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Microchannels quality depends on workpiece microstructure and milling parameters

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Abstract

More efficient processes are the goal when cutting microparts. Machining parameters such as mainly tool feed (uncut chip thickness) should be properly specified not only regarding the tool edge radius, but also considering the grain size of the workpiece material. This paper demonstrates that microchannels quality is affected if cutting parameters are not adequately chosen even when milling ultrafine-grained workpieces. Aluminium, low carbon steel and stainless steel with homogeneous microstructure (grain size < 1 µm) were micromilled with cemented carbide ball-nose endmill of 0.75 mm diameter and 2.24 ± 0.5 µm edge radius at 50 m/min cutting speed, and 50 and 80 µm depth of cut. Feeds per tooth of 0.25; 0.5; 1.0; 2.5 and 3.5 times the tool edge radius (r_e) were considered. Laser 3D microscopy qualified the burr formation, bottom deformation and geometrical deviations of the channels. Variance analysis quantified the surface finishing and burr size statistically. The greater the depth of cut is, the higher the aluminium strain is. Highest tool feed and depth of cut minimize the geometrical deviations of the low carbon steel and stainless steel, but burr size grows as depth of cut increases. Differently, only larger tool feed augments burr size statistically for aluminium. Therefore, the suitable adjustment between machining parameters and workpiece microstructure is crucial to ensure quality and accuracy of micromilled channels.

Tool edge radius. Channels micromilling. Ultrafine-grained workpiece. Burr formation. Surface finishing. Geometrical deviations.

1. Introduction

Microfluidic systems depend on liquid-surface interaction to ensure the efficiency during work, and this interaction is affected by microchannels quality [1]. When specific features are produced in microchannels, the microfluid flow can be improved [2]. Part microstructure plays an important role when microcutting steels. Current studies aim at understanding the relationship between part microstructure and machining conditions to improve the surface quality of microcomponents [3]. The milling process can create channels in a few minutes, depending on the complexity of the device, with vertical sidewalls, with good finish and geometrically defined corners [4]. The main advantages of this process is its versatility and ability to be combined with other microfabrication processes, in addition to generate a specific roughness or reproducing complex geometric details. Dimensional errors arising from the process also are smaller, ensuring quality of the manufactured part [5]. This research aimed to investigate the microchannels quality when fabricated by micromilling process, considering ultrafine-grained metals as workpiece material and machining parameters.

2. Experimental procedure

The micromilling tests were carried out using the CNC Kern D-82418 (Figure 1). The cutting parameters adopted were 50 m/min speed cutting, 50 and 80 µm depth of cut, and feed per tooth of 0.25; 0.5; 1.0; 2.5 and 3.5 times the tool edge radius (r_e). A carbide ball-nose tool TiN coated with 750 µm diameter, 0.4 mm corner radius and 2.24 ± 0.5 µm edge radius was used. The cutting edge radius and channel dimensions were measured by Olympus OLS4000 3D Laser Microscope. Three ultrafine-grained metals were used during the tests: low-carbon steel with 216 HV and 0.7 µm grain size, stainless steel with 470 HV and 0.2 µm grain size, and an aluminium with 117 HV and 1 µm grain size. Dry conditions were used during all experiments. Quantitative results were evaluated by using Analysis of Variance (ANOVA), statistical significance β=5%, and two replicates to determinate the effect of cutting parameters and materials on quality and accuracy of manufactured microchannels.

Figure 1. Experimental setup for micromilling of channels in ultrafine-grained metals.

3. Results and discussion

Figure 2 presents a micromilled channel with 50 µm depth of cut and 8 µm/tooth (3.5 × r_e). The workpiece material is the ultrafine-grained low carbon steel. All the materials used in this study were machined with the same shape of channels, so that the burr height were measured on both up and down milling sides.

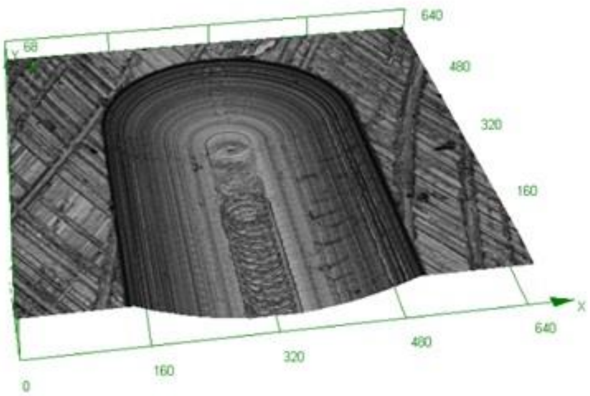

Figure 2. Microchannel milled in low carbon steel workpiece with 8 µm/tooth feed and 50 µm depth of cut (axes scale in µm).

Figure 3 presents the main effects plot for channel cross-section area to low-carbon steel. The analysis of channels accuracy considered the channels transversal area. The area of transversal section must be near to theoretical area, estimated with depth of cut and tool corner radius. The plot behaviour was observed to stainless steel and aluminium as well. However, considering statistical significance β=5%, only low-carbon steel and stainless steel showed β<5%, revealing a possible material hardness effect on the results [6]. The increase of feed per tooth improves the channels accuracy, with better shape and less deformed material non-removed due to the tool edge radius effect. The depth of cut effect still needs to be better evaluated by ANOVA.

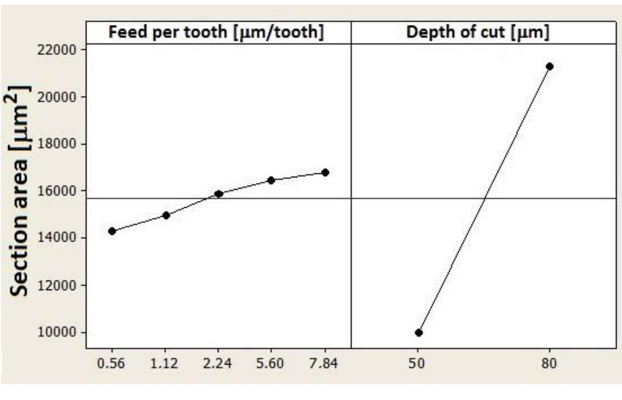

Figure 3. Main effects plot for section area to low-carbon steel workpiece.

When evaluating burr formation on up milling side, depth of cut showed statistical significance to the low carbon steel and stainless steel. However, the effects were opposite for both materials. The increase of depth of cut caused higher burrs during machining of the low carbon steel (from 0.75 to 1.70 µm), while lower burrs was measured to stainless steel (from 8 to 3 µm). Aluminium did not showed statistical significance to the cutting parameters.

By other hand, on down milling side, feed per tooth affected burr height during machining of the low carbon steel and aluminium, with statistical significance β<5%. The increase of feed per tooth caused lower burrs in the low carbon steel (from 2.5 to 0.5 µm) and higher burrs in the aluminium (from 1 to 6 µm). Stainless steel did not showed statistical significance to the cutting parameters.

As seen, when is evaluated the profile accuracy of the channels, the increase of feed per tooth is determinant to ensure better shape to channels, reducing tool edge radius effects. Mechanisms of cutting overcome the deformation process, producing microchannels without defects and non-removed material.

When evaluating burr height, the cutting parameters caused different effects to each ultrafine-grained material. Depth of cut was more relevant to the low-carbon steel and stainless steel, while feed per tooth was significant to the low-carbon steel and aluminium. The adjustment of cutting parameters together with ultrafine-grained material determinates the quality and accuracy of channels, improving the applications in which the channels will be used.

4. Conclusions

This study contributed to an evaluation of quality and accuracy of microchannels manufactured by using micromilling process. Ultrafine-grained metals were applied to guarantee a homogenous microstructure during cutting. The effect of feed per tooth and depth of cut upon burr formation, bottom deformation and geometrical deviations during micro end milling was evaluated. Cutting parameters affected burr height and accuracy of channel profile left by the ball-nose tool during cutting. However, different results were observed when different ultrafine-grained metals were machined. Low carbon steel and stainless steel were more affected by cutting parameters proved statistically by ANOVA. Despite the homogeneous microstructure of the workpieces, the choice of machining parameters proved to be also important to ensure the quality and accuracy of microchannels machined when different metals with ultrafine grains are applied. The next step is to evaluate the quality of multichannel plates injected into micromolds made from materials used in this investigation.

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