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Finding Sound Absorption Coefficients On Porous Absorber Material by Using COMSOL Simulation and Impedance Tube Method

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Abstract: There are several methods in finding the best sound absorption coefficient on three types of most common porous absorber [1]. The aim of this study is to conduct modelling of material sample on COMSOL Multiphysics to find the best sound absorption coefficient among the materials and the resulted sound absorption coefficient will be compared based on both methods used. The porous materials including melamine foam, wood wool cement board, glass fibre which will be tested on COMSOL Multiphysics and Impedance Tube. Noise Reduction Coefficient will be included in determining the best material that have the best sound absorption. Melamine foam has the best sound absorption properties based on the calculate NRC and there are slight inaccuracy in COMSOL Simulation which need to develop for future use.

Keywords: Sound Absorption Coefficient, Porous Absorber, COMSOL Multiphysics

1. Introduction

Porous absorber typically divided into two categories which are open cell foam and fibrous material. The main function of porous absorber is to damp the sound wave entering the materials by friction. Simulation on porous absorbent material will be conducted on COMSOL Multiphysics to find sound absorption coefficient of the materials [2]. As known, there are three methods in finding sound absorption that includes simulation, impedance tube method, and reverberation room method [3]. The most convenient and save cost method are simulation and impedance tube method. Therefore, comparison between these two methods will be conducted. The result would be very close since all porous absorbent is known to have high porosity that can absorb sound really well. However, the parameters of each materials are taken and the possible outcome would be melamine foam to have highest sound absorption coefficient since it has the highest porosity.

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2. Materials and Methods

2.1 Materials

Melamine foam, wood wool cement board, and glass fibre contained the porosity value of 99%, 58%, and 98% respectively [4,5,6]. Wood wool cement board has the highest tortuosity while the lowest airflow resistivity value since both of the properties are related. Glass fibre contained the highest value of thermal characteristic length which also provide into good sound absorption properties.

2.2 Methods

Overall, this study use COMSOL Multiphysics as platform in conducting simulation in finding sound absorption coefficient. However, the parameter used in COMSOL simulation were based on previous studies that conduct on same material by using Impedance Tube method. Melamine foam parameter were achieved by using three microphone impedance tube and inverse characterization technique. Wood wool cement board parameter were determined by using six-microphone impedance tube and the airflow resistivity is achieved in accordance to ISO 9053 [5]. Next, Glass fibre parameter is determined by using the same method as wood wool cement board. Limitations of this study is the experimental on impedance tube only restricted within low frequency. Mid and high frequency is not included so the comparison only limited within the frequency.

2.3 Equations

$$p_{inc} = exp^{-i(k.x)} \quad \text{Eq. 1}$$

$$k = k_0(\sin\theta - \cos\theta) \quad \text{Eq.2}$$

$$\alpha = 1 - |R|^2 \quad \text{Eq.3}$$

$$R = \frac{p_{scat}}{p_{inc}} \quad \text{Eq.4}$$

$$Z = \frac{1}{\rho c} \frac{p}{u_n} \quad \text{Eq.5}$$

$$Z_{ana} = \frac{1}{\rho c k} \frac{-iZ_c k_c}{\cot(k_x H_p)} \quad \text{Eq.6}$$

$$k_x = \sqrt{k^2_c - k^2_y} \quad \text{Eq.7}$$

$$k_y = k_0 \sin(\theta) \quad \text{Eq.8}$$

$$p(x) = p(x + d)e^{-i(k \cdot d)} \quad \text{Eq.9}$$

$$\Lambda = \frac{1}{c}\left(\frac{8\alpha_\infty \eta}{\sigma\phi}\right)^{\frac{1}{2}} \qquad \textit{Eq.10}$$

$$\Lambda' = \frac{1}{c'}\left(\frac{8\alpha_\infty \eta}{\sigma\phi}\right)^{\frac{1}{2}} \qquad \textit{Eq.11}$$

$$NRC = \frac{\alpha_{200} + \alpha_{400} + \alpha_{800} + \alpha_{1600}}{4} \qquad \textit{Eq.12}$$

2.4 Biot's Theory

Biot Theory is also called as Johnson-Champoux-Allard model of Biot Theory that explained about acoustic behaviour of porous media of certain models [7]. Johnson-Champoux-Allard indicates five important parameter that need to be include before running the simulation. The parameters are included as below:

- Porosity, φ (1), is described as fluid content volume fraction in any porous material,
- *Tortuosity,* α_∞ (1), is described as fraction of microscopic fluid velocity squared to the macroscopic fluid velocity squared averaged over a volume under zero viscosity assumption.
- *Static flow resistivity,* α_∞ (Nsm−4), is described as the difference of pressure over velocity of flow per unit length.
- *Viscous characteristic length, Λ* (m), is described as it improve the measurement of dissipation effects occurred because of viscous loss at the porous wall.
- *Thermal characteristic length, Λ'* (m), is described as the exchange in terms of thermal between the frame and the fluid at the boundary.

3. Results and Discussion

3.1 Modelled porous absorber

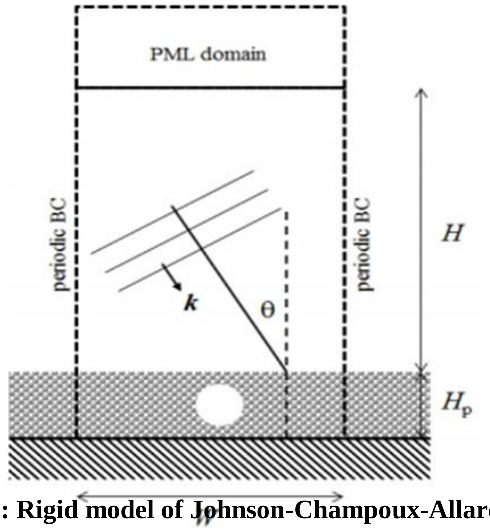

Figure 1: Rigid model of Johnson-Champoux-Allard

Model in Figure 1 shows the rigid model that was introduced by Johnson-Champoux-Allard. The porous layer located at the very bottom of the model that has the height of H_p. The ***k*** indicates the incident sound wave of 45° that hits the porous layer [8]. At the top of model, there is PML that stands for Perfectly Matched Layer that is modelled for air domain. The dotted lines around the rigid model represent the boundaries of the model. It will then be applied with Floquet boundary condition to extend the domain to infinity.

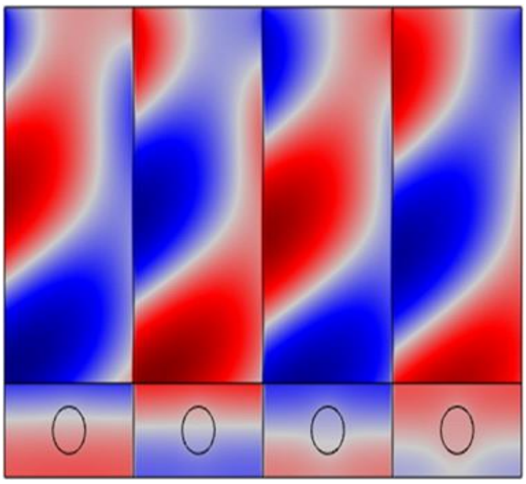

Figure 2: Model of porous absorbent by using COMSOL

Figure 2 shows the modelled porous absorbent panel by using COMSOL Multiphysics. This model of rigid frame is introduced by Johnson-Champoux-Allard in their study. The same shape and dimensions of panel will be used for all type of materials. The colours represent the sound wave that can range from 0 to 10000 Hz. Plus, the sound wave can be set into two type of incident wave whether 0° incident wave or 45° incident wave. Based on the figure, the current incident wave used is 45°.

3.2 Discussions

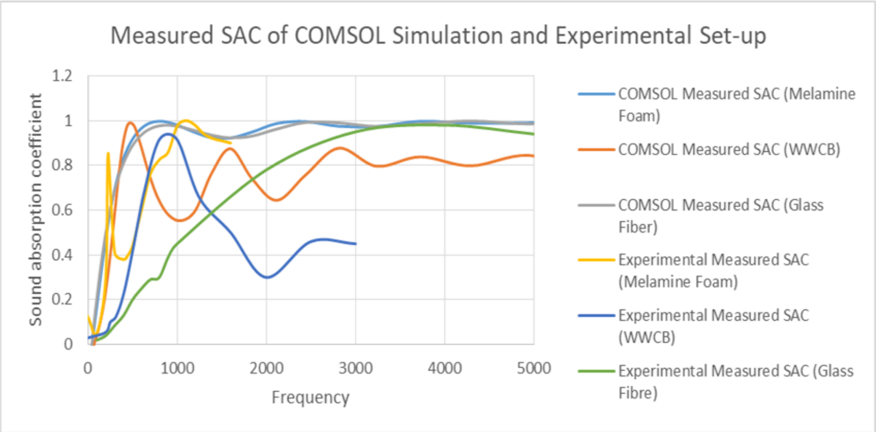

Figure 3: Measured SAC of COMSOL and Experimental Set-up

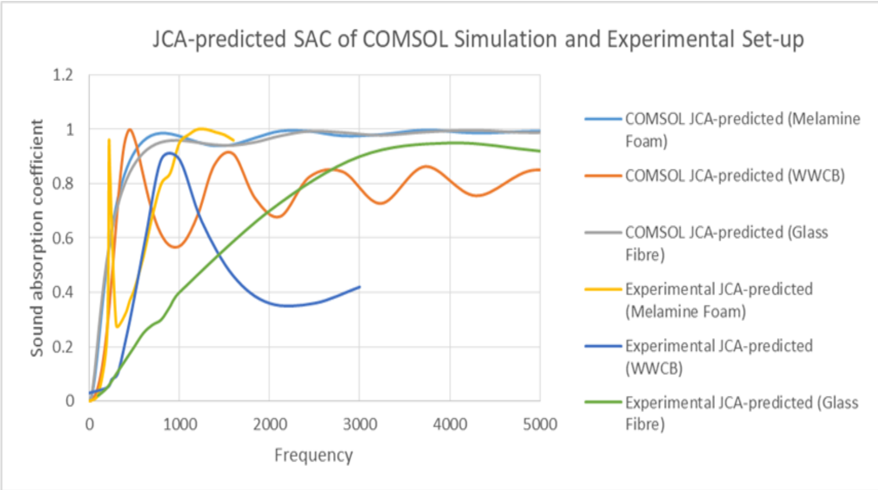

Figure 4: JCA-predicted SAC of COMSOL and Experimental Set-up

Figure 3 and Figure 4 shows the result of sound absorption coefficient that was obtained throughout the COMSOL simulation and impedance tube method. There are two graphs to differentiate between measured and JCA-predicted value. Measured value is the value that was taken directly from the equipment meanwhile JCA-predicted is a numerical way to determine sound absorption coefficient. The patterns of graphs between these two graphs are almost the same except that at certain points there are little fluctuations occurred. The pattern almost the same because the JCA-predicted shows good agreement towards measured value. In average, it is very clear that wood wool cement board has the lowest capability in absorbing sound. However, the most fluctuations occurred at wood wool cement board in both category. As observed, the huge drop in value of sound absorption coefficient occurred at melamine foam and WWCB that was run by experimental impedance tube.

3.3 Results

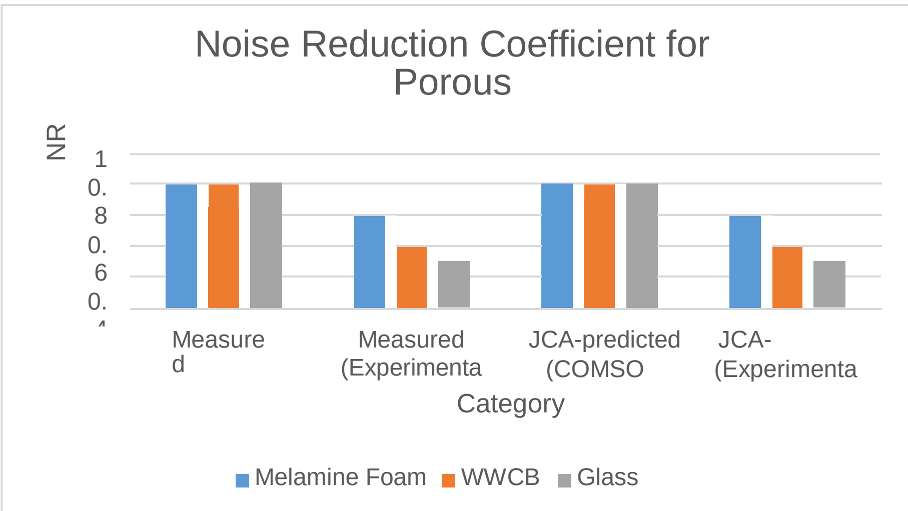

Figure 5: Result of NRC for porous absorbers

Bar chart in Figure 5 is the result after analyzing data from COMSOL Simulation and Impedance Tube method. It is categorized based on the method used and technique used so that it can be compared fairly. Noise reduction coefficient method is defined by the ASTM standard C423 [9]. NRC is the same as SAC as it ranges from 0 to 1 and will be rounded to the closest 0.05.

3.4 Figures

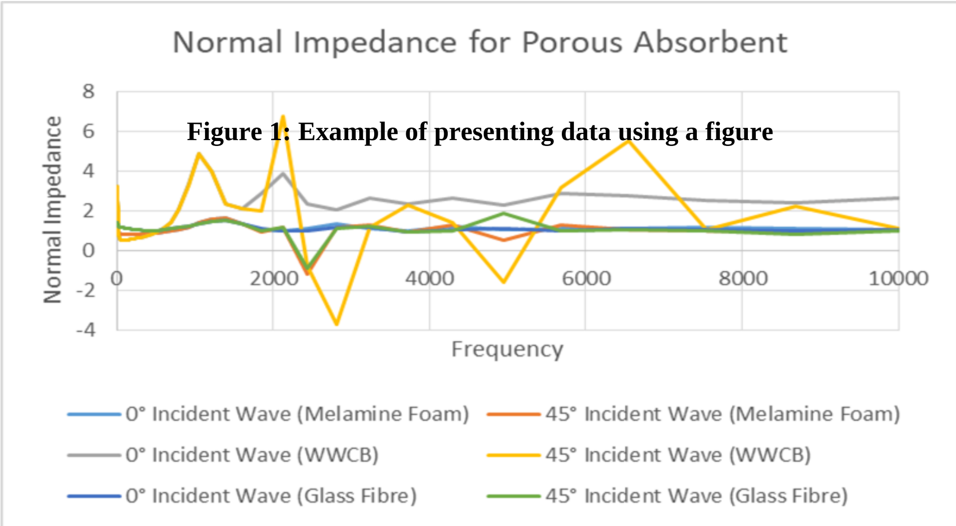

Figure 6: Normal Impedance of Porous Absorbent

Figure 6 shows surface normal impedance for all type of material. It is sorted based on the incident wave. As per observation, 45° incident wave give more impact towards surface normal impedance. It can be seen from WWCB and glass fibre as they fluctuates in a huge value. 0° incident wave give less impact towards surface normal impedance since the value only fluctuates in small value. 45° incident wave for all types of porous absorbent seems to have negative value at certain points of frequency. WWCB has the highest average value of normal impedance for both 0° and 45°.

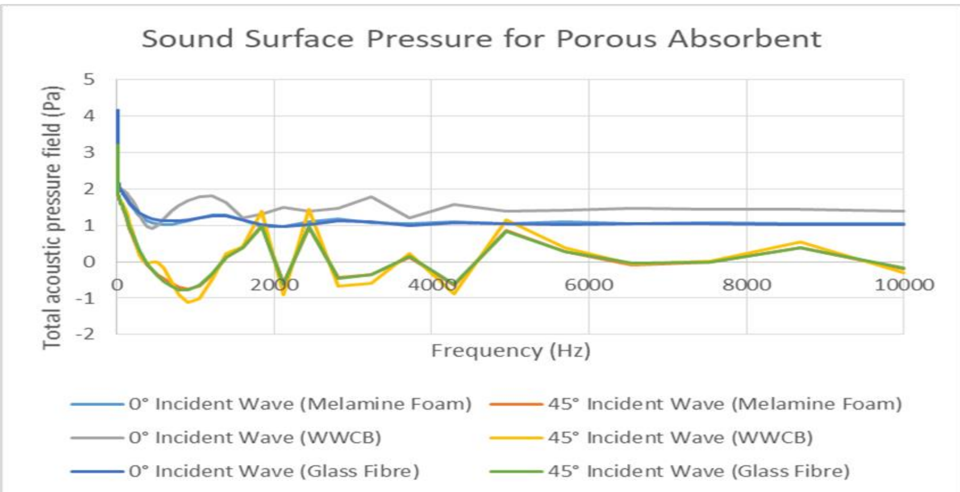

Figure 3.7: Sound surface pressure for porous absorbent

Initial value for all type of materials quite high within 2 Pa and 4 Pa. They suddenly dropped in value entering 1000 Hz. Most of the fluctuations happened for 45° incident wave. The pattern of the graph are almost the same for all porous absorbent categorized by the incident wave. For 0° incident wave, only WWCB showed clear fluctuation. For 45° incident wave, all porous absorbent fluctuates but as can see, WWCB has the highest fluctuates value compared to other type of porous absorbent. The fluctuations are very regular within 0 Hz to 4000 Hz. There is huge comparison within the fluctuation within the high frequency 4000 Hz to 10000 Hz.

4. Conclusion

Less fluctuations can be seen on both of the material if it run by COMSOL. If it was based on experimental set-up, more fluctuation that show huge gap of sound absorption coefficient can be seen. Between all three types of materials, it is very clear that WWCB has the lowest sound absorption capability. Based on Figure 4, calculated NRC showed that melamine foam has the highest value of NRC in most of category. Thus, it is picked as the best porous material that have highest sound absorption properties [10]. COMSOL introduce a wide flexibility when dealing with physical problem. In terms of acoustic studies, it allows simulation of surrounding scene that comes with noise source as well as problems that related to any measurement of acoustic wave [2]. As recommendation, future research and development could be done to minimize possible sources of error especially regarding the issue of initial value of measured sound absorption coefficient that happened to be negative.

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