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Fabrication of flatten grooved-sintered wick heat pipe

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Abstract: With the rapid rising of heat flux and reduction of heat dissipating space of microelectronic devises, flattened sintered heat pipe has become an ideal conducting element of use in the electronic cooling field. A manufacturing technology named phase change flattening process is presented to fabricate the flattened grooved-sintered wick heat pipe (GSHP for short). Deformation geometry of flattened GSHP and the elasto-plastic deformation of flattening process are analyzed theoretically and verified by experiments. The results show that the vapor pressure inside sintered heat pipe during flattening process is determined by the saturated vapor pressure equation; the width and vapor area of flattened heat pipe change greatly as the flattening proceeds; the maximum equivalent strain distributes at the interface between wick and vapor in the flat section; the buckling phenomenon can be well eliminated when the flattening temperature reaches 480 K; phase change flattening punch load increases with flattening temperature and displacement.
Key words: heat pipe; wick; flattening; elasto-plastic deformation; buckling; vapor pressure

1 Introduction

Nowadays, heat dissipation of microelectronic chips has two basic characteristics: high heat flux (almost 10^6 W/m^2) and limited cooling space (especially for notebook PC), which seriously limits further development of microelectronic chip [1]. Miniature heat pipe can cool high heat flux electronic chips due to its high heat conductivity, high reliability, long life, fast thermal response, and no extra electric power [2]. Flattening and bending miniature cylindrical heat pipe with a desired structure can well meet with the electronic cooling requirement of limited space [3−5]. According to different wick structures, miniature cylindrical heat pipe can be classified into powder sintered wick heat pipe, grooved heat pipe, woven wire wick heat pipe and so on. Powder sintered heat pipe has relatively high capillary pumping ability and good anti-gravity ability compared to grooved wick heat pipe and wire wick heat pipe [6] and most widely applied in CPU cooling of notebook PC. Therefore, flatting miniature cylindrical sintered heat pipe to a certain thickness is an important ring for packaging into a notebook PC with very limited space.

Thermal performance of flattened heat pipe like flattening grooved heat pipe and woven wire heat pipe has been well investigated [3,7−9], while research on fabrication and thermal performance of flattened sintered heat pipe is rare. Traditional pipe flattening fabrication method is lateral compression technology which can cause buckling phenomenon with two kinks on the central line [10−13]. To solve this problem, phase change flattening fabrication method was proposed to flatten grooved wick heat pipe in Ref. [14]. Working fluid inside heat pipe would phase change into vapor as heating temperature increases. The vapor pressure can stop the buckling forming and guarantee good flatness during the lateral compression of cylindrical heat pipe. Phase change flattening fabrication method can also be adopted to flatten sintered heat pipe while the flattening deformation of bimetallic pipe with porous internal layer is more complex.

The main goal of present work is to provide an optimal phase change flattening process for miniature

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cylindrical sintered wick heat pipe with good flatness: firstly, theoretically analyze deformation geometry of flattened grooved-sintered wick heat pipe (GSHP) and numerically calculate elasto-plastic deformation of phase change flattening process on the basis of an updated Lagrangian formulation; secondly, improve a universal material testing machine by installing flat loading plates with heating system and cooling system to simulate phase change flattening process; finally, discuss equivalent plastic stress and strain distribution, punch load, buckling and deformation geometry of flattened sintered heat pipe during the flattening process and optimize the phase change flattening process parameters.

2 Theory analysis

Phase change flattening process for fabrication of flattened GSHP, as shown in Fig. 1, is a modified lateral compression technology using phase change vapor pressure in heat pipe to avoid buckling and it is a quasi-static plane-strain compression process. The flattening process includes three stages. 1) Pipe expansion stage: heating the heat pipe to a given temperature, the working fluid phase changes into vapor, the vapor pressure in the heat pipe affects the sintered wick and expands cylindrical GSHP with a small elasto-plastic deformation. 2) Pipe flattening stage: keep heating temperature at a constant value and slowly move upper plate towards bottom plate to press GSHP with a large elasto-plastic deformation. This stage greatly determines the final shape of flattened GSHP, so the present research mainly focuses on this stage. 3) Pipe spring-back stage: cooling the flattened GSHP to room temperature, the vapor pressure decreases with temperature, unloading the upper plate, and the flattened GSHP springbacks with a small elastic deformation.

2.1 Deformation geometry

The analytical model of phase change flattening GSHP is based on the plane strain condition as shown in Fig. 1. During the flattening process, the deformation geometry of GSHP is pressed laterally from round section to oblong section, vapor area decreases, the contact area between plate and heat pipe changes from point contact to line contact, the bending curves such as arc *BCD* and arc *EFA* become more curved and unbending curves such as *AB* and *DE* become more straight and longer.

Several hypotheses should be set before the analysis of the deformation geometry: 1) wick thickness and wall thickness are constant as flattening proceeds; 2) the bent curves of flattened GSHP such as arc *BCD* and arc *EFA* are approximate to the semicircles; 3) pipe thickness δ_{hp} is relatively small compared with the radius of pipe wall R_w, so GSHP can be considered a thin bimetallic pipe; 4) the length of neutral layer at the mid-thickness of grooved pipe wall remains constant during the flattening process.

The diameter of neutral layer d_0 at the mid-thickness of grooved pipe wall before flattening can be expressed as

$$d_0 = 2R_w - \delta_w \tag{1}$$

where δ_w represents the sintered wick thickness of GSHP.

The height of the flattened GSHP H decreases with the punch stroke u which can be calculated by

$$H = 2R_b = 2R_w - u \tag{2}$$

where R_b represents the radius of pipe wall at the bending section.

The length of unbending curves *AB* and *DE*. W_s, increases with the punch stroke as flattening proceeds, which can be expressed as

$$W_s = \frac{\pi}{2}(2R_w - H) \tag{3}$$

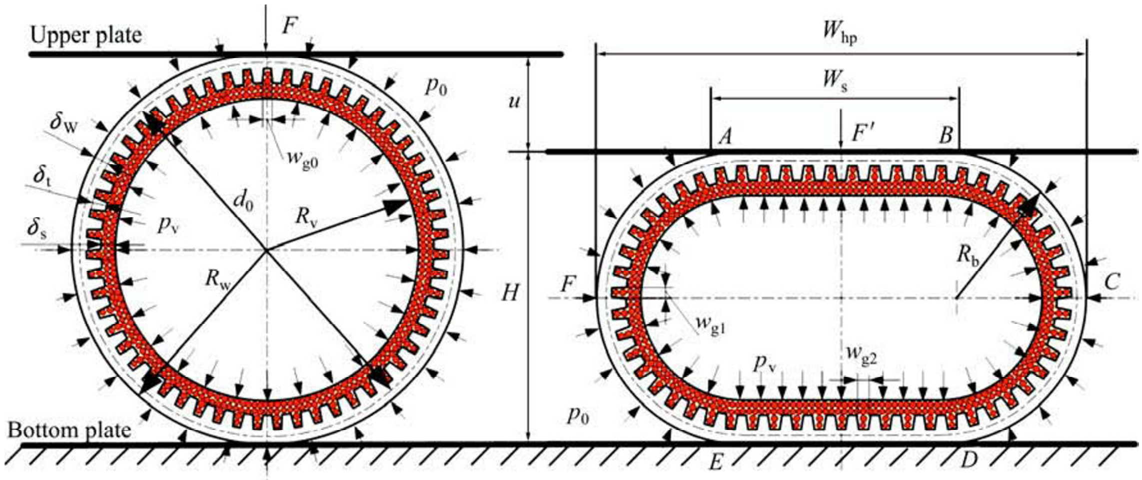

Fig. 1 Schematic diagram of GSHP phase change flattening process