Impedance-tube characterisation of additively manufactured slitted sound absorbers

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An acoustical characterisation of additively manufactured rigid slitted structures is considered. A set of six JCAL microstructural parameters is deduced from dynamic density and bulk modulus obtained from normal incidence surface acoustic impedance experimental data. The results show that the characteristic lengths are the most difficult to characterise.

1 Introduction

Sufficiently dense simple slitted structures have a tendency to absorb sound as efficiently as more sophisticated porous materials [1, 2]. The normal incidence sound absorption coefficient pertinent to several additively manufactured (i.e. 3D printed) slitted samples was studied in [3]. Rather poor agreement between predictions and measurement data was observed when slits were perforated in the direction perpendicular to the sample axis. To identify possible sources of discrepancies, experimental complex density, $\varrho_{\mathrm{eq}}(\omega)$, and bulk modulus, $K_{\mathrm{eq}}(\omega)$, are calculated and investigated ($\omega \equiv 2\pi f$, f is the temporal frequency). An acoustical characterisation of *six* Johnson-Champoux-Allard-Lafarge (JCAL) parameters that is based on $\varrho_{\mathrm{eq}}(\omega)$ and $K_{\mathrm{eq}}(\omega)$ is performed. The estimated parameters are: the open porosity, ϕ, (static) viscous permeability, k_0, (static) thermal permeability, k_0', (inertial) tortuosity, α_∞, and two characteristic lengths: viscous, Λ, and thermal, Λ'.

2 Slitted geometries

Two microstructures with parallel straight slits of width 0.3 mm normal to the incident surface and separated from each other by 0.4-mm thick solid strips were designed and 3D printed: a configuration with and without a periodic cylindrical perforation of diameter 2 mm and period 4.95 mm, perpendicular to the slit plane (see pictures in Figures 1b and 1c). The non-perforated sample was manufactured in the Fused Deposition Modelling technology, whereas the perforated one was produced from a cured resin in the UV LCD technology. Both samples had diameter of 29 mm and height of 49.5 mm.

3 Results of acoustical characterisation

A procedure to evaluate complex density and bulk modulus functions based on impedance-tube measurements, known as the two-cavity method, was proposed in 1989 [4]. According to it, $\varrho_{\mathrm{eq}}(\omega)$ and $K_{\mathrm{eq}}(\omega)$ are uniquely related to the normal incidence surface acoustic impedances obtained for a sample with two distinct air cavities behind. Knowing the sample height (i.e. material thickness) and some air properties, one computes $\varrho_{\mathrm{eq}}(\omega)$ and $K_{\mathrm{eq}}(\omega)$ that serve as an input for acoustical characterisation. The set of six geometrical parameters governing visco-inertial as well as thermal dissipation of sound waves in porous media described by the JCAL model is determined following References [5, 6, 7].

Table 1 shows the JCAL parameters characterised using the method described above (with air cavities of 20 mm and 40 mm, and 110 mm and 130 mm for the slitted sample with and without perforation, respectively), and computed on idealised cells representative for the two studied microgeometries by performing Stokes, Laplace and Poisson finite element analyses (see [3]). The corresponding normalised complex density and bulk modulus functions are plotted in Figure 1.

In both cases, there is a qualitative agreement between the numerically predicted, characterised, and experimental $\varrho_{\mathrm{eq}}(\omega)$ and $K_{\mathrm{eq}}(\omega)$. However, the discrepancy in the obtained model parameters, especially in Λ and Λ', suggests the difficulty of the approach in precise determination of true geometrical features of additively manufactured porous materials.

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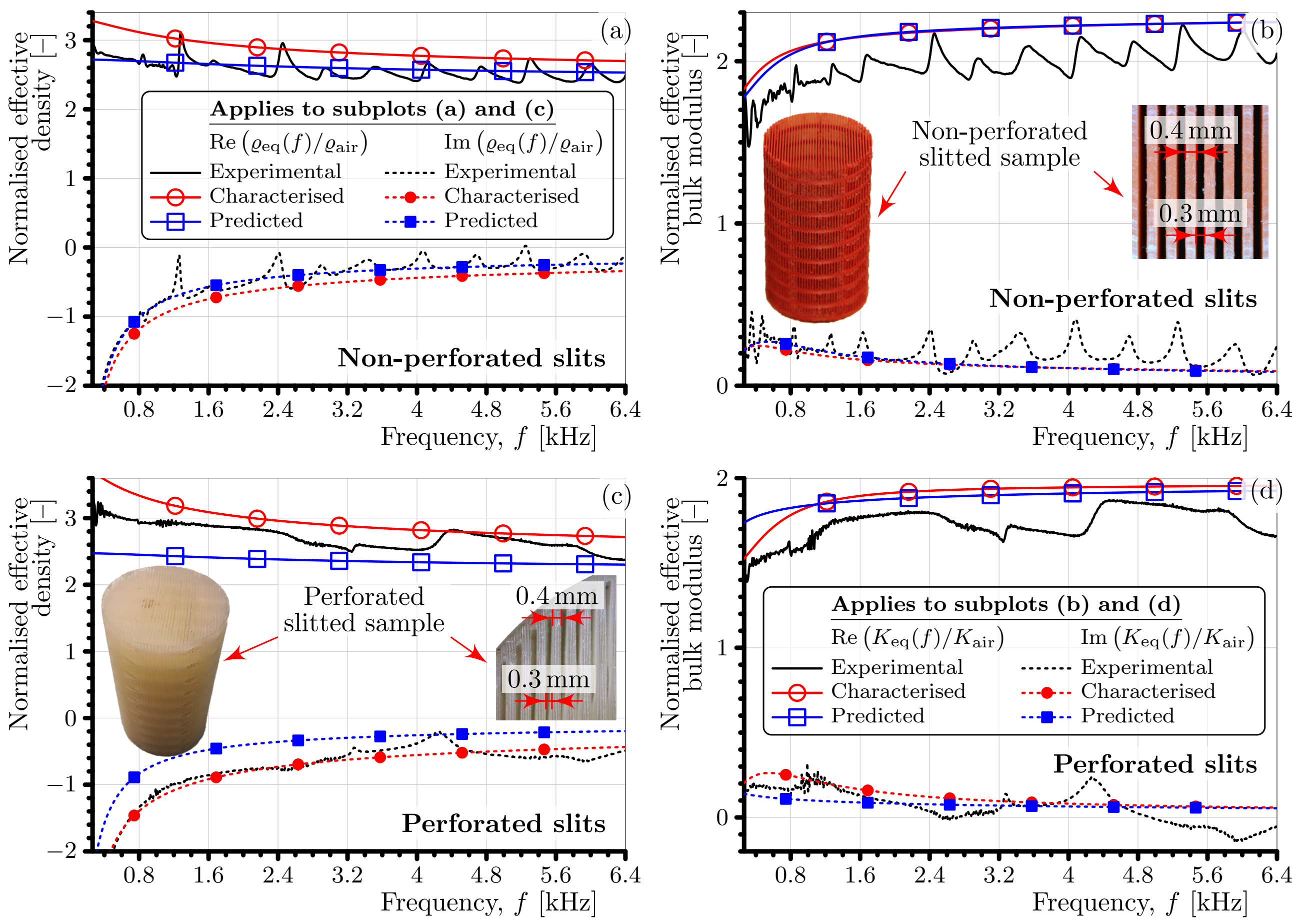

Figure 1: Normalised effective mass density (a,c) and bulk modulus (b,d) for the slitted structure without (a,b) and with (c,d) the cylindrical perforation. In the legends, ϱ_{air} is the mass density of air, and K_{air} denotes the bulk modulus of air.

	Geometrical parameters					
Geometry, case	ϕ [–]	k_0 $[10^{-9}\,\mathrm{m}^2]$	k_0' $[10^{-9}\,\mathrm{m}^2]$	α_∞ [–]	Λ [mm]	Λ' [mm]
Non-perforated, computed	0.4286	3.214	3.214	1.000	0.3000	0.3000
Non-perforated, characterised	0.4250	3.350	3.800	1.010	0.2000	0.2600
Perforated, computed	0.5018	3.915	20.65	1.070	0.3218	0.3806
Perforated, characterised	0.5000	3.311	4.000	1.150	0.1500	0.5000

Table 1: Computed and characterised geometrical model parameters.

References

[1] K. Attenborough, *Microstructures for lowering the quarter wavelength resonance frequency of a hard-backed rigid-porous layer*, Appl. Acoust., 130 (2018), pp. 188–194.

[2] K. Attenborough, *Macro- and micro-structure designs for porous sound absorbers*, Appl. Acoust., 145 (2019), pp. 349–357.

[3] K. C. Opiela, T. G. Zieliński, and K. Attenborough, *Manufacturing, modeling, and experimental verification of slitted sound absorbers*, in Proc. of ISMA2020 International Conference on Noise and Vibration Engineering/USD2020 International Conference on Uncertainty in Structural Dynamics, W. Desmet, B. Pluymers, D. Moens, and S. Vandemaele, eds., KU Leuven, Belgium, 2020, pp. 409–420.

[4] H. Utsuno, T. Tanaka, T. Fujikawa, and A. F. Seybert, *Transfer function method for measuring characteristic impedance and propagation constant of porous materials*, J. Acoust. Soc. Am., 86 (1989), pp. 637–643.

[5] L. Jaouen, E. Gourdon, and P. Glé, *Estimation of all six parameters of Johnson-Champoux-Allard-Lafarge model for acoustical porous materials from impedance tube measurements*, J. Acoust. Soc. Am., 148 (2020), pp. 1998–2005.

[6] X. Olny and R. Panneton, *Acoustical determination of the parameters governing thermal dissipation in porous media*, J. Acoust. Soc. Am., 123 (2008), pp. 814–824.

[7] R. Panneton and X. Olny, *Acoustical determination of the parameters governing viscous dissipation in porous media*, J. Acoust. Soc. Am., 119 (2006), pp. 2027–2040.