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Modelling of poroelastic media with localised mass inclusions

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1 Introduction

The main concept of this research is illustrated by Figure 1(left) showing a generic configuration of a poroelastic layer with elastic inclusions, which should enhance the sound absorption of such composite material in targeted frequency ranges. In the investigations presented here, the effect of small-size inclusions is examined, and it is expected that the mass of inclusions should play a predominant role. Therefore, a simplified modelling method (involving localised inertial terms added to the poroelastic formulation) is proposed and this approach is confronted with general fully-coupled solutions.

2 Modelling and computations

Two configurations were considered in calculations of the proposed poroelastic layer with elastic inclusions, namely: (1) a single-layer configuration with only poroelastic layer (with or without inclusions) backed by a rigid wall, i.e., the modelled domain shown in Figure 1(left), and (2) a double-layer configuration with the poroelastic layer and a layer of air of the same thickness, as shown in Figure 1(right).

Three cases were investigated for each configuration: (1) the poroelastic layer without inclusions, (2) the poroelastic layer with a small elastic inclusion (with diameter 1.2 mm) situated 4 mm from the layer's surface, (3) the poroelastic layer with an additional inertial term in the weak formulation of the problem, applied at the point of inclusion and adequate to its mass.

Finally, two numerical methods were applied for numerical computations: (1) Finite Element Method (FEM) using a weak-form implementation of the Biot's poroelasticity (the displacement-pressure formulation [1] involving also some effective fluid properties defined by the Johnson-Champoux-Allard-Pride-Lafarge model [2]), coupled to the problems of elastodynamics and Helmholtz acoustics; (2) Wave Based Method (WBM) based on a similar coupled implementation. Moreover, for the poroelastic layer without inclusions the analytical solutions based on the Transfer Matrix Method (TMM) were also applied to confirm the exactness of the numerical calculations by FEM and WBM.

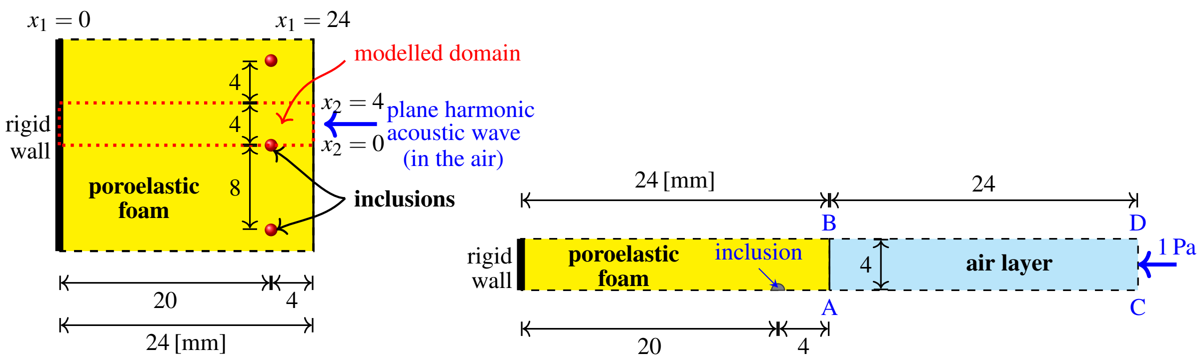

Figure 1: (left) Poroelastic layer with periodically set inclusions, and (right) a double-layer configuration of the poroelastic layer with a circular inclusion and a neighbouring layer of air of the same thickness

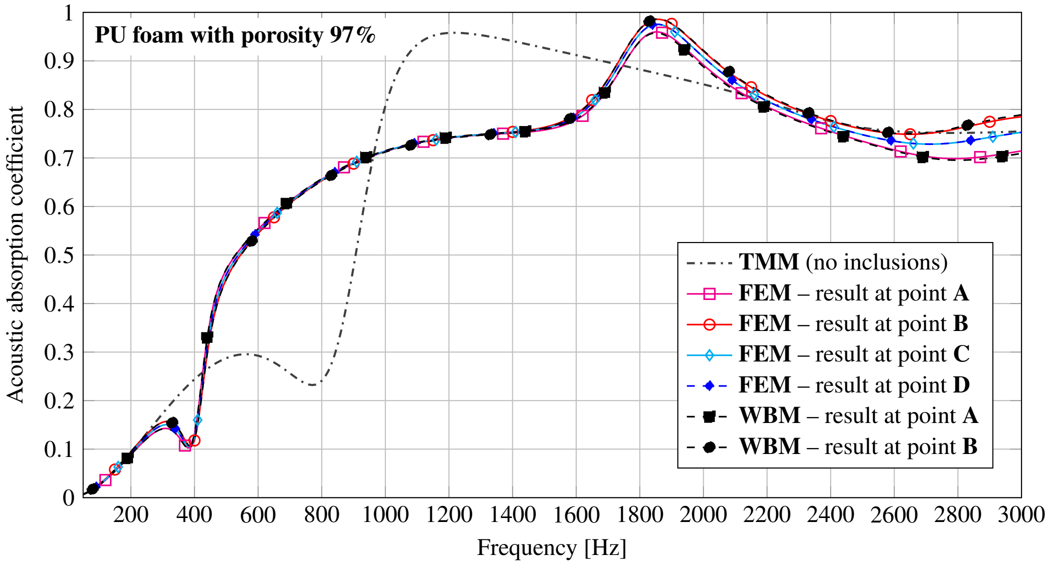

Figure 2: Acoustic absorption for a poroelastic layer with or without elastic inclusions: (a) TMM – analytical solution for the layer without inclusions (practically the same curve was also obtained using FEM and WBM), (b) FEM – finite element calculations of absorption at various points (A, B, C, and D, see Figure 1) for the layer with inclusions, (c) WBM – calculations of absorption using the Wave Based Method (the single-layer configuration with inclusions – results at points A and B)

Figure 2 presents some results of sound absorption computed in the frequency range from 50 Hz to 3 kHz for a poroelastic layer (a PU foam with open porosity of 97%) with inclusions in the form of a steel rods with diameter 1.2 mm. A very desirable improvement in absorption is achieved in a lower frequency band, from 450 Hz to 950 Hz. The acoustic absorption was determined from the surface acoustic impedance computed at points A or B on the surface of PU foam, or at points C or D on the surface of the neighbouring layer of air (see Figure 1). These four curves were found using FEM and they are nearly identical in the frequency range under 1.8 kHz. They very slightly diverge at higher frequencies in the case of computations at points A and B, where a local non-planar wave propagation occurs; at points C and D the propagation is plane and the overlapping curves C and D are in between the slightly diverging curves A and B. WBM was applied for the single-layer configuration, so only results computed at points A and B are presented: they are practically the same as the finite element calculations.

3 Conclusions

Effects related to the presence of mass inclusions are very promising with respect to the development of wave absorbing composites. This should involve some optimisations for which the approximative inertial-term modelling of localised inclusions may be applied in lower and medium frequency ranges.

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