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A. Duval[1], M. T. Hoang[1], V. Marcel[1], C. Perrot[2]

[1]Faurecia Interior Systems, Acoustic TechCenter, Z.I. François Sommer BP 13,
08210 Mouzon, France
[2]Université Paris-Est, Laboratoire Modélisation et Simulation Multi Echelle,
MSME UMR 8208 CNRS, 5 bd Descartes, 77454 Marne-la-Vallée, France

This extended abstract illustrate results examining how, on two case studies, sound absorbing and sound insulating properties of a real foam sample can significantly be improved via cellular structure in the audible frequency range; yielding to an increase of the sound absorption in the middle frequency range, and an increment of the sound transmission loss of 2 dB from 0.5 to 10 kHz. Starting from typical poroelastic parameters of the foam, numerical experiments are leading to the definition of two different sets of poroelastic parameters at macro-scale which represent reachable near optimal targets for absorption and insulation noise treatments. From literature analysis and numerical homogenization techniques, three key levers were identified to translate the targeted set of poroelastic parameters into feasible cellular structures: i) a homothetic reduction of the cell size; ii) an increase in the closure rate of the membranes; iii) and a decrease in the Young's modulus of the base material. Experimental data of the foams as manufactured are shown to compare fairly well with computational results. Further recommendations are given to improve the design of the cellular lightweight structures.

1 Introduction

The purpose of this extended abstract is to illustrate how novel procedures typically based on bottom-up approaches for microstructure optimization of sound proofing materials [1, 2] can readily serve as a support to the development of acoustically effective foams in an industrial context. This applied acoustics work in noise control engineering adds to the knowledge basis by linking effective sets of poroelastic parameters to morphological data at the pore size level that help to develop innovative foams. Two case studies are discussed through typical sound absorption and insulation problems, giving examples that could help others deal with similar cases. The main insights resulting from this applied work are essentially twofold. (i) A required increase in both resistivity and tortuosity identified at macro-scale for improving significantly the middle frequency sound absorption performance of standard foam can be achieved through membrane effects. (ii) A required increase in resistivity is obtainable thanks to a homothetic reduction of the size of open-cell foam, and can also be achieved through membrane effect. Its combination with a reduction of the skeleton's Young modulus - chemically tuned by the number of urethane bounds - lead to a + 2 dB insertion loss performance in the [500 Hz - 10 kHz] frequency range, when compared to the same initial standard foam.

2 Cellular structures recommendations

In response to this analysis, the following recommendations were made, for the sound insulating and sound absorbing foams respectively [Figure 1]: 1) the aspect ratio $L/2r$ of the periodic unit cells (PUCs) should be larger (resp. smaller) and in the order of 4.0 to reach a porosity around 0.95; 2) its closure rate of membranes δ/δ_{max}, that is to say a relative measure of the interconnection size between pores, should be slightly lower (resp. higher) and around 0.55 (resp. 1) to limit the tortuosity below 1.3 (resp. 2); 3) the actual pore size equal to 407 µm (resp. 520 µm) must be significantly reduced (resp. slightly increased) down to 315 µm (resp. up to 573 µm) to provide a higher resistivity (40 000 $N.m^{-4}.s$) combined with the targeted tortuosities; 4) the Young's modulus of the base material should ideally be around 2.3 MPa which is typically the lower bound for polymeric materials (with a Poisson's ratio of 0.25); and 5) the production processes should aim at reducing as much as possible the skin and gradient effects (thanks to a better control of mold temperatures).

3 Conclusion

As illustrated briefly throughout this extended abstract, a cellular structure was used as a lever for the development of acoustically effective foams with improved sound absorbing and sound insulating properties, and recommendations were made to guide the manufacturing of future foams, thanks to previously identified feasible morphological changes. This success with a three-dimensional periodic unit-cell based method, including membrane and elastic effects, confirm the accuracy and reliability of micro-macro approaches for computing acoustic properties of low-density reticulated foams and indicate that they are also crucial for designing the new generation of acoustic materials, thanks to an enhanced cooperation with chemists.

References

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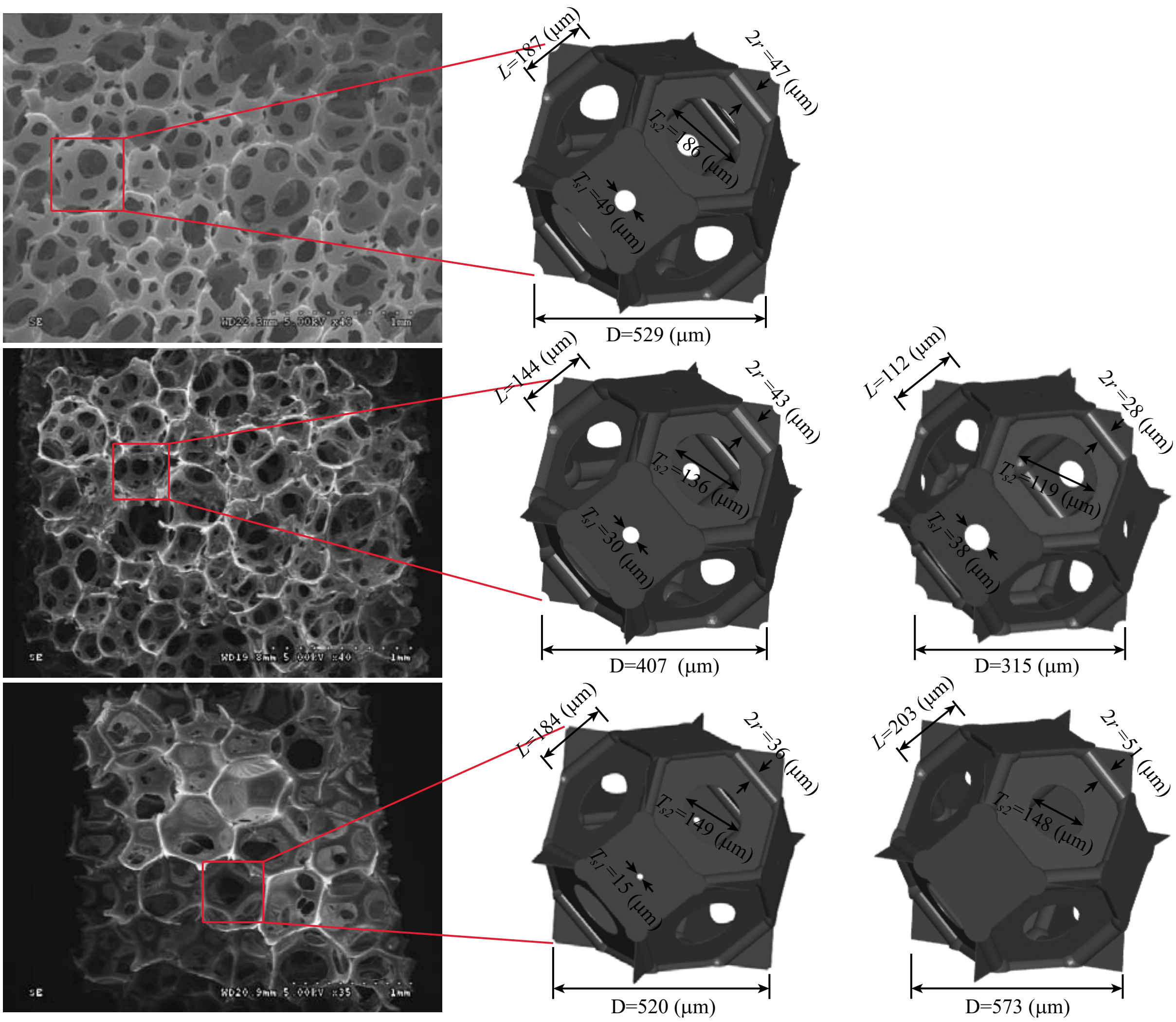

Figure 1 : Cellular structure modifications: (upper) H_0 standard, (central) H_{1b} sound insulating, and (lower) H_{2b} sound absorbing foams. Scanning electron micrographs (left), identification of the local characteristic lengths corresponding to the foams as manufactured (middle), and recommended feasible cellular designs to produce the targeted sets of poroelastic parameters (right).