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Heat transfer performance of porous titanium

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ABSTRACT

Porous titanium fibre materials with different structural parameters were prepared by vacuum sintering method. The thickness, porosity and wire diameter of prepared materials were investigated to understand the effects of structural parameters on pool heat transmission performance of titanium fibre porous material. As a result, better heat transfer performance is obtained when overheating is less than 10 ℃. In addition, when the wire diameter is smaller, the heat transfer is better. However, when superheating is above 10 ℃, heat transfer performance can be improved by increasing the wire diameter. Moreover, thickness influences the superficial area of the prepared material and affects the thermal resistance when bubbles move inside the material; superficial area and thermal resistance are the two key factors that jointly impact the heat transfer in relation to the thickness of the materials. Experimental results also show that the materials of 3 mm in thickness exhibit the best performance for heat transmission. Furthermore, changes in porosity affect the nucleation site density and the resistance to bubble detachment; however, the nucleation site density and the resistance to bubble detachment conflict with each other. In summary, the titanium fibre porous material with a 50% porosity exhibits suitable heat transfer performance.

1. Introduction

Porous metal materials are a new kind of functional material that has shown excellent physical properties and good machinability in recent years. Due to their light weight and large surface area per unit volume, porous media exhibit different characteristics in flow and heat transfer. They have been widely used in heat exchange and cooling equipments[1-4]. The heat transfer process of porous media consists of the direct contact between solid skeletons, the thermal conduction of fluid in the voids, and the convective heat transfer of fluid in the voids[5,6]. Huang et al.[7] studied the boiling properties of sintered copper baths with different porosities. It was found that the influence of porosity on heat transfer coefficient is the result of the interactive effect of the nucleation site density and bubble disengagement resistance when fibre diameters were identical. Zhi et al.[8] studied the influence of the diameter of a stainless steel fibre on heat transfer performance and found that the pool boiling heat transfer performance of the porous stainless steel fibre surface does not show a single trend with the change in fibre diameter. Arbelaez et al.[9] performed a pilot study on FC-72 in the porous aluminium foam radiator for pool boiling heat transfer. The results showed that, in the low heat flux density region, for identical pore densities, lower porosities led to better boiling heat transfers. For identical porosities, higher pore densities led to better pool boiling heat transfer. Chen et al.[10] studied the influences of pore size, porosity, and porous copper height on the heat transfer performance of a directionally solidified copper heat sink and showed that in the lengthwise direction, the hole diameter was 20 mm, the oriented porous copper diameter of the heat sink was 0.1－0.6 mm, the porosity was 30%－70%, and the height of the heat sink was 4 mm with excellent heat transfer performance. Sarangi et al.[11] studied the effect of particle size on the surface boiling heat transfer performance of the surface coating. With higher heat fluxes, the copper surface covered with a layer of 90－106 μm of free copper particles has better boiling heat transfer performance than the smooth copper surface. Liu et al.[12] prepared por-

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ous materials with titanium fibres of different porosities and showed that the formation and growth of a titanium fibre porous sintering neck depends on the sintering temperature and sintering heat preservation time.

In this paper, porous materials with different porosities, wire diameters, and thicknesses were prepared by vacuum sintering. The effects of wire diameter, porosity, and thickness on the heat transfer performance of porous titanium fibres were studied.

2. Experimental Method and Model

2.1. *Preparation of experimental samples*

Porous materials with different porosities, wire diameters, and thicknesses were prepared by vacuum sintering. Fig. 1 shows an example of a titanium fibre porous material. The specifications and parameters of the test samples are shown in Table 1.

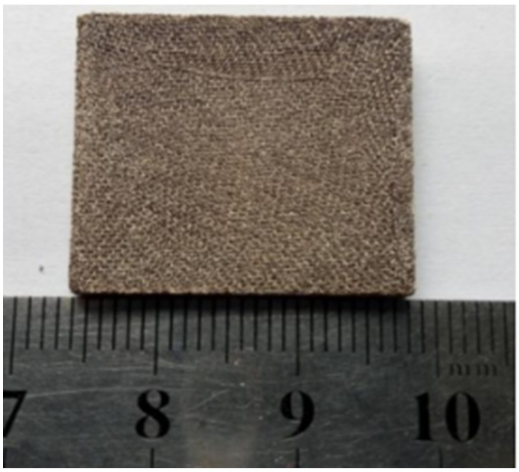


Fig. 1. Porous sample from Ti fibres.

Table 1
Experimental parameter of Ti fibre porous sample

Sample number	Fibre diameter/mm	Porosity/%	Thickness/mm
1	70	40	3
2	70	50	3
3	70	60	3
4	70	50	2
5	100	50	2
6	100	50	1
7	120	50	2
8	100	50	2
9	100	50	3

2.2. *Heat transfer model*

In a pool boiling heat transfer system, heat is introduced into the upper cooling zone through the porous material. The Darcy-Ergun model is taken as the momentum source term for porous media,

$$0=-\nabla \boldsymbol{p}-\frac{\mu}{k}\boldsymbol{v}+\rho\boldsymbol{g}-\frac{\rho C}{\sqrt{k}}\boldsymbol{v}|\boldsymbol{v}| \tag{1}$$

where, $\boldsymbol{p}$ is the pressure; k is the permeability coefficient; C is constant; μ is dynamic viscosity; $\boldsymbol{g}$ is gravitational acceleration; ρ is the density of steam; and $\boldsymbol{v}$ is the Darcy velocity.

The local thermal imbalances of liquid and solid in the porous region can be described using the two energy equations as follows.

Liquid energy equation

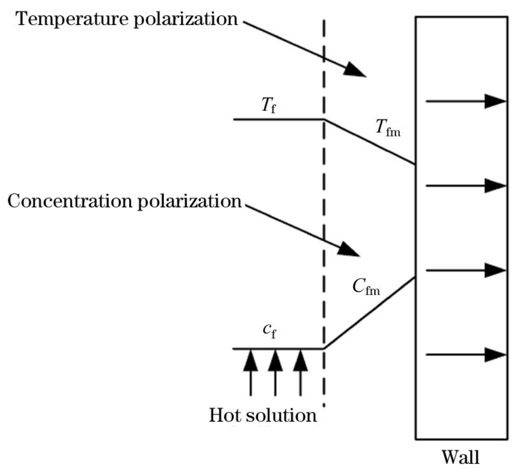
$$\varepsilon\rho_f c_f\frac{\partial T_f}{\partial t}+\rho_f c_f v\nabla T_f=\varepsilon K_f\left(\frac{\partial^2 T_f}{\partial x^2}+\frac{\partial^2 T_f}{\partial y^2}+\frac{\partial^2 T_f}{\partial z^2}\right)+ h_{sf}a_{sf}(T_s-T_f) \tag{2}$$

Solid energy equation

$$(1-\varepsilon)\rho_s c_s\frac{\partial T_s}{\partial t}=(1-\varepsilon)K_s\left(\frac{\partial^2 T_s}{\partial x^2}+\frac{\partial^2 T_s}{\partial y^2}+\frac{\partial^2 T_s}{\partial z^2}\right)+ h_{sf}a_{sf}(T_f-T_s) \tag{3}$$

where, ε is the porosity; ρ_f is the density of medium; c_f is the specific heat capacity of the liquid; c_s is the specific heat capacitity of the solid; K_f is the liquid thermal conductivity, W/(K · m); T_s and T_f are the saturation temperature of the solid and liquid, respectively, ℃; K_s is the solid thermal conductivity, W/(K · m); k_f is the liquid thermal conductivity, W/(K · m); h_{sf} is the surface heat transfer coefficient between the solid wall and the liquid; and a_{sf} is the specific surface area of the porous material, m^2.

Fig. 2 shows the heat and mass transfer in medium.



T_{fm}—Temperature at thermal side surface;
C_{fm}—Concentration at thermal side surface.

Fig. 2. Heat and mass transfer in medium.

After assuming the convection heat transfer in the bubble perturbation to be boiling heat transfer at nucleation state, the Rohsenow experimental correlation is used to calculate boiling heat transfer.

$$q=\mu r\left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2}\left[\frac{c_{pl}(T_w-T_s)}{c_{wl}rPr_l^s}\right]^2 \tag{4}$$

where, q is the heat flux density, W · m^{-2}; c_{pl} is