AN INDEX OF HETEROGENEITY OF SOUND ABSORBING POROUS MATERIALS

Yacoubou SALISSOU and Raymond PANNETON
GAUS, Department of mechanical engineering, Université de Sherbrooke, Québec, Canada, J1K 2R1
Yacoubou.Salissou@USherbrooke.ca, Raymond.Panneton@USherbrooke.ca

1. INTRODUCTION

Important intrinsic properties of a sound absorbing porous material are its characteristic impedance, complex wave number, dynamic density, and dynamic bulk modulus. The latter two dynamic properties are of utmost importance when modeling a porous material as an equivalent fluid. Acoustical methods have been developed for measuring these dynamic properties. The traditional standing wave method[1] was the first proposed. Nowadays, the two-cavity method by Utsuno *et al.*[2], the three-microphone method by Iwase *et al.*[3], and the transfer matrix method by Song and Bolton[4] are commonly used. However, some issues remain unsolved. In fact, all the aforementioned methods assume through-thickness homogeneity (TTH or symmetry) of the porous medium. Unfortunately, there exists no mean of quantifying simply the TTH of porous material.

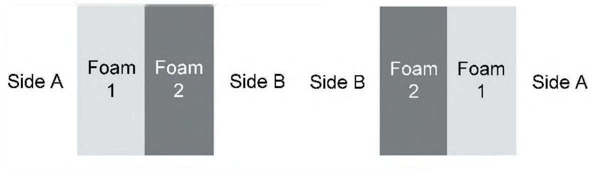
In this paper, an index of heterogeneity is worked out and discussed. The calculation of this TTH index only requires impedance tube measurements (ASTM E1050, ISO 10534) of the acoustical surface impedance on both faces of the tested material backed by the rigid termination of the tube. To verify the validity of this TTH index, a two-layer rigid frame porous system representing a single porous layer with a sudden change in its physical properties is studied. Following the two-cavity method, the sound absorption coefficient, complex wave number, and characteristic impedance of this equivalent single layer are computed in the normal and inverted positions (i.e., when both sides of the material are facing successively the incident wave).

2. WHY AN INDEX OF HETEROGENEITY?

We restrict our analysis to the potential impact of the TTH on the normal acoustical surface impedance. The analysis may easily be extended to other bulk properties. For the composite material shown in Fig. 1, let Z_{AB} be the normal acoustic surface impedance of the composite layer backed by a rigid wall with side A facing the incident sound wave, and Z_{BA} the normal acoustic surface impedance when side B is facing the incident sound wave. For a homogeneous medium, Z_{AB} is equal to Z_{BA} ; *a priori*, this is not the case for a heterogeneous medium. The question arising from this is, *where does homogeneity stop?*

Table 1: Foam parameters used for the composite samples

Property (symbol)	Foam1	Foam2	Foam3	Foam4	Units
Porosity (Φ)	0.97	0.96	0.90	0.99	
Static airflow resistivity (σ)	87 000	86 900	15843	10 900	Ns/m^4
Tortuosity (α_∞)	2.52	2.32	1.32	1.02	
Viscous characteristic length (Λ)	37	29	83	100	μm
Thermal characteristic length (Λ')	119	112	132	130	μm
Static thermal permeability (k'_o)	0.004	0.003	0.002	0.002	mm^2
Thickness	25	15	10	50	mm



(a) Configuration 1 (b) Configuration 2

Figure 1: Composite porous sample made up from two porous layers. (a) Configuration 1 or "Normal configuration" when side A is facing the incident sound wave. (b) Configuration 2 or "inverted configuration" when side B is facing the incident sound wave

Let us consider three motionless frame porous composite samples, each made up as shown in Fig. 1. The Johnson-Lafarge macroscopic parameters[5,6] and the dimensions of the foams used in the composites are given in Table 1. The three samples S1, S2 and S3 are respectively made from foam1/foam2, foam3/foam4, and foam1/foam4. The bulk dynamic properties of these samples have been simulated using the two-cavity method. Simulations were made for both normal and inverted configurations. From results shown in Figs. 2 and 3, it is obvious that sample 3 is heterogeneous, and sample 1 homogeneous (sample 1 is not shown since results for both configurations overlap). On the other hand, the answer is less obvious for sample 2. Indeed, comparing its absorption coefficients suggests assuming this material homogeneous. However, characteristic impedance curves seem to yield different conclusion, considering their deviations.

3. AN INDEX OF HETEROGENEITY

The heterogeneity of a material can be quantified by the average relative standard deviation (ARSD) of a bulk property measured respectively in both normal and inverted configurations. For a bulk property *P*, the ARSD writes,

Table 2: Bulk property ARSDs of the three composite samples

	Sample 1	Sample 2	Sample 3
ΔZ_s (%)	2.61	16.65	59.01
ΔZ_c (%)	2.60	15.63	58.89
Δk (%)	0.84	7.03	19.69
$\Delta \alpha$.(%)	1.02	2.15	19.72

Table 3: Range of foam parameters for the 50 composite samples

Property (symbol)	Range of values	Units
Porosity (Φ)	0.7-0.99	
Static airflow resistivity (σ)	1000-499000	Ns/m^4
Tortuosity (α_∞)	1.01-2.99	
Viscous characteristic length (Λ)	14-300	µm
Thermal characteristic length (Λ')	50-500	µm
Static thermal permeability (k'_o)	0.002-0.01	mm^2
Thickness	10-50	mm

$$\Delta P = \min\left[\frac{1}{n}\sum_{1}^{n}\left|abs\left(\frac{P_{BA}(\omega_i)}{P_{AB}(\omega_i)}\right)-1\right|;\frac{1}{n}\sum_{1}^{n}\left|abs\left(\frac{P_{AB}(\omega_i)}{P_{BA}(\omega_i)}\right)-1\right|\right]$$

P_{AB} and P_{BA} are the measured bulk property P when side A and B of the composite are facing the incident sound wave respectively, and ω_i is the i^{th} frequency. The ARSD values range between 0 (for ideal homogeneous material) and 1.

Table 2 gives the various bulk property ARSDs for the three composite samples (ΔZ_s for the surface impedance, $\Delta\alpha$ for the absorption coefficient, ΔZ_c for the characteristic impedance, and Δk for the complex wave number). From these results, it seems the ARSD is a good basis for a TTH index due to its sensitivity to heterogeneity.

In order to identify the most sensitive bulk property to TTH, we have computed the ARSD of the three latter bulk properties as a function of the one for the surface impedance for 50 different composites. The composites were made up from a combination of two foams having macroscopic parameters randomly selected in the ranges listed in Table 3. From Fig. 4, the ARSDs of the surface impedance and characteristic impedance seem to be equal. Moreover, these properties appear to be more sensitive to the heterogeneity of the material. Hence, the surface impedance ARSD is a good TTH index. As a criterion of heterogeneity, a TTH index of 5% is suggested as the threshold for heterogeneity.

ACKNOWLEDGEMENTS

N.S.E.R.C., REGAL, and ALCAN supported this work.

REFERENCES

[1] Scott, Proc. Phys. Soc. London, 58, 358-368 (1946)

[2] Utsuno *et al.*, J. Acoust. Soc. Am., 86, 637-643 (1989)

[3] Iwase *et al.*, Internoise 98, New Zealand. (1998)

[4] Song and Bolton, J. Acoust. Soc. Am., 107, 1131-1152 (2000)

[5] Johnson *et al.*, J. Fluid. Mech., 176, 379-402 (1987)

[6] Lafarge *et al.*, J. Acoust. Soc. Am., 102, 1995-2006 (1997)

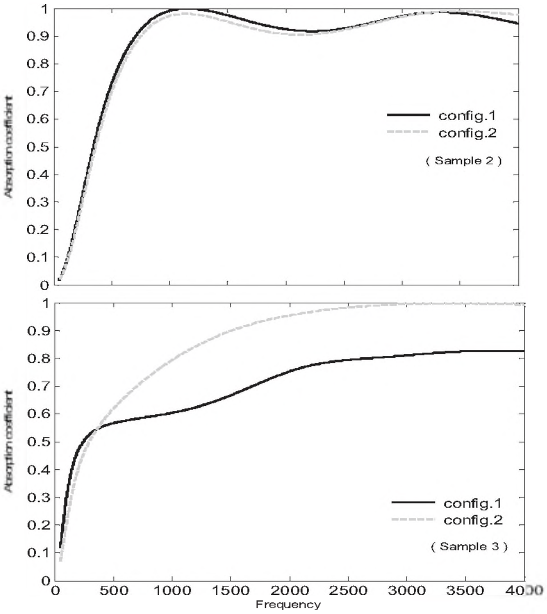


Fig. 2: Sound absorption coefficient of samples 2 and 3

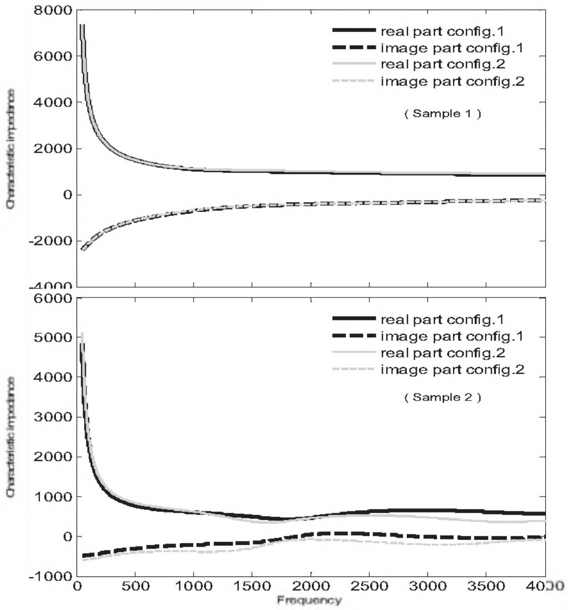


Fig. 3: Characteristic impedance of samples 1 and 2

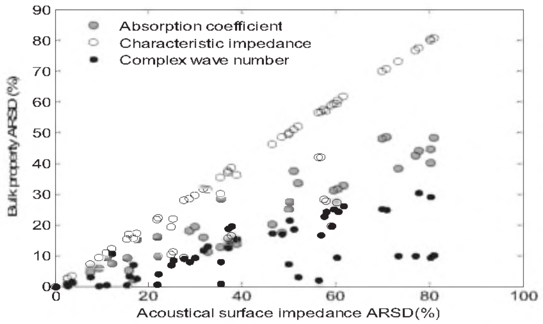


Fig. 4: Bulk property ARSD versus surface impedance ARSD