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Bio-inspired heat microsink manufactured by using micro end-milling process

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Abstract

Production of microchannels used in heat microsink has been improved given the advances in precision machining. A variety of part materials (e.g. silicon) can be applied to yield microsinks although metallic coating still needs to be applied to improve surface quality. The main problem to micromachine steel-based materials is to guarantee geometric precision and to minimize burr formation. Among several manufacturing processes, micromilling allows creating 3D structures with vertical sidewalls, good smoothness, external sharp corners and complex geometries, but parts with coarse microstructure can impair the machining efficiency. Thus, homogenous microstructure of the part materials has been investigated given the significant improvements in the cutting process which benefit the microchannels roughness. This surface integrity parameter is the most relevant one when machining channels for microsink. This papers aims to investigate the fabrication of bio-inspired heat microsinks by using micromilling process. This kind of device is more thermally efficient because the channels follow the vascular shape of plant leaves. Ultrafine-grained aluminium (1 µm grain size) was used to match machining scale (milling microparameters) to the workpiece microstructure (micrograin size) aiming at improving the surface generation and part-tool interaction. Surface analyses were carried out using laser 3D microscope. 0.2, 0.4, 0.8 and 2.0 mm diameter tungsten carbide end-mills were used in micromilling tests. The cutting parameters varied along the micromilling due to the different micromill diameters and microchannels geometry. Only feed per tooth (f_t) was at the same range of the cutting edge radii (r_e). The main results indicated that micromilling with $f_t \approx r_e$ reduced the surface roughness. In addition, no deformation of the microsink slots and small burrs on the top of the walls were found, respectively. Thus, micromilling process associated to a homogenous microstructure of the workpiece suggests to favour the microslots production of bio-inspired heat microsinks.

Microsink. Micro end-milling. Bio-inspired heat microsink. Ultrafine grain. Aluminium.

1. Introduction

Heat microsinks are device with high surface area per volume unit of work fluid, low thermal resistance, low mass and volume [1]. The growing necessity for cooling off electronics components in microscale has created demand for heat microsinks with channels to fluid flow in the range of 0.1 to a few hundred micrometres [2]. Many materials have been used to produce microdevices for heating exchange, among them aluminium and stainless steel. However, the efficiency of the device is defined by design of channels and contact area [3]. The design and manufacturing of heat microsink with microchannels of submicrometric thickness have been the biggest obstacle when researching miniaturization processes. Thus, since the current manufacturing techniques allow only using electro-discharge machining and machining with thin discs, these methods hinder the production of microchannels with different geometry [4]. Bio-inspired heat sinks based on vascular plant leaves are such examples. The porous structure in plants has shown good geometric configurations to higher rates of heat dissipation by minimizing the pressure loss during heat exchange [5]. In order to make feasible this type of microdevice, the objective of present research was to micromill a bio-inspired heat sink composed by ultrafine-grained aluminium.

2. Experimental procedure

The micromilling tests were carried out in a CNC Kern D-82418 machining centre. Micromills with different diameters were employed for the endmill operation. The cutting edge radii and microchannel wall were measured by Olympus OLS4000 3D Laser Microscope. All cutting parameters are presented in Tables 1 and 2 where d_φ is the endmill diameter, r_e is the tool edge radius, f_t is the feed per tooth, v_c is the cutting speed, a_p is the depth of cut and a_e is the width of cut. The cutting parameters were specified considering the relationship between part microstructure and tool edge radius [6]. RSA 6061 aluminium alloy with ultrafine microstructure (1 µm grain size) was used as workpiece material.

Table 1. Rough parameters

d_φ [mm]	r_e [µm]	f_t [µm]	v_c [m/min]	a_p [µm]	a_e [µm]
2.0	4.0 ± 0.9	12	300	400	2000
0.8	2.0 ± 0.2	8	120	160	240
0.4	1.5 ± 0.2	6	60	80	120
0.2	1.0 ± 0.1	1.5	30	30	60

Table 2. Finishing parameters

d_φ [mm]	r_e [μm]	f_t [μm]	v_c [m/min]	a_p [μm]	a_e [μm]
2.0	4.0 ± 0.9	4	300	200	2000
0.8	2.0 ± 0.2	2	120	80	240
0.4	1.5 ± 0.2	1.5	60	40	120

3. Results and discussion

Figure 1 shows the heat microsink milled with 25 mm length, 28 mm width and 2 mm height. External channel is for sealing purposes and appositive pockets are the regions to input and output of fluid flow. The microchannels were produced with width of cut ranging from 200 to 2000 μm due to the geometric complexity of the device. Micromilling process enabled to produce precisely the heat microsink with different endmill diameters according to the original design.

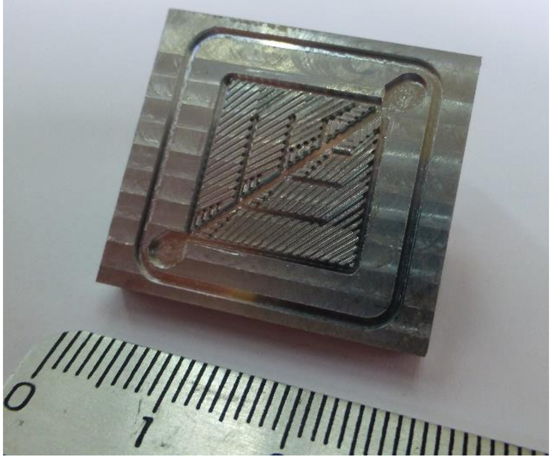

Figure 1. Heat microsink manufactured by micromilling

Figure 2 shows a 3D image of the thinnest walls where the microslots present very small burrs and no deformation in the walls. This result reveals the efficiency of micromilling to make microdevices with quality and geometric precision. The ultrafine-grained material facilitated the microcutting process, as also observed in previous research [7].

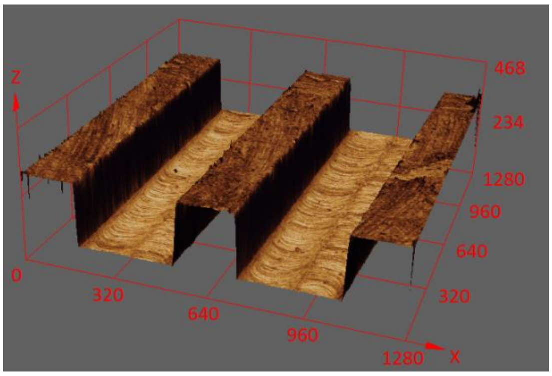

Figure 2. 3D image of the walls with 200 μm thickness (Axes units in μm)

Figure 3 shows a 3D image of a curved channel where changes in tool trajectory did not practically affect the machining quality such also observed in regions with linear toolpath.

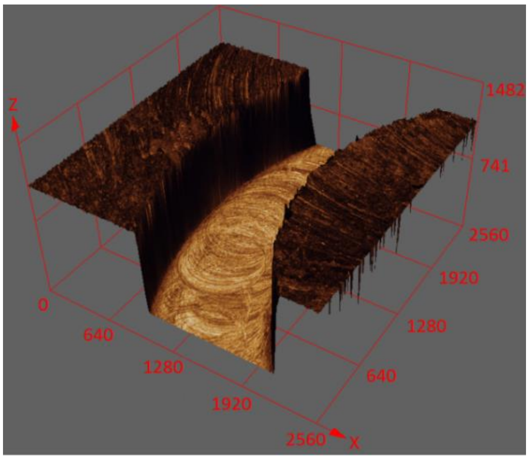

Figure 3. 3D image of a curved channel (Axes units in μm)

Figure 4 presents a 3D image of the pocket bottom where fluid for heat exchange inputs/outputs. A 4 μm maximum roughness was attained as noted in colour scale at z-axis. Bottom topography can be controlled through micromilling parameters and it will depend on function of the machined surface. For fluid flow the contact surface quality governs the heat exchange significantly [8].

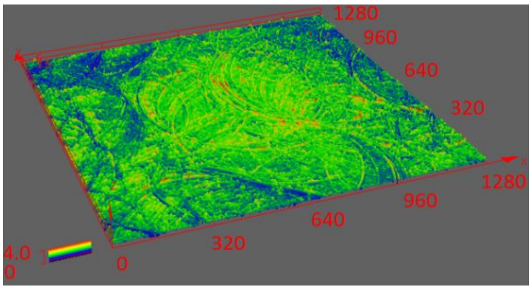

Figure 4. 3D high image of pocket base (Axes units in μm)

4. Conclusions

The present paper proposed to manufacture a bio-inspired heat microsink using micromilling process. Very thin walls without deformations and microchannels with negligible burrs were attained. The future step will evaluate the fluid-structure interaction aiming to determine the influence of the bottom roughness on heat exchange process. Further scale reduction will also be attempted to investigate the limits of such manufacturing strategy.

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