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Effect of Porous Materials Combination in Layers on Sound Absorption Characteristics

M.H. Zainulabidin[1,a*], M.H.M. Yusuff[2,b], A.E. Ismail[3,c], M.Z. Kasron[4,d] and A.S.M. Kassim[5,e]

[1,2,3,4]Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[5]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[a]hafeez@uthm.edu.my, [b]m.hafiez89@yahoo.com, [c]emran@uthm.edu.my, [d]zainorin@uthm.edu.my, [e]angzzas@uthm.edu.my

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Abstract. This paper describes the investigation and analysis on two materials in which one material is a relatively good sound absorber at low frequency range and another is a relatively good sound absorber at high frequency range, combined together in layers to form a better sound absorber for a wider range of frequencies. The layer combinations of the materials are varied and the values of Sound Absorption Coefficient, α are measured experimentally by using impedance tubes with two microphones transfer function method according to ISO 10534-2 standard. The results obtained are compared in terms of the order of material and the number of layer combinations of materials for each sample. The orders of combinations and number of layers of combinations have significant influence on the sound absorption characteristics. The order of materials has reversed effect on Sound Absorption Coefficient, α as the number of layer combination is increased. Increase in the combination number will make the specimen performed relatively better at a wider frequency range.

Introduction

A sound level particularly in a closed room could be reduced or controlled by the use of sound absorber. It works by preventing generation of echoes or reverberation produced in the room. The sound absorption performance is known to depend on the frequency of the incident sound wave that is, certain materials have an ability to absorb sound at a certain frequency. In practical, this characteristic is not favorable since we are exposed with sound with various frequencies.

Sound absorbers are categorized into three main types namely porous, cavity and membrane absorbers. Porous, cavity and membrane type absorbers are found useful for high, middle and low frequency range respectively [1]. Porous absorbers which are the subject of this study are materials with an open pore structure and commonly made of light and porous materials such as sponge, foam, cotton, wool, and asphalt. Based on the microscopic configurations, porous absorbers can be classified as cellular, fibrous or granular [2].

The acoustic performance of a porous absorber is influenced by its physical properties such as fiber size, airflow resistance, porosity, tortuosity, thickness, density and its position [3]. A decrease in fiber size will increase sound absorption coefficient [4]. A material with smaller fiber has more porosity hence more contact surface with the incident sound [5]. Airflow resistivity is the ratio of static pressure drop to a volume flow per unit thickness of the material. Materials with higher airflow resistance absorb sound better because more energy is transmitted into heat by friction [6]. Porosity is the ratio of interconnected void volume to total volume of a material.

According to Shoshani et. al, [7], porosity should increase along the propagation of sound in order to get a high sound absorption. Tortuosity is a measure of the elongation of the passageway through the pores compared to the thickness of the sample. Tortuosity mainly affects the location of the quarter wavelength peaks [8]. Numerous studies have been conducted to investigate the effect of thickness on the sound absorption characteristics. Generally, the sound absorption coefficient will increase in all frequency range as the thickness of the sample increases [9]. Koizumi et. al, [9] also showed that increase in the material density will also increase the sound absorption values in the middle to higher frequency region. Position of the absorption material will also affect the sound absorption characteristics. Everest [10] demonstrated that the most effective location to place an absorptive material in a rectangular room is near the corners and along the edges. Recently, Zainulabidin et. al, [11] studied the effect of combining two porous materials in fractions in which one material is a relatively good sound absorber at low frequency range and another is a relatively good sound absorber at high frequency range. The combinations of materials have a significant influence on the sound absorption properties. Combined materials with balance fractions of materials have relatively result in better sound absorption coefficient values over wider range of frequency.

This paper describes the work done on the sound absorption analysis of two types of synthetic materials, arranged in layers with different orders and number of layers. One material is a relatively good sound absorber at low frequency range and another is a relatively good sound absorber at high frequency range, combined together in layers to form a better sound absorber for a wider range of frequencies.

Theory and Formulation

Sound Absorption Coefficient. The Sound Absorption Coefficient, α is a quantity used to describe the sound absorption performance of a material. It is known to be the function of the frequency of the incident wave. It is defined as the ratio of energy absorbed by a material to the energy incident upon its surface. The absorption coefficient can be expressed as:

$$\alpha = 1 - \frac{I_R}{I_I} \quad . \qquad (1)$$

where α is the Sound Absorption Coefficient, I_R is the Reflected Sound Intensity and I_I is the Incident Sound Intensity.

The Sound Absorption Coefficient, α of materials are varies in the range of 0 to 1. Value 0 indicates zero sound absorption while value 1 indicates perfect sound absorption. In the case of α = 0, the sound is completely deflected by the material. On the other hand, α = 1 represents that the sound is completely absorbed by the material.

Experimental Analysis

Materials selection. Two materials were selected for the study based on its sound absorption property. The materials are rubber sponge for air-conditioning insulation and synthetic sponge for car seat cushion. Both materials have been tested and it was found that the rubber sponge has a relatively good sound absorption at low frequency which is approximately at 1000 Hz with peak sound absorption coefficient is approximately 0.92. Synthetic sponge has a relatively good sound absorption at high frequency which is approximately 0.9 between 3000-5000 Hz. The high frequency material has a wider frequency range with good α values if compared to the low frequency material.

Specimens preparation. The specimens have been prepared in 6 combinations as shown in Fig. 1(a)-(f). Each of the combination has been prepared in 2 sizes; large and small. The large size specimen 100 mm in diameter is for the low frequency test and the small size specimen 28 mm in diameter is for the high frequency test. The thickness of a single high and low frequency specimen is 25 mm and 20 mm respectively. Three specimens for all the combinations and sizes were prepared and tested. The average values were then computed.

(a) (b) (c)

(d) (e) (f)

Fig. 1: (a) Single Layer Low-High Combination (LH); (b) Double Layer Low-High Combination (LH,LH); (c) Triple Layer Low-High Combination (LH,LH,LH); (d) Single Layer High-Low Combination (HL); (e) Double Layer High-Low Combination (HL,HL); (f) Triple Layer High-Low Combination (HL,HL,HL).

Sound absorption measurement system. The impedance tube used was SCS9020B system which composed of two sets of tube setup. The large size tube with inner diameter of 100 mm is for low frequency measurement and the small size tube with inner diameter of 28 mm is for high frequency measurement. The frequency ranges for the large and small tubes are 90 - 1800 Hz and 450 - 7100 Hz respectively. The specimen was placed to a pre-adjusted depth at one end of the tube and the loud speaker was placed the opposite end as a sound source. The two microphones transfer function method according to ISO 10534-2 standard was used to measure the materials sound absorption properties. The actual assembly of the measurement systems is illustrated in Fig. 2.

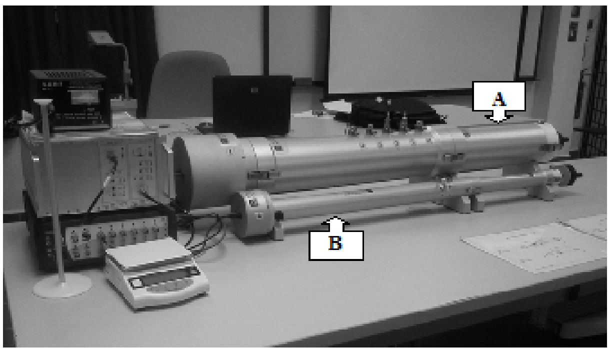


Fig. 2: Impedance tubes; **A** for low frequency test and **B** for high frequency test.

Results and Discussions

Effect of combination order on the sound absorption characteristics. Fig. 3(a) is the Sound Absorption Coefficient, α characteristics of uncombined high and low frequency materials that serves as a reference for further discussions. Fig. 3(b)-(d) show the effect of combinations order on the α characteristics. In general, combining two materials which is good at low and high frequency ranges produced a specimen that is better than the material on its own. The combined specimens performed relatively better at a wider frequency range. The order of material combinations have significant effect on the α characteristics. The single HL and LH combination curves in Fig. 3(b) can still be traced back to the H and L curves in Fig. 3(a) respectively. The material positioned at the front exhibit dominant characteristics if compared to the material positioned at the back. As the combinations are increased, the dominance characteristics are reversed. This characteristics can be seen in Fig. 3(d) as LH,LH,LH combination has higher and wider absorption values than HL,HL,HL combination at high frequency region. At the same time, the HL,HL,HL combination has a wider curve at low frequency region. These characteristics can be explained based on sound propagation through porous material theory. As sound wave collides with porous material, some will be reflected back and some will travel through the material. The sound that continues to travel will be absorbed and lost as heat energy, while some that has not been absorbed will be reflected back by the hard back wall. Some of the reflected sound will continue to travel through and out of the material, while some will be reflected or absorbed again by the material. In the single combination case, since the combined materials are relatively thinner, the sound wave propagation through the materials quite similar to the uncombined material. In the triple combination, since the combined materials are thicker, the contact surface inside the materials are larger and the contact time is longer hence more sound are absorbed. The concentration of re-reflected sound energy is denser closer to the wall hence higher absorption by the material closer to the wall.

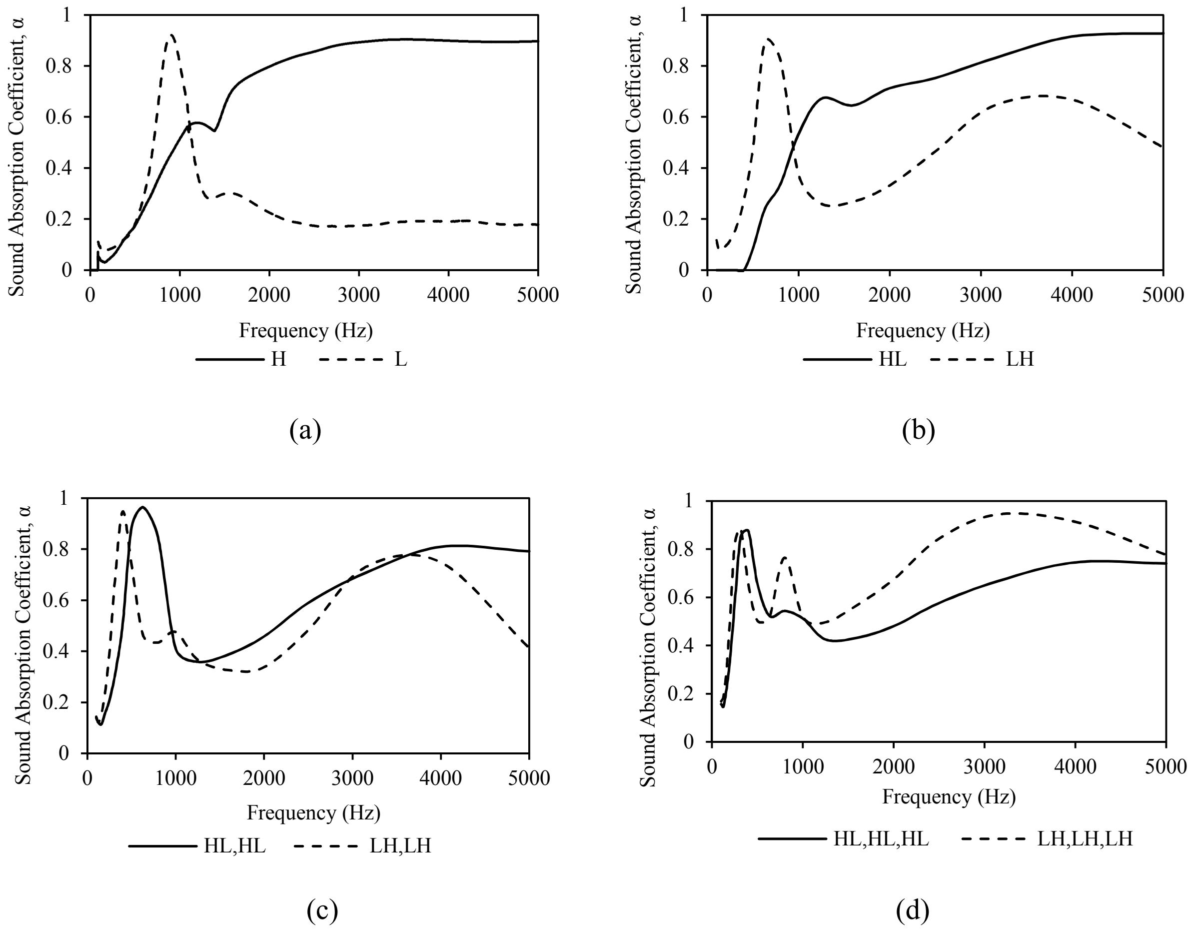
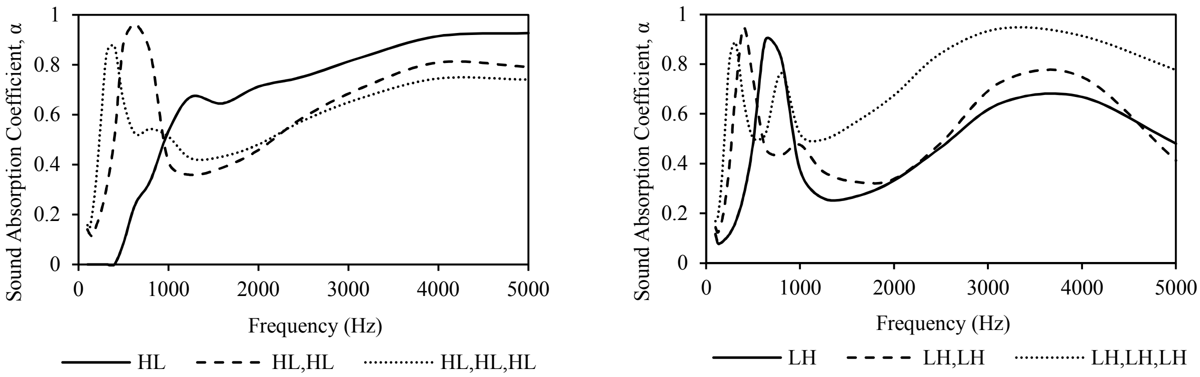


Fig. 3: Effect of combination order on the sound absorption characteristics.

Effect of combination number on the sound absorption characteristics. Fig. 4 shows the effect of combination number on the Sound Absorption Coefficient, α characteristics. In general, increasing the combination number will make the specimen performed relatively better at a wider frequency range. This effect can be seen clearly for the case in Fig. 4(b) as the combinations are increased, the α values are also increased with wider range of frequency. The trend is not really obvious in Fig. 4(a). This is because the high frequency material has a wider frequency range than the lower frequency material as can be seen in Fig. 3(a). The higher frequency material is more dominant in the combinations.



(a) (b)

Fig. 4: Effect of increasing number of layers on the sound absorption characteristics.

Conclusion

Combining two materials in layers in which one is a good absorber at a low frequency and another is good absorber at a high frequency range produced a specimen that perform better than the materials on its own. The combined specimens performed relatively better at a wider frequency range. The orders of combinations and number of combinations have significant influence on the sound absorption characteristics. Order of materials has reversed effect on Sound Absorption Coefficient, α as the number of layer combination increased. While, increasing the combination number will make the specimen performed relatively better at a wider frequency range.

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