Study on acoustic properties of multilayer impedance materials

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Abstract. Composite materials are produced using advanced material preparation techniques to optimize a combination of materials with different properties to form new materials. Such materials have the composite properties of their constituent materials. Composite materials have been widely explored for their use in the field of acoustic noise reduction as well as in automobile, aviation, and other fields. To further enhance the acoustic characteristics of composite materials, this letter proposes a multilayer composite structure comprising a resistive screen structure material (perforated screen material), foam, and fiber. The impedance tube method is used to investigate the rigid wall absorption performance and flow field transmission loss in seven types of resistive screen composite materials of various flow resistivities and porosities. The results show that the acoustic absorption and acoustic insulation performance of the resistive screen composite material are better than the foam–fiber multilayer material. The maximum acoustic absorption coefficient reached 0.95 at 3000 Hz and the maximum difference in sound reduction was 6.5 dB. This resistive screen material provides a new dimension to the design of new materials.

1. Introduction

Acoustic materials are composite organic materials that reduce noise and improve acoustic environments. These materials are widely used in the field of transportation, such as in automobiles, aircraft, and ships [1-3]. In recent years, natural fibers have received extensive attention owing to their environmental and cost benefits [4-8]. Comparisons of the acoustic absorption effects of the natural fiber and linen composite materials have been reported in the literature [9], and it was confirmed that the performance of the composite materials is better than that of noncomposite-layer structures. To validate the acoustic properties of multilayer composites, some researchers have studied the acoustic absorption coefficients and acoustic transmission loss of natural tea and sponge fibers [10], rice straw-wood particle composite sheets [11], natural organic multilayer coconut shell fibers [12-14], and tea layers [15]. However, there have been no reports on the use of film-based multilayer materials, especially fiber–foam multilayer composite materials containing a resistive screen material (perforated screen material). Resistive screen materials facilitate a simple but limited thin-porous model characterized by its flow resistivity and unit surface roughness, with good acoustic absorption and sound reduction.
properties. In this study, the flow resistivity and porosity performance parameters of resistive screen material (perforated screen material) are studied and compared. The acoustic absorption performance and flow field transmission loss of the resistive screen material (perforated screen material)–foam–fiber multilayer structure are determined under the conditions of rigid wall and flow field using seven types of composite materials. The factors affecting the acoustic absorption and sound reduction of the resistive screen material are compared and analyzed to open new dimensions to the design of new materials.

2. Testing and processes

Firstly, the flow resistance and porosity of perforated screen materials (white, black and leather), resistive screen materials (white, black and leather), foam and natural fiber materials were tested. The results are shown in table 1, and the Flow resistance test instrument is shown in figure 1 (B). Next, a multilayer structure was prepared. Figure 1(A) shows the microstructure of the multi-layered structure. The first layer is a perforated screen material (type 6) with a thickness of 0.4 mm. The second layer is a foam material with a thickness of 12 mm, and the third layer is a natural fiber material with a thickness of 12 mm. Subsequently, a multilayer composite material is fabricated. To evaluate the acoustic performance of the multilayer material, the samples were divided into seven multilayer composites, as shown in Figure 2(A),(A: fiber+ foam, B: resistive white Screen + foam+ fiber, C: resistive leather screen + foam +fiber, D: resistive black screen + foam +fiber, E: perforated white screen + foam +fiber, F: perforated leather screen + foam +fiber, G: perforated black screen + foam+ fiber)In the next step, an impedance tube was used to determine the acoustic performance of the multilayer materials. The principle of the tests is shown in Figure 2(B). The excitatory acoustic source was set to be a plane wave, and the incident angle was normal. The backend of the multilayer samples was a rigid wall, and the dimensions of the impedance tube were d = 29 mm, s = 20 mm, and L = 35 mm.

In the impedance tube method, the normal incidence reflection coefficient $L(f)$ can be expressed by using the following equation:

$$L(f) = \frac{H_{12}(f) - e^{-jk_s}}{e^{jk_s} - H_{12}(f)} e^{2jk(s+L)}$$

(1)

Where $H_{12}(f)$ is the acoustic transfer function from $\tilde{p}_1$ to $\tilde{p}_2$ and $K = 2\pi f / c$ is the wave number, with $c$ being the speed of sound in air, $f$ being the working frequency, and $j = \sqrt{-1}$. The acoustic absorption coefficient can be determined from the reflection coefficient in the above equation: $\alpha(f) = 1 - |L(f)|^2$ (2).While $H_{12}(f)$ is obtained from measurements, $L(f)$ and $\alpha(f)$ are calculated using equations (1) and (2).The same impedance tube was used to measure the acoustic transmission loss of all the test samples. However, four microphones were needed to determine the value of the transmission loss of the test samples [16].

| Table 1. Acoustic parameters of multilayer structures |
|-----------------------------------------------------|
| Porosity $\varphi$ | / | / | / | 0.06 | 0.08 | 0.03 | 0.99 | 0.95 |
| Flow resistivity $\sigma$ (N.s/m$^4$) | 17000 | 137000 | 350000 | 17000 | 137000 | 350000 | 10900 | 1500 |
Figure 1. (A), microstructure of the multi-layered structure (B), Flow resistance measuring device
Figure 2. (A), According to different flow resistance and porosity composed of 7 kinds of multi-layer structure (B), Schematic diagram of impedance tube test under rigid wall condition

3. Results and discussion
The acoustic absorption coefficient and reflection characteristics of the multilayer structure are shown in Figures3 (A-B), respectively. From the measurement results, it can be seen that the resistive screen structure–foam–fiber composites of different flow resistivities and porosities have different absorption properties. The absorption coefficient of the foam–fiber structure gradually increased as the frequency increased from 0 to 3000 Hz, and the sound absorption coefficient gradually stabilizes from 3000 to 6000 Hz. The acoustic absorption coefficient of the resistive screen -type multilayer structure increased as the flow resistivity increased; (white resistive screen + foam + fiber)> (black resistive screen + foam + fiber)> (leather color resistive screen + foam + fiber). Thus, the flow resistivity of the resistive screen structure has positive correlation with the acoustic absorption coefficient. In the perforated screen structure, the sound absorption coefficient increased significantly at low frequencies from 0 to 2000 Hz and gradually decreased in the range 2000–6000 Hz. A comparison of the seven types of composites showed that the optimal resistive screen structure was the white resistive screen –foam–fiber multilayer, where the acoustic absorption coefficient reached 0.95 at 3000 Hz, and its performance was superior to the fiber–linen multilayer structure described in the literature [9]. Adding a 0.4-mm resistive screen material to the multilayer material caused a rapid improvement in the acoustic absorption performance.

From test results shown in Figure 3(C) that the sound insulation quantity of the multilayer material increases with an increase in frequency. The foam–fiber composite had the least amount of sound reduction, which is related to its low surface density. The two composite structures with the best acoustic performance were the perforated white screen –foam–fiber and perforated leather screen –foam–fiber structures. The surface density of these two types of resistive screen material is almost similar, with the difference that the perforated white screen has half of the porosity of the perforated leather screen; therefore, the amount of sound reduction is negatively correlated with the material porosity under the same surface density conditions. The maximum sound reduction was 8.5 dB with the perforated white
screen–foam–fiber structure, which is 6.5 dB higher than the sound reduction from the foam–fiber multilayer structure. This shows that the perforated white screen–foam–fiber structure has a significant sound reduction effect. This sound reduction effect would be further enhanced if a compact skeleton were added to the multilayer material [17].
4. Conclusion

Acoustic properties of resistive screen–foam–fiber multilayer structure material were studied. To our knowledge, this is the first report in the literature describing the acoustic properties of a composite resistive screen structure of this type. The results show that there is a positive correlation between the flow resistivity and acoustic absorption coefficient of the multilayer structure. As the flow resistivity increased, the acoustic absorption coefficient increased continuously, and the maximum acoustic absorption coefficient reached 0.95 at 3000 Hz. In the foam–fiber multilayer material, the amount of sound reduction with the resistive screen material was significantly improved. The maximum sound reduction with the perforated white screen–foam–fiber composite material was 8.5 dB, which is 6.5 dB higher than that achieved by using the foam–fiber multilayer structure. This shows that the introduction of the perforated white screen has a significant sound reduction effect. This new multilayer resistive screen structure can provide innovative ideas for the design of acoustic materials.

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References

[1] J. Z. Feng, J. Feng, Y. G. Jiang, C. R. Zhang, Ultralow density carbon aerogels with low thermal conductivity up to 2000°C, Mater. Lett. 65 (2011) 3454 – 3456.
[2] R. Baetens, B. P. Jelle, A. Gustavsen, Aerogel insulation for building applications: a state-of-the-art review, Energy Build. 43 (2011) 761 – 769.
[3] H. Reuter, Sol-gel processes II investigation and application, Adv. Mater. 3(1991) 568 – 571.
[4] E. Bodros, I. Pillin, N. Montrelay, C. Baley, Could biopolymers reinforced by randomly scattered flax fiber be used in structural applications? Compos. Sci. Technol. 67 (2007) 462 – 470.
[5] H. L. Bos, J. Müssig, M. J. A. Van Den Oever, Mechanical properties of short-flax fiber reinforced compounds, Compos. Part A—Appl. Sci. Manuf. 37 (2006) 1591 – 1604.
[6] P. Wambua, J. Ivens, I. Verpoest, Natural fibres: can they replace glass in fiber reinforced plastics Compos. Sci. Technol. 63 (2003) 1259 – 1264.

[7] S. Fatima, A.R. Mohanty, Acoustical and fire-retardant properties of jute composite materials, Appl. Acoust. 72 (2011) 108 – 114.

[8] P. S. Allan, A. Ahmadnia, R. Withnall, J. Silver, Sound transmission testing of polymer compounds, Polym. Test. 31 (2012) 312 – 321.

[9] Hasan Koruk a, n, Garip Genc, Investigation of the acoustic properties of bio luffa fiber and composite materials, Materials Letters 157 (2015) 166 – 168.

[10] B. Ekici, A. Kentli, H. Kucuk, Improving sound absorption property of polyurethane foams by adding tea-leaf fibers, Arch. Acoust. 37 (2012) 515 – 520.

[11] H. S. Yang, D.J. Kim, H. J. Kim, Rice straw-wood particle composite for sound absorbing wooden construction materials, Bioresour. Technol. 86 (2003)117 – 121.

[12] M. Hosseini Fouladi, M. Ayub, M. J. Mohd Nor, Analysis of coir fiber acoustical characteristics, Appl. Acoust. 72 (2011) 35 – 42.

[13] N. Zulkar, R. Zulkifli, M. J. Mohd Nor, Effect of porous layer backing and perforation ratio of perforated plate on acoustic characteristics of coconut fibre as a sound absorbent, Sains Malays. 40 (2011) 623 – 629.

[14] R. Zulkifli, M. J. Mohd Nor, M.F. Mat Tahir, A.R. Ismail, M.Z. Nuawi, Acoustical properties of multi-layer coir fibers sound absorption panel, J. Appl. Sci. 8 (2008) 3709 – 3714.

[15] S. Ersoy, H. Kucuk, Investigation of industrial tea-leaf-fiber waste material for its sound absorption properties, Appl. Acoust. 70 (2009) 215 – 220

[16] Pulse LabShop, Brüel & Kjaer, Copenhagen, Denmark, 2013.

[17] Rui Yao, Zhengjun Yao, Jintang Zhou, Pore morphology and acoustic properties of open-pore phenolic cryogel acoustic multi-structured plates, Materials Letters 176 (2016) 199 – 201.