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ACOUSTIC MODELLING OF MATERIAL OBTAINED BY ADDITIVE MANUFACTURING PLACED IN THE WALL OF A DUCT.

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ABSTRACT

The objective of this study is to model and characterize the behaviour of different materials made with 3D printing when they are placed in the wall of a duct. The considered materials present a periodic structure of a volume linked to the volumes of other cells by small channels. Cubic and spherical volumes are used. Two model of the materials are studied. The first is based on a macroscopic description using an equivalent fluid by its dynamic characteristic functions. The semi-phenomenological parameters of the JCALP model are obtained using a hybrid multi-scale approach. The second model consists in describing the material as a whole at the microscopic scale and solving the Linearized Navier- Stokes equations in the material. The results of the two models are compared in normal incidence and in a duct wall. The behavior of the various materials is also investigated experimentally. Measurements at normal incidence are conducted in a circular Kundt Tube. The measurements in the wall of a duct are performed in the MATISSE experimental bench. The experimental and model results show a correct agreement. Finally, the potential differences between the model and the experiment are discussed.

Keywords: *3D Printed, absorbing material, duct wall*

1. INTRODUCTION

With the outbreak of the 3D printing technique, the opportunity to design absorbing material for specific applications has generated increasing interest. Among the possible realisations, the focus of this work is put on open porosity designs realised by a network of cells linked to each others. This implies an acoustic behaviour supposed as an extended reaction in opposition with tuned Helmholtz resonators or other labyrinthine structure showing a local response. It is thus false to model such geometries by surface impedance [1]. The aim of this work is to evaluate the ability of a macroscopic modelling to predict the acoustic behaviour of different structures in simple or more complex cases, thereby paving the way of a geometry optimisation.

The different geometries are detailed in Sec. 2. Then the modelling techniques are presented in Sec. 3. The acoustic performances are first compared with the prediction in normal incidence in Sec. 4. The predictions of the performance in the wall of a duct are then discussed in Sec. 5. Finally, the conclusions are presented, and some optimisation leads are mentioned.

2. GEOMETRIES PRESENTATION

The basic geometry, named One Pore Cell (OPC), is inspired by the round robin study [2] presented by Zielinski et al.. The geometry is composed of the repetition of cubic cells made of a central cavity (spherical or cubic) connected to the cavities of adjacent cells by cylindrical channels. For the OPC geometry (Fig. 1a), the cell size is $a = 9\,\mathrm{mm}$, the diameter of the sphere is $d = 8\,\mathrm{mm}$ and the diameter of the channel is $w = 1.5\,\mathrm{mm}$. For the cubic

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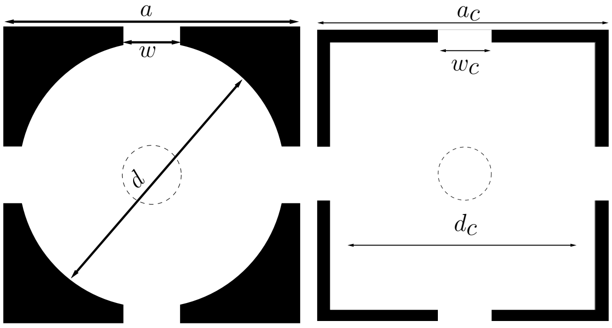
geometry (Fig. 1b), the cell size is $a_c = 9\,\mathrm{mm}$, the size of the cube is $d_c = 8\,\mathrm{mm}$ and the diameter of the channel is $w_c = 1.5\,\mathrm{mm}$.

The work of the round robin study aimed at studying the impact of different printing techniques on the acoustic performances. The conclusion of their study and previous results leads to the choice of the stereolithography technique and an adapted resin to realize more reliable samples.

The geometrical change implies thinner wall for cubic geometry, and a whole sample less massive. This results in a more fragile sample and can lead to realisation difficulties.



(a) (b)

Figure 1: Unit cell of the two designs (a) OPC and (b) cubic geometry

3. NUMERICAL METHOD

In order to achieve optimisation, one should be able to model the sample designs efficiently and adjust the parameters to the targeted absorption. For that purpose, the modelling technique used to predict the acoustic behaviour of the samples is based on an equivalent fluid approach. Following the hybrid multiscale methodology detailed in Zielinski et al. [3] and based on Boutin [4] the 8 parameters of the Jonhson Champoux Allard Pride Lafarge (JCAPL) model are determined from the geometry of the elementary cell of the material. The sample is then modelled analytically for the normal incidence case, and with finite elements for the duct wall case. The commercial software COMSOL® is used for all the calculations. The implementation of this methodology has been previously validated by comparing the results at normal incidence and on a duct wall with ones obtained with a direct numerical simulation solving Navier-Stokes Linearised equations (NSL) [1]. The fluid equivalent approach saves a large amount of computation resources. For example, the calculation on the wall of a duct solving NSL takes around 24 hours on a cluster, using 6 nodes of 32 cores with a total of 1.08 TB of memory. The same case using the hybrid multiscale methodology requires 6 minutes on a local workstation (7 cores and 32 GB) to obtain the JCALP parameters, and another 10 minutes to solve the case on the duct wall.

As detailed in [5], the dimensions of the cells were measured for several printed samples. The measured values are slightly different from the design values and shows a noticeable variability. The observed dimension variability is responsible for a variation of the acoustic performances. Thus, for this present study, the model results are obtained with corrected dimensions which are averaged from measurements. The parameters of the JCAPL model are presented for the two geometries in Tab.1. One can note that the porosity and the tortuosity are greater in the cubic geometry than in the OPC geometry.

4. RESULTS AT NORMAL INCIDENCE

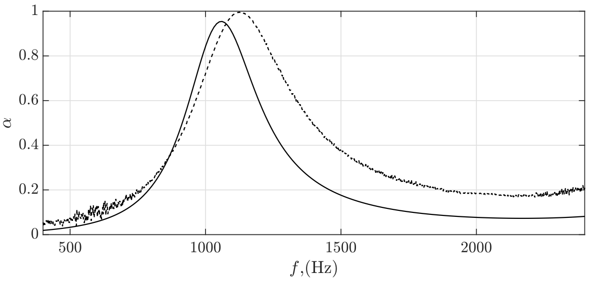
The results at normal incidence are presented in terms of acoustic absorption. Fig.2 shows the absorption coefficient of the OPC and cubic geometry determined from the measurements and the numerical model. The two predictions show quite a good agreement with the experimental data. As mentioned above, the increase in tortuosity in cubic geometry leads to a shift of the absorption peaks towards the low frequencies. The usual reduction in the absorption band observed in such cases seems to be compensated by the increase in porosity.

5. RESULTS ON THE WALL OF A DUCT

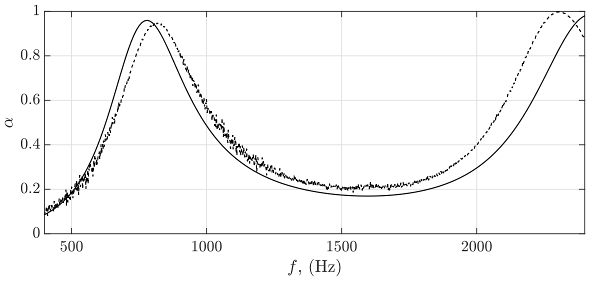
Fig. 3 shows a sketch of the set-up used to evaluate the performance of the materials on the wall of a duct. The duct has a square section of 66 mm on the wall of which samples of 31.5 mm thickness and 150 mm length are placed. The transmission loss is used to characterise the performance of the material. It is defined as the ratio of the incident power to the transmitted power. In Fig.4 the results are presented for the OPC and cubic geometries, comparing the model with the experimental results. For the OPC case, the frequency of the absorption peak is well predict. The performance differences between the model and experimental results for the OPC geometry are proba-

Table 1: Obtained JCAPL parameters for OPC and cubic geometry

Parameters	**OPC**	**Cubic**
Porosity, Φ	0.371	0.727
Viscous length, Λ_v	6.913×10^{-4} m	3.086×10^{-4} m
Kinematic Tortuosity, α_∞	5.642	9.833
Viscous permeability, K_0	4.340×10^{-9} m²	4.364×10^{-9} m²
Viscous static tortuosity, α_{0v}	8.037	14.689
Thermal length, Λ_{th}	2.643×10^{-3} m	1.419×10^{-3} m
Thermal permeability, θ_0	3.941×10^{-7} m²	9.667×10^{-7} m²
Thermal static tortuosity, α_{0th}	1.440	1.533



(a) OPC design



(b) Cubic design

Figure 2: Absorption for the prediction (——) and the measurement (- - -)

bly linked with leakage around the sample. As for normal incidence, the absorption peak with the cubic geometry is achieved at a lower frequency according to both model and experiment. The model and the experiment shows a better agreement for the case of the cubic geometry in terms of performance. The OPC geometry could be more sensitive to leakage due to the low porosity.

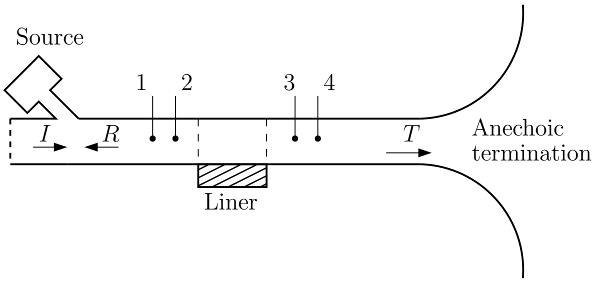


Figure 3: Sketch of the lined duct used in the experiments

6. CONCLUSION

3D printed absorbing samples have been considered. Two different design have been studied. The hybrid multiscale methodology has been used to identify the JCAPL parameters for both geometry. The prediction obtained with this methodology at normal incidence shows good agreement against measurments. The difference of acoustic behaviour between the two geometries is explained in comparison with the calculated JCAPL parameters. Finally, the acoustic performance of the two geometries on the wall of a duct is studied. The absorption achieved by the two geometry are compared with the prediction. The frequency of the absorption peak is well predict. The observed differences between the model and the experiment are mainly due to the experimental realisation. As a perspective, further optimisation will be studied, for instance a double nested network of cells is under investigation.

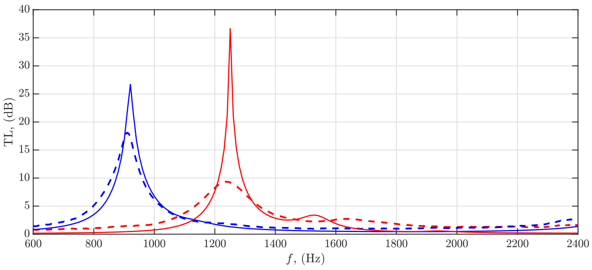


Figure 4: Transmission Loss for (red) OPC and (blue) cubic geometries : (solid line) numerical model and (dashed) experimental results.

7. ACKNOWLEDGMENTS

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