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REPORT

FOR: Client name
TEST: MNS200XXXXX-XX
ON: Material ID
DATE: Date
BY: Experimenter

Characterization of
Sound Absorbing Materials

DESCRIPTION OF THE SPECIMENS

Type: (ANY TYPES OF POROUS MATERIALS: Foams, fibers, fabrics, felts, carpets, perforates,…)
Name: xxxxxxx
Code: xxxxxxx

The specimens used for the characterization tests were cut from four (30 x 30 cm^2) layers provided by the client. Two layers have a nominal thickness of 50 mm, and two layers have a nominal thickness of 20 mm. Eight specimens per layer were cut using pressurized water jet cutting as shown in the next figure. Large (Li) specimens are 99.2-mm diameter. Medium (Mi) specimens are 44.5-mm diameter. Small (Si) specimens are 29.1-mm diameter. These diameters ensure a radial compression less than 0.5% in impedance tube and resistivity meter holders, and prevent leaks. A visual inspection showed no major defects in the specimens. Note that the small specimens (Si) were not used during the characterization tests since no acoustical measurements were asked or required in the high (4000 to 6000 Hz) frequency range.

POROUS MATERIAL CHARACTERIZATION RESULTS

Material properties and characterization methods are described in references and appendix 1.

Results of the physical properties are given in Table I.

- Special remarks on porosity (give details)…
- Special remarks on resistivity (give details)…
- Special remarks on tortuosity (give details)…
- Special remarks on characteristic lengths (give details)…
- Special remarks on elastic characteristic (give details)…

Table I – Characterized material properties – physical parameters

	Material properties	Number of tests and specimen ID	Mean value	Standard deviation	Equipment (See Appendix 1)
σ	Resistivity (Ns/m^4)[a] Airflow rate: **98.4 ccm**	L1,L2,L3 L1′,L2′,L3′	11 453	806	SIG System
ϕ	Open porosity[b]	L1,L2,L3 L1′,L2′,L3′	0.969	0.011	PHI System
ρ	Bulk density (kg/m^3)[b]	L1,L2,L3 L1′,L2′,L3′	8.213	0.153	PHI System
α_∞	Geometrical tortuosity	L1,L2,L3 L1′,L2′,L3′	1.031	0.008	TOR System
Λ	Viscous length (m)	M1, M2, M3 M1′, M2′, M3′	113e-6	7e-6	Foam-X
Λ'	Thermal length (m)	M1, M2, M3 M1′, M2′, M3′	115e-6	7e-6	Foam-X
E	Young’s modulus (Pa)	M1, M2, M3 L1, L2, L3	353 248	19 298	QMA System
ν	Poisson’s ratio	M1, M2, M3 L1, L2, L3	0.376	0.003	QMA System
η	Damping loss factor	M1, M2, M3 L1, L2, L3	0.114	0.015	QMA System

[a] Note equivalence: 1 Ns/m^4 = 1 MKS rayls/m

[b] Measurements with a balance readability of 0.001g

[c] Prime (′) indicates samples with a nominal thickness of 20 mm. Otherwise, thickness is 50 mm.

DETAILS ON ELASTIC CHARACTERIZATION

Material properties and characterization methods are described in references and appendix 1.

Results of the characterization are given in Table II and Figure 1.

Last column of Table II gives the number of valid combinations used to obtain the elastic parameters in a given frequency range. A valid combination is a combination of two samples of different aspect ratio (see above special remarks on elastic characterization) for which the determined properties fall within ± one standard deviation from the mean.

- Young’s modulus. In Figure 1, it is observed that the variation of the Young’s with frequency is small. The error on the frequency dependent Young’s modulus is small.
- Loss factor. In Figure 1, it is observed that the Loss factor increases slightly with frequency. The error on the frequency dependent Loss factor is small.
- Poisson’s ratio. In Figure 1, it is observed that the Poisson’s ratio is constant with frequency and has a mean value of 0.376. The error on the Poisson’s ratio is small.

Table II – Measured elastic properties of the 0.5-in thickness. Measurements were performed at T = 21.3°C with mean initial strain of 2 %.

Range (Hz)	E (kPa)		η		ν		Number of combinations
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
[10-20]							
[20-30]	322.0	11.2	0.088	0.004	0.3748	0.003	24
[30-40]	339.6	6.8	0.096	0.004	0.3755	0.003	20
[40-50]	352.2	14.7	0.121	0.005	0.3754	0.003	22
[50-60]	356.0	14.0	0.125	0.008	0.3758	0.003	22
[60-70]	358.1	7.0	0.116	0.004	0.3759	0.003	20
[70-80]	362.7	7.5	0.122	0.005	0.3760	0.003	20
[80-90]	362.8	7.6	0.121	0.007	0.3761	0.003	20
[90-100]	372.4	17.0	0.124	0.011	0.3760	0.004	22
[10-100]	**353.2**	**19.2**	**0.114**	**0.015**	**0.376**	**0.003**	

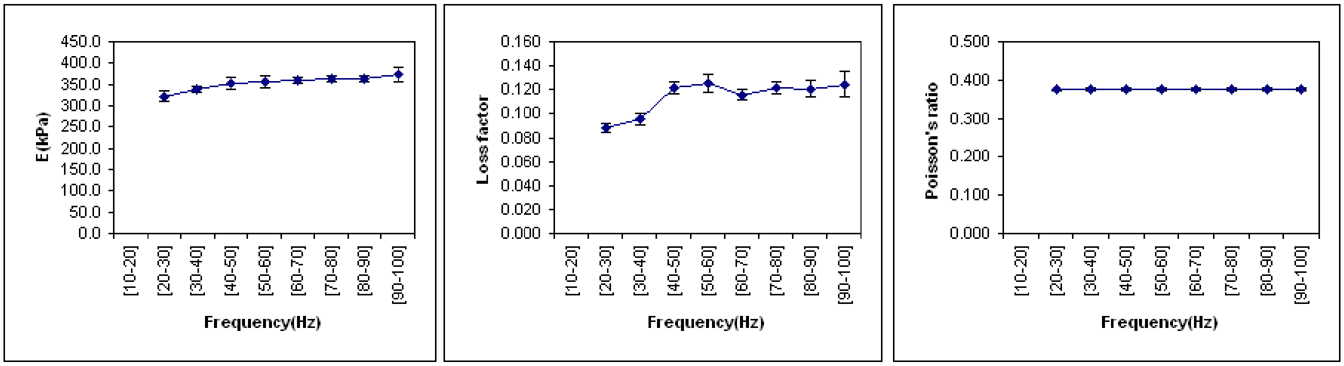


Figure 1 – Variation of the elastic properties with frequency

DETAILS ON ACOUSTICAL CHARACTERIZATION

The sound absorption coefficients (SAC) measured on the specimens are presented in Figure 1.

All measured normal incidence sound absorption coefficients presented in this document are obtained following international standard ASTM E 1050-86 with a 44.44-mm diameter MNS impedance tube. The cutoff frequency of the tube is 4200 Hz.

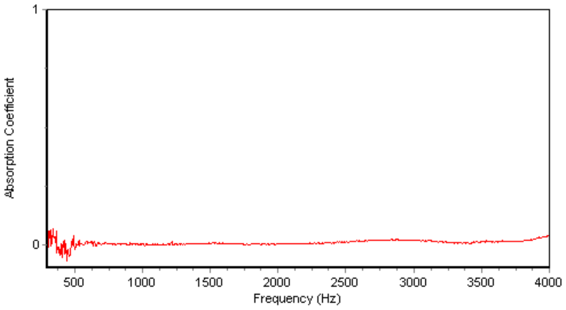
Mounting of the specimens

The specimens are mounted in the tube with a thin air gap (<1mm) between the specimens and the rigid termination of the tube. This eliminates (or minimize) the compression resonance in the elastic frame of the specimens. Following this mounting, the behavior of the specimens is mostly rigid. This rigid behavior is preferable when using the impedance tube results for inverse identification with Foam-X.

The diameter of the specimens is 44.5-mm which is slightly larger than the inside diameter of the tube to minimize leaks around the sample.

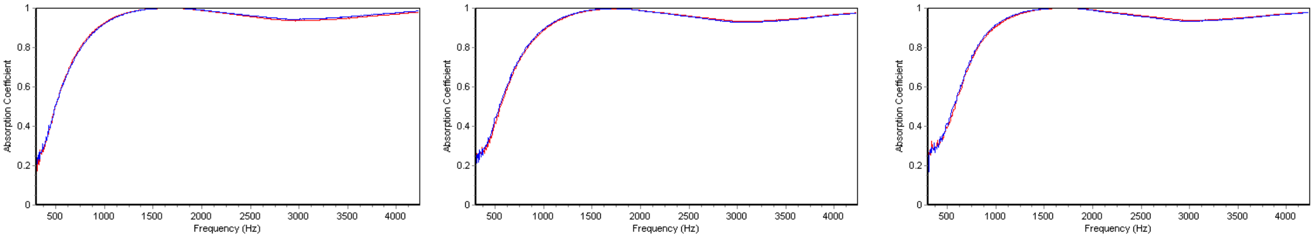
Zero absorption test (hard termination)

The sound absorption of the rigid termination is first measured. As shown in the next figure, the sound absorption is very close to zero for the valid frequency range of the 44-mm diameter tube.



Symmetry check

The symmetry of the specimens is verified. A specimen is symmetric if the absorption coefficient is the same on both faces. The next figure shows a symmetry check for specimen M1, M2, and M3, respectively. As noted, the specimens are symmetric.



Sound absorption coefficient

The following figures show the sound absorption coefficients for specimens M1, M2, M3, M1’, M2’, and M3’.

Simulations and sensitivity analysis

Simulations (black curve) are compared to measurements for the 20 and 50 mm thick specimens. The simulations used the rigid frame limit of the Biot-Allard model with the mean properties and **uncertainties** given in Table 1. For both thicknesses, the mean absorption with its upper and lower limits are plotted.

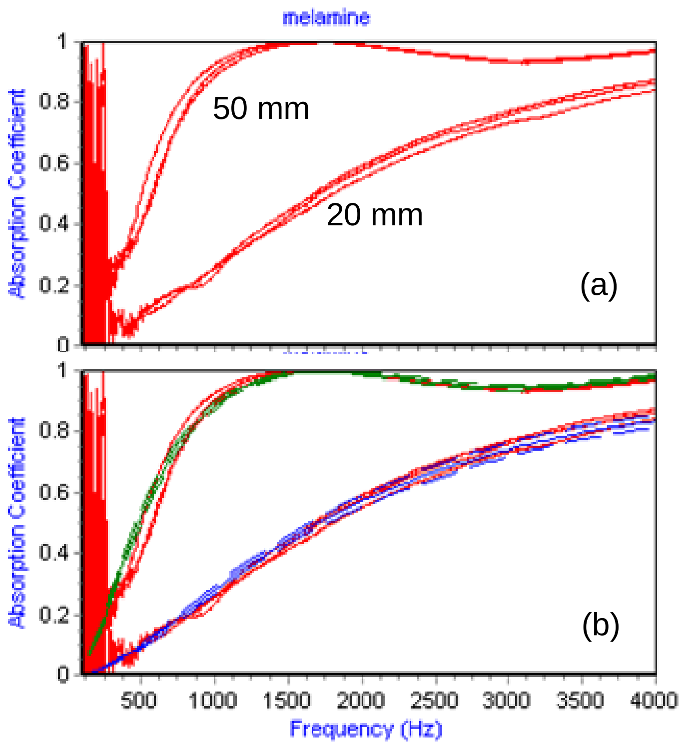


Figure 1 – Sound absorption coefficients (SAC).
(a) Impedance tube measurements. (b) Sensitivity simulation compared to impedance tube measurements. Simulations use mean values and uncertainties given in Table I.

Files

The full impedance tube results (sound absorption coefficient α, complex reflection coefficient $\mathbf{R}$ and normalized surface impedance $\mathbf{Z}_{sn}$ are given in the attached ASCII files.

REFERENCES

Porosity

[1] Y. Salissous and R. Panneton, “Pressure/mass method to measure open porosity of porous solids,” J. Appl. Phys. 101, 124913(2007).

[2] R. Panneton and E. Gros, “A missing mass method to measure the open porosity of porous solids,” Acta-Acustica 91(2), 342-348 (2005).

Resistivity

[3] M.R. Stinson and G.A. Daigle, "Electronic system for the measurement of flow resistance" J. Acoust. Soc. Am. 83, 2422-2422 (1988).

Tortuosity

[4] J.F. Allard et al., “Evaluation of tortuosity in acoustic porous materials saturated by air,” Rev. Sci. Instrum. 65, 209-210 (1994).

Elastic properties

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Characterization of porous materials

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[8] R. Panneton and X. Olny, “Acoustical determination of the parameters governing viscous dissipation in porous media,” J. Acoust. Soc. Am. 119, 2027-40 (2006).

[9] X. Olny and R. Panneton (2007), “Acoustical determination of the parameters governing thermal dissipation in porous media,” J. Acoust. Soc. Am. 123, 814-824 (2008).

Normal sound transmission loss

[10] Y. Salissou and R. Panneton, “A general wave decomposition method for the measurement of normal incidence sound transmission loss,” J. Acoust. Soc. Am. 125(4), 2083-2090 (2009).

[11] R. Panneton, “Normal incidence sound transmission loss evaluation by upstream surface impedance measurements,” J. Acoust. Soc. Am. 125(3), 1490-1497 (2009).

Material symmetry and edge effects in impedance tube

[12] Y. Salissou and R. Panneton, “Quantifying the through-thickness asymmetry of sound absorbing porous materials,” J. Acoust. Soc. Am. 124(4), EL28-EL33 (2008).

[13] D. Pilon, R. Panneton, and F. Sgard, “Behavioral criterion quantifying the effects of circum-ferential air gaps (…) standing wave tube,” J. Acous. Soc. Am. 116(1), pp. 344-356 (2004).

[14] D. Pilon, R. Panneton, and F. Sgard. “Behavioral criterion quantifying edge-constrained ef-fects on foams in standing wave tube,” J. Acous. Soc. Am. 114(4), pp. 1980-1987 (2003).

Software and equipments

[15] Foam-X™ Flyer – Foam and fiber geometric parameter analyzer (www.esi-group.com)

[16] Nova™ Flyer – Multi-layered material acoustic simulation and design (www.esi-group.com)

[17] PHI System Flyer – Porosity and density meter (www.mecanum.com)

[18] SIG System Flyer – Static airflow resistivity meter (www.mecanum.com)

[19] QMA System Flyer – Quasi-static mechanical analyzer (www.mecanum.com)

[20] TOR System Flyer – Ultrasound tortuosity meter (www.mecanum.com)

[21] MNS Impedance Tube (www.mecanum.com)

APPENDIX 1 – MATERIAL PROPERTIES AND THEIR CHARACTERIZATION METHODS

STATIC AIRFLOW RESISTIVITY AND PERMEABILITY

Equipment: Static Airflow Resistivity Meter (SIGMA System by Mecanum inc.)
Standard: ASTM C 522
Method: Electronic system for the measurement of flow resistance (J. Acoust. Soc. Am. 83, 2422-2422, 1988)
Property: σ - static airflow resistivity (Ns/m^4); **k** - static permeability (m^2)
The static airflow resistivity expresses the frictional retardation to a quasi-static flow (here acoustic wave in air at rest) through the pores, i.e. the pressure drop required to force a unit flow through the material. The static permeability is an effective fluid flow surface independent to the saturating fluid.

OPEN POROSITY AND TRUE BULK DENSITY

Equipment: Porosity and Density Meter (PHI System by Mecanum inc.)
Standard: none
Method 1: Isothermal pressure/mass method (J. Appl. Phys. 101, 124913, 2007)
Method 2: A missing mass method to measure open porosity of porous solid (Acta Acustica 91, 342-348, 2005)
Property: ϕ - open porosity; ρ_1 – bulk density (kg/m^3)
The open porosity is defined as the fraction of volume that is occupied by the fluid in the interconnected porous network. The bulk density is the in vacuum density of the porous aggregate.

GEOMETRICAL TORTUOSITY

Equipment: Ultrasound Tortuosity Meter (TOR System by Mecanum inc.)
Standard: none
Method: Evaluation of tortuosity in acoustic porous materials saturated by air (Rev. Sci. Instrum. 65, 209-210, 1994)
Property: α_∞ - tortuosity
The geometrical tortuosity, or identically the structure factor, is a geometrical measurement of the deviation of the actual path followed by an acoustical wave from a direct path.

YOUNG'S MODULUS, POISSON'S RATIO, DAMPING LOSS FACTOR

Equipment: Quasi-static mechanical analyzer (QMA System by Mecanum inc.)
Standard: ISO 10846-2 (for the mechanical setup and dynamic stiffness)
Method: Quasistatic mechanical characterization of poroelastic materials (J. Acoust. Soc. Am. 110, 3032-3040, 2001)
Property: **E** – Young's modulus (Pa); $\boldsymbol{\nu}$ – Poisson's ratio; η – loss factor
The elastic properties needed to feed acoustical models are in vacuum properties. For isotropic poroelastic materials, the elastic properties to be characterized are: Young's modulus, Poisson's ratio, loss factor.

FOAM-X : GEOMETRIC PARAMETERS

Equipment: Foam-X Acoustic property identification for foam and fiber (www.esi-group.com)
Standard: ASTM E1050-98 or ISO 10534-2:1998 (for sound absorption measurements using impedance tube)
Method 1: Inverse acoustical method (Canadian Acoustics 33(1), 11-24, 2005)
Method 2: Indirect acoustical method (J. Acoust. Soc. Am. 119, 2027-40, 2006; J. Acoust. Soc. Am. 123, 814-824, 2008)
Property: Λ - Viscous characteristic length (m); Λ' - thermal characteristic length;
ϕ - open porosity; σ - static airflow resistivity (Ns/m^4); α_∞ - tortuosity
Foam-X uses an inverse algorithm that works with acoustic data output from ASTM E1050 impedance tube tests to identify porous material properties. It calculates the "geometric parameters" viscous and thermal characteristic lengths and tortuosity. It can also calculate flow resistivity and porosity. The viscous and thermal characteristic lengths are average macroscopic dimensions of the cells related to viscous and thermal losses, respectively. The former may be seen as an average radius of the smaller pores, and the later as the average radius of the larger pores.