Acoustical properties of packings of porous grains[1]

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Abstract

Granular materials have been conventionally used for acoustic treatment due to their sound absorptive and sound insulating properties. An emerging field is the study of the acoustical properties of double porosity materials. An example of these is a granular material in which the particles are porous. In this paper, analytical and hybrid analytical-numerical models describing the acoustical properties of packing of pervious grains are presented. The model predictions are compared with measurements on expanded perlite and activated carbon showing satisfactory agreement.

Results

Most of the results published in [1] are recalled in this paper. Two fluid networks with well-separated characteristic sizes can be identified in a packing of porous grains. The material properties strongly depend on the ratio, ε_0, between the characteristic size of the meso-heterogeneities l_p and that of the micro-heterogeneities l_m. At moderate inter-scale ratio values, e.g. $\varepsilon_0 \approx 10^{-1}$ (low permeability contrast), the two fluid networks strongly interact and influence both the macroscopic fluid flow and heat conduction [2]. For small inter-scale ratio values, e.g. $\varepsilon_0 \approx 10^{-3}$ (high permeability contrast), the macroscopic flow is determined by the mesoscopic fluid network. However the dynamic bulk modulus is modified due to pressure diffusion effects in the microdomain. This leads to an additional dissipation term which depends on the material microstructure [2].

Expanded perlite P3 (low permeability contrast material) with overall porosity $\phi_{db} = 0.9776$ has been modelled as a packing of identical porous spheres. The equivalent particle radius $r_p = 0.475$ mm has been calculated as half of the average between the upper and lower limit of the 80%-band grain size. The inter-granular porosity has been set to that of the BCC close-packing array, i.e. $\phi_p = 0.32$. Scanning electron microscope images have revealed the foam-like inner structure of the P3 grains which has then been modelled as an array of monodisperse perforated truncated octahedra. The cell size $C_s = 47.582 \pm 9.659$ μm has been calculated from image processing using manual segmentation. The wall thickness has been set to $h_w = 3 \cdot (0.474 \pm 0.088)$ μm to match the overall porosity. Semi-phenomenological models [3] [4] have been used to calculate the acoustical properties of the array of perforated truncated octahedra. Their parameters have been calculated numerically using FEM. As shown in Figure 1a the single porosity model is not capable of reproducing the absorption coefficient data while the double porosity model provides a reasonably good agreement.

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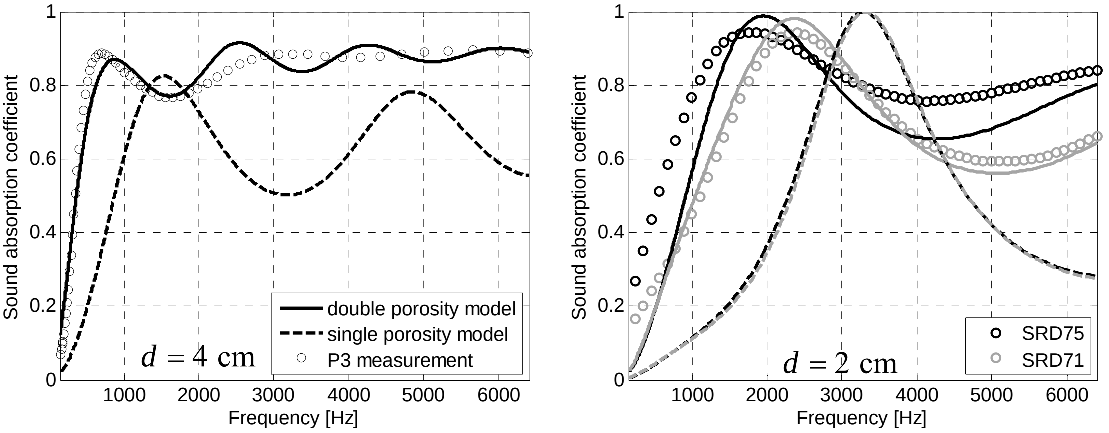
Two samples of activated carbon samples, denoted as SRD71 and SRD75, have been considered as examples of double porosity high permeability contrast granular materials. The samples are very similar in terms of mesoscopic characteristics but differ in their inner structure. The measured overall porosity was 0.7427 for SRD71 and 0.8477 for SRD75. The activated carbon samples have been modelled as packings of identical porous spheres. The inner structure of the spheres is modelled as an array of straight cylindrical pores. The mean value of the equivalent particle radius measured using optical granulometry is equal to $r_p = 0.7536 \pm 0.1609$ mm for SRD71 and $r_p = 0.7364 \pm 0.2056$ mm for SRD75. Flow resistivity measurements have been taken to justify the applicability of the high permeability contrast assumption. The flow resistivity of SRD71 and SRD75 are 21.068±1.444 kPa.s/m^2 and 24.5923±1.5104 kPa.s/m^2 respectively. These values lead to estimated mesoporosity of 0.3083±0.0055 for SRD71 and 0.2997±0.005 for SRD75 (assuming identical non pervious grains). The microporosity values have been calculated from the meso- and overall porosity values. The micropore radii ($r_m = 0.7125$ μm for SRD71 and $r_m = 0.9881$ μm for SRD75) have been found through a best fitting routine. These values correlate well with the mean size of the transport pores commonly found in activated carbon. As shown in Figure 1b the double porosity model provides much closer agreement with absorption coefficient data than the single porosity model. However, significant differences at low frequencies are observed.



(a) (b)

Figure 1 Sound absorption coefficient of a rigidly-backed layer of expanded perlite with thickness 4 cm (a) and two activated carbon samples with thickness 2 cm (b). Markers − measurements. Continuous lines − double porosity model predictions. Dashed lines − single porosity model predictions.

To provide an insight into the low frequency behaviour, the dynamic bulk moduli of the activated carbon samples have been measured using the two-thickness method and is shown in Figure 2. It has been found that the measured normalised static bulk modulus is smaller than 1, i.e. $K^* = K(\omega \to 0)/P_0 < 1$ while the theoretical value is $K^* = 1/\phi_{db} > 1$. The most likely physical processes that could explain the unusual low frequency behaviour of the dynamic bulk modulus are sorption and mass transfer processes [1].

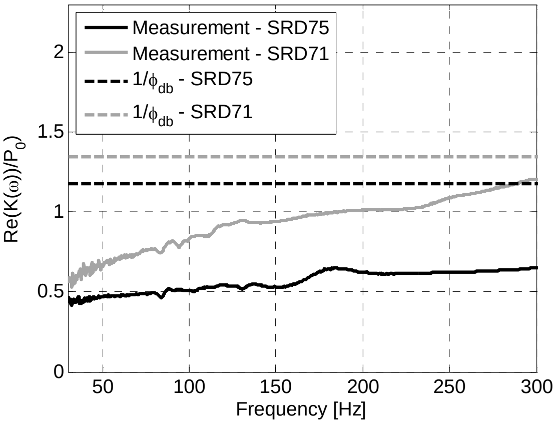


Figure 2 Normalised real part of the dynamic bulk modulus for the activated carbon samples SRD71 and SRD75.

Conclusions

The acoustical properties of packings of porous grains have been studied theoretically and experimentally. Expanded perlite has been used as an example of a granular material with low permeability contrast. High permeability contrast has been achieved in samples of activated carbon. Materials consisting of porous grains provide much improved low frequency sound absorption compared to that of the same size solid particles at reduced weight. It has been found that the low frequency properties of activated carbon cannot be completely explained by their double porosity structure as the measured static values of the bulk moduli are lower than those predicted by the theory. This might be an indication of mass transfer and sorption processes happening in smaller pores. The investigation of these effects and their use in designing new acoustic materials are interesting topics for future research.

Acknowledgments

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