

Thermal Conductivity and Sound Absorption Properties of Carbon Nanotube / Foam Aluminum Composites

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Abstract. This article uses powder metallurgy technology to prepare foamed aluminum and carbon nanotubes (CNTs) / foamed aluminum composites. The laser thermal diffusion analyzer, thermal analyzer, and transfer function sound absorption coefficient test system were used to study the thermal conductivity and sound absorption properties of aluminum foam and its composites, respectively. The results show that the thermal conductivity of aluminum foam with 79% porosity is only $5\text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$, which is much smaller than the thermal conductivity of aluminum. So it can be used as an ideal thermal insulation material; The thermal conductivity of carbon nanotubes (CNTs) / foamed aluminum-based composites increases first and then decreases with the increase in the mass fraction of CNTs. As the test temperature increases, the thermal conductivity of the material gradually increases. When the mass fraction of CNTs is 0.75%, the thermal conductivity of foamed aluminum-based composites reaches the maximum. As the test frequency increases, the sound absorption performance of foamed aluminum first increases, then decreases, and then gradually increases, reaching a maximum value around 1000 Hz. The sound absorption performance of CNTs / foam aluminum matrix composites decreases at lower test frequencies as the mass fraction of CNTs increases. At higher frequencies, as the mass fraction of CNTs increases, the sound absorption coefficient of foamed aluminum decreases first and then increases.

1. Introduction

Foamed aluminum has many advantages, such as low density, high specific surface area, good heat insulation and sound insulation and noise reduction. It is widely used in automobile manufacturing, ship hull, aerospace and construction industries, and other fields[1-3]. Due to its excellent mechanical properties, thermal conductivity and sound absorption properties, carbon nanotubes (CNTs) can be used as a lightweight reinforcing phase to improve the thermal conductivity and sound absorption properties of foamed aluminum.

The heat transfer process of Foamed aluminum mainly includes four parts: thermal conduction between solid matrix; heat conduction between pores; convection heat transfer between fluid and solid matrix in the pores; Radiation heat transfer between solids and between solids and fluids[4]. Compared with traditional sound-absorbing materials such as polymer materials and asbestos, foamed aluminum metal materials have better mechanical properties, and have good processing properties, moisture resistance, high temperature resistance, flame retardancy, easy cleaning, and no release of toxic gases. So it has more advantages [5-6].

In this paper, aluminum foam and carbon nanotube (CNTs) / aluminum foam composites were prepared by powder metallurgy technology. The thermal conductivity and sound absorption properties of foamed aluminum and its composites were studied by laser thermal diffusivity analyzer, thermal



analyzer and transfer function absorption coefficient test system respectively, providing experimental support for future research and application of aluminum foam composites.

2. Experiment

2.1. Sample

In this paper, pure foamed aluminum samples with porosity of 41% to 79% were prepared by powder metallurgy method, and foam aluminum composite samples with porosity of 60% and CNTs content of 0.25%~1.5% were prepared. The microstructure of the 60% foamed pure foamed aluminum and the CNTs aluminum foam composite with 0.75% added amount is shown in Fig.1.

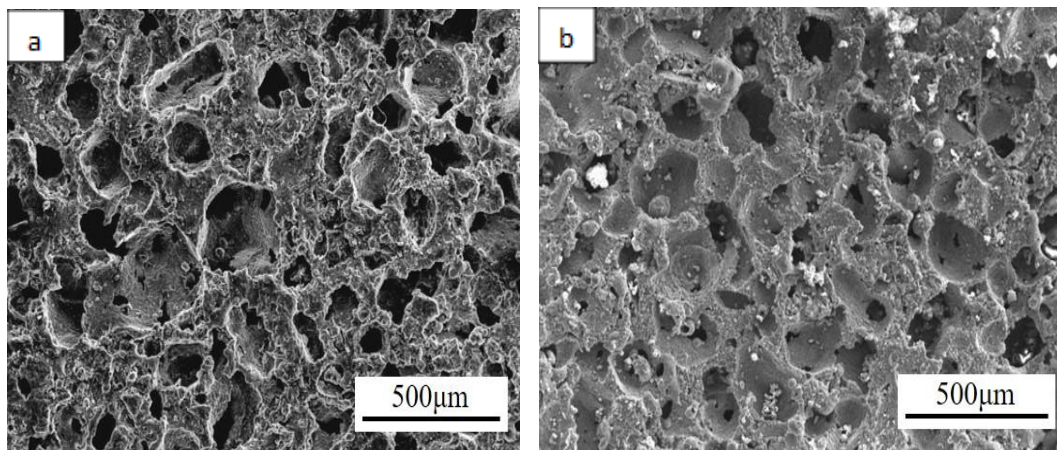


Figure 1. 60% the micro morphology of pure aluminum foam (a) and 0.75%CNTs foam aluminum composite (b) with porosity.

2.2. Thermal Conductivity Test

The aluminum foam sample was cut into discs with a diameter of 10mm and a thickness of about 1mm, which was smoothed with fine sand paper. The thermal diffusivity of foam aluminum and its composites was measured by laser thermal diffusivity analyzer, and the specific heat capacity of the material was measured on the DSC Q2000 thermal analyzer. Finally, according to formula (1), the thermal conductivity of the material was calculated.

$$\kappa = \alpha \cdot \rho \cdot C \quad (1)$$

Where α is the thermal diffusivity, unit: $\text{cm}^2 \cdot \text{s}^{-1}$; κ is the thermal conductivity, unit: $\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$; ρ is the actual density, unit: $\text{g} \cdot \text{cm}^{-3}$; C is the specific heat capacity, unit: $\text{J} \cdot \text{g}^{-1} \cdot \text{K}^{-1}$.

2.3. Sound Absorption Performance Test

A cylindrical foamed aluminum sample with a diameter of 30mm and a thickness of 20mm was tested for the sound absorption coefficient of the foamed aluminum material by means of the AWA6290T transfer function sound absorption coefficient test system.

3. Results and Analysis

3.1. Thermal Conductivity of Foamed Aluminum

3.1.1. Thermal conductivity of pure foam aluminum

Fig.2 (a) is a line chart of the thermal diffusion coefficient of foamed aluminum with different porosities. It can be seen that the thermal diffusion coefficient of foamed aluminum decreases significantly with increasing porosity. Thermal diffusivity is a measure of the rate at which temperature disturbances at one point in an object are transmitted to another point. When the object is heated and heated, the heat

entering the object is continuously absorbed along the way, causing the entrapped temperature of the material to rise, and this process continues until the internal temperature of the object is all the same. Because the heat transfer rate in the matrix part of the foamed aluminum is faster than that in the pores, when the porosity is relatively high, the proportion of the matrix body is smaller, so the thermal diffusion coefficient of the material is smaller. Fig.2 (b) shows the specific heat of foamed aluminum with different porosities. It can be seen that the specific heat of foamed aluminum changes relatively little at the same porosity between 25 °C and 100 °C. The centralized change is between 1 ~ 1.2 J·g⁻¹·K⁻¹, and the change is relatively small. It can also be seen in the figure that the specific heat capacity of foamed aluminum first increases and then decreases with the increase of porosity. The cause of this phenomenon may be due to errors, because the size of the material sample is required when testing the specific heat of the material. Small and thin, the accidental error caused during the test will be relatively large. Fig.2 (c) is a line chart of the thermal conductivity of foamed aluminum with different porosities calculated according to formula (1). It can be seen that the thermal conductivity of foamed aluminum decreases significantly with increasing porosity. Within the range of 41% to 79% porosity, the thermal conductivity of pure foamed aluminum at room temperature is between 5W·m⁻¹·K⁻¹ and 30W·m⁻¹·K⁻¹, when the porosity is about 79%, the thermal conductivity of aluminum foam is 5 W·m⁻¹·K⁻¹, which is much smaller than that of solid aluminum (237W·m⁻¹·K⁻¹). Therefore, when the porosity of foam aluminum is relatively large, it can be used as an ideal insulation material.

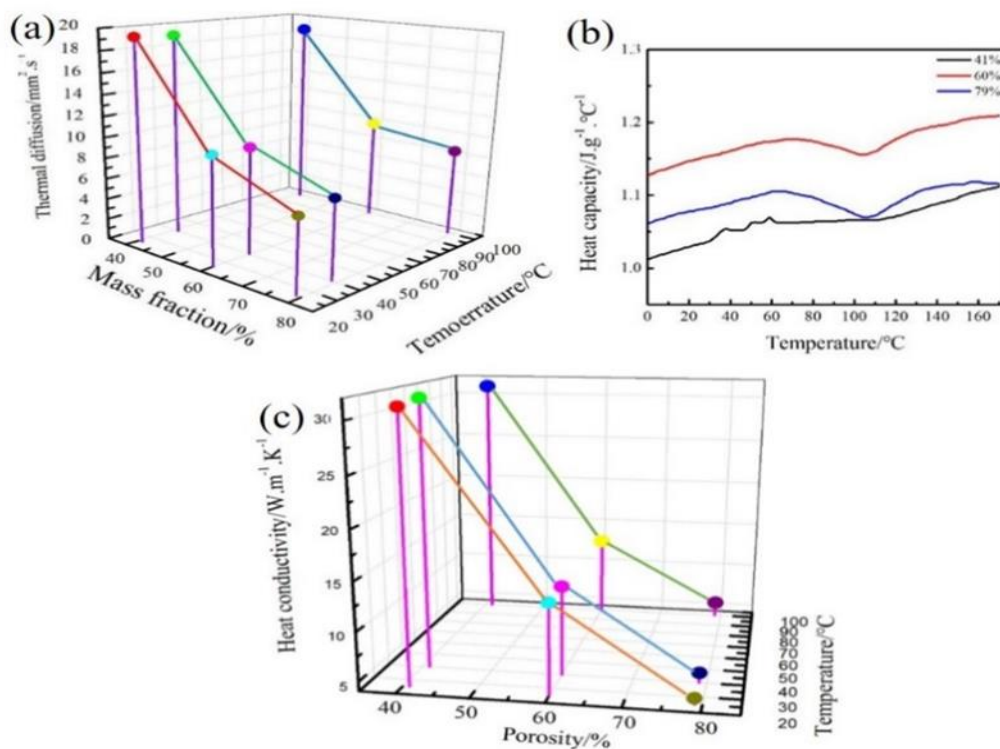


Figure 2. Effect of porosity on thermal conductivity of aluminum foam

(a) Line chart of thermal diffusion coefficient; (b) Curve of specific heat capacity; (c) Line chart of thermal conductivity

3.1.2. Thermal conductivity of CNTs / foam aluminum matrix composites

Fig.3 (a) is a line chart of the thermal diffusion coefficient of foamed aluminum matrix composites with different mass fractions of CNTs and a porosity of 60%. Fig.3 (b) is a graph of the specific heat capacity of foamed aluminum matrix composites reinforced with different mass fractions of CNTs. Fig.3 (c) is a thermal conductivity line chart of CNTs reinforced aluminum matrix composites with different mass fractions added after calculation. It can be seen that as the mass fraction of CNTs increases, the thermal

conductivity of foamed aluminum-based composites also increases. This is mainly because the thermal conductivity of CNTs itself is higher than that of aluminum, so the addition of CNTs Will increase the thermal conductivity of the material. It can also be seen in the figure that the thermal conductivity of the foamed aluminum-based composite material does not change much at room temperature, but when the temperature is 100°C, the thermal conductivity of the material increases significantly, as can be seen from Fig.3 (b) that under the same curve, the specific heat capacity of the material increases with increasing temperature, which causes the thermal conductivity of foamed aluminum to increase as the temperature increases. It can also be seen in the figure that with the increase of the mass fraction of CNTs, the thermal conductivity of the material first increases and then decreases. This is mainly because when the CNTs exceed a certain mass fraction, the agglomeration phenomenon becomes more serious, which makes the foamed aluminum matrix The thermal conductivity of the composite material decreases. When the mass fraction of CNTs is 0.75%, the thermal conductivity of the foamed aluminum-based composite material reaches a maximum value, and the thermal conductivity is $19.993 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ at room temperature, which is 1.6 times of the thermal conductivity of pure foamed aluminum.

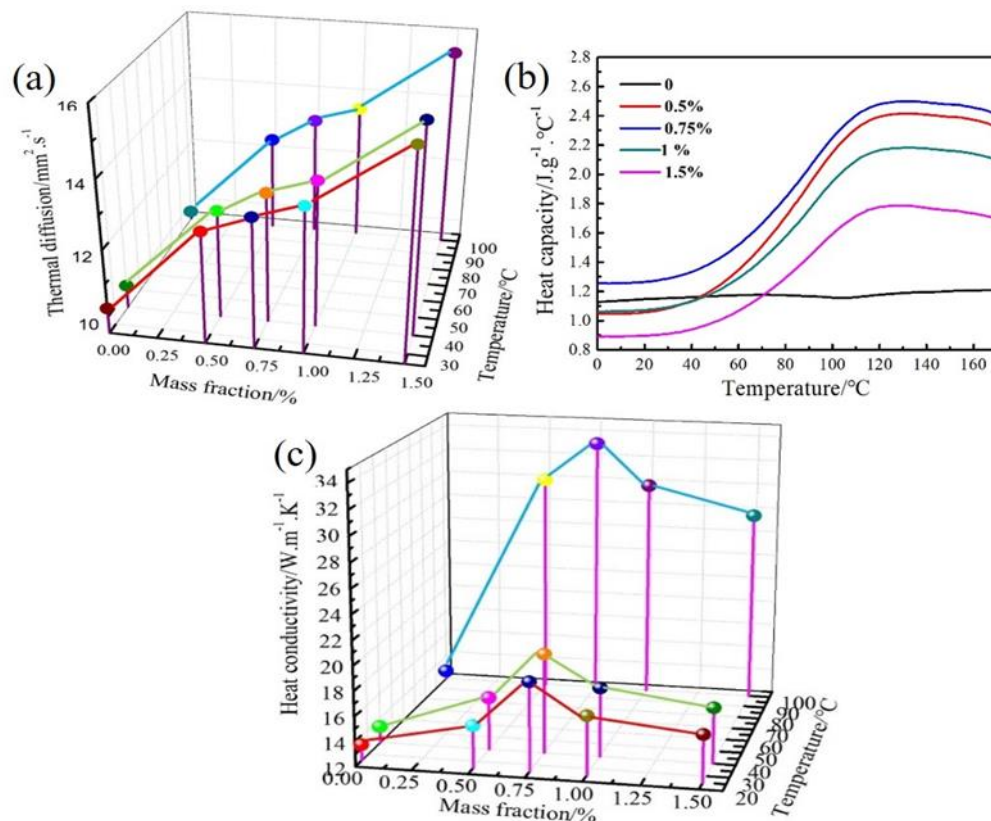


Figure 3. Line chart of the effect of CNTs on the thermal conductivity of 60% porosity aluminum foam

(a) Line chart of thermal diffusion coefficient; (b) Curve of specific heat capacity; (c) Line chart of thermal conductivity

3.2. Foamed Aluminum Sound Absorption Performance

3.2.1. Sound absorption performance of pure foam aluminum

The special pore structure inside the foamed aluminum has good sound absorption performance. When sound waves pass through the pores, the air in the pores periodically vibrates with the effect of noise, causing friction with the pore wall, and a part of the energy is generated and the heat energy is lost. In addition, the air in the hole will also undergo volume changes under the action of sound waves, thereby generating thermal energy; there will also be inelastic collisions between sound waves and the hole walls,

which can also consume part of the sound energy, especially at high frequencies inelastic collisions absorb more sound.

Fig.4 is the sound absorption performance curve of foamed aluminum with different porosities. It can be seen that the sound absorption coefficient of foamed aluminum material has different behaviors at different frequencies, and all show that as the frequency increases, the curve first rises then decreases and then gradually increases, reaching a peak at around 1000Hz[7]. At lower frequencies, the sound absorption coefficient of foamed aluminum decreases as the porosity increases, but at higher frequencies, the sound absorption coefficient of foamed aluminum increases as the porosity increases, because at lower frequencies, the energy of the sound wave is lower. When the sound wave reaches the inside of the foamed aluminum, the sound wave is mainly obstructed by the foamed aluminum pore wall matrix, and the proportion of the foamed aluminum matrix with a lower porosity is larger. The obstacles are greater. When the frequency is higher, the propagation of sound waves in foamed aluminum is more complicated. When the sound is propagated internally, the air in the pores will vibrate accordingly, and the number of collisions with the pore wall will increase. Due to the retarding force, the sound energy is continuously converted into thermal energy, so that the sound absorption effect is better [8]. In addition, aluminum foam with high porosity has low strength, and the bubble wall is easy to rupture and cause through holes. And consume sound energy[9].

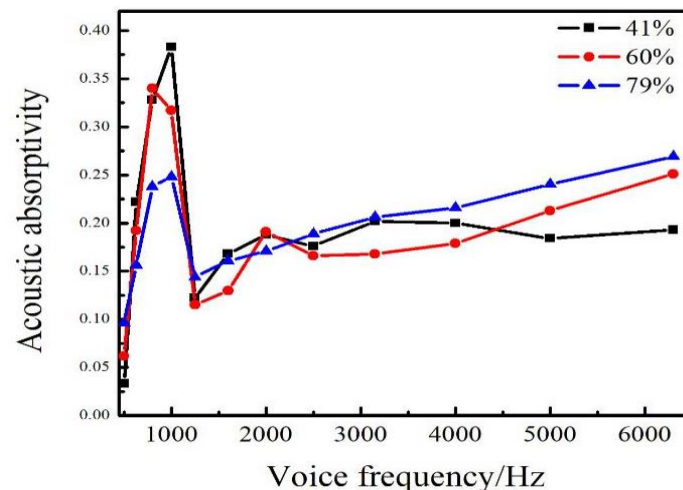


Figure 4. Curve of sound absorption coefficient of foamed aluminum with different porosities

3.2.2. CNTs enhanced sound absorption of foamed aluminum matrix composites

Fig.5 is a graph of the sound absorption coefficient of a foamed aluminum composite with different mass fractions of carbon nanotubes and a porosity of 60%. It can be seen that the sound absorption coefficient curve is similar to that of pure foamed aluminum. As the frequency increases, the material's sound absorption coefficient is first increased, then decreased, and then gradually increased, and a peak appears at about 1000 Hz. In addition, it can be seen that as the mass fraction of CNTs increases, the sound absorption coefficient curve of foamed aluminum matrix composites decreases with the increase of the mass fraction of CNTs at lower frequencies, and at higher frequencies, with the increase of CNTs mass fraction, it first decreases and then increases. This is because at lower frequencies, due to the lower energy, sound waves are mainly hindered by the foamed aluminum pore walls when propagating inside the foamed aluminum. However, as the mass fraction of CNTs increases, the relative density of foamed aluminum will be smaller. Lowering reduces this blocking effect on sound waves. At higher frequencies, due to the higher energy, the acoustic wave is more severely affected in the process of propagating inside the foamed aluminum. Related studies have shown that carbon nanotubes not only introduce additional acoustic mass resistance in this process, but also introduce Auxiliary sound absorption mechanisms such as friction and vibration at the interface between carbon nanotubes and micro-perforated plates have been used to make the sound absorption performance of this composite sound absorber better[10]. It can

be seen in the figure that when the mass fraction of CNTs is 0.75%, the sound absorption coefficient curve of the foamed aluminum-based composite material is the lowest. This is because when the mass fraction of CNTs is 0.75%, the mechanical properties of the material are the strongest, resulting in when the sound wave propagates in the foamed aluminum, the vibration caused by the material is small, and the energy loss caused is also small, which results in the smallest sound absorption coefficient of the foamed aluminum-based composite material.

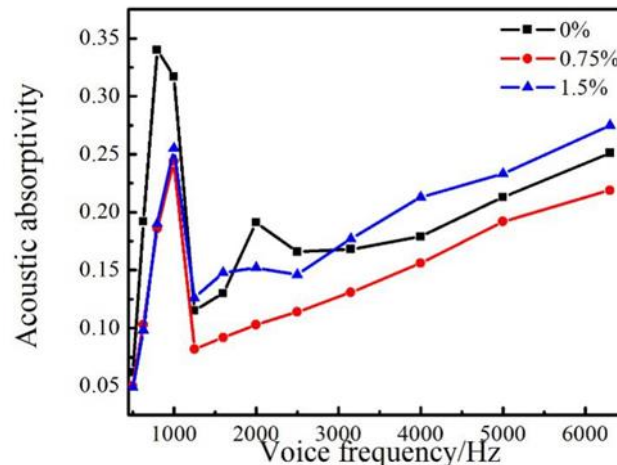


Figure 5. Effect of CNTs on sound absorption coefficient of 60% porosity aluminum foam

4. Conclusion

(1) The thermal conductivity of foamed aluminum material decreases significantly with increasing porosity. When the porosity is 79%, the thermal conductivity of foamed aluminum is only $5\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, which is much smaller than the thermal conductivity of aluminum. The ideal thermal insulation material is used; the thermal conductivity of foamed aluminum-based composites increases first and then decreases with the increase of the mass fraction of CNTs, and the thermal conductivity of the material gradually increases with the increase of the test temperature. The quality of CNTs When the fraction is 0.75%, the thermal conductivity of the foamed aluminum-based composite material reaches the maximum.

(2) As the test frequency increases, the sound absorption performance of foamed aluminum first increases, then decreases, and then gradually increases, reaching a maximum value around 1000 Hz; the sound absorption performance of CNTs / foamed aluminum-based composites at lower test frequencies, as the mass fraction increases and decreases. At higher frequencies, as the mass fraction of CNTs increases, the sound absorption coefficient of foamed aluminum decreases first and then increases.

5. References

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