Effect of Inverted Geometric Parameters on Normal Incidence Sound Absorption and Transmission Loss

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Introduction

Acoustic poroelastic materials are indispensible in building acoustics and Transport industry for noise control applications. The characterization of these porous materials is very important as it plays a crucial role in design and development stage itself for predicting acoustic behavior of multilayer porous materials for higher sound absorption and transmission loss. This prediction depends upon accuracy of macroscopic physical parameters which are very difficult to measure except porosity and flow resistivity, which is the only standardized test till today, also availability of such rigs is also a problem for manufactures as they are available only at specialized test labs. To circumvent this problem, inversion techniques are already proposed and available in literature. These inversion techniques are based on minimization algorithms like Genetic Algorithm or Nedler-Simplex optimization and use surface properties like surface impedance, reflection coefficient or sound absorption for inversion. But it is always important to check the effect of these inverted parameters on complex acoustical parameters as well as on sound absorption and transmission loss because sometimes the result of inversion technique could be only mathematical solution rather that physical solution. This paper presents comparison of prediction results with experimental values. This paper also presents effect of predicted sound absorption from Johnson-Allard-Champoux model with experimental results measured in impedance tubes as well with transmission loss of the material measured in four microphone tube.

The Equivalent Fluid: Johnson-Champoux-Allard Model

Open cell Poroelastic materials are very well described by Biot theory [1]. At the same time, in many situations when a material sample is excited by acoustical waves, the frame of this material behaves approximately as acoustically rigid (motionless) over a wide range of frequencies. In this case, the 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. In the widely used equivalent fluid model of Johnson-Champoux-Allard, these effective quantities depend on five macroscopic parameters: the flow resistivity (σ) , the porosity (ϕ), tortuosity (α_∞), and the viscous (Λ) as well as thermal (Λ') characteristic lengths. The dynamic density $\rho(\omega)$ and complex compressibility $K(\omega)$ for Johnson Model are given by following equations.

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

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

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.

For a porous sample of thickness d , backed by rigid wall, its specific acoustic surface impedance is

$$Z_s = -j\frac{Z_c}{\rho_0 . c_0}\cot(k.d)/\varphi \qquad (3)$$

where Z_c and k_c are the characteristic impedance and the complex wave number of the porous specimen respectively. They are related to the effective properties of the porous medium by

$$Z_c = \left(\rho(\omega)K(\omega)\right)^{1/2} \qquad (4)$$

$$k_c = j\omega.\left[\rho(\omega)/K(\omega)\right]^{1/2} \qquad (5)$$

Optimization Based Method-Genetic Algorithm

Genetic algorithm is based on the Darwin's theory of Evolution. It is used to solve the optimization problem with constraints and bounds on the solution. It repeatedly modifies a population of individual points using rules modeled on gene combinations of biological reproduction. At each step, the genetic algorithm selects individuals at random from the current population to be "parents" and uses them produce the "children" for the next generation. Over successive generations, the genetic algorithm improves the chances of finding a global solution. In the final analysis, normalized surface impedance was used as cost function [3]. The cost function minimized is defined as

$$Z_s = \sum \left| Z_{s,Mea} - Z_{s,Model} \right| \qquad (6)$$

The optimization problem with constraints was implemented in Matlab®.

Characterization Methods:

For Experimental measurements, 4 different types of porous as well fibrous materials like Melamine foam, Polyurethane foam, Soft Felt and Kenaf were selected with density in between 10 and 40 kg/m^3 and thickness in between 20 and 30mm. The diameter of all samples was 45mm. The open porosity was directly measured by a method based on Boyle's law [4] which uses isothermal compression of air volume within and external to the tested material. The static flow resistivity was measured by flow resistivity test rig based on standard ISO-9053 [5]. Finally, the tortuosity was determined by a method based on determination of the high frequency limit for the complex phase velocities within the air and the material [6]. While the characteristic lengths were inverted using Genetic algorithm with directly measured porosity, flow resistivity, tortuosity as additional input to Genetic Algorithm. The directly measured physical material parameters are tabulated in the table 1. Afterwards the surface acoustic properties (i.e. surface impedance and the normal incidence sound absorption coefficient) were measured according to the ISO 10534-2 [7]. Finally, the normal incidence sound transmission loss of similar 100 mm samples was measured in four microphone tube by means of a transfer matrix approach [8].

Melamine Foam 8.8 *Kg/m*^{3}-29.4 mm					
Parameters	σ	ϕ	α_∞	Λ	Λ'
Exp.	10518	0.99	1.01	107	137
Inverse	10872	0.99	1.00	99	142
Polyurethane Foam 40 *Kg/m*^{3}-25 mm					
Parameters	σ	ϕ	α_∞	Λ	Λ'
Exp.	24119	0.98	1.76	48	240
Inverse	23327	0.99	1.72	43	258
Soft Felt 24 *Kg/m*^{3}-25 mm					
Parameters	σ	ϕ	α_∞	Λ	Λ'
Exp.	6114	0.99	1.03	140	230
Inverse	5931	0.99	1.02	165	294
Kenaf 40 *Kg/m*^{3}-20 mm					
Parameters	σ	ϕ	α_∞	Λ	Λ'
Exp.	6215	0.99	1.05	68	177
Inverse	6731	0.99	1.01	67	180

Table 1: Physical Parameters of Samples

Melamine Foam-29 mm

PU-Foam 25mm

Soft Felt- 25 mm

Kenaf -20 mm

Figure 1: Material Samples

Results and Discussion

The measured and inverted parameters are compared in table 1. From the table it is clear that there is good correlation between experimental and inverse parameters of all samples.

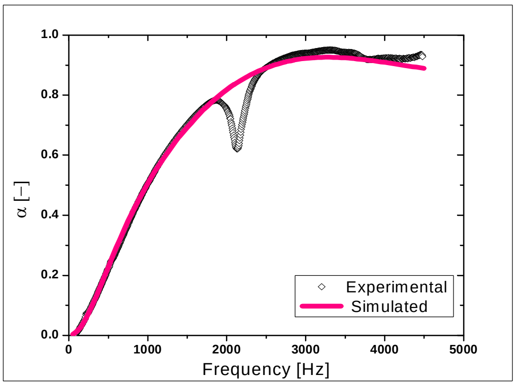

Figure 2: Sound Absorption Coefficient of Melamine Foam

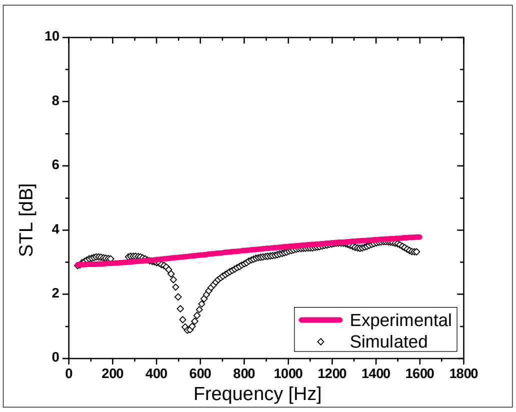

Figure 3: Sound Transmission Loss of Melamine Foam

In table 2, percentage error in all physical parameters is tabulated. For porous materials, it is less than 10 % for all parameters but for fibrous samples, it is higher for some of the parameters as difficult to maintain thickness of the samples during tests due to loose nature of fibres.

% Error	σ	ϕ	α_∞	Λ	Λ'
Melamine	3.37	0.00	0.99	7.48	3.65
PU Foam	3.28	1.02	2.27	10.42	7.50
Soft Felt	2.99	0.00	0.97	17.86	27.83
Kenaf	8.30	0.00	3.81	1.47	1.69

Table 2: % Error in all physical parameters for porous samples

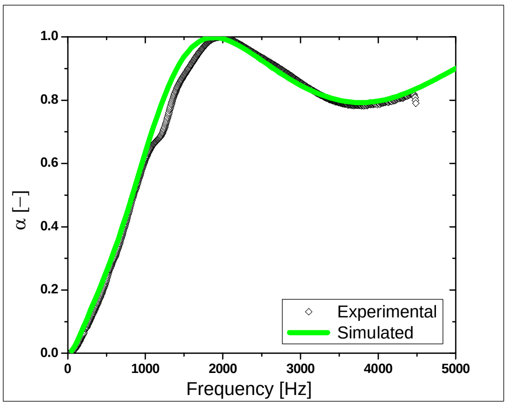

Figure 4: Sound Absorption Coefficient of PU-Foam

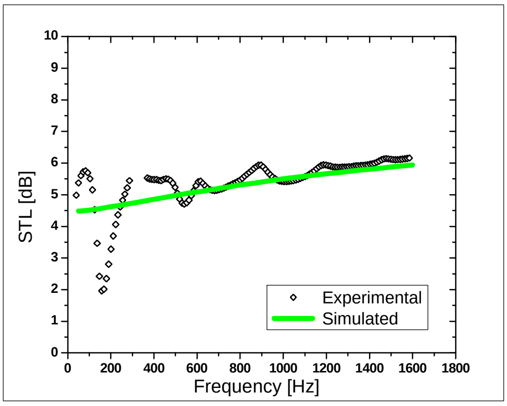

Figure 5: Sound Transmission Loss of PU-Foam

Sound absorption coefficient of materials is predicted with inverse five parameters using Johnson-Champoux-Allard model (JCA). The results for Melamine foam and PU-foam are shown in figures 2 and 4. Also using same model, sound transmission loss of the materials was also predicted and comparison of experimental transmission loss measured in 4-microphone tube and predicted is shown in figures 3 and 5. The results seems to be reliable except at low frequency where frame resonance is dominating and JCA model can predict resonance dips as it does not take into account elastic parameters of the porous materials. Also variations in terms of the function Δ, which is the average of the difference between the experimental sound absorption coefficient and predicted sound absorption coefficient with inverse as well as directly measured parameters using the JCA model analyzed and tabulated in table 3.

Δ	Melamine	PU	Felt	Kenaf
Direct	0.00	0.012	0.04	0.011
Inverse	0.01	0.014	0.00	0.00

Table 3: Average difference between Experimental SAC and SAC predicted using directly measured as well Inverse Parameters

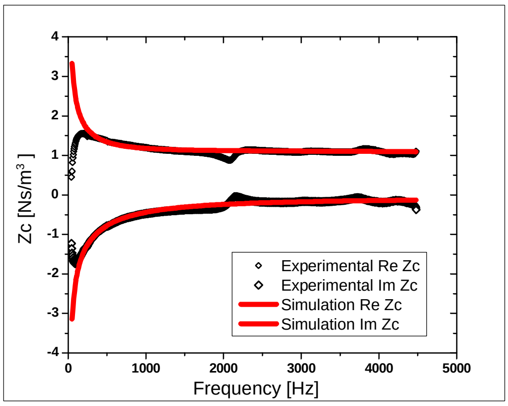

Figure 6: Characteristic Impedance of Melamine Foam

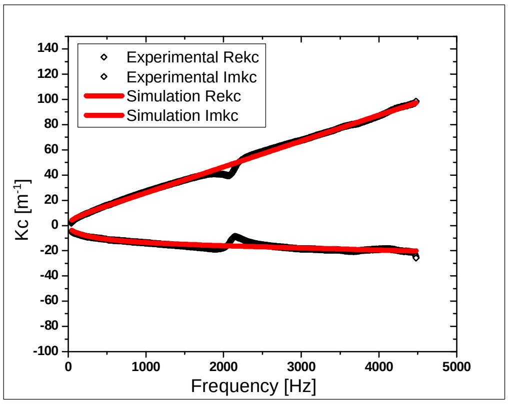

Figure7: Complex Wave number of Melamine Foam

From this data it is clear that the average difference in sound absorption coefficients is almost low in both cases and near to zero. Finally complex acoustical properties like complex characteristic impedance Z_c and complex wave number K_c are compared with predicted complex properties of the materials. The results for real and imaginary parts for characteristic impedance are shown in figures 6 and for complex wave number in figure 7. These figures show that inverse parameters can also provide reliable results for complex acoustical properties as well as for normal incidence sound absorption and transmission loss of the porous materials. So it is possible to use inverse schemes for prediction of sound absorption as well as transmission loss of the porous materials as a substitute to directly measured parameters when direct measurement of physical parameters is impossible.

Conclusions

The effect of inverted parameters calculated from Genetic optimization scheme is checked with experimental sound absorption and transmission loss of the material and good correlation is found. The results for inverted parameters calculated from Genetic optimization technique are found to be reliable with directly measured physical parameters. This paper also shows applicability of inverse parameters for prediction of absorption and transmission loss.

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