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Phase change flattening process for axial grooved heat pipe

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ABSTRACT

A novel processing technique named phase change flattening process has been developed to fabricate the flattened grooved heat pipes, which are in high demand for electronics cooling. The phase change vapor pressure in the flattened heat pipe is analyzed on the basis of its operating principle. An elasto-plastic FEM simulation is proposed to analyze stress and strain distribution for the flattening process. An experiment is also set up to verify this elasto-plastic deformation of axial grooved heat pipe (AGHP). Results show that the vapor pressure is determined by the saturated vapor pressure equation of heat pipe. Punch load of the upper plate greatly increases due to its higher vapor pressure and the buckling phenomenon can be well eliminated when the vapor pressure reaches 1.002 MPa at vapor temperature 453 K. The maximum equivalent plastic stress and strain distribute on the maximum bend points at the bending wall of heat pipe when the punch stroke is over 3 mm. The width, vapor area and grooves of flattened heat pipe change greatly as the flattening proceeds.

1. Introduction

High heat flux has greatly affected the performance of electronics, which can weaken reliability, service life and security. The heat emission problem becomes more and more serious due to performance enhancement, miniaturization and integration of electronic products, especially for CPU of notebook. The heat pipe is an ideal component to solve the high heat flux problem due to its high efficient thermal conduction. Xie et al. (2008) evaluated the heat sink performance with integrated heat pipe for high flux chip. Vasiliev (2008) also presented a review on the thermal performance of micro and miniature heat pipes which were applied in high heat flux spreading in a limited space. Nowadays, the design of electronics cooling system requires excellent cooling performance with the restriction of the geometrical structure and limited space. Thang et al. (2000) reported that miniature heat pipes, flattened to desire thickness due to the restriction of space, were commonly used to improve heat spreading and more efficiently transfer heat generated from the CPU of notebook PC to a remote heat dissipation area. Kim et al. (2003) reported that round mini-axial grooved heat pipes often needed secondary fabrication process which was flattening. So far, Mahmood and Akhanda (2008) and Tao et al. (2008a,b) have done a lot of work about the thermal performance of flattened grooved heat pipe, but the flattening fabrication technology special for round heat pipes has not been introduced up to now by any other papers.

Two main fabrication methods could be used to fabricate common flat tube from a round one: lateral compression technology and cold roll forming technology. Mahmoud (2003) and Gupta et al. (2005) researched on lateral compression of a round tube between two rigid and parallel plates and found that a buckling phenomenon with two kinks formed on the central line, one at the top and the other at the bottom near the loading plates, might occur. Thus, the lateral compression technology cannot be adapted to flatten heat pipes due to the buckling phenomenon. Cole et al. (1970) and Laila (2002) supposed to fabricate flattening tube by the cold roll forming technology which was cold flattening of a round tube into a regular oblong shape through rolling between two flat rolls. However, the cold roll forming technology is not suitable for fabrication of flattened heat pipe with variable thicknesses or various cross-sectional shapes along its longitudinal direction. In order to fabricate flattened heat pipe with good flatness, a novel flattening processing based on the operating principle of heat pipe is provided on the present work. The working fluid inside the heat pipe will phase change into vapor when the heating temperature increases. The vapor pressure can stop the buckling forming during the lateral compression of heat pipes. This processing is defined as phase change flattening process.

In this work, the forming mechanism of phase change flattening process will be analyzed by both FEM simulation and experiments. The stress and strain distribution along the heat pipe during the flattening process will be discussed. The experimental results will be used to verify the FEM results from three aspects: punch load of

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Nomenclature

A	area (m^2)
d	diameter (m)
h	height of flattened heat pipe (m)
L	length of heat pipe (m)
m	mass (kg)
N	punch load (N)
n	amount of substance (mol)
P	vapor pressure (Pa)
R	radius (m)
r	change rate
T	absolute temperature (K)
u	punch stroke (m)
V	volume (m^3)
w	width (m)

Greek symbols

δ	thickness (m)
$\bar{\varepsilon}$	the effective strain
λ	porosity
ρ	density (kg/m^3)
$\bar{\sigma}$	the effective stress (Pa)

Subscripts

b	bending; buckling
g	groove
hp	heat pipe
i	ideal gas state
l	liquid
s	saturated vapor; straightened
t	tear
v	vapor
w	wall

flattening plates, buckling phenomenon and variation of geometric structure of flattened heat pipe.

2. Analysis of phase change flattening process

The entire heat pipe deformation of phase change flattening process can be divided into three stages: (1) heating heat pipe at a constant temperature, it is the pipe-expansion small elastic–plastic deformation process due to the vapor pressure inner heat pipe; (2) laterally compressing heat pipe with vapor pressure, it is the pipe-flattening elastic–plastic large deformation process; and (3) cooling heat pipe at room temperature and unloading the flattening pressure, it is the flattened heat pipe elastic spring back deformation process. The second process is the key stage that greatly determines the shape of flattened heat pipe, so the research focuses on this process.

2.1. Deformation geometry

The analytical model of phase change flattening round heat pipe is based on the plane strain condition as shown in Fig. 1. The ratio of wall thickness δ_w to the wall radius R_w is small, thus heat pipe can be considered as thin tube. As the round heat pipe is compressed laterally between two rigid parallel plates, it shapes plastically into oblong section. During the deformation process, the curves in contact with the loading plates are unbent to become flat and the remaining curves are bent to become even more curved. Before analysis of the deformation geometry of heat pipe, several hypotheses are set: (1) applying the constancy of volume principle on the copper lining, the neutral layer at the mid-thickness of heat pipe is assumed to be a constant length during the flattening process; (2) the bent curves away from the loading plates are approximated to a semicircle; and (3) the thickness of heat pipe is a constant value during the flattening process.

The diameter of neutral layer can be calculated

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

The height of flattened heat pipe is given by

$$h = 2R_b + \delta_w = 2R_w - u \tag{2}$$

The length of unbending curve can be expressed as

$$2w_s = \frac{\pi}{2}(2R_w - h) \tag{3}$$

The length of flattened heat pipe can be calculated by

$$w_{hp} = \frac{\pi}{2}(2R_w - h) + h \tag{4}$$

The cross section area of vapor chamber can be calculated by

$$A_{hp,v} = \frac{\pi}{2}\left(2R_w - \delta_w - \delta_t - \frac{h}{2}\right)(h - 2\delta_w - 2\delta_t) \tag{5}$$

Assumed that the length of heat pipe is L_{hp}, the volume of vapor chamber is given by

$$\begin{aligned} V_{hp,v} &= A_{hp,v} \times L_{hp} \\ &= \frac{\pi}{2}\left(2R_w - \delta_w - \delta_t - \frac{h}{2}\right)(h - 2\delta_w - 2\delta_t) \times L_{hp} \end{aligned} \tag{6}$$

When flattening proceeds, the grooves of heat pipe are deformed and a buckling phenomenon with two kinks on the central line may be formed as shown in Fig. 2. The width of grooves nearby unbending curve is stretched to become wider and is shortened at the bending curves. The width of grooves has great effect on the capillary force of wick, which is the key factor to the thermal

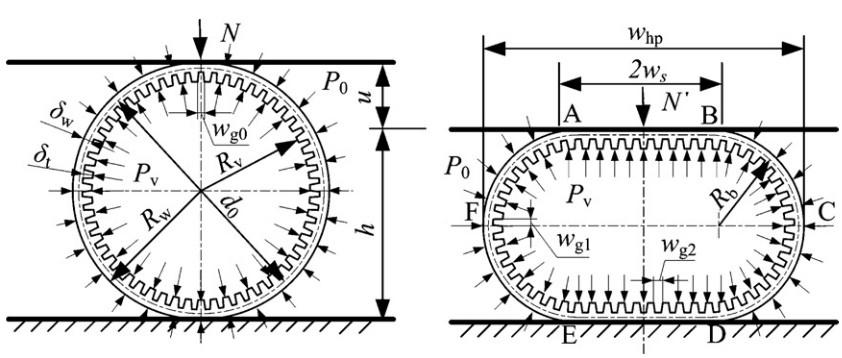

Fig. 1. Schematic diagram of heat pipe phase change flattening process.