INFLUENCE OF MICRO-STRUCTURAL PROPERTIES ON THE ACOUSTIC PERFORMANCES OF NOVEL METALLIC FOAMS

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1. INTRODUCTION

Smart design of acoustic materials is fast becoming one of the main research interest of the acoustic community. This is a necessary step in order to develop new and more efficient sound absorbing materials for tomorrow's applications. Two main approaches can be used to achieve this goal: a microscopic approach and macroscopic one. The microscopic approach consist in developing an acoustic wave propagation model which is directly based on the microstructure of the given material. The macroscopic approach involves establishing links, through either analytical or empirical methods, between the micro-structural properties of porous materials and their macroscopic acoustic properties. Once these links have been established, they are substituted in the macroscopic models and the necessary tools for optimizing the microstructure of an acoustic material are then available. In both approaches, the ability to produce the porous materials with the desired micro-structural properties is also an important part of this equation.

The materials evaluated in this study are newly developed metallic foams having an interesting combination of properties, including good sound absorption qualities [1, 2]. A distinctive feature of the process is its ability to control some of the foam's final micro-structural properties such as the average pore D_p and window D_w diameters. With such a process, the concept of smart design of acoustical materials can be deemed attainable. The main objective of the work presented here is to establish links between the micro-structural properties of the metal foams and their acoustic properties and to then study the influence of the micro-structural properties on the acoustic performances.

Some models correlate wave propagation in porous media with some micro-structural parameters. Usually, they are only valid for simple pore geometries: cylindrical pores with constant circular, rectangular, triangular or slit section. More general models developed by Johnson et al. and by Champoux and Allard [3, 4] are valid for a wide range of porous materials with arbitrary pore geometry. They introduced two parameters, the viscous Λ and thermal Λ' characteristic lengths that are known to represent, from a macroscopic point of view, the radius of the small and large pores respectively [3, 4]. Generally speaking, these models are semi-phenomenological models and are not truly based on the microstructure of the studied materials. In 1999, Wang and Lu [5, 6] developed an analytical model for an acoustic material having an honeycomb structure. They optimized the microstructure of the material in order to maximize its acoustic sound absorption. In 2000, Lu et al [7] develop a theory based on the acoustic impedance of circular openings and of cylindrical cavities to model the acoustical behavior of an aluminum foam having this type of microstructure. They completed a parametric study to identify the influence of the micro-structural properties on the sound absorption of the foam and then identified an optimal pore size.

The approach of developing a micro-structural model for a new type of material is quite interesting, but can be difficult for complex microstructure geometries. Hence, as a first step, the approach that will be used here is based on linking the acoustic parameters of the Johnson-Champoux-Allard models, mainly the viscous Λ and thermal Λ' characteristic lengths, to the window and pore diameters of the metallic foams. This should lead to the development of a semi-phenomenological model which takes micro-structural properties as input parameters. Such a model will allow for the study of the influence of micro-structural properties on the acoustical performances of the metal foams.

2. MATERIAL CHARACTERIZATION

For the purpose of this research, five different metallic foams were produced. Various manufacturing parameters were used to obtain materials with different pore size distributions and densities. In the end, four disk shaped samples (diameter of 29 mm and thickness of 10 mm) were made for each metallic foam.

2.2 Micro-structural properties

The micro-structural analysis of the metallic foams was done measuring the pores and windows on micrographs taken with a SEM (model JEOL JSM-6100). The pore D_p and window D_w diameters were evaluated by image analysis on the digitalized SEM micrographs. The windows are defined here as the opening between two adjacent pores.

Each pore and window micrographs are taken at 20X and 50X magnification respectively. The large and small diagonals of the pores and windows were measured using an image analysis software. It is important to point out that windows smaller that 10 μm are not taken into account in the measurements, since they are too small to be measured on a 50X micrograph. The average pore and window diameter measurements are presented in Table 1.

Table 1. Comparison of acoustic and SEM measurements

	Window		Pore	
Metal foam	2Λ (μm)	D_w (μm)	$2\Lambda'$ (μm)	D_p (μm)
A	87	92	357	363
B	74	91	297	305
C	83	101	384	389
D	47	83	238	256
E	77	103	667	676

2.2 Macroscopic acoustic properties

The viscous Λ and thermal Λ' characteristic lengths of the 5 metallic foams are also presented in Table 1. All measurements described here were performed on all four samples of each metallic foam. The viscous and thermal lengths were measured using an acoustical [8] method. The mechanical properties of the metallic foams (E, ν, and η) were not measured here since the rigid frame hypothesis was used to model the acoustic behavior of the foams. The metallic nature of the frame justifies the use of this hypothesis.

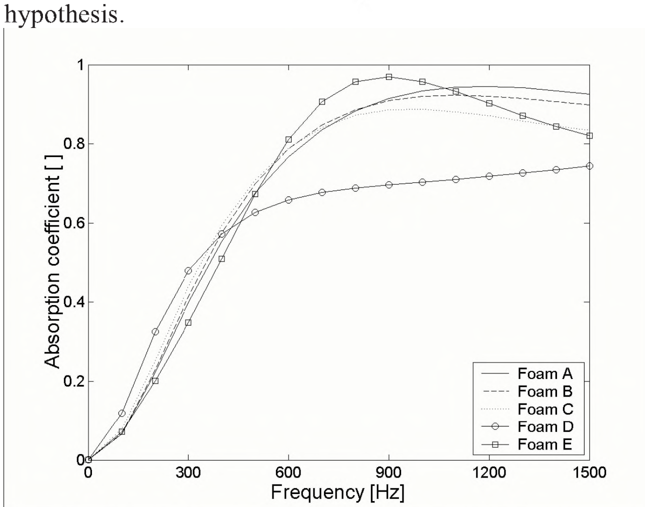

Figure 1. Absorption coefficient for the 5 metal foams with a thickness of 50 mm.

3. RESULTS

The agreement between the measured average pore diameter D_p and $2\Lambda'$ is good for all five metallic foams. This confirms that the thermal characteristic length is equivalent to the pore radius. As for the viscous characteristic length Λ, the agreement is initially not as convincing: Λ is smaller that the average window radius $D_w/2$. This result was nevertheless expected. Since windows smaller than 10 μm are not considered in the measurement of D_w, it is reasonable to assume that the actual average window diameter is smaller that the one measured.

Figure 1 presents the absorption coefficient for the 5 metallic foams with a thickness of 50 mm. As it can be seen, the metal foam with the smallest pore diameter, material D, is clearly the less effective from an acoustical point of view. As for the material with the largest pore diameter, material E, it presents the highest absorption peak of all 5 foams.

4. CONCLUSION

It has been shown that a direct link exists between the thermal characteristic length Λ' of the Johnson-Champoux-Allard model and the average pore diameter D_p ($\Lambda' \approx D_p/2$) and between the viscous characteristic length Λ and the average window diameter D_w ($\Lambda \approx D_w/2$) in the studied open-cell metallic foams. By introducing these relations in the Johnson-Champoux-Allard model, it becomes possible to asses the influence of the pore and window diameters on the acoustical performances of the foam and hence, identity the optimal microstructure. Considering that the metal foam production process used allows a good control of the final micro-structural properties, smart design of acoustical materials, namely optimization of the microstructure to obtain specific acoustical performances, can be deemed attainable with these new materials.

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