A Test Rig for Measurement of Porosity of Sound Absorbing Materials

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Abstract

Sound absorbing materials are widely used in Transport Industry for noise control applications. The acoustic performance of sound absorbing materials is evaluated in terms of Sound absorption coefficient and sound transmission loss. These properties can be measured using impedance tubes as per ISO 10534-2/ASTM 1050 or in Reverberation Suite as per ISO 354/ASTM 423 or can be predicted using commercially available simulation softwares. Sound absorption coefficient and sound transmission loss are dependent upon intrinsic physical parameters of sound absorbing materials like porosity, flow resistivity, tortuosity and characteristics lengths. The prediction of sound absorption and sound transmission loss requires these intrinsic physical parameters as input. This paper discusses an air based method is proposed for the measurement of porosity of sound absorbing materials. A test rig based on Boyle's law has been designed and developed to measure porosity of sound absorbing materials. It can measure porosity of the materials ranging from 0 to 0.99. In this paper simulation results are also discussed for the effect of porosity on sound absorption and sound transmission loss of materials by varying porosity from low to high values. The paper discusses a detailed procedure for measurement of porosity with test results for different types of sound absorbing materials. The results are then also compared with Inter-laboratory test results for same materials.

Introduction

A porous sound absorbing material is a solid containing interconnected air cavities. One of the important parameter of such porous material is open porosity (ϕ). The open porosity is defined as the fraction of interconnected air volume to the total volume of a porous material. Sound propagation models for porous materials uses open porosity to relate effective properties of the saturating air with the effective properties of porous aggregate. The literature survey on porosity measurement of sound absorbing material shows that different procedures have been developed for measuring porosity. Most of these methods are based on Boyle's Law, using isothermal compression of air volume within and external to the materials. The first porosity meter was developed by J. Van den [1]. Later L. Beranek [2] used similar test rig with some modifications. Champoux and Stinson [3] proposed a new method for the measurement of porosity based on air as a pore filling fluid and measurement of pressure difference by differential pressure transducer. Laclaire *et al.* [4] used the method based on comparison of air volumes, this method was also similar to method used by Beranek. A similar approach is proposed by Penneton *et al.* Their method is based on measurement of the apparent (in air) and true mass (in vacuum) of the porous material [5]. In their method missing mass in air is measured and related to volume of solid phase of material through Archimedes principle

Measurement of Porosity

The apparatus developed for measuring porosity consists of an MS chamber, of diameter 110 mm and height of 110 mm respectively with internal volume 1045364 mm^3. The total volume of the cylinder is changed by using a rigid piston positioned on the bottom of the chamber and connected to it through a small hole. The piston can be moved using the handle system and the pressure signal is acquired by means of an electrical differential pressure transducer connected to the sample holder. A sample of 100 mm diameter is used to measure porosity of sound absorbing materials. The principle of operation is given below.

Principle of Operation

Consider a porous sample of volume V_m placed in a sealed chamber. The porous sample has open pores filled with air of volume V_a. The idealized sketch of the system is shown in figure 3.6. The total volume of air in the measurement chamber is given as:

$$V_T = V_0 + V_a \quad (1)$$

where V_0 is the residual volume of the measurement chamber outside the sample.

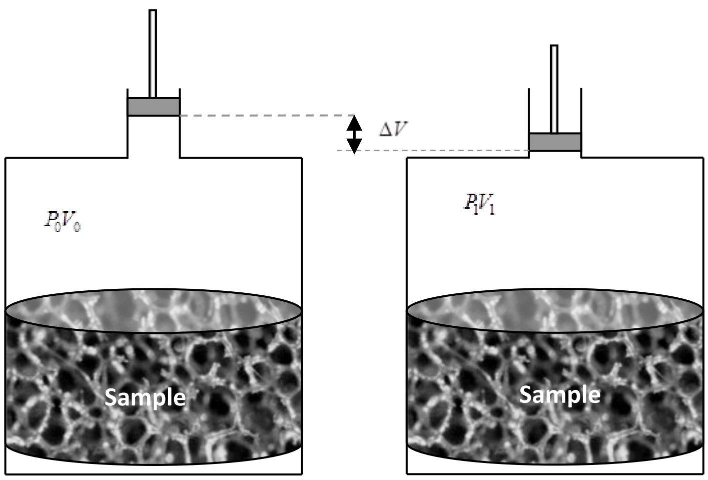

Figure 1– Idealized sketch of test rig for measurement of Porosity

Let us assume that, initially the chamber was at atmospheric pressure P_0. Now the piston is moved inward to reduce the volume by amount ΔV so that pressure will change by amount ΔP. Now for an isothermal expansion of ideal gas in the chamber, one can write

$$P_0 V_T = (P_0 + \Delta P)(V_T - \Delta V) \tag{2}$$

The total volume V_T can be determined by measuring change in pressure ΔP, volume ΔV and atmospheric pressure P_0 as

$$V_T = \left[-(P_0 + \Delta P)/\Delta P \right] \Delta V \tag{3}$$

Then volume of air will become

$$V_a = V_T - V_0 \tag{4}$$

then porosity will be calculated as

$$\phi = \frac{V_a}{V_m} \tag{5}$$

Results and Discussions

Calibration of the Rig

The calibration of the test rig was carried out using a steel cylinder of 100 mm diameter and 25 mm thickness. For steel cylinder, porosity should be classically zero. Three measurements were carried out on the same steel cylinder to check the repeatability in porosity values. The results are shown below in table 1.

Table 1: Porosity for Steel cylinder

Sample	Porosity [-]	Std. dev.
Steel Cylinder	0.025	0.008
	0.013	
	0.009	

From table 1, it is observed that experimental porosity of steel cylinder is very close to zero and standard deviation is also 0.008 which shows better repeatability of the results.

Measurements

Porous samples of different types of typologies were tested for the measurement of porosity. The sample was placed in the measurement chamber and volume of the chamber was reduced slowly in steps of every 15 seconds to achieve thermal equilibrium inside the chamber using a stepper motor. The initial pressure may not be zero due to the residual temperature effects because of which differential pressure shows a small, but steady drift with time. To overcome this problem, the measurements of differential pressure transducer were fitted to linear function. Similar approach is followed for the data when piston is moved completely. A number of samples were tested using the test rig and results are discussed below. The samples used to measure porosity are Nitrile Rubber, Felt, Polyurethane foam and Rockwool. The diameter of all the samples was 100 mm. The temperature was around 25 ±2^{o}C during the test.

Table 2: Porosity values for four different materials

Nitrile Rubber 50 mm- 50 kg/m^3		
Sample	**Porosity [-]**	**Std. dev.**
Nitrile Rubber	0.970	0.007
	0.965	
	0.980	

Soft Felt 15 mm- 60 kg/m^3		
Sample	**Porosity [-]**	**Std. dev.**
Soft Felt	0.890	0.002
	0.885	
	0.888	

Polyurethane Foam 20 mm- 48 kg/m^3		
Sample	**Porosity [-]**	**Std. dev.**
PU Foam	0.953	0.005
	0.957	
	0.965	

Cellular Rubber 41 mm- 64 kg/m^3		
Sample	**Porosity [-]**	**Std. dev.**
Cellular Rubber	0.867	0.0014
	0.872	
	0.87	

From above results, it is observed that there is very good correlation in repeatability tests for all the samples. It is planned to do inter-laboratory study for comparison of porosity values. These results will be presented at the conference.

Effect of Porosity on Sound Absorption Coefficient

In this section, sound absorption coefficient of two different types of materials like Polyurethane foam and Cellular Rubber is compared as shown in figure 2. Here is PU foam is a high porosity material while Cellular rubber is low porosity material. The intrinsic physical parameters of the PU foam and Cellular rubber are given in table 3. From figures 2, it is clear that high porosity results into higher absorption in mid and high frequency region compared to low porosity material. At low frequencies, low porosity material is having higher absorption because of very high flow resistivity value. Porosity of the material also affects flow resistivity and other intrinsic parameters of the material.

Table 3: Intrinsic physical parameters used for Simulation

	PU Foam 48 kg/m^3	Cellular Rubber 64 kg/m^3
Thickness	50	50
Porosity [ϕ]	0.95	0.86
Flow Resistivity [σ]	5359	150388
Tortuosity [α_∞]	1.08	2.97
VCL [Λ]	119	29
TCL[Λ']	235	29

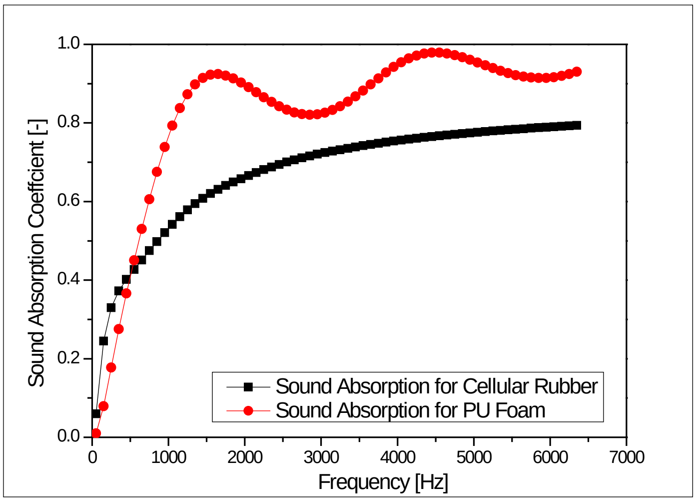

Figure 2: Simulation of Sound Absorption Coefficients with Porosity 0.99 and 0.86

The basic property of any sound absorbing material is that it should be porous in nature, i.e. it should provide path to sound waves to propagate through it. Here a simulation is carried out to check effect of porosity on sound absorption coefficient by varying porosity of the material from 0.5 to 0.99 while keeping other parameters constant as given in table 4. The figure 3 shows effect of porosity on sound absorption coefficient.

Table 4: Intrinsic physical parameters used for Simulation

Melamine Foam 10 kg/m^3	
Porosity [ϕ]	0.5-0.99
Flow Resistivity [σ]	10512
Tortuosity [α]	1.012
VCL [Λ]	95
TCL [Λ']	185

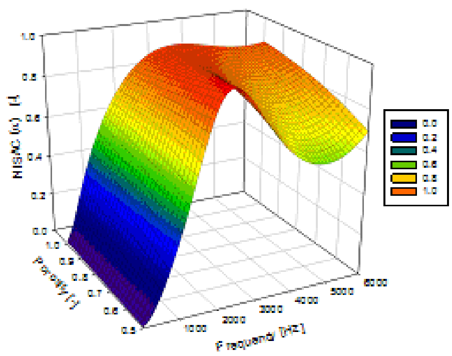

Figure 3: Effect of Porosity on Sound absorption Coefficient

From this figure, it is clear that as porosity increased from 0.5 to 0.99, sound absorption increases attains maximum value in the mid frequency range where porosity is important.

Conclusions

In this paper, an air based test rig required for measurement of porosity of sound absorbing materials is discussed in detail. The rig is developed in-house and porosity value measured using this rig is used in simulation of sound absorbing materials. The speciality of the rig is that it gives actual values of porosities (volumetric porosity of sound absorbing materials rather than just calculating porosity from density of frame material). Also a simulation is carried out to check the effect of porosity on sound absorption coefficient and it is concluded that porosity is an important parameter in the mid and high frequency region.

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