Synthesis of Co$_3$O$_4$ micro-needles on the cell walls and their effect on the sound absorption behavior of open cell Al foam

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Abstract

Open cell Al foams usually show poor sound absorption performance due to excessively low flow resistance. In order to overcome this shortcoming, several measures have been taken including compression, cell surface erosion and modification, etc. In the present study, a cell surface modification process is adopted to synthesize needle like Co$_3$O$_4$ on the cell walls of open cell Al foams via hydrothermal method. The phase and morphology of micro-Co$_3$O$_4$ needles are characterized, and the airflow resistance as well as the sound absorption behavior of modified Al foams is examined. The Co$_3$O$_4$ needles have the diameter of around 5μm and lengths of 10-50μm. After the modification, the airflow resistance of the foams increases from 30Pa·s/m to 93Pa·s/m, and the height of sound absorption coefficient peak increases from 0.65 to 0.95. This demonstrates that the coverage of a rough Co$_3$O$_4$ needle layer can enhance the interaction between the air and the cell surface, not only the friction force but also the thermal exchange strength because Co$_3$O$_4$ needles possess both high thermal conductivity and high specific surface area, giving rise to increased flow resistance and increased sound absorption capability.

1. Introduction

Open cell Al foams with a 3-D net structure have a variety of functional properties including excellent heat exchange, wave absorption and catalyst support property, etc. These functionalities make open cell Al foams promising candidates in a number of engineering fields (Gibson and Ashby (1997)). However, the open cell Al...
foams usually show poor sound absorption properties, particularly at low frequencies due to their excessively open cell structure, as demonstrated by other researchers (Hakamada et al. (2006), Hakamada et al. (2006), Han et al. (2003), Lu et al. (2000), Li et al. (2011)). Generally, sound wave is dissipated in rigid porous materials through the friction between the air and the cell surface due to the vibration of air in the cells, viscous resistance and the thermal conduct of cell walls. For the open cell Al foams, therefore, tailoring the surface morphology to strengthen the friction between the air and cell surface should be one of the most effective measures to improve the sound absorption behavior. Based on this analysis, several methods have been attempted, including compressing Al foams to increase the tortuosity of cells, etching the cell surface to form rougher surfaces and growing micro-fibers on the cell surface to enhance the interaction between the air and the cell walls. In our previous studies, ZnO micro-rods were synthesized on the cell walls of open cell Al foams, and their effect on the sound absorption properties was clarified (Ren et al. (2013)). In the present study, synthesizing micro-Co$_3$O$_4$ needle clusters on the cell walls of open cell Al foams was investigated and the sound absorption behavior of resulting Al foams was examined to give useful information to related studies and applications.

2. Experimental approach

2.1. Synthesis of Co$_3$O$_4$ needles

The open cell Al foams used in the present study were produced by an investment casting method using polymer foams as the pattern and plaster mold as the framework. The porosity and average pore diameter are 92% and 2.5 mm (10ppi), respectively. The typical cell morphology is shown in Fig. 1. The synthesis of Co$_3$O$_4$ needles included the following steps: (1) dissolving 14.55g Co(NO$_3$)$_2$$\cdot$6H$_2$O and 2g NH$_4$NO$_3$ in 160ml deionized water; (2) slowly adding 90ml ammonia solution with the concentration of 25wt.% in the deionized water solution and stirring for 10min; (3) putting the stirred solution into a drier and drying at 90$^\circ$C for 2h; (4) soaking an Al foam sample with the size of $\phi$29×30mm in the solution and staying at 90$^\circ$C for 12h, in which stirring the solution every 2h to make the distribution of concentration uniform; (5) taking out the foam sample from the drier, rinsing it with deionized water and then putting it into the drier again to remove the water; (6) putting the foam sample into a resistance furnace and calcining at 300$^\circ$C for 2h.

2.2. Characterization of Co$_3$O$_4$ needles

The morphologies of cells and Co$_3$O$_4$ needles were characterized by field emission scanning electron microscope (SEM, SIRION 200). The constituent phases in Co$_3$O$_4$ micro-needles were analyzed by X-ray diffraction meter (XRD, X’pert Pro MPD). The flow resistance of Al foam samples was measured by a specially designed experimental setup according to the standard of ASTM C522-73, and the sound absorption coefficient against frequency was measured using an impedance tube apparatus by the transfer function method.

3. Results and discussion

3.1. The morphology of Co$_3$O$_4$ needles

Fig. 2 (a) through (f) show the morphologies of Co$_3$O$_4$ needles after varied growing times. It is seen that the Co$_3$O$_4$ needles exhibit a randomly and overlapped distribution. As the growing time increased, both the density and length of Co$_3$O$_4$ needles increased but the diameter kept almost unchanged. In the present conditions, the diameter of Co$_3$O$_4$ needles is about 5μm whereas the length is ranged from 30μm at the growing time of 2h to 50μm at the growing time of 10h.
3.2. The constituent phases in the Co$_3$O$_4$ needles

It is seen from Figs. 3 and 4 that the Co$_3$O$_4$ needles contain only Co and O elements, and there is single Co$_3$O$_4$ phase in the needles. The diffraction peaks located at 31.1°, 36.8°, 44.8°, 59.3° and 65.1° corresponds to the crystalline planes of (220), (311), (400), (511) and (440), respectively.

![Typical pore morphology of open cell Al foam sample.](image)

Fig. 1. Typical pore morphology of open cell Al foam sample.

![Effect of growing time on the morphology of Co$_3$O$_4$ needles: (a) and (b) 2h; (c) and (d) 6h; (e) and (f) 10h.](image)

Fig. 2. Effect of growing time on the morphology of Co$_3$O$_4$ needles: (a) and (b) 2h; (c) and (d) 6h; (e) and (f) 10h.
The effects of Co$_3$O$_4$ needles on the flow resistance and sound absorption behavior are shown in Figs. 5 and 6. It is seen that, as the growing time increased, both the flow resistance and the sound absorption peak were continually raised. The flow resistance increased from around 30Pa·s/m for the original Al foam to 93Pa·s/m for the modified Al foam at the growing time of 10h. Similarly, the height of absorption coefficient peak was increased from around 0.65 to 0.95. Moreover, the location of sound absorption peak shifted towards low frequency with increasing the growing time, suggesting that the modification does be effective for improving the low-frequency absorption of open cell Al foams.
Fig. 6. Effect of Co$_3$O$_4$ growing time on the sound absorption coefficient of Al foams.

4. CONCLUSION

The clusters of needle like Co$_3$O$_4$ were synthesized on the cell walls of open cell Al foams. Compared with the original Al foams, the modified ones show obviously increased flow resistance and sound absorption coefficient, particularly at lower frequencies, which is more beneficial for improving the low-frequency sound absorption of the foams.

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