EFFECT OF VARIABILITY IN MICRO-GEOMETRY OF POLYURETHANE FOAMS ON THE DOUBLE WALL TRANSMISSION LOSS

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1 Introduction

Propagation of waves in elastic porous media, e.g. polymeric foams, is described by Biot-Allard's theory [1]. Two classes of characteristic parameters are needed to describe the porous media in this theory. First, non-acoustic parameters: porosity ϕ, thermal characteristic length Λ', viscous characteristic length Λ, flow resistivity σ, and tortuosity α_∞ which are used in Johnson-Champoux-Allard (JCA) semi-phenomenological model [1]. Second, mechanical parameters, which in the case of isotropic material, are: bulk density ρ, Young's modulus E, loss factor η, and Poisson coefficient ν. The mechanical and non-acoustical properties are inherently dependent on the micro-structure of these materials. But, the internal structure of most porous material, e.g. polyurethane (PU) foam, is too complicated to be studied quantitatively. Therefore, the lattice of PU foams with low relative density (ρ_r) is commonly idealized by a tetrakaidecahedral, periodic unit cell (called PUC) and the macroscopic behavior recovered from a dedicated micro-macro approach. Furthermore, the cell windows can be randomly or partially closed, and cells are elongated in the rise direction. Measurements of such lattice results in variability in micro-structure properties of PUC. Hence, a clear understanding of the impact of variability associated with micro-structure properties measurement, and macroscopic Biot's parameters on vibro-acoustical performance of PU foams is of great importance in the design and optimization of such foams.

The impact of microstructure variability on JCA non-acoustical parameters and sound absorption was investigated by Doutres *et. al* [2]. This paper build on this work by investigating (i) the effect of the microstructure variability on the elastic properties of the foams and (ii) on the transmission loss of the foam when coupled with an elastic system (a double wall system is studied here). In this regard, a global sensitivity analysis (the FAST method) is applied to the micro-macro based models presented by Doutres *et. al* [3] and Gholami *et. al* [4]. The former model links the microstructure properties of PUC (thickness and length of struts, and the closed windows content) of polyurethane foams to their non-acoustical parameters of JCA model. While, the latter model correlates the micro-structure properties and membrane thickness of PU foam to the Young's modulus in Biot-Allard's model.

2 Methodology

2.1 The micro-macro model

The microstructure and non-acoustical properties of PU foams are linked using microstructural based models [3]. Gong's [5] analytical correlation between Young's modulus and micro-structure of fully reticulated PU foam was modified by Gholami *et. al* [4], numerically, to add the effect of closed pore content and membrane thickness on the Young's modulus:

$$\left(\frac{E}{E_s}\right)_{R_w} = C_E\left(1-Rw\right)^{1.4} + \left(\frac{E}{E_s}\right)_{R_w=1}. \quad (1)$$

where $C_E = 0.0017$ when memebrane thickness is $2.1\mu m$, and $(E/E_s)_{R_w=1}$ is the relative Young's modulus of fully reticulated PU foam [5].

2.2 Sensitivity Analysis Method

The contribution of input parameters on the output, in variance based techniques, is investigated by quantifying the impact of input variation on the output variance. A global sensitivity analysis method is used to determine the output sensitivity when the inputs vary over wide ranges. The FAST method is an efficient technique to explore the n-dimensional space of inputs [6]. FAST is used to estimate the first sensitivity index $SI(i)$ (which is the main effect of parameter i), and to calculate the total sensitivity index TSI which is defined as the sum of all SIs. The ratio of standard deviation to the mean of output, namely Normalized Standard Deviation (NSD) is an efficient indicator that shows the level of variability of the feature of interest [6].

2.3 Description of vibro-acoustic systems

As shown in Fig. 1, $15mm$ PU foam is bonded to the excited, $1mm$ steel plate. The foam is relaxed from a $2mm$ heavy layer (septum) by adding a $5mm$ air space. Decoupling the heavy mass from PU foam by air-gap allows us to account, at the same time, for absorption and isolation problem. Laterally infinite considered system is excited acoustically by an oblique plane wave. The transmission loss is calculated using transfer matrix method [1].

3 Results

3.1 Variability in PUC and Biot'a properties

Two studies are performed in this section. First, the impact of variability in PUC properties of two representative foams, $V1$ and $V2$ (see Table 1), are studied. $V1$ is considered to present a highly reticulated foams and $V2$ contains a low content of

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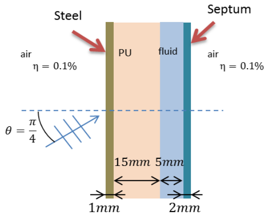

Figure 1: Vibro-acoustic configuration of double-wall system.

opened windows. The variability in the PUC is set to 10%. In the second study, the impact of variability in Biot-Allard's parameter (see Table 2), plate properties, and mass layer on the TL is studied. The impact of variation in PUC properties of $V1$ and $V2$ are shown in Fig. 2. It is shown that strut length is main parameter for $V1$. While, the reticulation rate is the dominant parameter for $V2$ mainly at double wall frequency, frame born resonance and at high frequency in the cavity absorption region. The contribution of macroscopic parameters of vibro-acoustic system on TL are shown in Fig. 3. As expected the mass of plate and septum are the dominant parameter at low frequency. However, tortuosity and flow resistivity are dominant at high frequency in the cavity absorption controlled region where the performance of the foam is important. Mechanical properties of the foam are important at the frame resonance of of the foam.

Foam	$t \times 10^{-6}(m)$	$l \times 10^{-6}(m)$	$R_w(\%)$
$V1$	$[51.3,\ 62.7]$	$[157.9,\ 192.5]$	$[70,\ 90]$
$V2$	$[51.3,\ 62.7]$	$[157.9,\ 192.5]$	$[10,\ 30]$

Table 1: Inferior and superior limits for microstructure properties.

Parameters	Inferior limit	Superior limit
$\phi(-)$	0.95	0.98
$\sigma(N.s.m^{-4})$	5,000	40,000
$\alpha_\infty(-)$	1.05	2.00
$\Lambda(mm)$	0.041	0.205
$\Lambda'(mm)$	0.190	0.319
$E(kPa)$	320	480
$\nu(-)$	0.3	0.4
$\rho(kgm^{-3})$	22	27
$\eta(-)$	0.1	0.15
$\rho_{Septum}(kgm^{-2})$	4	6
$\rho_{Al}(kgm^{-3})$	2605	2879
$E_{Al}(GPa)$	65.55	72.45

Table 2: Inferior and superior limits for Biot's properties.

4 Conclusions

The impacts of PU foam microstructure variability and macroscopic properties on the TL of a laterally infinite double wall system are studied. It is shown that the impact of strut length is dominant where foam is highly reticulated. While, the reticulation rate takes the lead when close pore content is high. Therefore, measuring precisely these parameters helps to reduce uncertainty in TL prediction of such a system. It should be mentioned that, for macroscopic properties, septum mass and plate are important at low frequencies, mechanical properties of the foam are dominant at foam resonance and non acoustical properties are important at high frequency.

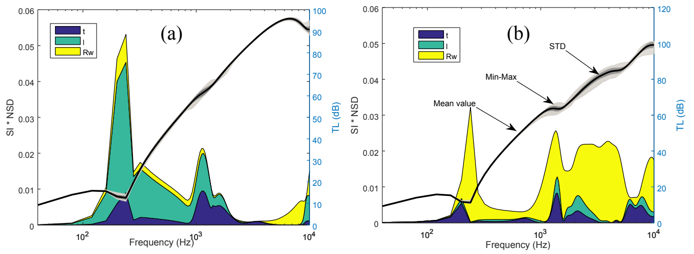

Figure 2: PUC variability impact on TL foam. a) V1, b) V2.

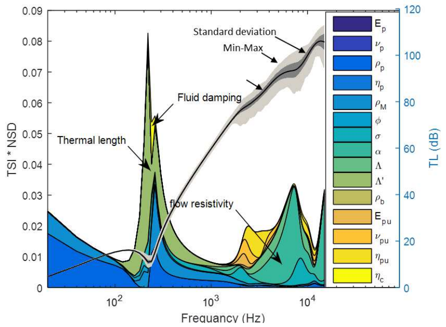

Figure 3: Macroscopic properties variability impact on TL.

Acknowledgments

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for providing financial support, and to gratefully acknowledge Dr. Morvan Ouisse for his kind generous support on the sensitivity analysis section.

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