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A Study on the Manufacturing Technology for the Development of Heat Pipes with a Sintered Metal Wick

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소결 금속 윅 히트파이프 개발을 위한 제조 기술 연구

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Abstract

The most the electronic industry has recently accelerated the modularization, the miniaturization and the high integrated trend of electronics fields such as electronics components, appliances and etc., the most increasingly the heat generation problem rises. Even though the conventional cooling technologies are widely used in order to reduce the heat loads, the technologies are not easy to meet the present trends due to the fact that most of many conventional methods are relative to external form environments such as size, design and so on. With regardless of those environments, however, a heat pipe is one of the most efficient systems to improve the heat transfer performance. And then the performance of the heat pipe depends on a wick structure. Of various wick structures, sintered metal wick is known so that it has some advantages such as smaller pore size, increasing porosity as well as high reliability. In this study sintered metal wicks, thickness 0.7 mm, 0.8 mm and 0.9 mm, were manufactured as of 100μm copper powder to obtain the manufacturing technology of heat pipes mounted with a sintered metal wick. Furthermore, experiments for the operational performance factors such as capillary limit, thermal resistance were not only performed but also compared with a theoretical model simultaneously. Experimental results agreed with the theoretical model, and then it seems to be required to study various development processes of sintered metal wicks for the high performance of a heat pipe system.

1. Introduction

The rapid growth of the electronic industries have accelerated the modularization, the miniaturization and the high integrated trend in the electronic field. As results of the growth, such electronic components as CPU, amplifier and etc. are significantly increasing heat generated per the these areas in spite of the fact that their process capability is being considerably improved. To reduce the rising temperature from heat generation, there is widely used to conventional cooling technologies. On the other hand, the technologies are difficult to get the heat transfer performance effectively over all heating areas generated in the electronic components on account of the fact that its technologies are not easy to cool over large heat loads.

In order to improve its heat transfer performance, the phase change heat transport systems are introduced. Of the phase change heat transfer systems, a heat pipe is one of the most efficient systems known well. And then the performance of the heat pipe depends on a wick. The wick should possess several characteristics such as the small pore size, high porosity and chemical compatibility with working fluid.

With regardless of the design concept of heat pipes, the capillary transport of the working fluid, vaporization and conductive heat transfer occurs in the porous space in the wick. While small pores are needed at the liquid-vapor interface to develop high capillary pressures, large pores preferred within the wick so that the movement of the liquid is not restricted too greatly.

For this reason, many different types of wick structures have been developed in order to optimize the performance of the capillary, porosity and permeability. Various porous wicks of such a conventional structure as grooved surfaces, wire meshes, high density and polyethylene so as to improve heat transport capabilities have been studied. But conventional wick structures may be not satisfied with the requirement of the high performance.

For optimal porous wicks, a sintered metal wick was introduced for the purpose of intensification of such processes and increase in the heat transport capabilities. Compared with the conventional wick structures, a sintered metal wick has some advantages such as smaller pore size, increasing porosity as well as high reliability. However, it is not easy to get the optimal process of the sintered metal wick because its process conditions such as temperature, pressure and etc. are required to be correctly obtained. Therefore,

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the manufacturing technologies such as the heat pipe design with the sintered wick, sintering methods for wicks and etc. are required to satisfy the recent trends.

In this study, as of developed sintering condition both manufacturing technology and design of heat pipe with each metal wick, its thickness 0.7 mm, 0.8 mm and 0.9 mm, made of copper powder were peformed.

2. Theory for the design of the heat pipe

The operation of the heat pipes relies on the heat transfer limits determined by the maximum heat transfer rate that a heat pipe is able to achieve under certain working conditions such as its working fluid and the phase change characters. The limitations are classified according to each and every specific characters of heat pipes. In case of the heat pipe with a sintered wick, a capillary limit should be taken in consideration mainly due to the fact that the capillary limit is lower value than the other limits. Basically, the capillary limit has to be considered as an important factor at 40 to 100℃ of the heat pipe working temperature.

The maximum available pump pressure (P_{pm}) is defined as

$$P_{pm} = P_{cm} - \rho_l \, g \, L_t \sin\psi \qquad (1)$$

Here P_{cm} is the capillary pressure defined as

$$P_{cm} = \frac{2\sigma}{\gamma_c}, \gamma_c = 0.21D \qquad (2)$$

where D is a particle diameter of powder.

The heat transport factor $(QL)_{c,\max}$ defined as

$$(QL)_{c,\max} = \frac{P_{pm}}{F_l + F_v} \qquad (3)$$

Here F_l and F_v are, respectively, the frictional coefficient for the liquid flow and for the vapor flow. They're defined as

$$F_l = \frac{\mu_l}{K A_w \rho_l h_{fg}} \qquad (4)$$

$$F_v = \frac{(f_v Re_v)\mu_v}{2\gamma_{h,v}^2 A_v \rho_v h_{fg}} \qquad (5)$$

where K is the permeability represents a property of the wick which characterizes its ability to transmit liquid and depends only on the geometry of wick structure. Generally, the permeability of sintered metal can be evaluated by the Blake-Kozeny equation[1] defined as

$$K = \frac{D^2 \psi^3}{150(1-\psi)^2} \qquad (6)$$

where ψ is the porosity.

Consequently, the maximum heat transfer rate below the capillary limit can be obtained as

$$Q_{c,\max} = \frac{(QL)_{c,\max}}{0.5L_c + L_a + 0.5L_e} \qquad (7)$$

When operating below the capillary limit, the performance of the heat pipe can be characterized by a coefficient of heat transfer U_{HP} that is defined as

$$Q = A\,U_{HP}(T_{p,e} - T_{p,c}) \qquad (8)$$

The contents in detail of eq. (8) are described on the references [1-5]. From above equation, the thermal resistance is defined as

$$U_{HP} = \frac{1}{R_{p,e} + R_{w,e} + R_v + R_{w,c} + R_{p,c}} \qquad (9)$$

Here, the coefficient of heat transfer U_{HP} is described by each thermal resistance obtained along the heat transfer paths from an evaporator to a condenser. Where, $R_{p,e}$, $R_{w,e}$, R_v, $R_{w,c}$ and $R_{p,c}$ are, respectively, the thermal resistance for the heat pipe wall at the evaporator, the saturated wick at the evaporator, the vapor flow from the evaporator to the condenser, the saturated wick at the condenser, and the pipe wall at the condenser, that is,

$$R_{p,e} = \frac{r_o t_p}{2L_e k_p} \qquad (10\text{-a})$$

$$R_{w,e} = \frac{r_o^2 t_w}{2L_e r_i k_e} \qquad (10\text{-b})$$

$$R_v = \frac{\pi r_o^2 F_v (\frac{1}{6}L_e + L_a + \frac{1}{6}L_c) T_v}{h_{fg}\rho_v} \qquad (10\text{-c})$$

$$R_{w,e} = \frac{r_o^2 t_w}{2L_c r_i k_e} \qquad (10\text{-d})$$

$$R_{p,c} = \frac{r_o t_p}{2L_c k_p} \qquad (10\text{-e})$$

As of above equations, k_e is the effective thermal conductivity of the liquid-saturated wick as described below.

$$k_e = \frac{k_l[(2k_l + k_w) - 2(1-\psi)(k_l - k_w)]}{[(2k_l + k_w) + (1-\psi)(k_l - k_w)]} \qquad (11)$$

Where k_l is the thermal conductivity of working fluid, k_w is the thermal conductivity of wick, ϵ is the porosity and A_w is the wick cross sectional area.

3. Experimental Facilities

Of many metal powders, 100 ㎛ copper powder has received considerable attention because of their excellent thermal conductivity as well as the compatibility with the working fluids, i.e., distilled water, used in this study. The Table 1 is listed in the component of copper powder as shown in Fig.1.

A copper pipe was washed by alcohol in order to remove impurities prior to the fact that a SUS310 jig putted in the copper powder was inserted into the copper pipe. And then the copper tube was followed to ASME standards code as listed in the Table 2. To fabricate the sintered metal wick, the sintering process was treating by heating at 850℃ through an electric furnace was used in this study together with argon gas to eliminate the risk of oxidization of copper metal powder. The standards of Table.3 is correctly satisfied with the operation condition because the theoretical vapor core diameter is 0.045m, provided that the maximum heat transfer limit is 60W and the operation temperature is 40℃. In order to measure the porosity of sintered metal wicks, an imbibition method was adopted in this study among several measurement methods are widely used.

4. Performance Test

Fig.2 is shown about the schematic diagram for performance test. Once lines of electric resistance was uniformly wound on the outside of the evaporator, Tefron tape and adiabatic material were wrapped again to insulate the evaporator. The condenser was set up with a water cooling vessel to remove the heat of transporting cooling water provided by a waterbath (MCH-013D, MO-NOTECH ENG. Co.). In order for the measurement of each heat pipe section temperature, thermocouples (T-type,0.12mm) were attached to each section as shown in Fig.2.

For performance testing, the heat pipe was driven by supplying the heat loads with the inclination angle against gravity was 10°, 20°, 45° and 90° from which the condenser is located below the evaporator section. Also, it was provided with the heat loads at the interval of 10W. When the heat pipe was driven under the steady state condition, each section temperature was recorded by a data acquisition device (DR230, Yokogawa Co.). Every and each tests were performed at the vapor temperature 40℃.

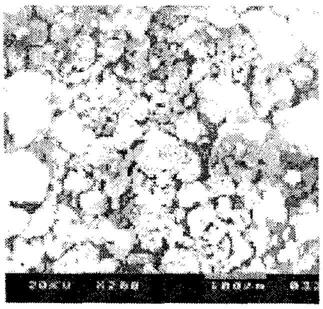

Fig. 1 The microscopic structures of 100 ㎛, Cu powder

Table.1 The components of copper powder

	Cu	Ag	Ca	Cr	Fe	Si	Sn
component (%)	99.9	0.001	N.D.	N.D.	0.001	N.D.	0.003

Table.2 The operating environment

Operating Condition	Evaporator length	Adiabatic length	Condenser length
℃ / W	mm	mm	mm
40 / 10-60	130	40	130

Table.3 The tube data

Pipe outer dia.	m	0.0127		
Pipe inner dia.	m	0.0111		
Tube diameter ratio (do/di)		1.144		
		1	2	3
vapor core dia.	m	0.0097	0.0095	0.0093
wick thickness	m	0.0007	0.0008	0.0009
wick cross-sectional area	m^2	2.286x10^{5}	2.587x10^{5}	2.883x10^{5}
porosity		0.40-0.45		

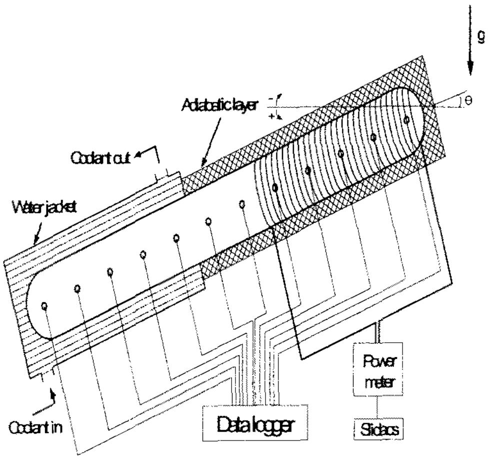

Fig. 2 Schematic diagram for performance test

5. Results

The heat transfer limitations about the wick thickness according to the inclination angle were obtained as listed in Table.4.

As above results about both porosity and maximum heat transfer limitation of each and every thickness of wicks, the calculated values of porosity according to the thickness of wicks agreed relatively well between 10W and 60W. In addition, the calculated porosity value given as of the maximum heat transfer limitation was similar to the porosity values measured by the Immersion method. That is, the more the thickness of wick increases, the more the heat transfer limitation increases. As shown in Fig.3 regarding to the relation between the maximum heat transfer rate and inclination angle according to wick thickness 0.7 mm, 0.8 mm and 0.9 mm, we knew the maximum heat transport rate was decided by the capillary heat transfer limit.

Table.4. Experimental and calculated values for each wick thickness

Inclination angle	thickness t=0.7 mm		
	Experimental Value [W]	Calculated Value [W]	Rel. Err. [%]
10°	20	32.687	38.814
20°	20	30.047	33.438
45°	20	24.392	18.006
90°	20	20.121	0.601
Porosity		0.41	

Inclination angle	thickness t=0.8 mm		
	Experimental Value [W]	Calculated Value [W]	Rel. Err. [%]
10°	40	41.162	2.823
20°	30	37.838	20.714
45°	30	30.176	0.583
90°	20	25.330	21.042
Porosity		0.42	

Inclination angle	thickness t=0.9 mm		
	Experimental Value [W]	Calculated Value [W]	Rel. Err. [%]
10°	60	62.724	4.342
20°	40	57.659	30.627
45°	30	46.804	35.903
90°	30	38.585	22.249
Porosity		0.45	

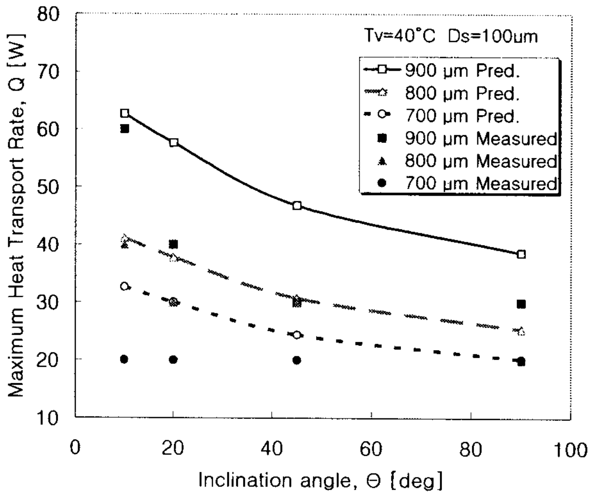

Fig. 3 Maximum heat transport rate vs. inclination angle for different values of wick thickness

6. Conclusion

The sintered metal wick is considerably affected to the properties of wicks such as the porosity and the permeability according to the sintering process. As results, the sintered metal wick affected both the capillary limit and the thermal resistance of the heat pipes. The heat pipe with the sintered metal wick for this study approached the theoretical analysis results more nearly except for 7mm wick thickness. In case of 7mm wick thickness, it seems that the calculated results do not agree with the experimental results because thin thickness is not easy to turn out in the sintering process. For the manufacturing of the high performance heat pipes, it will be required to study various development processes of sintered metal wicks that have not only high porosity but also high permeability as of popular metal powders.

7. References

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