sub-wavelength and broadband perfect sound absorption. *Applied Physics Letters*, 117(25):251902, December 2020.

[2] J.-P. Groby, W. Lauriks, and T. E. Vigran. Total absorption peak by use of a rigid frame porous layer backed by a rigid multi-irregularities grating. *The Journal of the Acoustical Society of America*, 127(5):2865–2874, May 2010.

[3] L. Lagarrigue, J.-P. Groby, V. Tournat, O. Dazel, and B. Nennig. Acoustic panel.

[4] J. A. Nelder and R. Mead. A Simplex Method for Function Minimization. *The Computer Journal*, 7(4):308–313, January 1965.

[5] V. Romero-García, G. Theocharis, O. Richoux, and V. Pagneux. Use of complex frequency plane to design broadband and sub-wavelength absorbers. *The Journal of the Acoustical Society of America*, 139(6):3395–3403, June 2016.