A STUDY ON HOMOGENEITY AND HETEROGENEITY OF POLYURETHANE FOAMS – AN INDIAN SCENARIO

S.K. Jain, Manasi Joshi, Paresh Shravage and N.V. Karanth

NVH Lab, Automotive Research Association of India, Off Paud Road, Kothrud, Pune 411 001, India

e-mail: jain.nvh@araiindia.com

In India, polyurethane (PU) foams have huge market. Polyurethane foams are used in Automobiles, Genset industry as they are easily available and economical. Flexible and semi-flexible polyurethane foams are used extensively for interior components of automobiles such as in seats, headrests, dash panel, roof liners, instrument panels and in canopies for reducing noise. These Polyurethane foams are manufactured by many manufacturers in different densities and thicknesses across India. In present paper, an acoustic study has been carried out for sound absorption and sound transmission loss measurements for PU foams from different manufacturers for different densities and thicknesses. Intrinsic parameters like airflow resistivity, porosity, tortuosity and characteristic lengths were also evaluated using direct and indirect techniques. As PU foams are highly inhomogenous and heterogeneous in nature, this can be re-verified by the extensive acoustic study carried out in this paper. The paper discusses sound absorption results for tests carried out in two microphone impedance tube and reverberation chamber for same density and thicknesses for different manufactures. It also envisages effect of inhomogeneity on airflow resistivity of PU foams sample of similar densities from different manufacturers. This paper also discusses simulation results carried out using intrinsic physical properties of PU foams which are then validated with experimental results.

1. Introduction

Polyurethane foams are widely used for many industrial applications for their good acoustic and thermal properties. Polyurethane foams are made of an isocyanate and polyol, sometimes small amounts of blowing agents are added to give less dense foam, better cushioning, sound absorption or thermal insulation properties. These PU foams are manufactured by no of manufactures in India and supplied for various applications. In this paper, a study has been carried out to check inhomogeneity of PU foams in terms of acoustic properties. A number of PU foams samples of same density and thickness from different manufactures were tested for airflow resistivity, normal as well as random incidence sound absorption coefficient and random incidence sound transmission loss.

Intrinsic parameters such as porosity, tortuosity and characteristics lengths were evaluated using two microphone impedance tube and inverse software. These data were used to predict random incidence sound absorption coefficient which was validated with experimental data from a reverberation chamber. It has been observed that the acoustic properties differ largely for PU foams having same density and thickness from different manufactures.

2. TEST PLAN

In this study, samples of PU foams from different manufactures across India were evaluated. The densities and thickness of the PU foams are given in table 1.

2.1 Selection of PU foam sample of same density and different manufacturers

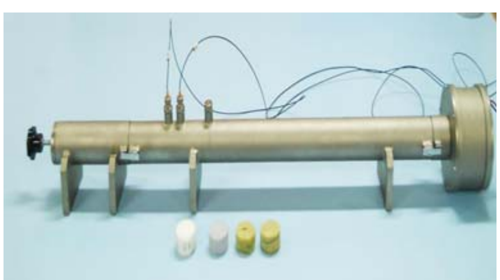
For this study PU foam samples 4 nos of 28 kg/m^3 and 25 mm and 4 nos of 46 kg/m^3 and 50 mm were considered, as given in table 1.

Table 1. PU Foam Suppliers

Manufactures	Density (kg/m^3)	Thickness (mm)	NRC
A	28	25	0.50
B	28	25	0.47
C	28	25	0.66
D	28	25	0.59
E	46	50	0.84
F	46	50	0.73
G	46	50	0.94
H	46	50	0.91

2.2 Experimental Sound Absorption and Sound Transmission Loss Testing-

Initially the large samples were tested for random incidence sound absorption coefficient in a Reverberation room as per ASTM C423 / ISO 354 [1]. The experimental test set up is given in figure 1. The sound transmission loss test was carried out in a reverberation room suite as per ISO 10140-2 [2].



(a): Normal Incidence Impedance Tube

(b): Reverberation Chamber

Figure 1. Experimental Test set up for sound absorption coefficient measurements

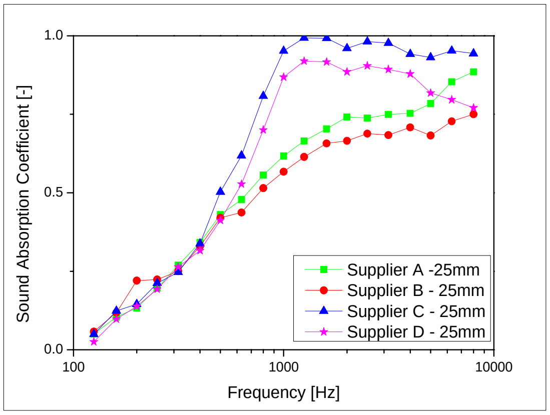


Figure 2(a). Comparison of Sound Absorption Coefficient for 28 kg/m^3-25 mm

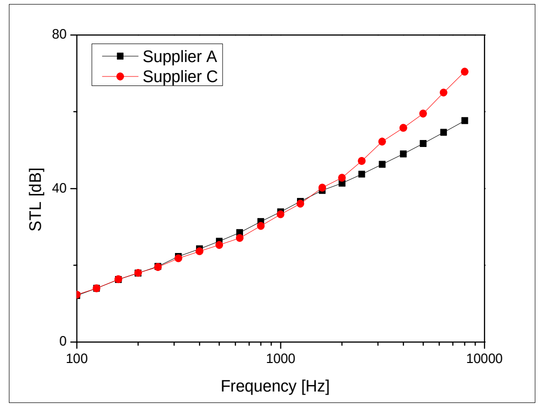


Figure 2(b). Comparison of Sound Transmission Loss for 28 kg/m^3-25 mm

Figure 2(a) shows measured random incidence sound absorption coefficient in a Reverberation room. It is observed that there is huge variation in sound absorption coefficients (SAC) and noise reduction coefficient (NRC) measured for same density and thickness PU foams. The NRC is single number value, which is given by average value of sound absorption at 250, 500, 1000 and 2000 Hz frequencies. The percentage variation in NRC values was 6% - 40% for 28 kg/m^3 - 25 mm samples. Similarly for 46 kg/m^3 - 50 mm samples the deviation was 15% to 30%. This is due to in-homogenous and heterogeneous nature of PU foams and variation in manufacturing process used by different manufacturers. Figure 2(b) shows the sound transmission loss (STL) of PU foam samples A and C along with 1.2 mm steel plate, which shows 4-5 dB variation in STL at high frequencies region.

2.3 Causes of variation in SAC and STL

The airflow resistivity of all the samples were measured as per ASTM C522 [3] and the values are depicted in table 2 along with standard deviation. From table 2, it observed that there is huge variation in airflow resistivity values from manufacturer to manufacturer even though the density of foam samples supplied by all the suppliers was same. It was observed that for PU foams of same densities the variation is in the range of 4% - 170% for 28 kg/m^3 foams while for 46 kg/m^3 foam samples the variation is in the range of 31% to 250%. This result confirms that even though the density of PU foams manufactured in India is similar, there is enormous variation in acoustic properties of PU foams samples from supplier to supplier.

To identify the variation in acoustic properties, further study has been carried out to find out intrinsic properties such airflow resistivity, porosity, tortuosity and characteristics lengths.

Table 2. Comparison of Airflow Resistivity for Same Density PU Foams

Manufacturer	Density 28 (kg/m^3)		Manufacturer	Density 46 (kg/m^3)	
	Air-flow Resistivity (Ns/m^4)	NRC		Air-flow Resistivity (Ns/m^4)	NRC
Supplier A	5543 ± 803	0.5	Supplier E	8109 ± 641	0.84
Supplier B	5319 ± 6	0.47	Supplier F	3686 ± 627	0.73
Supplier C	14070 ± 3935	0.66	Supplier G	26837 ± 5400	0.94
Supplier D	13354 ± 2159	0.59	Supplier H	22562 ± 2950	0.91

3. INTRINSIC PARAMETER EVALUATION

The performance of sound absorbing materials can be predicted with prior measurement of five intrinsic physical parameters like porosity, flow resistivity, tortuosity, viscous and thermal characteristic lengths and three mechanical parameters like Young's modulus, Poisson ratio and loss factor. Tortuosity and characteristic lengths are inverted using optimization technique based on Inverse Algorithm. This technique requires prior measurement of sound absorption coefficient with surface impedance using two microphone impedance tube along with measured porosity and flow resistivity to fit a mathematical model. The global solution of this optimization gives tortuosity and characteristic lengths. For this purpose, Johnson-Champoux-Allard model is used which considers frame of porous material as a rigid, motionless frame. Hence porous material can be replaced on a macroscopic scale by an equivalent fluid of effective density $\rho(\omega)$ and effective bulk modulus $K(\omega)$. The motionless frame condition can occur either because of high density or elasticity modulus, or because of particular boundary conditions imposed during the test. The dynamic density $\rho(\omega)$ and bulk modulus $K(\omega)$ for Allard model [4] are given by following equations.

$$\rho(\omega) = \rho_0 \alpha_\infty \left[1 + \frac{\sigma\phi}{j\omega\rho_0\alpha_\infty} \sqrt{\frac{4j\alpha_\infty{}^2\eta\omega}{\sigma^2\Lambda^2\phi^2}} \right] \tag{1}$$

$$K(\omega) = \gamma P_0 \left[\gamma - (\gamma-1) \Big/ 1 + \frac{8\eta}{j\Lambda' N_{pr}\omega\rho_0} \sqrt{1 + j\rho_0 \frac{\omega N_{pr}\Lambda'}{16\eta}} \right]^{-1} \tag{2}$$

Where, ρ_0 is density of fluid, P_0 is atmospheric pressure, γ is specific heat ratio N_{pr} is Prandtl number, η is coefficient of viscosity of air and ω is circular frequency.

From figure 1 & 2 the characteristic impedance Z_c and the complex wave number k_c of the porous specimen are calculated as given by Eq. (3).

$$Z_c = (\rho(\omega)K(\omega))^{1/2} \qquad k_c = j\omega.[\rho(\omega)/K(\omega)]^{1/2} \tag{3}$$

For a porous sample of thickness d, backed by rigid wall specific acoustic surface impedance is given by Eq. (4).

$$Z_S = -j\frac{Z_c}{\rho_0.c_0}\cot(k_c\ d)/\phi \tag{4}$$

Now to get inverse parameters, experimental surface properties are used to fit the mathematical model of a porous material, so that global optimization will yield intrinsic parameters of PU foams as given in Eq. (5).

$$\chi\{\phi,\sigma,\alpha_\infty,\Lambda,\Lambda'\} = \left|Z_{Exp} - Z_S\right|^2 \tag{5}$$

The global minimum of Eq. (5) gives intrinsic parameters which can be validated using experimental results of impedance tube. In this study only five physical intrinsic parameters were considered for simulation as mechanical parameters does not affect acoustic behaviour of sound absorbing materials.

The physical intrinsic properties of PU foam samples measured using specialized test rigs and evaluated from inverse software are given in table 3. These parameters were used for simulation of normal incidence sound absorption coefficient. The results are compared in figure 3, which shows that intrinsic parameters evaluated using inverse characterization are actual intrinsic parameters of PU foam and they can be used to predict random incidence sound absorption coefficient.

Table 3: Measured physical parameters of sound absorbing materials

Material Samples	***Porosity*** [-]	***Flow Resistivity*** [Ns/m^4]	***Tortuosity*** [-]	***VCL*** [μm]	***TCL*** [μm]
Supplier B-25 mm	0.99	3735	1.38	125	210
Supplier C-25 mm	0.91	21540	1.0	18.7	598
Supplier G-50 mm	0.98	32534	2.19	48	164
Supplier E-50 mm	0.97	8986	1.46	100	332

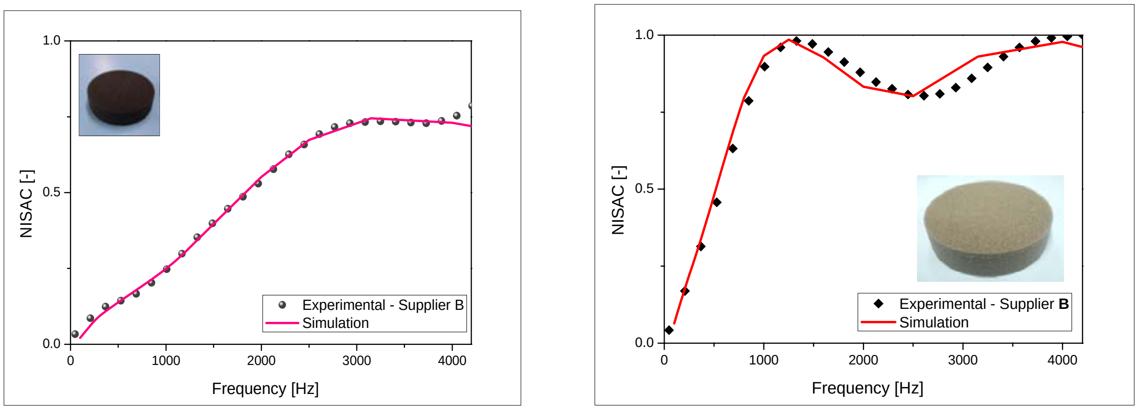


Figure 3. Comparison of experimental normal incidence sound Absorption Coefficient with predicted sound absorption coefficient for density 28 and 46 kg/m^3

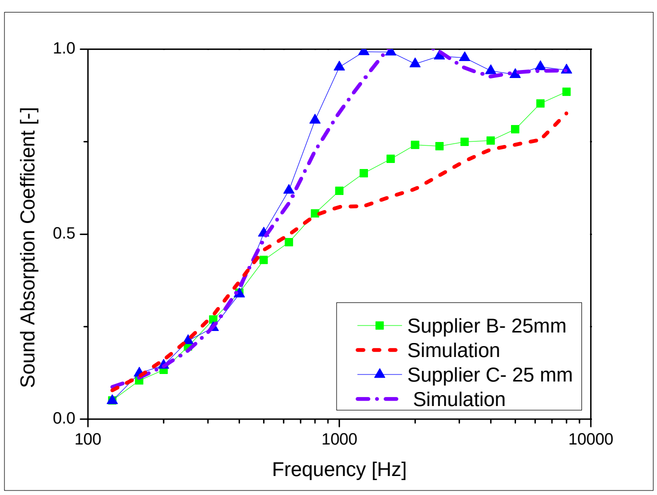


Figure 4. Comparison of experimental sound Absorption Coefficient with predicted sound absorption coefficient for density 28 kg/m^3

Table 2 and 3 shows that even though PU foam samples were having same density, the intrinsic properties for same density samples are different. For simulation the angle of incidence for random incidence prediction was considered from 0^0 to 89^0. Sound absorption at 0^0 gives absorption at normal incidence after that it becomes maximum at grazing (i.e. 75^0-89^0). The Paris formula considers integration over all the angles of incidence. Once these intrinsic properties were validated with normal incidence sound absorption coefficient, same intrinsic properties were used to predict random incidence sound absorption coefficient. Finally the predicted results were validated and compared with experimental result for low FR and high FR values foam samples as shown in Figure 4. The predicted result compares well with experimental results at low frequency region however at mid and high frequency region the significant deviation is observed. As the simulation study was carried out on small samples cut from one piece and the testing was carried out on bigger sample of size 6 m^2 which might cause variation in the results. This emphasizes in-homogenous and heterogeneous nature of PU foam.

Conclusion

It is observed that PU foams samples manufactured by different manufacturers are highly inhomogeneous and heterogeneous in nature. This variation is due to chemical composition and manufacturing process from manufacture to manufacture. Due to these variations, the end users get inconsistent sound absorption and sound transmission loss properties of PU foam samples. The manufacturer has to control the manufacturing process in controlled environment and carry out quality checks regularly.

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