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 (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%.
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...

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**Fig.1. Concept of deformational cutting method**

**Fig.2. Grooved heat pipe wicks made by DC 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 inserted into flexible transparent PVC tube 3.

In permeability experiments water effused through the sample under hydrostatic load \(\Delta P\). Water flow-rate measured by volumetric method for a certain period of time. Liquid permeability was determined by Darcy formula\(^11\):

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

where \(Q\) - mass flow rate through the porous structure,
\(\mu\) - coefficient of kinematic viscosity,
\(L\) - length of filtering path,
\(F\) - total flow area of microchannels,
\(\Delta P\) - pressure drop across the inlet and outlet of a porous structure.
Table 1

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Pitch, mm</th>
<th>Height of grooves, mm</th>
<th>Width of grooves, mm</th>
<th>Surface porosity of the structure, %</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0,1</td>
<td>0,41</td>
<td>0,02</td>
<td>22</td>
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<tr>
<td>2</td>
<td>0,15</td>
<td>0,58</td>
<td>0,035</td>
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</tr>
<tr>
<td>3</td>
<td>0,12</td>
<td>0,6</td>
<td>0,025</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>0,2</td>
<td>0,8</td>
<td>0,1</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>0,16</td>
<td>0,72</td>
<td>0,065</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>0,12</td>
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<tr>
<td>7</td>
<td>0,1</td>
<td>0,35</td>
<td>0,045</td>
<td>50</td>
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</table>

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

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 Table 2. 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 Table 2, the structures obtained DR surpass the best fibrous structures in 6 times.

Table 2
Capillary-transport parameters of structures obtained by DC method and their comparison with published data for other types of capillary structures

<table>
<thead>
<tr>
<th>Type a porous structure</th>
<th>Material</th>
<th>Porosity, %</th>
<th>$K \cdot 10^{-11}$, m$^2$</th>
<th>$H$, mm</th>
<th>$K \cdot H \cdot 10^{-11}$, m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous</td>
<td>Nickel</td>
<td>0.868</td>
<td>4.4</td>
<td>405</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>0.825</td>
<td>3.4</td>
<td>405</td>
<td>1.38</td>
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<tr>
<td></td>
<td>Steel 12Cr18Ni10Ti</td>
<td>0.916</td>
<td>54.6</td>
<td>155</td>
<td>8.48</td>
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<td></td>
<td>0.808</td>
<td>19.6</td>
<td>226</td>
<td>4.43</td>
<td></td>
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<tr>
<td></td>
<td>0.822</td>
<td>116</td>
<td>135</td>
<td>15.7</td>
<td></td>
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<tr>
<td>Mesh</td>
<td>Nickel</td>
<td>0.625</td>
<td>66.3</td>
<td>48.5</td>
<td>3.22</td>
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<tr>
<td></td>
<td>0.676</td>
<td>7.7</td>
<td>234</td>
<td>1.8</td>
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<tr>
<td>Powder</td>
<td>Nickel</td>
<td>0.696</td>
<td>30.0</td>
<td>175</td>
<td>5.25</td>
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<tr>
<td>Fibrous</td>
<td>Copper</td>
<td>0.800</td>
<td>15.5</td>
<td>362</td>
<td>5.61</td>
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<tr>
<td>Mesh</td>
<td>Steel 12Cr18Ni10Ti</td>
<td>–</td>
<td>34.6</td>
<td>79.4</td>
<td>2.74</td>
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<tr>
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<td>Nickel</td>
<td>0.690</td>
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<td>199</td>
<td>0.76</td>
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<tr>
<td>Fibrous</td>
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<td>0.590</td>
<td>2.5</td>
<td>311</td>
<td>0.78</td>
</tr>
<tr>
<td>Powder</td>
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<td>2.4</td>
<td>304</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Fibrous</td>
<td>Nickel</td>
<td>0.850</td>
<td>11.3</td>
<td>226</td>
<td>2.56</td>
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<tr>
<td></td>
<td>0.800</td>
<td>6.6</td>
<td>305</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>0.800</td>
<td>18.6</td>
<td>162.5</td>
<td>3.02</td>
</tr>
<tr>
<td>Mesh</td>
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<td>0.600</td>
<td>13.3</td>
<td>127</td>
<td>1.69</td>
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<tr>
<td>Powder</td>
<td>Nickel</td>
<td>0.650</td>
<td>0.1</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

1. DC microgrooved

IV. CONCLUSION

The experimental results and comparison with literature data show that the constructional capillary-porous 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
- $\Delta P$ = hydraulic drop
- $\mu$ = coefficient of kinematic viscosity
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