Multiphysics Modelling of Sound Absorbing Fibrous Materials

Tomasz G. Zieliński

Institute of Fundamental Technological Research, Polish Academy of Sciences
ul. Pawinskiego 5B, 02-106 Warszawa, Poland
e-mail: `tzielins@ippt.pan.pl`

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 fibres 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 fibres 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 fibre 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 and 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 fibres can give good predictions.
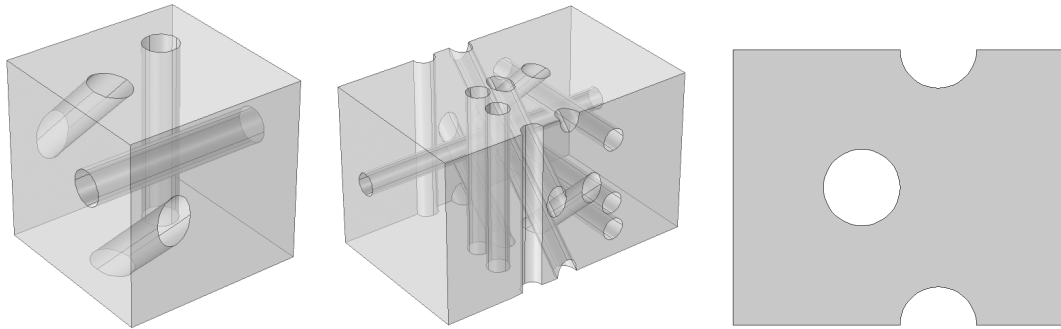
Figure 1: Two Representative Volume Elements (RVE-1 and RVE-2) and a two-dimensional cell representative for a fibrous medium with porosity 90%
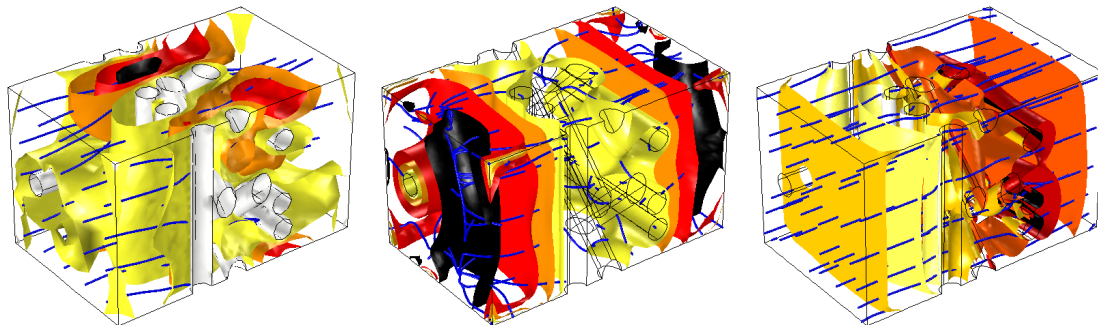
Figure 2: Results of finite-element analyses (the Stokes' flow, the heat transfer, and the Laplace problem) in the fluid domain of RVE-2
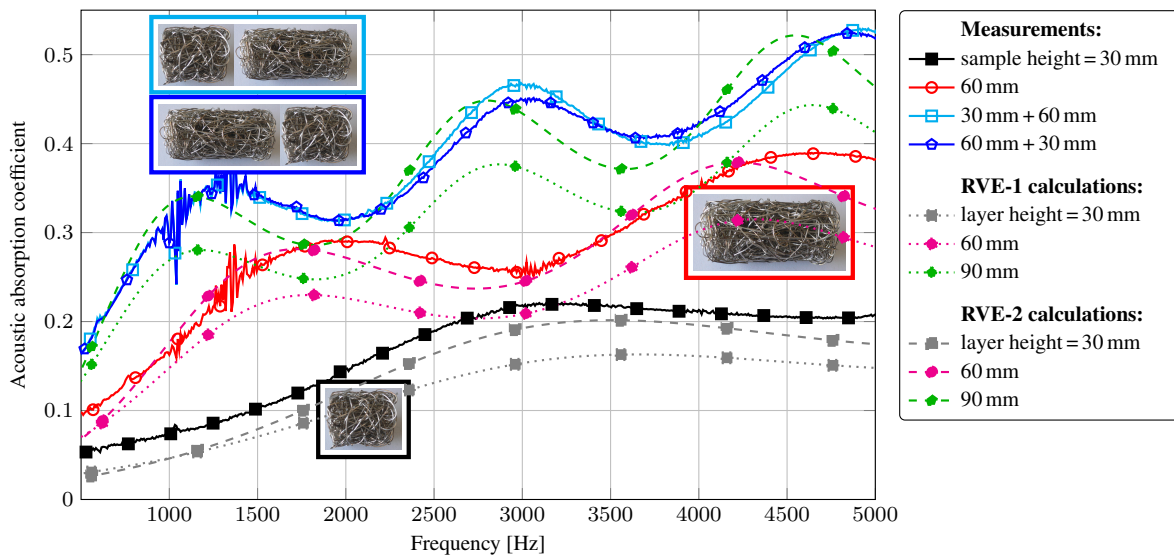
Figure 3: Sound absorption of fibrous layers (with porosity 90% and fibre diameter 0.5mm): numerical and experimental results

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References

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