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Checking of an Optimal Sound Absorbing Microporous Structure

Bottom-up Approach for Microstructure Optimization of Sound Absorbing Materials

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63

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Introduction

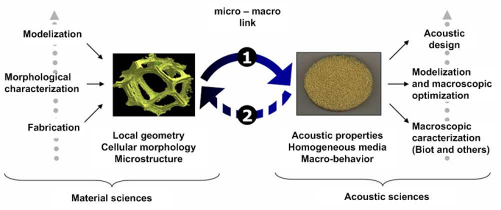


Fig 1. Linking micro-structure and acoustical macro-behaviour

A variety of performance demands are increasingly being placed on sound absorbing material systems.

A bottom-up approach for microstructure optimization of long-wavelength sound absorbing materials was recently presented using hybrid estimates based on direct numerical evaluation of macroscopic parameters and analytical models [1].

Results of this paper tend to demonstrate the existence of a microstructural configuration maximizing the area under the sound absorption spectrum, together with the optimal range of local characteristic lengths.

This is a crucial conclusion, notably for foam and fibrous materials manufacturers, which need to be confirmed with a more general formulation proposed by Lafarge (see [2]).

Numerical Calculations

Bottom

A. Model geometry [3]

- ***Motionless solid fibers***
- ***l and r as local characteristic lengths***
- ***Cross- section shapes of a foam ligament evolves from a circle to a concave triangle***

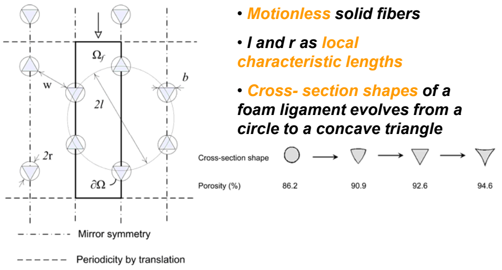


Fig 2. A typical 2D hexagonal arrangement of solid fibers.

B. Computational method ([4]-[5])

Hybrid estimates based on direct numerical evaluation of macroscopic parameters and analytical models:

➊ ***Solve numerically the asymptotic low (steady Stokes) and high (electric) frequency viscous boundary value problems using the FEM***

➋ ***Compute***

2.1) the "standard macroscopic parameters", i.e., the static viscous permeability k_o, the viscous characteristic length Λ, and the tortuosity α_∞ as defined by Johnson et al. [6]

2.2) the additional macroscopic parameters, i.e., the static tortuosity α_0, and the static thermal permeability k'_o as defined by Lafarge.

by appropriate volume averaging of the corresponding asymptotic velocity fields

➌ ***Derive the frequency-dependant viscous and thermal response functions such as the effective density $\rho(\omega)$ and bulk modulus $K(\omega)$ using analytical models of (3.1) Johnson et al. [6] and Allard and co-workers [7], and (3.2) Lafarge (refined model) [2].***

Up

MOTIVATION

Need to increase or adapt the sound absorption spectrum of commonly used sound absorbing materials

- Inefficient materials in the low frequency range
- Need to adapt the absorption spectrum to the emission spectrum

OBJECTIVE

Improve our general understanding of relationships between microstructure and acoustic macro-behavior of porous media, see Fig. 1.

RESULTS SUMMARY

➢ For a given fiber radius, an optimal throat size controlling the sound absorption level can be found, corresponding to an intermediate resistivity

➢ Given an optimal throat size, the fiber radius essentially modulates the absorption curve

➢ The optimal absorption curve minimizes the viscous characteristic length at constant throat size (design guide)

➢ Practical investigation charts proposed to indicate local geometry parameters tending to maximize the sound absorption coefficient (validity corroborated by comparison with measured local geometry parameters)

PERSPECTIVES

➢ Optimization of real porous materials based on specific industrial fabrication processes

➢ Use molecular dynamics to tackle physical acoustics of nano-porous materials

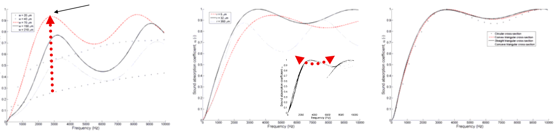
Results

An optimal throat size controlling the sound absorption level can be found

The fiber radius (i.e. cell size) essentially « modulates » the absorption spectrum

Weight reduction

Intermediate resistivity: $28 < \sigma < 75$ k N.m^{-4}.s



- ***r = cste ~ 200 μm***
- ***w_{opt} = 70 μm determined by an iteration process***

- ***$w = w_{opt}$***
- ***r varied to find the optimum***
- ***r_{opt} = 32 μm***
- ***↓ Λ and Λ'***

- ***w_{opt} and r_{opt} a priori fixed***
- ***triangular cs inscribed in circular ones***
- ***Λ' = cste, ↓ Λ***

Fig 3. Throat size (left), fiber radius (center), and cross-section shape (right) effects.

This section reports and quantifies differences obtained with the simplified and refined models, see Fig. 4.

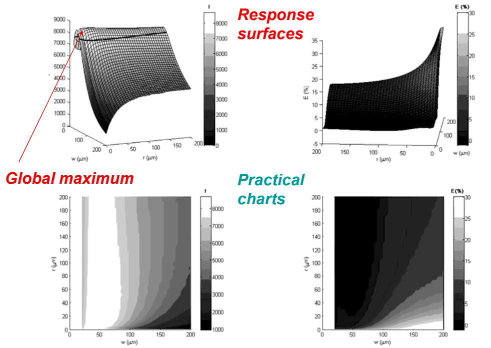


Fig 4. Response surface of the performance index I representing the area under the sound absorption curve in the frequency range 0 - 10 000 Hz for varying (w-throat size, r-fiber radius) couples (top-left); and associated 2D practical chart (bottom-left). Response surfaces of the error E made on I when using the simplified model instead of the refined one (top-right); and corresponding practical chart (bottom-right).

Concluding Remarks

The optimal microstructural configuration is correctly estimated from a simplified model with only 3% of uncertainty on the global performances.

However, for very diluted (large porosities) porous structures, the simplified model underestimates significantly the material performances with uncertainties reaching up to 30%.

Moreover, in this limit, where the best absorbing structure may lie, the physics have to be reconsidered (because both the nonslip conditions for velocity and temperature loose their physical justifications).

More sophisticated computational methods such as molecular dynamics will be considered to tackle physical acoustics of nano-porous materials as a future work.

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