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Design and fabrication of sintered wick for miniature cylindrical heat pipe

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Abstract: Miniature cylindrical metal powder sintered wick heat pipe (sintered heat pipe) is an ideal component with super-high thermal efficiency for high heat flux electronics cooling. The sintering process for sintered wick is important for its quality. The sintering process was optimally designed based on the equation of the heat transfer limit of sintered heat pipe. Four-step sintering process was proposed to fabricate sintered wick. The sintering parameters including sintering temperature, sintering time, sintering atmosphere and sintering position were discussed. The experimental results showed that the proper sintering temperature was 950 °C for Cu powder of 159 μm and 900 °C for Cu powders of 81 and 38 μm, respectively, while the wick thickness was 0.45 mm and sintering time was 3 h. The optimized sintering time was 3 h for 0.45 and 0.6 mm wick thickness and 1 h for 0.75 mm wick thickness, respectively, when copper powder diameter was 159 μm and sintering temperature was 950 °C. Redox reduction reaction between H_2 and CuO during sintering could produce segmentation cracks in Cu powders as a second structure. Sintering at vertical position can effectively avoid the generation of gap between wick and the inner wall of pipe.

Key words: heat pipe; wick; sintering; porosity; shrinkage

1 Introduction

Heat pipe has been widely used in applications ranging from cooling high heat flux electronics to temperature regulation in satellites due to its high heat conductivity, high reliability, fast thermal response, and no extra electric power [1]. As a heat transfer component based on phase change, heat pipe essentially consists of 3 parts: sealed container, working fluid and wick. The wick structure provides the necessary capillary driving force to maintain a closed circulation of working fluid and thus facilitate heat transfer. The property of wick structure is mainly characterized by porosity, effective pore radius and permeability. To maximize the function of cylindrical heat pipe, the wick structure is expected to be with high permeability and high capillary pumping force. Sintered heat pipe has relatively high capillary pumping ability and good anti-gravity ability, compared to grooved wick heat pipe and screen wick heat pipe [2]. The fabrication process of sintered wick in miniature heat pipe for electronics cooling is worth studying.

Current research on sintered wick heat pipe is mainly focused on its heat transfer mechanism and thermal performance [3−14], but less on fabrication process of sintered wick for heat pipe. Solid-state sintered method is always adapted to fabricate sintered wick for flat plate heat pipe, loop heat pipe, micro heat pipe, and grooved-sintered heat pipe. LEONG et al [15] fabricated rectangular sintered wicks with copper powders (63 μm) for flat plate heat pipes at sintering temperatures of 800 and 1000 °C. The size of most pores was obtained in the range of 30−40 μm. CHIU et al [16] fabricated oxide-reduced and water-atomized copper powder sintered wicks at temperatures of 800−1000 °C in a reduction stream of 10% hydrogen and 90% argon. The results showed that 900 °C was a recommended sintering temperature for producing wicks with lower volume shrinkage and higher permeability. XIN et al [17] fabricated capillary wicks for loop heat pipes by cold-

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pressing sintering method and direct loose sintering method. It was found that the optimal capillary wick with 90% nickel and 10% copper was obtained by sintering at 650 °C for 30 min with direct and loose sintering technique. LI et al [18,19] investigated the fabrication process of the sintered wick in the micro heat pipe. Results showed that the sintered wick with copper powders of 140−170 μm at sintering temperature of 900−950 °C and sintering time of 30−60 min had low manufacturing cost and high thermal performance. JIANG et al [20] fabricated grooved-sintered wick in the heat pipe. Results demonstrated that grooved-sintered wick with 150 μm spherical copper powders had high porosity and low radial shrinkage at the sintering temperature of 950 °C for 3 h. According to above discussion, the solid-state sintered process parameters for sintered wick were in confusion and the wick sintering process for miniature sintered cylindrical heat pipe was rare and worth investigating.

The main goal of this research was to design and fabricate copper powder sintered wick for miniature cylindrical heat pipe with high thermal performance. To achieve this goal, firstly, sintered wick was characterized and thermal performance was calculated to optimize structure parameters and its sintering process; secondly, four-step sintering process for sintered wick was proposed to fabricate the experimental samples; finally, appropriate sintering parameters to fabricate sintered heat pipe of high thermal performance and low cost would be discussed.

2 Theory analysis

2.1 Characterization of sintered wick

The sintered wick of heat pipe is fabricated by single-component system loose solid-state sintering method. The sintering principle for sintered wick of miniature cylindrical heat pipe is shown in Fig. 1. A pipe with one shrunk end is used as the outside wall, a stainless steel bar is insert into the pipe as the inner mandrel. Powders are then filled into the gap between wall and mandrel. The pipes with full filled powders are placed vertically in the furnace and sintered at appropriate temperature. Finally, the powders are sintered together as the sintered wick on inner pipe wall.

During the sintering process, the atoms migrate between the contact powders and metal powders are then fused, the sintering necks are formed, and the bonding strength of sintered wick is improved. The effective thermal conductivity and volume shrinkage of sintered wick increase, while the porosity of sintered wick decreases. In order to better analyze sintering process of sintered heat pipe, the parameters like sintering neck, shrinkage and porosity should be firstly characterized.

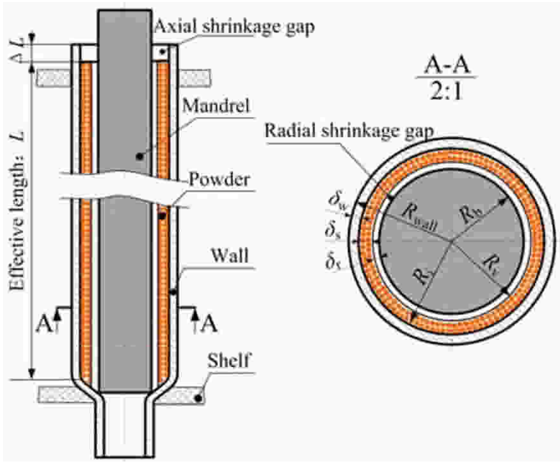

Fig. 1 Sintering principle of sintered wick

2.1.1 Sintering neck growth rate

Sintering neck formation can be analyzed by the ball−ball sintering model [21,22], as shown in Fig. 2. The sintering neck growth equation [23] can be expressed by

$$\eta^n = \left(\frac{x}{r_{\mathrm{Cu}}}\right)^n = \frac{F(T_{\mathrm{s}})}{r_{\mathrm{Cu}}^m} t_{\mathrm{s}} \tag{1}$$

where n and m are the sintering mechanism characteristic parameters; T_s is the sintering temperature; $F(T_s)$ is the sintering temperature function; t_s is the sintering time; x is the length of sintering neck and r_{cu} is the copper powder radius. Neck growth ratio η is defined as a neck dimension divided by the powder diameter. According to Eq. (1), the sintering growth rate is a function of sintering time, sintering temperature and sintering powder radius. The experimental powder radius r_{Cu} always fluctuates in a considerable range and can be calculated by the mean value of two bonded powders radius. Thus, the sintering growth rate can be expressed as

$$\eta = \frac{x}{r_{\mathrm{ave}}} = \frac{2x}{r_{\mathrm{Cu1}} + r_{\mathrm{Cu2}}} \tag{2}$$

where r_{ave} is the average radius of copper powders.

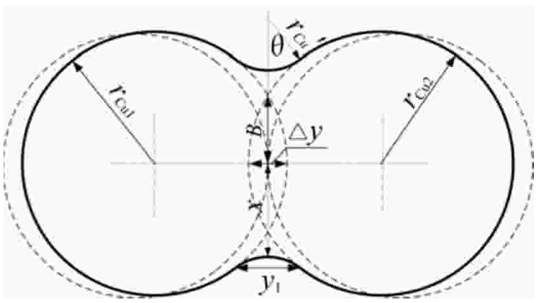

Fig. 2 Ball−ball sintering model