Morphology versus acoustic modelling of simple and structured porous media

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This paper focuses on the relationship between morphology, effective parameters and acoustic modelling of simple and structured porous media. In structured media, conversely to simple media, the Representative Elementary Volume (REV) involves several (usually two) well distinct characteristic sizes. The REV may be constituted either by porous media crossed by large (open or closed) pores, or two porous media with large permeability contrast.

This question is addressed through a review of results established by the homogenisation method of periodic media (HPM) combined with a systematic use of dimensional analysis. This approach provides a rigorous way to determine the macroscopic behaviour and to calculate numerically the effective coefficients on chosen REV's morphology. Further, as the morphology of real media is not precisely known, the self consistent (SCM) method is also explored. This approach reduces the REV morphology to the most basic geometrical information, i.e. for porous media, a bi-composite fluid-solid spherical pattern, defined by the porosity and the pore size. SCM models provide analytical expressions which traduce the essential parts of the physics and which are easily parametrizable.

Note that, by principle, both approaches apply provided that a sufficiently good scale separation between the macro scale and the REV scale is fulfilled.

For simple porous materials, the morphology is of first importance for the acoustic properties, meanwhile different morphologies may lead to the same acoustic features. This ambivalent role relies on the fact that, instead of the pore geometry itself, the acoustic description is governed by effective parameters traducing the phenomena occurring at the pore level with their specific morphology.

The HPM limited to the zero order approximation, leads to the Biot-Allard modelling. Consequently, the effects of pore morphology are encapsulated in the dynamic and thermal permeabilities. To identify the actual influence of morphology, we calculated the permeability of porous media made of simple cubic, body-centred cubic and faced-centred cubic periodic arrays of solid inclusions of two types : either non-overlapping and overlapping solid spheres of the same radius or non-overlapping solid polyhedrons (cube, truncated octahedron, rhombic dodecahedron).

On the whole range of porosity, the three packing of polyhedrons lead to very close values, in excellent agreement with the SCM analytical estimates. This stems from the fact that the flow around polyhedrons is quite similar to the flow in the bi-composite spherical pattern. As for arrays of spheres, when porosity > 0.6, the agreement with estimates is excellent. The increasing discrepancies for lower porosity is related to the change in the flow pattern, passing from a "smooth" field around non-overlapping spheres, to a "highly" variable field through the corrugated channels in between the overlapping spheres. This phenomenon does not exist for polyhedrons packing, which explains the better agreement.

Structured porous media introduce a meso-morphology associated to the contrast between the two different pores networks. In such strongly heterogeneous system (double porosity case) a new mechanism may appear : the interesting situation arises when the domain of weak permeability undergo an out-of-equilibrium mechanism of diffusion-compression of pressure, while the mesopores lie in quasistatic equilibrium. In that case, two dynamics occur conjointly, one at the macroscale, mostly driven by the large permeability network, and one in the mesoscale within the low permeability network. Since, this effect is related to a inner "resonance" (i.e. the diffusion-compression wave length is of the order of the micro porous domain), it appears in a specific frequency range defined by both morphology and permeability contrast.

This example shows that strong contrasts in the pores morphology, change the expressions of the effective parameters, but also modify drastically the nature of the acoustic modelling. The equivalent continuum behaviour deviates from that of single porosity media : at the leading order, the inner resonance in the weak permeability domain, induces a time delay in the response (non-local effect in time) and in turn an additional dissipation. This latter can not take place in single porosity media.

Again, a self consistent scheme adapted to this specific physics (bi-composite porous-porous spherical pattern) enables simple assessment of the effective parameters of structured porous media. The estimates apply to periodic packing of porous spheres or polyhedrons embedded in a matrix of much higher permeability.

To conclude, the condensation of the morphological effect into a few parameters constitutes the basis of the design of sound absorbing materials. Hence, the combined use of HPM and SCM for the prediction of the acoustic modelling from the basic morphological information of the medium is of interest for both scientific and industrial fields. However the SCM bi-composite geometry is not sufficient to capture the all complexity of the actual geometry as illustrated by the effect of overlapping spheres. For this reason, the SCM estimates may apply to simple or structured porous media of sufficiently regular morphology, but should be used only as general trends otherwise. Conversely, the results derived from HPM are of wider use but require detailed information on the morphology.

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