FROM MICRO-STRUCTURE TO MACRO-PROPERTIES

The "micro-macro" research field is an attempt to predict the acoustical macro-properties or performances of a porous material (e.g. sound transmission loss of a given material sample) from the knowledge of its micro-structure (e.g. pore size for foam or fiber size for fibrous...).

Microscopic definition of a porous medium

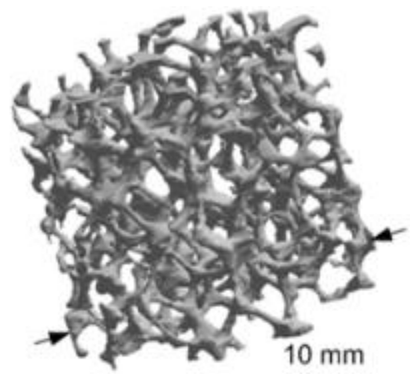
Two distinct ways are used to define the microscopic structure of a porous medium. One is to stay as close as possible to the actual micro-structure using a microtomography scan of a material sample. The second relies on the choice of an idealized and simplified representative periodic cell.

Both methods end up with the definition of the smallest representative volume of the material with respect to the visco-inertial and thermal phenomena. This smallest volume is called the Representative Elementary Volume (REV).

Microtomography scans

Microtomography scans are used to digitized the micro-structure of a porous material. The main difficulty is then to identify the Representative Elementary Volume, in particular for real micro-structures (see picture).

To obtain a convergence of the results (solutions of the visco-inertial and the thermal problems), this method often implies to use a large volume as the REV which will imply important numerical resources to solve the sound propagation equation in this REV.



Example of a foam microstructure extracted from a 3D X-Ray tomography (picture courtesy of Camille Perrot).

Idealized periodic unit cells

An alternative to the microtomography acquisitions is to choose a simplified micro-structure. This simplified micro-structure will be composed by a repeated idealized unit cell. The REV is then reduced to this idealized unit cell.

This method can be used for optimization purposes as a unit cell can be described with a known set of parameters such as the size of the pores or the size of the interconnection between two pores etc. However the choice of a unit cell to describe a given material requires a prior knowledge of the physics of this material.

Example of an idealized periodic cell: the Kelvin cell.

Macroscopic properties from microstructure

Once the micro-structure is defined it remains to compute the macroscopic properties of a material samples e.g. its sound absorption coefficient or sound transmission loss.

These macroscopic properties are derived from the information on the micro-structure by solving two linearized and frequency-dependent problems in the harmonic regime: (i) the Navier-Stokes equation with a local incompressibility condition to solve the dynamic visco-inertial problem and (ii) the heat equation to solve the dynamic thermal problem.

From a practical point of view, two quantities are computed from which all macro-properties can be deduced. These two characteristic quantities of the material are the dynamic mass density $\tilde{\rho}_{eq}$ and the dynamic bulk modulus $\tilde{K}_{eq}$.

Analytical calculation

For a small number of micro-structure morphologies (slit-like pores, cylindrical pores with circular, triangle or square cross-sections, cylindrical or spherical solid inclusions...) the visco-thermal problem can be solve analytically. See our dedicated page on motionless skeleton models for expressions of $\tilde{\rho}_{eq}$ and $\tilde{K}_{eq}$ in such particular cases.

Direct numerical computation

For most micro-structures (in particular for the first two ones illustrated in this document), numerical computations are required. The visco-thermal dissipative problem being frequency dependent, one computation is required for each studied frequency. Thus, this direct numerical approach is memory and time consumming.

Hybrid numerical computation

This approach allows to determine the acoustic behavior of a material in a wide frequency range while requiring only three numerical computations.

The original idea by is to estimate the parameters of semi-phenomenological models, for example the Johnson-Champoux-Allard-Pride-Lafargemodel, from the micro-structure morphology and 3 asymptotic behaviors.

- the open porosity ϕ and the thermal characteristic length Λ' are geometrical parameters and can be deduced from the micro-structure morphology.

- The static airflow resistivity σ (or static viscous permeability k_0) and the static viscous tortuosity α_0 are computed from the steady Stokes problem.
- The viscous characteristic length Λ and the high frequency limit of the dynamic tortuosity α_∞ are calculated from the visco-inertial problem assuming a perfect incompressible fluid (without viscosity). The solution to this problem is analogous to the electrical conduction problem (see*[JKD87]*).
- The static thermal permeability k'_0 and the static thermal tortuosity α'_0 are solved using the thermal conduction problem in the fluid phase where the solid skeleton is considered as a thermostat.

To describe the sound propagation in the fluid phase accounting for visco-thermal dissipation effects, the dynamic mass density $\tilde{\rho}_{eq}$ and the dynamic bulk modulus $\tilde{K}_{eq}$ are then derived from the computed macroscopic parameters listed above.

Source:
http://apmr.matelys.com/PropagationModels/MicroStructureToMacroProperties.html