Microstructure generation for design of sound absorbing foams with spherical pores

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The paper presents an approach for a morphological design of foams with spherical pores. It involves an algorithm for random generation of foam microstructure (controlled by some parameters), which is used to compute the transport parameters, and then, the effective speed of sound. Eventually, the sound absorption of such designed foam can be estimated.

1 Controlled random generation of foam microstructure

The proposed algorithm for generation of microstruture for open porosity foams with spherical pores is similar to the Lubachevsky-Stillinger algorithm [1, 2] and it is essentially based on the dynamics of rigid spheres subject to random mixing involving elastic collisions. Figure 1(left) presents a two-dimensional idea of such periodic mixing. In 3D each sphere belongs to an assembly of eight spheres placed in the vertices of a cube with edge-length equal to the actual edge-length of the shrinking representative cubic cell, so that only one complete sphere is always present inside the cell cube. The shrinking of representative cell is stopped when the assumed porosity is accomplished (the spheres become pores). Then, the whole cell is scaled in order to set the assumed average radius of pores. Thus, the porosity and the average size of pores are two independent design parameters. The standard deviation of pore size is set by assuming the appropriate initial radii of spheres in the periodic cell. During mixing, the spheres may penetrate each other: it is controlled by the so-called maximal penetration parameter ζ, shown in Figure 1(right). In some indirect way this parameter controls the average size of windows linking the pores since for two identical spheres (i.e., $R_1 = R_2 = R_\mathrm{p}$) the maximal widow radius R_w is related to the pore radius R_p in the following way: $R_\mathrm{w}/R_\mathrm{p} = \sqrt{\zeta - \zeta^2/4}$. Figure 2 presents a randomly generated periodic arrangement of five spheres and the corresponding skeleton of the designed open foam with porosity 70%; the meshed fluid domain of such Representative Volume Element (RVE) is also shown together with a result of the microstructural analysis of a steady thermal flow in the foam.

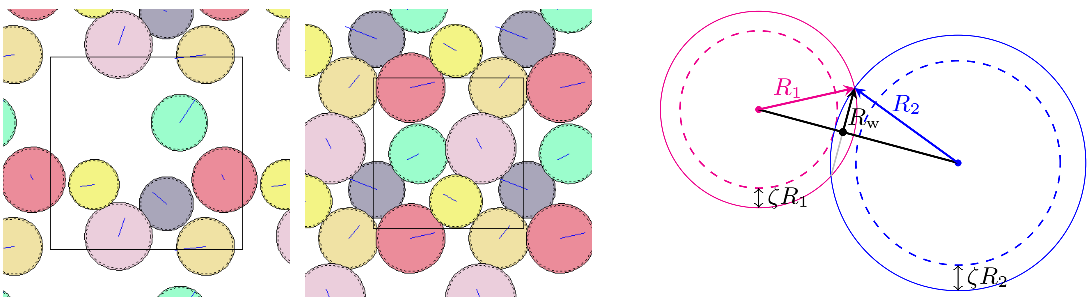

Figure 1: (Left:) a random mixing of spheres in a shrinking periodic cell. (Right:) the mutual penetration of two spheres (pores).

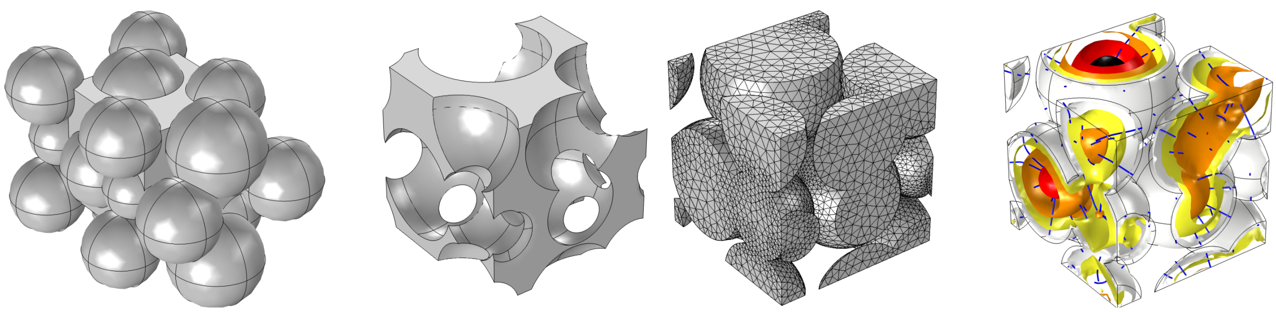

Figure 2: (Left:) a periodic arrangement of spheres. (Middle:) the corresponding RVE (the solid skeleton and meshed fluid domain). (Right:) the computed field of temperature.

2 Microstructure-based prediction of sound velocity and absorption

The generated representative microstructure of the designed foam with porosity 70% (scaled to set the average pore radius to 0.16 mm) was used to estimate the sound absorption of such material. To this end, three finite-element analyses were carried out on the fluid domain of RVE (see Figure 2(middle)) [3, 4, 2]: (1) the viscous incompressible flow (i.e., the Stokes flow) with no-slip boundary conditions on the skeleton walls; (2) the steady heat transfer with isothermal boundary conditions on the skeleton walls; (3) the Laplace problem. The solutions of these problems – i.e., the fields of flow velocity, temperature (see Figure 2(right)), and electric potential – were averaged over the fluid domain and scaled by the formulas derived from the multi-scale modelling, in order to calculate some transport parameters, namely: the permeability and the low-frequency limit of tortuosity (Stokes flow); the thermal permeability and the low-frequency limit of thermal tortuosity (heat flow); the tortuosity and the viscous characteristic length (Lapalace problem). The thermal characteristic length was computed directly from the geometry of RVE as the ratio of the doubled volume of pores to the total surface of pores [3, 4]. All these parameters and the set parameter of porosity were used by the formulas of the Johnson-Champoux-Allard-Pride-Lafarge model [5, 4] to calculate the effective speed of sound in the designed foam, assuming that its skeleton is made up of a stiff material. This eventually allowed to determine the acoustic absorption coefficient for such foam layers of various thicknesses. Figure 3 shows the acoustic wave celerity and absorption coefficient computed in the frequency range up to 5 kHz.

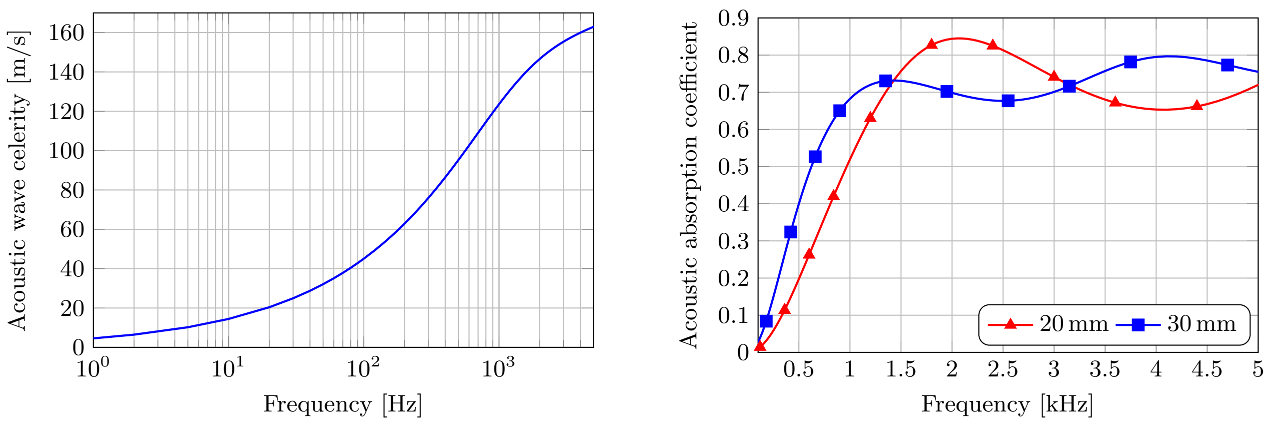

Figure 3: (Left:) the sound wave celerity in the designed rigid foam. (Right:) the acoustic absorption for rigid foam layers with thickness of 20 mm or 30 mm.

Acknowledgements

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References

[1] D. Lubachevsky and F. H. Stillinger, *Geometric properties of random disk packings*, J. Stat. Phys. **60**, pp. 561-583, 1990.

[2] T. G. Zieliński, *Controlled random generation of microstructure and prediction of sound velocity and absorption for open cell foams with spherical pores*, J. Appl. Phys. (in review).

[3] C. Perrot, F. Chevillotte, and R. Panneton, *Bottom-up approach for microstructure optimization of sound absorbing materials*, J. Acoust. Soc. Am. **124**, pp. 940-948, 2008.

[4] C.-Y. Lee, M. J. Leamy, and J. H. Nadler, *Acoustic absorption calculation in irreducible porous media: A unified computational approach*, J. Acoust. Soc. Am. **126**, pp. 1862-1870, 2009.

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