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Thermal properties of closed-cell aluminum foams prepared by melt foaming technology

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Abstract: Closed-cell aluminum foam has incomparable advantages over other traditional materials for thermal insulation and heat preservation because of small thermal conductivity coefficient. Spherical bubble three-dimensional model of aluminum foam is built to deduce the relationship among pore wall thickness, porosity and average pore size. Non-uniform closed-cell foam aluminum model with different structural parameters and random pore distribution is established based on the relationship via C programming language. And the temperature distribution is analyzed with ANSYS software. Results indicate that thermal conductivity increases with the reducing of porosity. For the aluminum foam with the same porosity, different pore distributions result in different thermal conductivities. The temperature distribution in aluminum foam is non-uniform, which is closely related with the pore size and distribution. The pores which extend or distribute along the direction perpendicular to heat flow strengthen obstructive capability for heat flow. When pores connect along the direction perpendicular to heat flow, a “wall of high thermal resistance” appears to decline the thermal conductivity rapidly, which shows that only porosity cannot completely determine effective thermal conductivity of closed-cell aluminum foam.

Key words: closed-cell aluminum foam; thermal conductivity; porosity; pore distribution; temperature distribution

1 Introduction

Aluminum foam is a new type of porous functional and structural material, which combines the porous structure characteristics. Due to the low relative density, large crash energy absorption capacity and high damping insulation of vibration, sound and heat, aluminum foam is found to have an increasing range of applications in many fields such as the automobile, railway and aerospace industries [1−4].

Closed-cell aluminum foam has incomparable advantages over other traditional insulation materials for thermal insulation and heat preservation because of small thermal conductivity coefficient [5−8]. At present, there are many researches concerning the thermal property of closed-cell aluminum foam. Some scholars obtained the calculation formula of thermal property through experimental data [9,10]. GIBSON and ASHBY [11] simplified the structure of aluminum foam and deduced the analytic expression of the effective thermal conductivity by parallel model and series model. NIELD [12] considered the irregularity of the pore structure and investigated the geometric mean model. Archie’s law [13] proposed an empirical equation with the viscosity index. ZHU et al [14] studied the thermal conductivity of closed-cell aluminum foam based on the 3D geometrical reconstruction, and discovered that the thermal conductivity depends on both of the porosity and the size of pores. WANG et al [15] discovered that the Maxwell−Eucken equation is suitable for the thermal conductivity research of aluminum foam with small porosity and big pore distance. HASHIN and SHTRIKMAN [16] discussed the heat conduction process of porous media by using the spherical structure model and variational principle. XIA et al [17] proposed a two-dimensional reconstruction method to discuss the thermal properties of foam. However, the available thermal conductivity theoretical models, due to their limitations, are difficult to provide the relationship between the thermal conductivity process and the complex structure of aluminum foam. Most of the model equations contain only porosity as a feature parameter, and some equations include uncertain empirical constant.

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Therefore, it is difficult to reveal the law of heat transfer and the temperature distribution in aluminum foam accurately.

In this work, spherical bubble three-dimensional model of aluminum foam was built by modeling software, and the relationship among pore wall thickness, porosity and average pore size of aluminum foam model was deduced. Non-uniform closed-cell foam aluminum model with different structural parameters and random pore distribution was established via C programming language and using the relationship among pore wall thickness, porosity and average pore size. The temperature distribution was analyzed with ANSYS software. Consequently, the influence law of temperature with pore structure and the relationship among porosity, pore shape and thermal conductivity were deduced.

2 Experimental

2.1 Preparation of aluminum foam materials

Aluminum foam materials were successfully prepared by melt foaming technology using ZL106 alloy as the raw material. The foam was made by stirring 2.0% (mass fraction) Ca into the melt at 680 °C to increase the viscosity, and adding 1.4% TiH_2 (mass fraction) to the melt.

2.2 Treating of aluminum foam for characterization

The treating process mainly included the following steps: Firstly, intercept specially the section of aluminum foams with suitable contrast between the pores and pore walls by superficial treatment, and acquire the section photographs. Then, convert the section photographs to gray images by using image processing software Photoshop, and transform the gray images into binary images by scientific computing software Matlab with suitable threshold values. Finally, calculate and measure the corresponding parameters using the image analysis software.

Figures 1(a) and (b) show the macro digital photo and binary image of aluminum foam, respectively. Image binarization process converts the color image or gray image into the black-and-white photograph. Its characteristic is that the image is saved in memory reservoir matrix only using 0 and 1 to represent the black and white pixels, so the threshold is easy to be selected with fast speed and high precision [18].

Figure 2 reveals the statistical process diagram. According to the selected boundary conditions, the statistical process analysis software can recognize the closed pixel area automatically. The number of pixels within enclosed area represents the image acreage of the region, and the number of closed pixel area and average image acreage can also be calculated in the statistical process automatically. Finally, the real number and acreage of pores can be obtained after conversion.

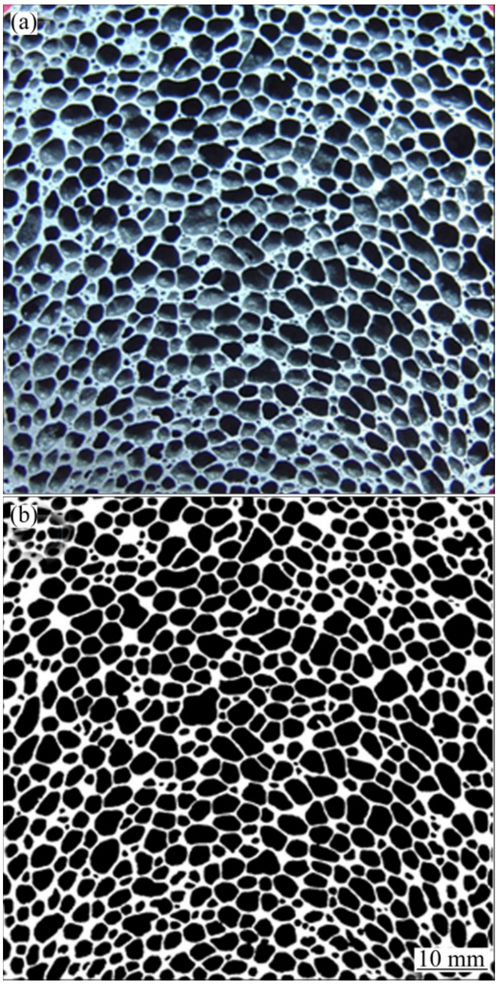

Fig. 1 Section photograph (a) and binary image (b) of aluminum foam

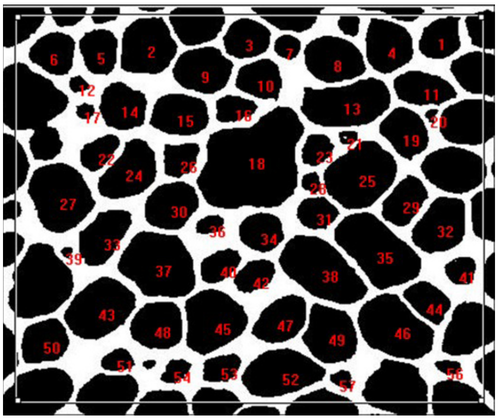

Fig. 2 Statistical process diagram of image analysis software

2.3 Establishment of aluminum foam model

The structure characterization parameters of pore such as porosity and pore size depend on the type, the shape and the distribution of the pores [11]. In order to make the deduction more intuitive, the spherical bubble