Study on Thermal Conductivity of Microporous Aluminum Based on Numerical Simulation

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Abstract: micro porous aluminum heat conduction principle is mainly based on aluminum foam thermal conductivity measuring device with a specific size, aperture porosity micro porous aluminium specimen, coefficient of thermal conductivity analysis according to the researchers, and can be found: porosity is the main factor that influence the thermal conductivity of porous aluminum, the coefficient of thermal conductivity of porous aluminum with the porosity of the raised large decline; The pore diameter directly affects the thermal conductivity of porous aluminum, and the porosity does not become the premise, and the thermal conductivity increases as the pore diameter increases.

1. Introduction

Micron aperture porous aluminum refers to the diameter of the hole is 1-100μm, the porosity reaches between 30%-70%, with through hole structure can be divided into porous aluminum and porous aluminum alloy. At present, the current seepage method used in our country can only be used for porous aluminum with pore size of more than 200μm. Because the pore size is very small, the pressure needs to be increased when the deformed powder flows through the porous aluminum, and it is difficult to maintain the integrity of the deformed powder filling mold, so the seepage method has obvious effect on the preparation of micro-porous porous aluminum with pore size below 100μm. Aluminum has active metal properties and is easy to be oxidized with air. Therefore, powder sintering, fiber sintering and other methods of preparing porous metals with micropore size cannot meet the requirements of preparing porous aluminum with micropore size.[1-4]

1.1 Research Trends

At present, the methods of preparing porous aluminum with a pore size of more than 20μm have been well developed, among which, the casting method has achieved low cost industrial production.

In recent years, special attention has been paid to the manufacturing of porous aluminum with micrometer diameter. The main reason is that aluminum reacts with acid and base and reacts with oxygen to produce alumina at room temperature. Other methods of preparing porous metals with micron pores are not suitable for the preparation of porous aluminum with micron pores. Therefore, the research on the preparation method of porous aluminum with micron pore size and its related properties is still in the blank stage, but the application prospect of porous aluminum with micron pore size is very broad, and it has a great demand in the field of filtration, catalytic carrier and other fields with high surface area and small pore size.

In recent years, in addition to the vacuum pressure-sintering method proposed by Ti of Kunming University of Science and Technology, there are basically no experts and scholars at home and abroad who have successfully prepared porous aluminum with micron pore size between 1-100μm. Research on the preparation and performance of porous aluminum with micron pore size is still in a blank state, and a lot of research is needed to fill in. The vacuum pressure-sintering process is to mix the pore-making agent powder and aluminum alloy powder with the diameter of 50-100μum evenly, press them into billets, place them in the vacuum sintering furnace for sintering, remove the

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pore-making agent and get porous aluminum with micrometer diameter.

However, the vacuum pressure-sintering process needs to be carried out in a vacuum environment, which increases the preparation cost of porous aluminum with micron pore size and makes it difficult to achieve large-scale industrial production, so further improvement is needed.

1.2 Application Prospects

With the progress of social science and technology, the application demand of microporous materials in filtration and separation, energy catalysis, flue gas dust removal and other fields is increasing day by day. The pore size of porous aluminum obtained by traditional porous aluminum preparation method is all over 100m, which can only be used in primary filtration and separation, but can not meet the requirements in fields with smaller pore size such as flue gas dust removal and energy catalysis. This need has forced researchers to propose new methods and processes for the successful preparation of porous aluminum with pore sizes ranging from 1 to 1100um.

2. Thermal Conductivity and Thermal Conductivity of Porous Aluminum

Porous aluminum interior has a lot of porosity, gas can flow freely within the pores, through these pores will distinguish between porous aluminum and the real metal thermal conductivity, thermal conductivity is refers to the interaction between porous aluminum frame and gas, so that the porous aluminum internal metal produce 36% ~ 40% of the volume is referred to as entities, thermal conductivity is done through the electronic freedom of migration. When other gases occupy the interior of porous aluminum, the thermal movement of gas molecules is also one of the thermal conduction methods of porous aluminum. When porous aluminum produces temperature difference, the heat convection generated by gas flowing inside porous aluminum contributes to heat conduction. In addition, the radiation generated between the hole walls is transmitted through conduction, convection and radiation.

The thermal conductivity of aluminum foam is generally composed of four components, namely: the thermal conductivity of the cell wall metal; The thermal conductivity of the gas inside the cell λ_c^*;Convective heat transfer coefficient of intracellular gas λ_s^*,Heat transfer coefficient of radiation between cell walls λ_r^*,The formula is as follows:

$$\lambda^* = \lambda_s^* + \lambda_g^* + \lambda_c^* + \lambda_r^*$$

For porous aluminum, the thermal conductivity of the gas in the cell wall λ_g^* Is proportional to the volume of gas in porous aluminum, and the formula is as follows:

$$\lambda_g^* = \lambda_g^* X$$

Similarly, the thermal conductivity of the metal skeleton $A\lambda_s$ It's proportional to its volume fraction X.

$$\lambda_s^* = A\lambda_s(1 - X)$$

Porous aluminum belongs to a kind of inhomogeneous and discontinuous porous materials, the coefficient of thermal conductivity of porous aluminum can be seen as a continuum of the apparent coefficient of thermal conductivity, by putting a small sample in the sample under test and the known standard sample together, make the whole testing apparatus in insulation condition, the heat flow along the direction of the rod sample axial flow and negligible heat loss, through the sample under test $Q_{\text{Under test}}$ Compared with the standard sample, the default heat flow formula of the sample to be tested can be: $Q_{\text{Under test}} = -\lambda A \Delta T_1 \Delta X_1$

Type Δ T1 to stay in the test sample temperature measuring point, the temperature difference between the delta X1 for temperature measuring points, the axis of the distance between A is under test sample size, as shown in figure 1

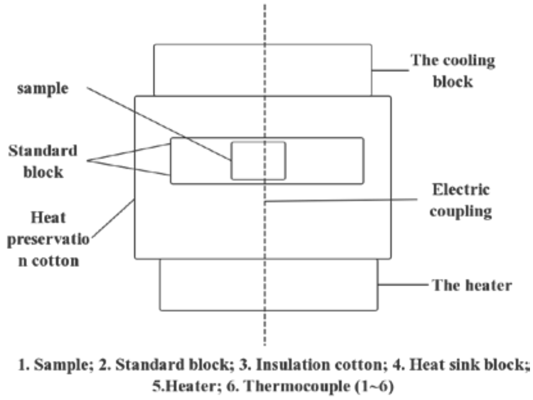

Fig.1 Schematic Diagram of Thermal Conductivity Measurement Device for Porous Aluminum

3. Method

The diameter and thickness of the sample to be tested were 40mm and 20mm, the temperature measuring point was located on the central axis of the sample, and the distance between the two end faces was 2mm. The two ends of the sample were ground flat. After ensuring that the sample was fully in contact with the standard copper block sample, the porous aluminum thermal conductivity measuring device obtained was shown in Figure 1. The heat source will transfer the heat to the standard test block through the heater, and then transfer the heat to the porous aluminum sample, and then disperse the heat through the radiator. After 57 hours of heat preservation treatment, the heat flow in the porous aluminum sample is ensured to be constant, so that the temperature of the system is kept constant. By comparing the temperature of the sample measured by thermocouple with that of the standard block, the thermal conductivity of the standard block can be obtained as λ, and the thermal conductivity of the porous aluminum sample can be calculated by the thermal conductivity coefficient of λ.[5-7]

4. Research Results and Analysis

The measurement results are shown in Table 1.

Table 1 Determination Results Of Thermal Conductivity of Porous Aluminum Sample

Sample number	Size/mm	Porosity / %	Thermal conductivity /(W*mK)	The aperture/mm	Average temperature /℃
T1	40<20	0.47203	10.24	1.43	82.66
T2	40<20	0.6921	15.25	1.43	79.70
T3	40<20	0.6578	27.66	1.43	85.45
T4	40<20	0.6247	28.58	1.43	75.95
T5	40<20	0.5894	32.50	1.43	91.80
T6	40<20	0.6798	16.56	0.53	81.60
T7	40<20	0.6728	21.31	2.25	79.33

It can be seen from Table 1 that porous aluminum has a low thermal conductivity. The thermal conductivity of general metals and alloy metals is generally 10-300W/ (mK), and the thermal conductivity of heat insulation materials is less than 0.2W/ (mK). Therefore, it can be concluded that the thermal conductivity of aluminum foam is between the two. Through the analysis of the volume thermal conductivity of porous aluminum, the following curve can be obtained (see Figure 2 for details). Thus, it can be known that the thermal conductivity increases with the increase of the volume fraction of matrix, showing a linear relationship. According to the linear relationship, the porosity is 0.6763, the pore diameter is 1.43mm, and the thermal conductivity is 19.04 W /m°K. The thermal conductivity coefficient of porous aluminum was compared and analyzed (see Figure 3 for details). When the porosity is the same, the thermal conductivity of porous aluminum increases with the pore size of the porous aluminum sample. With the pore size increasing, the flow capacity of porous aluminum can be effectively improved, which is helpful to improve the convective heat transfer coefficient of air in porous aluminum and increase the thermal conductivity of porous aluminum.[8-10]

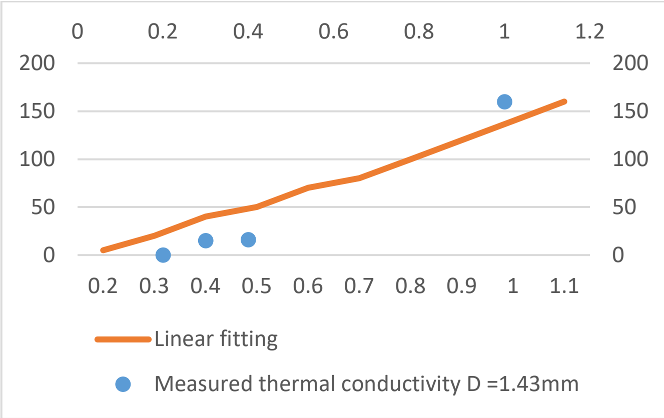

Fig.2 Relationship Curve between Thermal Conductivity and Porosity

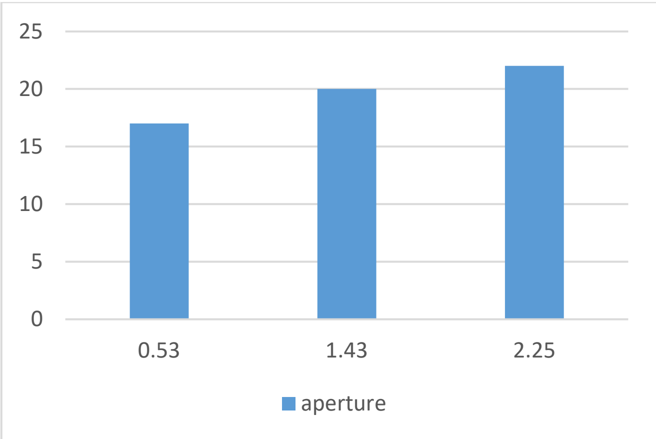

Fig.3 Relationship between Thermal Conductivity and Pore Size

5. Conclusion

The thermal conductivity of porous aluminum is jointly affected by three factors: conduction, convection and radiation. The temperature of the main application occasions of porous aluminum is not high, so the effect of thermal radiation is not needed to be considered. Therefore, the thermal conductivity is mainly affected by two factors: conduction and convection. The porosity is the main factor affecting the thermal conductivity of porous aluminum. With the increase of porosity, the thermal conductivity of porous aluminum decreases. The pore size has a significant effect on the thermal conductivity of porous aluminum. Under the condition of constant porosity, the thermal conductivity increases with the increase of pore size.

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References

[1] Zou Y , Gu H , Huang A , et al. Characterisation and properties of low-conductivity microporous magnesia based aggregates with in-situ intergranular spinel phases[J]. Ceramics International, 2020.

[2] Feng J , Liu M , Fu L , et al. Study on the influence mechanism of Mg2+ modification on

vermiculite thermal expansion based on molecular dynamics simulation - ScienceDirect[J]. Ceramics International, 2020, 46(5):6413-6417.

[3] Gao Y , Zhang X , Tang D , et al. Unexpected anisotropy of (14,14,14)-Graphyne: A comprehensive study on the thermal transport properties of graphyne based nanomaterials[J]. Carbon, 2019.

[4] Zhou G , Zhao M , Liang R , et al. A Study of the Mechanism of Binding between Neratinib and MAD2L1 Based on Bolecular Simulation and Multi-spectroscopy Methods[J]. Current Pharmaceutical Design, 2019, 25(40).

[5] Bhatti M M , Khalique C M , TA Bég, et al. Numerical study of slip and radiative effects on magnetic Fe3O4-water-based nanofluid flow from a nonlinear stretching sheet in porous media with Soret and Dufour diffusion[J]. Modern Physics Letters B, 2019, 34(2):2050026.

[6] Wang X , Gu T , Luo X , et al. A User Study on the Capability of Three Geo-Based Features in Analyzing and Locating Trajectories[J]. IEEE Transactions on Intelligent Transportation Systems, 2019, 20(9):3375-3385.

[7] Lee M Y , Li Y , Chuang M H , et al. Numerical Simulation of Thermal Conductivity of SiNW-SiGe0.3 Composite for Thermoelectric Applications[J]. IEEE Transactions on Electron Devices, 2020, PP(99):1-5.

[8] Liu F , Zhu Z , Li X , et al. Study on thermal stability and bifurcation analysis of FCC carbon nanotube-based nanolattice as hydrogen storage materials[J]. International journal of hydrogen energy, 2019, 44(56):29597-29603.

[9] Wang X , Zeng S , Wang Z , et al. Identification of Crystalline Materials with Ultra-Low Thermal Conductivity Based on Machine Learning Study[J]. The Journal of Physical Chemistry C, 2020, 124(16):8488-8495.

[10] Zhao Z , Zhang H , Zou G , et al. A Predictive Model for Thermal Conductivity of Nano-Ag Sintered Interconnect for a SiC Die[J]. Journal of Electronic Materials, 2019.