Book of Abstracts
of the 38th Solid Mechanics Conference
Warsaw, Poland, August 27–31, 2012

Edited by:

Ryszard Pęcherski
Jerzy Rojek
Piotr Kowalczyk

Institute of Fundamental Technological Research (IPPT)
Polish Academy of Sciences

CONCURRENCE OF THE MICRO-SCALE CALCULATION AND INVERSE IDENTIFICATION OF PARAMETERS USED FOR MODELLING ACOUSTICS OF POROUS MEDIA

T. G. Zieliński
Institute of Fundamental Technological Research, Warsaw, Poland

1. Introduction

There are several widely-used acoustic models of porous media, starting from that simple, purely phenomenological, model proposed by Delany and Bazely, and finishing with semi-phenomenological propositions of Johnson et al., combined with the ones of Champoux and Allard, with some important variations proposed by Pride, Lafarge, and others [1]. All these models use some average macroscopic parameters, namely: the total porosity and flow resistivity (or permeability) – for the Delany-Bazely model – which are supplemented by the average tortuosity of pores and their characteristic dimensions – in the case of more advanced semi-phenomenological models. These models allow to describe the acoustic wave propagation in porous media in a wide frequency range, provided that the skeleton is rigid. However, using some formulas derived for these models with the Biot's theory of poroelasticity permits to describe correctly sound propagation in soft porous materials. Thus, the determination of the above-mentioned parameters is very important. For direct, experimental measurements specialistic equipment is required, different for various parameters. Therefore, an inverse identification based on curves of, for example, acoustic impedance or absorption (measured for samples of known thickness) can be used to estimate the model parameters. In this work, it will be shown that knowledge of micro-structural geometry of porous medium is very helpful to validate correct estimation. Moreover, a periodic microscopic cell consisting of a few pores representing an average morphology of porous ceramics is proposed to serve for numerical analyses to estimate permeability parameters. The concurrence of such micro-scale derivation and inverse identification is discussed.

2. Inverse identification and microstructural analysis

Samples of porous ceramics Al_2O_3, with the known total porosity of 90%, are examined in the impedance tube using the transfer function method, in the frequency range from $500\,$Hz to $6.4\,$kHz. Experimentally-determined curves of acoustic impedance and absorption are then used for an inverse identification of the remaining model parameters, namely: tortuosity α, viscous and thermal permeabilities, k_0 and k_0', and two characteristic lengths – for viscous and thermal effects, Λ and Λ'. To this end, five dimensionless parameters, $p_1,\ldots,p_5$, are defined in some relation with the model parameters and then, an optimization procedure with appropriate constraints is carried out, in order to match the curves measured experimentally with the ones calculated from the equations of the Johnson-Allard model [1]. As a matter of fact, some experimental data are used for the determination of parameters while the other data – obtained for another sample of the same porous ceramics, yet having different height – serve for the validation purposes. The absorption curves, obtained for two samples of different height, namely, $h = 18\,$mm and $h = 24\,$mm, are shown in Figure 1(a). Figure 1(b) presents the identified values of the five dimensionless parameters, whereas the corresponding initial and identified values of model parameters are given in Table 1. It is observed that the identified characteristic length for thermal effects corresponds very well to the average radius of pores, whereas the characteristic length for viscous forces is similar with the average radius of "windows" linking the pores (cf. also $2\Lambda = 127\,\mu$m and $2\Lambda' = 581\,\mu$m from Table 1 with, respectively: $113\,\mu$m and $529\,\mu$m found in Table 1 in [2]). This is a very important agreement which validates the results of identification.

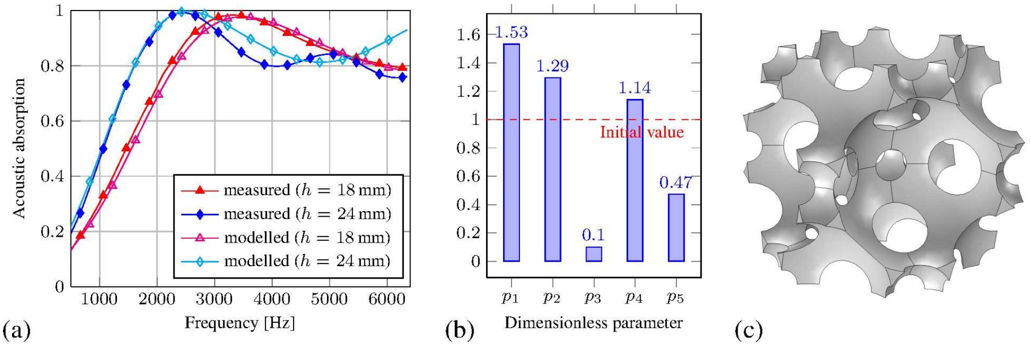

Figure 1. (a) Absorption curves (measured and modelled after parameter identification) for samples of porous ceramics of height h, (b) identified values of dimensionless parameters, (c) periodic cell with porosity of 90%.

	α	Λ [m]	Λ' [m]	k_0 [m^2]	k'_0 [m^2]
(a)	1.0000e+000	2.0000e-005	2.0000e-005	9.0000e-010	9.0000e-010
(b)	1.5318e+000	6.3439e-005	2.9044e-004	6.9538e-010	8.9897e-009

Table 1. Initial (a) and identified (b) values of model parameters.

Moreover, using these average radii of pores and windows, a periodic cell with porosity of 90% is constructed, see Figure 1(c). It is used for three-dimensional numerical analysis of the micro-macro transition approach for sound absorbing porous media [3, 4]. To this end, the multi-scale asymptotic method is applied [5], which permits to determine the macroscopic material description from knowledge of the physics and geometry at the microscopic level. The viscous permeability, obtained in that way, corresponds to the value identified from the experimental curves.

Acknowledgments

The author wishes to express his sincere gratitude to Dr. Marek Potoczek from Rzeszow University of Technology for providing samples of porous ceramics. Financial support of the Foundation for Polish Science Team Programme co-financed by the EU European Regional Development Fund Operational Programme "Innovative Economy 2007-626 2013": Project "Smart Technologies for Safety Engineering SMART and SAFE", No. TEAM/2008-1/4, and Project "Modern Material Technologies in Aerospace Industry", No. 629 POIG.01.01.02-00-015/08, is gratefully acknowledged.

References

[1] J.F. Allard, N. Atalla (2009). *Propagation of Sound in Porous Media: Modelling Sound Absorbing Materials*, 2nd ed., Wiley.

[2] M. Potoczek (2008). Gelcasting of alumina foams using agarose solutions, *Ceram. Int.*, **34**, 661667, **24**, 334-357.

[3] C. Perrot, F. Chevillotte, R. Panneton (2008). Dynamic viscous permeability of an open-cell aluminum foam: Computations versus experiments. *J. Appl. Phys.*, **103**, 024909-1-8.

[4] C. Perrot, F. Chevillotte, R. Panneton (2008). Bottom-up approach for microstructure optimization of sound absorbing materials, *J. Acoust. Soc. Am.*, **124**(2), 940-948.

[5] C.-Y. Lee, M.J. Leamy, J.H. Nadler (2009). Acoustic absorption calculation in irreducible porous media: A unified computational approach. *J. Acoust. Soc. Am.*, **126**(4), 1862-1870.