Modeling the Dynamic Viscous and Thermal Dissipation Mechanisms in a Fibrous Porous Material

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Abstract

The main mechanisms of acoustic attenuation in a bundle of fibres typical of lightweight fibrous porous materials are the dynamic viscous drag forces on the surface of the fibres, and the thermal heat transfer between the solid fibres and the surrounding fluid.

Microstructure models have been recently developed which consider these micro-level interactions analytically, allowing the simulation of coupled acoustic and structural wave propagation through the three-dimensional, highly porous acoustic thermalinsulation material using only the geometrical fibre properties, and the constitutive properties of the solid fibre material and surrounding interstitial fluid. The main advantage being that the modelling and measurement of flow resistance, characteristic viscous and thermal lengths, tortuosity and permeability parameters required for traditional Biot poroelastic material models are not required using this approach. This simplifies the description of the physical behaviour of the material, leading to efficient material optimisation and also provides direct links to the characteristics of the manufacturing of the material itself. In our current work, this approach has been applied to not only fibrous porous materials, but also to open Kelvin-celled foam structures as well.

A key assumption in this analytical approach is that the viscous and thermal dissipation fields of the fibres should not significantly interact, i.e. the analytical representation of the fibrous material assumes a statistical distribution of fibre diameters and orientations of infinitely long cylinders oscillating both longitudinally and transversely. In order to assess the range of validity of this approach, the thermoviscous acoustic fluid analysis capabilities of COMSOL have been used to analyze the dissipative coupled viscous and thermal boundary layers on the cylindrical fibres for a range of frequencies and temperatures. These results are shown to be accurate within 0.1% compared against the analytical expressions for dynamic drag force loading, which is impressive considering that the viscous and thermal boundary layers on the surfaces of the fibre diameters considered have length scales of the order of micrometres and nanometres.

These validated COMSOL thermoviscous acoustic fluid models have then been extended to include simplified arrays of multiple fibres in order to understand the practical range of applicability of the analytical model, i.e. the fibre spacing or porosity ranges where the interaction of the viscous and thermal boundary layers is not significant between neighbouring fibres.

Figures used in the abstract

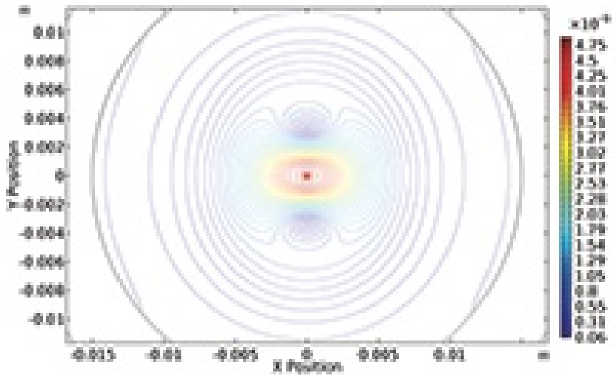

Figure 1: Viscous velocity field surrounding a microfibre oscillating at 1 Hz.