Multiscale and Multiphysics Modelling of an Adaptive Material for Sound Absorption

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Abstract

A concept of an adaptive sound absorbing material is proposed and investigated numerically using the COMSOL Multiphysics® Software suitable for the required advanced dual-scale modelling which involves solution of various problems of physics at the microscopic and macroscopic levels. A periodic microstructure of adaptive porous material is designed and generated in COMSOL Multiphysics® in the form of a periodic representative cell of pores and linking channels with a valve ball inside the large pore. The balls can block some channels and, in that way, change the material (viscous) permeability and tortuosity, as well as the viscous characteristic length and static viscous tortuosity, especially, in the direction parallel to the blocked channels, since the flow is then directed through auxiliary channels which are oblique and narrow. The balls can change their position inside pores thanks to the gravity or an inertial force, and the modifiable (in that way) transport parameters are strongly related to the sound absorption of porous medium.

At the macroscopic scale, the adaptive porous material is modelled as a homogenised equivalent fluid using the so-called Johnson-Champoux-Allard-Pride-Lafarge (JCAPL) model available from the Acoustics Module of COMSOL Multiphysics®. This model requires 8 transport parameters of porous medium, namely: the open porosity, the (inertial) tortuosity, the viscous permeability (or, alternatively, the flow resistivity), the thermal permeability, the viscous and thermal characteristic lengths, and the static viscous and thermal tortuosities.

The transport parameters are calculated from the periodic microstructure of the artificial adaptive material. The porosity and thermal length are determined directly from the porous micro-geometry. The remaining transport parameters are found by solving three different problems on the fluid domain of pores inside the Representative Elementary Volume (RVE), namely: (1) the Stokes (viscous, incompressible) flow through the porous cell, (2) the Laplace problem which simulates the electric conduction of a porous material with dielectric skeleton and conductive pore-fluid, and (3) the Poisson problem which, in a re-scaled way, simulates the thermal transport inside the pores. Lateral faces of RVE require application of the appropriate periodic boundary conditions which are implemented in COMSOL Multiphysics®. Moreover, the Stokes problem is available from the CFD Module of COMSOL Multiphysics®, and its appropriately re-scaled version can also be implemented using one of the PDE Interfaces. The Laplace and Poisson problems are

implemented in COMSOL Multiphysics® as Classical PDEs. The solutions of the micro-scale problems are averaged over the fluid domain in order to determine the relevant transport parameters.

A cuboid sample of the adaptive sound-absorbing porous material was 3D-printed in order to verify the proposed design. It was experimentally tested in a special set-up of impedance tube with square-to-circular-shape adapter. A quarter of porous cuboid with an adjacent layer of air is modelled in COMSOL Multiphysics® using the Helmholtz equation of linear acoustics and the JCAPL model. The frequency-dependent macroscopic numerical analyses allowed to determine the surface acoustic impedance and sound absorption coefficient of the porous absorber for two positions of valve balls inside pores. The predictions show significant differences between the two cases which are confirmed by the experimental results.

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Figures used in the abstract

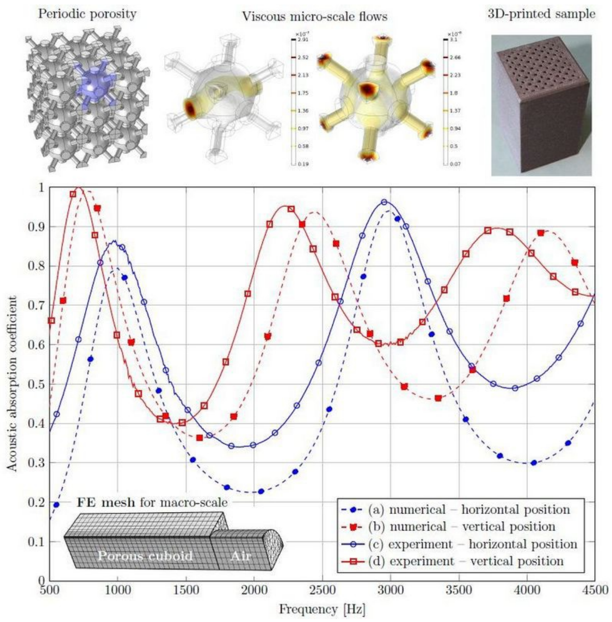

Figure 1: Numerical calculations and experimental results for the cuboid sample of adaptive sound absorbing material.