Microgrooved Wicks for Heat Pipes Made by Edge Cutting Machining

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ABSTRACT

The paper discusses the use of deformational cutting method for manufacturing microgrooved wicks for heat pipes. Experiments were conducted to estimate their permeability and height of capillary rise. Comparison of microgrooving with sintered and fiber capillary structures showed their advantage in permeability under similar height of capillary rise. Paper proposes to make microgrooved structures inside heat pipe with different geometrical shapes and parameters for evaporator, condenser and adiabatic sections.

I. INTRODUCTION

Constructional capillary structures on the inner side of heat pipe shell in form of rectilinear longitudinal channels possess the greatest liquid permeability and the maximum heat conductivity in radial direction. For existing technological methods of their fabrication a capillary pressure is inadmissible small in view of essential restrictions for groove width.

In Bauman Moscow State Technical University developed the machining method – the deformational cutting[1] (Fig.1). The totality of partially cut and plastically deformed layers, which retained on the base material, forms an extended macro- or microrelief in form of fins, pin-fins or other shapes. The DC is embodied by using standard metal cutting equipment and is a waste-free and high-efficient process, and allows all geometrical characteristics of the obtained macro-micro relief to be controlled. Interfin gaps with sizes ranging from a few micrometers to a few millimeters can be obtained. The degree to which this process can be realized in practice depends in the main on the plasticity of material being processed and ratio cutting depth/pitch. For materials with relative elongation of more than 30% (the majority of nonferrous metals) the height of fins may be up to 7 finning pitches. For materials with relative elongation ranging from 18 to 30% (this category encompasses the majority of steel) maximum fin height is 3-5 pitches. The DC machining can increase the surface area up to 12 times for copper and up to 6 times for steel. The main limiting factors for DC are workpiece ductility and hardness. A stable DC process can be achieved in materials with hardness smaller than HB220 and elongation larger than 18%.

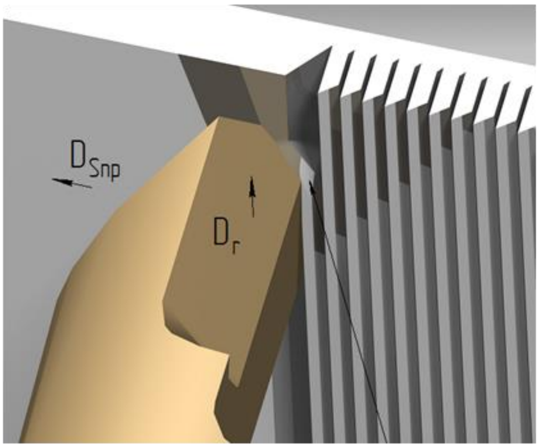

Fig.1. Concept of deformational cutting method

There are a number of different application areas of the DC technology. The main application area is heat exchange intensification, for example finning of tubes for heat exchangers[2], including internal enhancement[3], surfaces for pool boiling[4,5], heat distribution elements and vapor removal channels in loop heat pipes[6]. The other DC application areas are electrical joints manufacturing[7,8], metal micromesh and polymer filtering tube making[9], surface quench hardening[10] and other.

II. DC method for making heat pipes weeks

Using DC-method it is possible to make microgroove capillary structures (Fig.1a) on a metal tapes and sheets with a width of capillary gap from units of microns and above with pitch from 50 microns with groove height up to 6-7 pitches for nonferrous metals.. The tape (sheet) pulls on the drum, installed on screw-cutting lathe. The process of grooving is the same as turning cut, but without chip. The cutting tool is micrograin carbide insert, having special geometry.

After DC processing with obtaining microgrooves, the tape is formed in a shell of a heat pipe (Fig.1b), edges of a tape weld, end faces are plugged, forming a heat pipe.

It is possible to make microgrooves now on a majority of materials produced in form of tape or sheet (copper, aluminum, titanium, stainless steel, zirconium, polymers etc.) with a length of

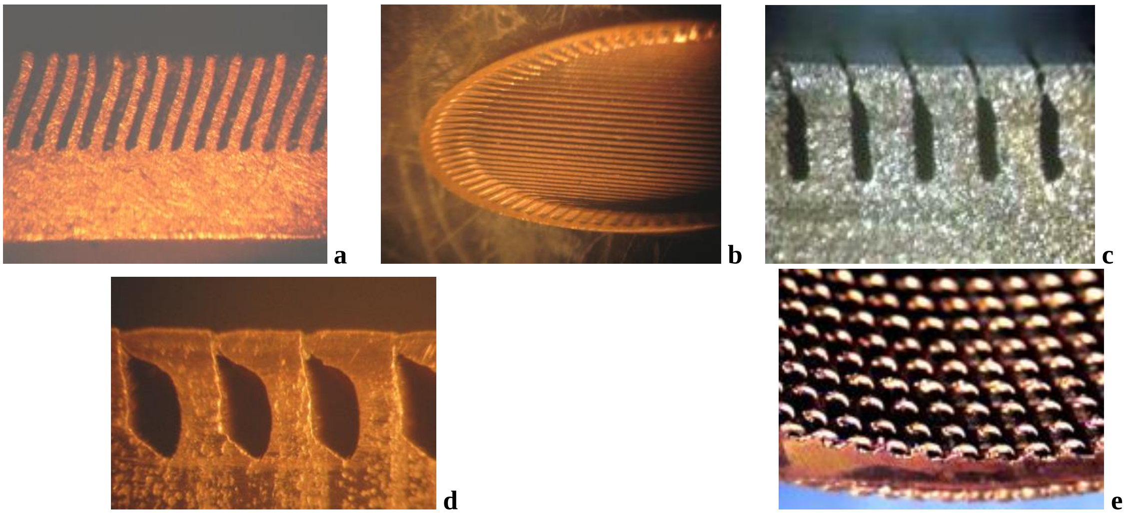

Fig.2. Grooved heat pipe wicks made byDC method. a-microgrooves on metal tape, b-molded heat pipe shell, c-boiling site of heat pipe with subsurface caverns and slots for vapor exit, d-adiabatic site with locked capillaries, e-pin-fin site for condensation

grooved tape 450 mm with tape thickness 0.15-1.2 mm. Minimum obtained groove width is 4 microns. In principle it is possible to obtain the length of finned site up to 2 meters with drum diameter 640 mm, which can installed on majority lathes having center height over bed more than 320 mm.

On one tape it is possible to obtain continuous grooves, having different shape and size along its length. For a heat pipe boiling section it is possible to make subsurface caverns (Fig.1c) having increased heat-transfer coefficient[4,5]. For a heat pipe adiabatic section it is possible to obtain complete closing of fin tops (Fig.1d), eliminating interaction of liquid moving in capillaries and vapor moving inside the heat pipe in opposite directions. For a site of condensation it is possible to obtain micro pin fin surface (Fig.1e) which has heat-transfer coefficient 30% more, than a simple finned surface.

III. PERMEABILITY AND CAPILLARY PROPERTIES OF DC MICROGROOVING

Experimental determination of liquid permeability K and capillary rising H for structures manufactured by DC method was made using one side microgrooved copper strip. The geometrical parameters of finning are presented in Table1. Structures 1-3 have inclined grooves (not perpendicular to the base metal). The working fluid used was distilled water. Finned strip 1 (Fig.2a) squeezed between two half cylinder parts 2. Assembly insreted into flexible transparent PVC tube 3.

In permeability experiments water effused through the sample under hydrostatic load ΔP. Water flow-rate mesured by volumetric method for a certain period of time. Liquid permeability was determined by Darcy fomula[11]:

$$K = \frac{Q \cdot \mu \cdot L}{F \cdot \Delta P},$$

where Q - mass flow rate through the porous structure,
μ- coefficient of kinematic viscosity,
L- length of filtering path,
F- total flow area of microchannels,
ΔP- pressure drop across the inlet and outlet of a porous structure.

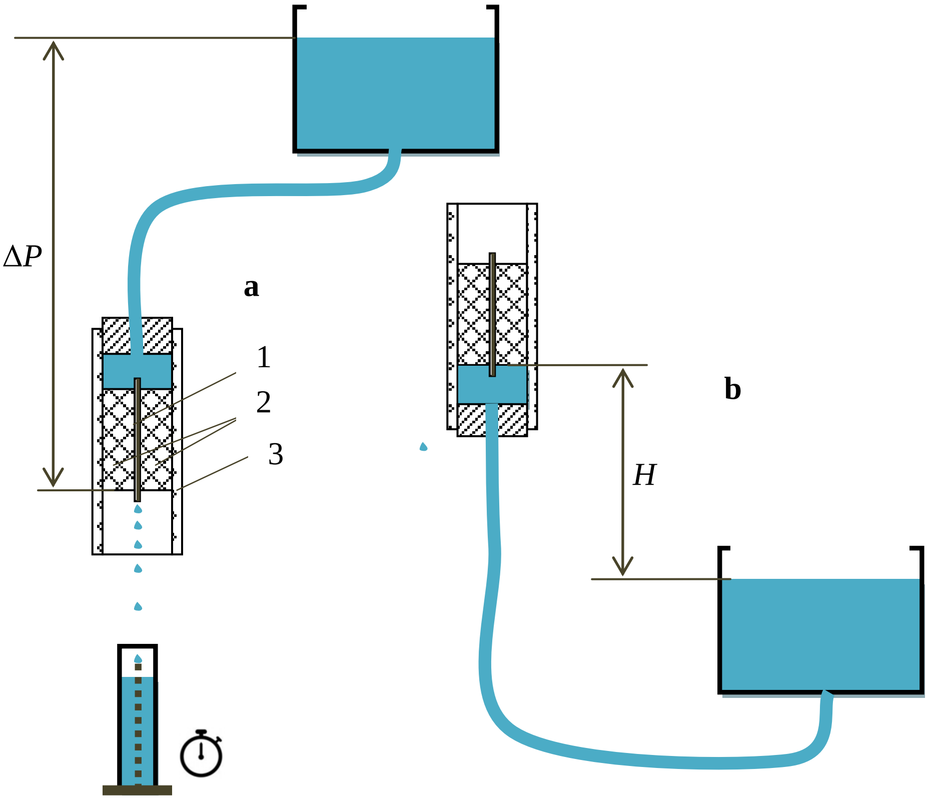

Fig.3. Experimental setup. a-for estimation of permeability, b-for estimation height of capillary rise

Table 1

Parameters of microgrooved samples

Sample #	Pitch, mm	Height of grooves, mm	Width of grooves, mm	Surface porosity of the structure, %
1	0,1	0,41	0,02	22
2	0,15	0,58	0,035	33
3	0,12	0,6	0,025	33
4	0,2	0,8	0,1	50
5	0,16	0,72	0,065	50
6	0,12	0,4	0,057	50
7	0,1	0,35	0,045	50

Determination of the height of capillary rise was made by slow lifting of the examined sample inserted in transparent tube above other communicating vessel (Fig.2b). Fixation of *H* was carried out at the appearance of air bubbles from the capillaries. Before each experiment, the air carefully removed from the pore space of the samples. The value of this hydrostatic pressure *H* was assumed equal to the height of capillary rise.

The results of experiments are shown in Table2. For comparison, data are presented on the characteristics of capillary-porous structures of other types, taken from Ref.11.

Generalized indicator of capillary-transport characteristics of heat pipe wicks is the multiplication of permeability coefficient *K* to the height of capillary rise *H*. According to this indicator, which is also presented in Table2. The structures obtained DR surpass the best fibrous structures in 6 times.

Table2

Capillary-transport parameters of structures obtained by DC method and their comparison with published data for other types of capillary structures[11]

Type a porous structure	Material	Porosity, %	*K*·1011, m2	*H*, mm	*K*·*H*·1011, m3
Fibrous	Nickel	0,868	4,4	405	1,78
		0,825	3,4	405	1,38
	Steel 12Cr18Ni10Ti	0,916	54,6	155	8,48
		0,808	19,6	226	4,43
		0,822	116	135	15,7
Mesh	Nickel	0,625	66,3	48,5	3,22
		0,676	7,7	234	1,8
Powder	Nickel	0,696	30,0	175	5,25
Fibrous	Copper	0,800	15,5	362	5,61
Mesh	Steel 12Cr18Ni10Ti	–	34,6	79,4	2,74
Fibrous	Copper	0,590	2,5	311	0,78
Mesh	Steel 12Cr18Ni10Ti	0,690	3,8	199	0,76
Powder		0,570	2,4	304	0,74
Fibrous	Nickel	0,850	11,3	226	2,56
		0,800	6,6	305	2,01
	Copper	0,800	18,6	162,5	3,02
Mesh	Nickel	0,600	13,3	127	1,69
Powder	Nickel	0,650	0,1	–	–
1 DC microgrooved	Copper	0,22	4,45	680	3,03
2		0,33	46,8	300	14,0
3		0,33	35,7	400	14,3
4		0,50	417	130	54,2
5		0,50	83,3	160	13,3
6		0,50	31,3	230	7,2
7		0,50	6,97	320	2,23

IV. CONCLUSION

The experimental results and comparison with literature data show that the constructional capillary-porouse structures obtained DC have the height of capillary rise is not inferior to the best sintered fiber and powder structures, and in liquid permeability significantly exceed them. Greater restriction for meshes, powder or fibrous structures due to the fact that the capillary fluid movement occurs via a curved path having multiple narrowing and expansion. Interfin gaps of grooved structures are straightforward and their flow area are constant along its length.

NOMENCLATURE

F = total area of microchannels
H = capillary rise
K = coefficient of permeability
L = length of filtration
ΔP = hydraulic drop
μ = coefficient of kinematic viscosity

REFERENCES

[1]N. Zoubkov, A. Ovtchinnikov, “Method and apparatus of producing a surface with alternating ridges and depressions,” U.S. Patent 5 775 187, Jul. 7, 1998.

[2]Kukowski R. “MDT - Micro deformation technology,” *Proceedings of the ASME Int. Mech. Eng. Congr. RD&D Expo,* Washington, DC, 2003, pp. 305–308.

[3]P.Thors, N. Zoubkov, "Method for making enhanced heat transfer surfaces", U.S. Patent 8 573 022, Nov. 5, 2013.

[4]Popov I. A., Zubkov N. N., Kas’kov S. I., and .Shchelchkov A. V. "Heat Transfer during the Boiling of Liquid on Microstructured Surfaces. Part 1: Heat Transfer during the Boiling of Water", *Thermal Engineering,* Vol. 60, No. 3, 2013, pp. 157–165.

[5] Popov I. A., Zubkov N. N., Kas’kov S. I., and .Shchelchkov A. V. "Heat Transfer during the Boiling of Liquid on Microstructured Surfaces. Part 2: Visualization of Boiling and Critical Heat Fluxes", *Thermal Engineering,* Vol. 60, No. 4, 2013, pp. 285–294.

[6]Yakomaskin A., Afanasiev V., Zubkov N. and Morskoy D. "Investigation of Heat Transfer in Evaporator of Microchannel Loop Heat Pipe". *Journal of Heat Transfer.* Vol. 135. Issue 10. 2013. 7 p.

[7]Solovyeva L., Zubkov N., Lisowsky B., and Elmoursi A. "Novel Electrical Joints Using Deformation Machining Technology Part I: Computer Modeling". *IEEE Transactions on Components, Packaging, and Manufacturing Technology*. Vol. 2, No. 10. 2012. pp.1711-1717.

[8]Solovyeva L., Zubkov N., Lisowsky B., and Elmoursi A. "Novel Electrical Joints Using Deformation Machining Technology-Part II: Experimental Verification" *IEEE Transactions on Components, Packaging, and Manufacturing Technology*. Vol. 2, No. 10. 2012. pp.1718-1722.

[9]Vasiliev S.G and Poptcov V.V. "Surface Hardening Using Thermal Action of Deformational Cutting", *Izv. Vyssh. Uchebn. Zaved.,Mashinostr.,* No.12. 2011, pp. 37–43.

[10]Zubkov N. and Sleptsov A. "Production of Slotted Polymer Tubes by Deformational Cutting" *Russian Engineering Research.* Vol.30, No.12, 2010, pp.51-53.

[11]Semena M.G., Gershuni A.N and Zaripov V.K. *Heat pipes with metal fibers capillary* – Vishcha Shkola, Kiev, 1984, p.41.