3D Simulation of Impedance Tube: Effect of Mesh Size on Sound Absorption Characteristic

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Abstract
In order to investigate the acoustic absorption of one kind of porous material, finite element method (FEM) was used. Here, we assessed the sound absorption of polyurethane foam as one of the widespread and multipurpose-usage porous material. A research was conducted to determine the sound absorption coefficient versus frequency and study the influence of mesh size on the quality of the noise absorption as a result of FEM simulation. The two microphone method as an experimental test was applied since verification of the finite element results. FEM outcomes were compared with experimental ones. Due to the gathered data, the best mesh size was specified. From the results of this investigation an equation is proposed to achieve the optimum mesh size to simulate models and to attain the closest answer to the experimental data.

Key words:
noise absorber, simulation, finite element, impedance tube.

1. Introduction

Noise pollution is increasingly recognized as a serious, worldwide public health concern. (1) Because of this, the issue of noise control has received considerable critical attention. So, the requirement of low cost, lightweight materials with wide frequency absorption range is highlighted. (2) Since this, it's essential that to predict the acoustic performance of the noise absorbers. The porous materials such as foams have widely usage in passive noise control. (3,4) En règle générale polymer-based foams since their thermal, mechanical, electrical and acoustic features are utilized in industries.(5) These foams act as sound absorber by conversion of sound energy to heat because of air friction and viscous friction respectively inside polymeric cells and between adjoining polymer chains.(6) Polyurethane (PU) is one of the most applicable such foams.(7) Some of the noteworthy properties of the PU are consist of lightweight, high viscoelasticity, commercial accessibility and availability, simple usability and simple processing.(2) In this paper, we are interested in studying the acoustic properties of a PU foam sample. This paper introduces a 3D finite element analysis to predict the sound insulation ability of a polyurethane foam as a passive noise absorber. The sound absorption coefficient is the most important acoustic index for porous materials. Here, the sound absorption coefficient of the model vs frequency is presented and discussed by different mesh sizes. There are different methods to determine acoustic properties of the absorptive materials: a) impedance tube (8, 9) b) reverberation room (10). In this study impedance tube is used to determine the sound absorption coefficient of the selected material in order to compare the data obtained from FEM simulation with experimental results.

2. Method

2.1. Impedance Tube

The acoustic index, “noise absorption coefficient”, can be measured in impedance tube as an experimental apparatus (11) by the methods as described in ISO 10534-1(8) and ISO 10534-2 (9, 12). As specified in both, they’re similar. Although, the measurement technique is unlike. (9) A schematic of a two microphone impedance tube which comprises of impedance tube, microphone, loud speaker (plane wave source) and digital frequency analyzer is shown in Fig1. The setup of experimental acoustic test system is displayed in Fig 2. In these methods, impedance tube with a sound source is connected to one end and the specimen is placed in the sample holder. Two microphones are placed at x1 and x2 points. The pressure transfer function is obtained betwixt microphones from following:

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$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{j2k(L+s)} \quad (1)$$

$$k = \frac{2\pi f}{c} \quad (2)$$

Here c is the sound speed and f is the frequency. While s is the distance between the microphones 1, 2 and L is the distance between the specimen and the first microphone.

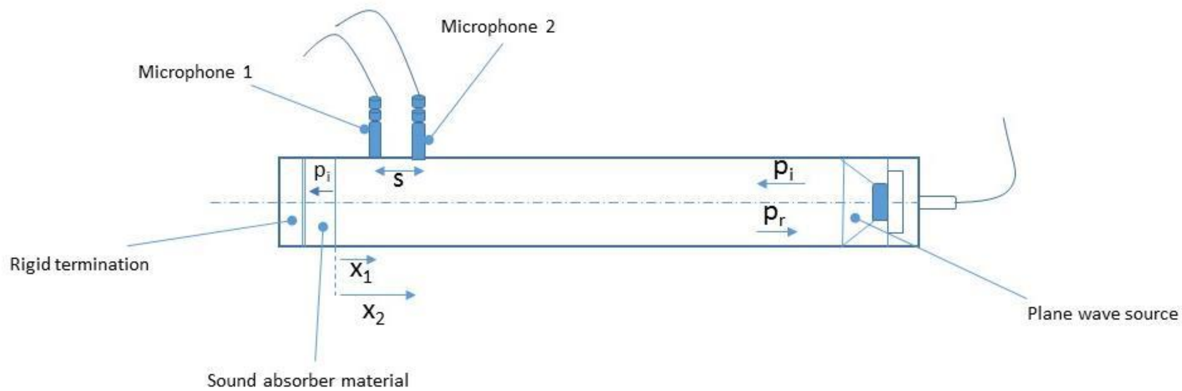

Fig. 1 Two microphone impedance tube

Absorption coefficient (α) can be determined according to the below :(9, 13)

$$\alpha = 1 - |R|^2 \quad (3)$$

Fig. 2 Experimental acoustic test system setup

2.2. Configuration of sound absorption test

Sound absorption test was done in a two microphone impedance tube (BSWA-SW422, SW477) according to ISO 10534-2:1998 (GB/T 18696.2-2002) to gather data to characterize the acoustic specification of the intended material. Samples were provided by cutting them with 100 mm diameter inasmuch as impedance tube's diameter and 30 mm thickness. The material parameters are represented in Table 1. Specimens fixation in the impedance tube was very good. The frequency range of the fast Fourier transform analysis was 250 – 2000 Hz in one third octave band. All the measurements performed in an authenticated laboratory.

2.3. Finite element modeling

The effect and application of different mesh sizes was investigated on the sound absorption coefficient as a FEM simulation result here. Experimental test set up, was modeled 3D and configured as well as defined in ISO 10534-2:1998 (GB/T 18696.2-2002). The model configured in COMSOL. To cover the round edge of the tube and other components of the model free tetrahedral element was selected. Mesh sizes were changed in 16 models at each frequency according to Table 2. The model was analyzed by Johnson-Champoux-Allard. Absolute pressure was considered 1 (atm). The effect of humidity and temperature was considered the same as experimental test condition. A model of sound absorption was presented by a PU elastic foam. Validation of the finite element prediction, was done by comparing the FEM analysis results with experimental ones that was fulfilled in an authenticated lab. Finally, mesh sizes in which the best answer gained were selected as the new model.

Table 1: Material parameters

Description	Density	thickness	Flow resistivity	porosity	tortuosity	Thermal characteristic length	Viscous characteristic length
Unit	Kg/m3	m	Nm-4s	-	-	m	m
Value	1.2	0.03	12569	0.99	1.02	0.000192	0.000078

Table 2: Element size division regarding to frequency at 1/3 octave band (The table below shows the mesh sizes under each model vs. frequency)

Frequency (Hz)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model10	Model11	Model12	Model13	Model14	Model15	Model16
250	1.373	0.686	0.458	0.343	0.275	0.229	0.196	0.172	0.153	0.137	0.125	0.114	0.08	0.10	0.15	0.19
315	1.090	0.545	0.363	0.272	0.218	0.182	0.156	0.136	0.121	0.109	0.099	0.091	0.08	0.10	0.15	0.19
400	0.858	0.429	0.286	0.215	0.172	0.143	0.123	0.107	0.095	0.086	0.078	0.072	0.08	0.10	0.15	0.19
500	0.686	0.343	0.229	0.172	0.137	0.114	0.098	0.086	0.076	0.069	0.062	0.057	0.08	0.10	0.15	0.19
630	0.545	0.272	0.182	0.136	0.109	0.091	0.078	0.068	0.061	0.054	0.050	0.045	0.08	0.10	0.15	0.19
800	0.429	0.215	0.143	0.107	0.086	0.072	0.061	0.054	0.048	0.043	0.039	0.036	0.08	0.10	0.15	0.19
1000	0.343	0.172	0.114	0.086	0.069	0.057	0.049	0.043	0.038	0.034	0.031	0.029	0.08	0.10	0.15	0.19
1250	0.275	0.137	0.092	0.069	0.055	0.046	0.039	0.034	0.031	0.027	0.025	0.023	0.08	0.10	0.15	0.19
1600	0.215	0.107	0.072	0.054	0.043	0.036	0.031	0.027	0.024	0.021	0.020	0.018	0.08	0.10	0.15	0.19
2000	0.172	0.086	0.057	0.043	0.034	0.029	0.025	0.021	0.019	0.017	0.016	0.014	0.08	0.10	0.15	0.19

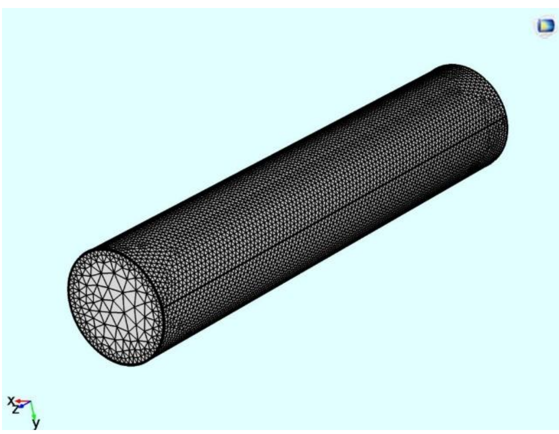

Fig. 3 Element size distribution of new model at 250 (Hz) frequencies

3. Result

As mentioned above mesh sizes in which the best answer gained, were determined. Here, we consider them as a new model. These mesh sizes as the characteristic of the new model are shown in Table. 3.

Fig. 3 presents the element size distribution of the model that desired results is obtained by at 250 (Hz) frequency. Available experimental measurement approach and 3D acoustical finite element simulation results were compared. The results, as shown in Fig. 4, indicated that the outcomes from new model and the Lab tests' have a good compatibility. Due to the measured and modeling results comparison, the lowest difference 0.01 was observed at 2000Hz and the highest difference 0.09 at 1600Hz with average difference of 0.05 at 1000 and 400 Hz.

Table 3: Mesh sizes (m)of the new model.

Frequency (Hz)	New model
250	0.19
315	0.363
400	0.172
500	0.15
630	0.1
800	0.054
1000	0.043
1250	0.034
1600	0.027
2000	0.021

Gathered data from this study illustrate that; how mesh can affect the modeling result, and the acoustic absorption changes by mesh size variation under normal wave incidence. Based on this study, we may say that to achieve desired sound absorption the mesh size can be satisfied the following equation:

$$\ln(s) = \ln(463.727)+(-1.325 * \ln(f)) \quad (4)$$

Where f is the frequency and s is maximum element size.

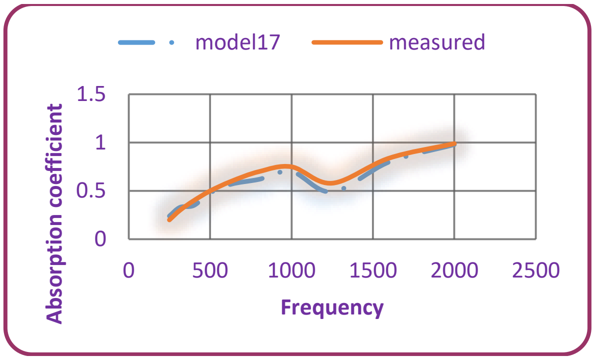

Fig. 4 Absorption coefficient: The comparison between experimental results and predicted results by mesh size of the new model.

4. Conclusion

The most obvious finding to emerge from this study is that, the best results for 250 – 2000 Hz frequency range can be achieved at mesh sizes of new model which is shown in Table. 3. For the aforementioned reasons, it's clear that simulation by finite element method can be applied instead, whenever measurement equipment like impedance tube and suchlike are not available. It can thus be suggested that further observation can be done on lower and upper frequency ranges extended from 250 to 2000 Hz and optimum mesh sizing for those frequencies.

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