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Air flow resistance and sound absorption behavior of open-celled aluminum foams with spherical cells

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Abstract

Aluminum foams with spherical cells were produced by a pressure infiltration process, and their sound absorption behaviors were examined and correlated with the air flow resistance. It is shown that the small apertures or pore openings on the cell walls play an important role in determining the sound absorption behavior of the foams due to the significant influence on the air flow resistance of the foams. The foams with the same porosity and pore opening size but different pore sizes have similar air flow resistance and sound absorbing performance, suggesting that there is no necessary relationship between the pore size and sound absorption performance of the present aluminum foams. With decreasing the pore opening size, the air flow resistance increased and the low-frequency absorption peak shifted towards lower frequencies but the height decreased. When the two samples with different pore sizes were put together, the sound absorption behavior of the combined samples was dependent on the pore size of sample facing the sound waves. Relatively large pores in the face side lead to relatively high low-frequency absorption peak.

Keywords: Sound absorbing materials; sound absorption behavior; flow resistance.

1. Introduction

Open-celled metal foams exhibit a variety of functionalities including thermal dissipation, electromagnetic wave shielding and sound absorption, etc. (Gibson and Ashby (1997)). Among them, the sound absorption property is one of the most important properties and has been extensively studied in recent years (Miyoshi et al. (2000), Perrot et al. (2012), Hakamada et al. (2006), Han et al. (2003), Lu et al. (2000), Li et al. (2011)). It has been demonstrated that...
the cracks or small holes on the cell walls have a determining effect on the sound absorption behavior of closed cell or semi-open cell metal foams due to enhanced viscous and thermal losses of sound energy. In our previous studies, the relationship between the sound absorption coefficient and the area of pore openings was quantitatively studied. It is found that the sound absorption coefficient of open cell aluminum foams increases with increasing the number or decreasing the diameter of pore openings in a certain range of pore diameters (Li et al. (2011)). In order to understand the dissipation mechanisms of sound energy when the sound waves pass the pore openings, the sound absorption behavior was examined and correlated with the air flow resistance for the aluminum foams with controllable sizes of both pores and pore openings in the present study. Moreover, the sound absorption properties of combined samples with varied pore structures were examined to further clarify the effect of flow resistance on the sound absorption behavior of the foams.

2. Experimental Approach

2.1. Preparation of samples

The aluminum foam samples were produced by an air pressure infiltration process using spherical sodium chloride (NaCl) particles as the space holder material that was prepared by sintering the NaCl powders. The sizes of pores and pore openings of resulting foams were controlled by adjusting the NaCl particle size and compacting pressure in the preparation of infiltration framework. Four NaCl particle sizes, 0.9, 1.3, 1.6 and 1.9 mm, and three pore opening sizes, 0.26, 0.31 and 0.36 mm, were selected in the present study. The porosity was ranged from 57% to 63%. The detailed structural information and typical pore morphology of the present aluminum foams are shown in Table 1 and Figure 1, respectively.

2.2. Measurement of sound absorption coefficient

The impedance tube and transfer function methods were used to measure the sound absorption coefficient in the present study. In the measurement, a broadband stationary random sound wave was generated by a loudspeaker in the tube. The sound absorption coefficient was determined by measuring the sound pressure of a standing wave with two fixed microphones and calculating the complex transfer function using a two-channel digital frequency analyzer.

Table 1: Structural parameters of aluminum foam samples

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Pore size (mm)</th>
<th>Porosity (%)</th>
<th>Opening size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.6</td>
<td>57</td>
<td>0.26</td>
</tr>
<tr>
<td>B</td>
<td>1.6</td>
<td>60</td>
<td>0.31</td>
</tr>
<tr>
<td>C</td>
<td>1.6</td>
<td>63</td>
<td>0.36</td>
</tr>
<tr>
<td>D</td>
<td>0.9</td>
<td>60</td>
<td>0.31</td>
</tr>
<tr>
<td>E</td>
<td>1.3</td>
<td>60</td>
<td>0.31</td>
</tr>
<tr>
<td>F</td>
<td>1.9</td>
<td>60</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Figure 1: Typical pore morphology of aluminum foam sample.
2.3. Measurement of air flow resistance

The air flow resistance of each sample was measured by a specially designed experimental apparatus. The air flow was supplied by a pressurized tank and was controlled by a mass flow meter to guarantee a stable gas supply. A digital monometer with a resolution of ± 0.01 Pa was used to measure the pressure drop of air flow across the samples after reaching a steady flow. A number of readings were recorded at varied flow velocities, from which the air flow resistance $\sigma$ was calculated by the following equation

$$\sigma = \frac{\Delta p}{(U/A)} \quad (1)$$

where $\Delta p$ is the pressure drop across the sample; $A$ is the surface area of sample, and $U$ is the volume flow velocity of air.

3. Results

The typical sound absorption coefficient against frequency in varied sample thicknesses is shown in Figure 2. It is seen that the sound absorption coefficient exhibited oscillated changes with frequency. An absorption peak appeared at a relatively low frequency, which shifted towards lower frequencies as the sample thickness increased.

When a gap was inserted between the sample and the rigid wall, however, a series of absorption peaks appeared and shifted towards lower frequencies with increasing the gap depth, as shown in Figure 3.

Figure 2: Typical sound absorption coefficient against frequency for the sample B.

Figure 3: Sound absorption coefficient against frequency at varied gap depths for the sample B.

Figure 4: Changes of flow resistance with pore opening size and flow velocity.

Figure 5: Sound absorption coefficient against frequency for the samples with varied pore opening sizes.
The changes of flow resistance with pore opening size and corresponding sound absorption coefficient curves are shown in Figures 4 and 5. As expected, the flow resistance decreased as the pore opening size increased although the pore size kept unchanged. For the sound absorption coefficient, the height of low-frequency peak increased with increasing the pore opening size or decreasing the flow resistance, while the location shifted towards lower frequencies with decreasing the pore opening size or increasing the flow resistance. If only the low-frequency absorption peak is taken into account, relatively low flow resistance is beneficial for high absorption, as demonstrated by Figures 6 and 7. When the sound waves entered the samples from the large-pore side, the low-frequency peak kept almost unchanged although the back small-pore side had different pore sizes. On the contrary, increasing the pore size at the facing side is beneficial for the low-frequency absorption.

4. Conclusion

The flow resistance and sound absorption behavior of open-celled aluminum foams with spherical cells were studied. It is found that the pore openings have a determining effect on the sound absorption behavior and flow resistance. When the pore size is constant in a certain range, appropriately increasing the number or the size of pore openings is beneficial for improving the sound absorption properties at relatively low frequencies due to decreased flow resistance.

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References