Rapid additive manufacturing of optimised anisotropic metaporous surfaces for broadband absorption

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Porous materials and metamaterials play a key role in sound absorbing and insulation solutions in acoustics. With the growing interest in additive manufacturing techniques, recent work has focused on the printing of porous and resonant structures for acoustic purposes. Usual metaporous surfaces/interfaces are generally built by periodically inserting resonant elements in an existing porous layer. This complex manufacturing process can be significantly simplified by using additive manufacturing techniques, which also eases the design and optimisation of the metaporous surface. In this work, the acoustic properties of the metaporous surface are controlled by simple geometric parameters defining both the anisotropic porous layer and the shapes of the resonators. Hence, we focus on optimising split-ring resonators embedded in a micro-treillis porous layer, which are built in a single part using additive manufacturing techniques. A finite-element method together with the Bloch wave decomposition provides a numerical model used to predict the reflection and absorption coefficients under normal incidence. The geometric parameters of the anisotropic metaporous surface are then optimised by non-linear minimisation techniques to maximise acoustic absorption. An optimal metaporous surface is 3D printed by fused-deposition modeling and its acoustic properties are measured in an impedance tube. The measurements are in good agreement with the predicted optimal broadband absorption coefficient. This work demonstrates the benefits of additive manufacturing for designing metaporous acoustic surfaces.

1 Optimal design

Porous materials and metamaterials are commonly used in acoustics, for absorption and insulation purposes[1, 2, 4, 3]. In this work, we propose an optimal design of resonant metaporous surface for acoustic absorption purposes. The design of the metaporous surface consists in acoustically rigid 2D split-ring resonators (SRR) periodically embedded in a transverse isotropic porous material, as in Figure 1. By tuning the macro-geometry of rigid resonators as well as the micro-geometry of the porous medium, we maximise the absorption in the frequency range between 1 and 4 kHz for a material thickness of 25 mm. The metaporous surface provides strong broadband absorption capabilities and subwavelength quasi-perfect absorption.

In order to optimise the geometric parameters of the metaporous surface, a constrained non-linear minimisation routine is employed. We jointly optimise the micro- and macro-geometry of the metaporous surface using the Nelder-Mead method [5, 6]. In order to do so, we define a cost function that translates how far the current vector of parameters is from the optimal value $\alpha = 1$. The acoustic absorption coefficient is maximised when the cost function gets closer to zero. The cost function is the arithmetic average of the absorption within $f_{\min} = 1000\,\mathrm{Hz}$ and $f_{\max} = 4000\,\mathrm{Hz}$, with $N_{\mathrm{f}} = 10$, the number of frequencies.

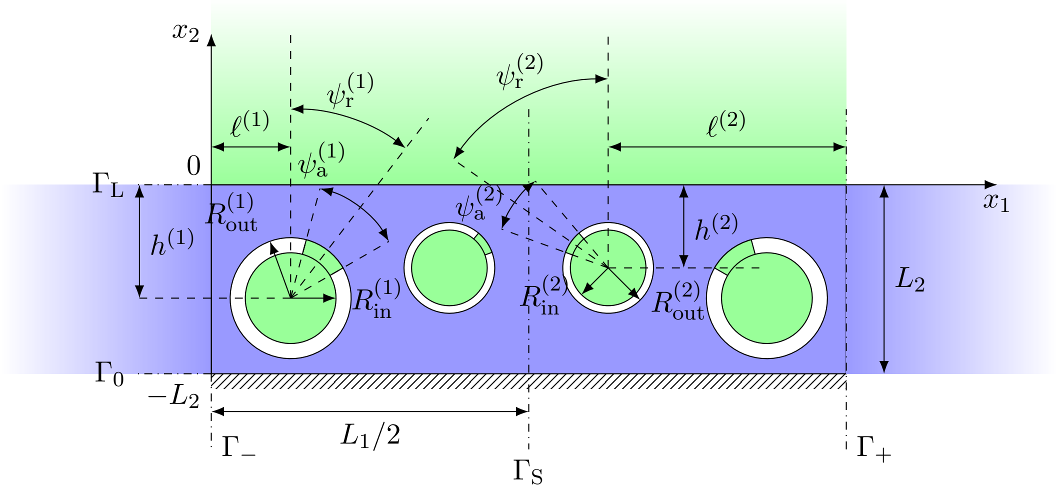

Figure 1: Geometry of the metaporous surface.

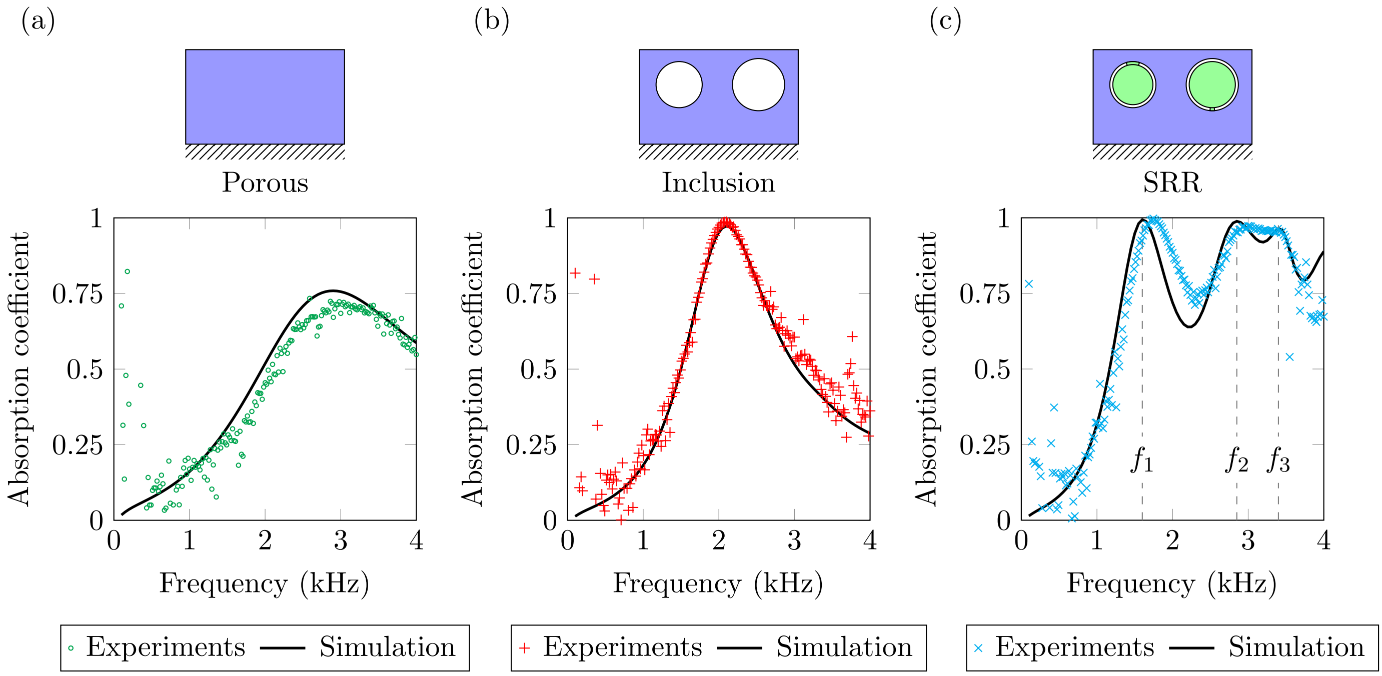

Figure 2: Experimental and predicted results.

2 Conclusions

The numerical simulations based on FEM provide a predictive model for the reflection and absorption coefficients. This predictive model is used in the cost function for the minimisation algorithm, whose goal is to maximise the absorption in the target frequency range. Experiments have been conducted in an impedance tube with a square cross section. They provide a validation of the numerical model, as the experimental data are in good agreement with the simulated results. Additive manufacturing techniques have proved their ability to build resonant metaporous surfaces. The present work demonstrates the capabilities of metaporous surfaces for absorbing sound waves, and highlights the use of additive manufacturing for such acoustic treatments. While the design and manufacturing of materials incorporating inclusions is usually tedious, the solutions presented here are fabricated in a single stage. In addition to offering a solution that is easy and quick to implement, this first prototype was developed at low cost. Finally, the optimisation of the shape and number of inclusions could offer more possibilities regarding the compromise between structural dimensions and absorption capabilities.

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