Multiphysics Modeling of Sound Absorbing Fibrous Materials

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Abstract

INTRODUCTION:
Many of fibrous materials are very good sound absorbers, because the acoustic waves, which propagate in air and penetrate a fibrous layer, interact with the fibers so that the wave energy is dissipated. The dissipation is related to some viscous and thermal effects occurring on the micro-scale level. On the macroscopic level, a fibrous medium can be treated as an effective inviscid fluid, provided that the fibers are stiff. Such a fluid-equivalent approach allows to use the Helmholtz equation for the macroscopic description of sound propagation and absorption [1]. It is applied by the advanced Johnson-Allard models, which require from 5 to 8 parameters related to the micro-geometry of fibrous microstructure. These are the so-called transport parameters in porous media: the open porosity and tortuosity, the permeability and its thermal analogue, two characteristic lengths (for viscous forces and thermal effects), etc. Moreover, some parameters for air (which fills the medium) are also necessary.

USE OF COMSOL MULTIPHYSICS:
The transport parameters can be calculated for fibrous/porous media provided that a periodic representation of the micro-geometry is available [2,3,4]. Such representations can be constructed directly in COMSOL Multiphysics or they can be imported using CAD Import Module if they are externally built from, e.g., computed tomography scans. Then, three uncoupled steady-state problems must be solved on the periodic fluid domain:
(1) the viscous incompressible flow through fibrous microstructure with the no-slip boundary conditions on the fiber surfaces,
(2) the steady thermal flow with the isothermal boundary conditions,
(3) the Laplace problem.

These problems can be solved using the main module of COMSOL Multiphysics, although the CFD Module (for the Stokes' flow) and the Heat Transfer Module (for the thermal flow) can be useful. The solutions are averaged over the fluid domain and relevant formulas are used to calculate the transport parameters. The averaging is done in COMSOL, however, in order to proceed with further calculations the LiveLink™ for MATLAB® is very useful. On the macro-scale level the Acoustics Module of COMSOL can be used, or for the problems of plane wave propagation in layered media analytical solutions are available.

RESULTS AND CONCLUSIONS:
Two Representative Volume Elements and a simple two-dimensional cell are proposed for a fibrous material made up from a copper wire with diameter 0.5mm (Figure 1). For each of these periodic geometries, the microstructure-based analyses are solved using COMSOL Multiphysics (Figure 2), and the transport parameters are computed. They are used to determine the effective density and speed of sound for the equivalent fluid. Finally, the sound absorption for fibrous (i.e., equivalent fluid) layers is calculated and compared with the experimental results (Figure 3) to prove that representations with locally straight fibers can give good predictions.

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Reference

[1] J.F. Allard and N. Atalla,
"Propagation of Sound in Porous Media: Modelling Sound Absorbing Materials. Second Edition".
Wiley (2009).

[2] C. Perrot et al. ,
"Bottom-up approach for microstructure optimization of sound absorbing materials".
J. Acoust. Soc. Am., 124(2):940-948 (2008).

[3]. T.G. Zielinski,
"Microstructure-based calculations and experimental results for sound absorbing porous layers of randomly packed rigid spherical beads".
J. Appl. Phys., 116(3):034905 (2014).

[4] T.G. Zielinski,
"On representativeness of the representative cells for the microstructure-based predictions of sound absorption in fibrous and porous media".
Proceedings of EURONOISE2015 – 10th European Congress and Exposition on Noise Control Engineering,
31 May – 3 June 2015, Maastricht, The Netherlands (2015).

Figures used in the abstract

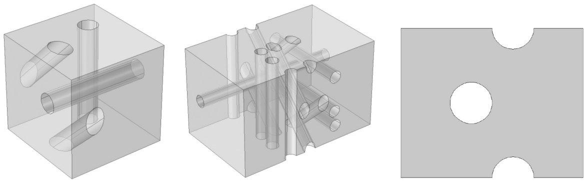

Figure 1: Two Representative Volume Elements and a two-diemnsional cell representative for a fibrous medium with porosity 90%.

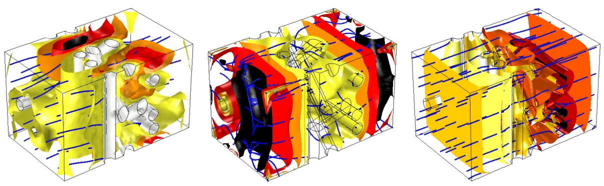

Figure 2: Results of finite-element analyses (the Stokes' flow, the heat transfer, and the Laplace problem) in the fluid domain of RVE-2.

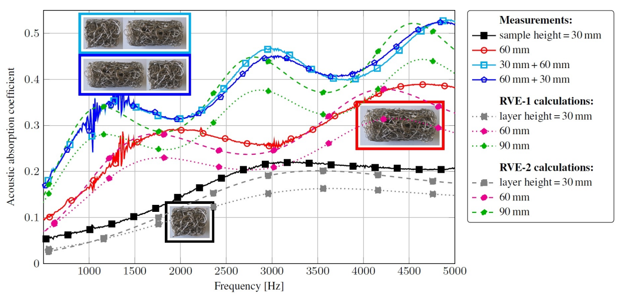

Figure 3: Sound absorption of fibrous layers (with porosity 90% and fibre diameter 0.5mm): numerical and experimental results.