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Burr formation during micro end-milling of ultrafine-grained materials

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Abstract

In conventional machining, the milling process is useful when complex geometries are required. At the same time, micromilling also demonstrates a suitable process to remove material and produce microdevices (microparts). However, there are restrictions about materials selection and size of the parts, particularly when cutting steel microstructures. The limitations are related to micro endmill size (stiffness), roughness and geometric precision of the part. Another problem in micromilling is the burr formation during cutting, caused by material deformation towards the tool before minimum cutting thickness is not reached. The objective of this research is to evaluate the burr formation in micromilling of ultrafine-grained materials, considering the edge radius effect of the micro endmills. Aluminium, low carbon steel and stainless steel with a homogeneous microstructure and ultrafine grains were used to meet the machining condition scale in the burr formation and material/tool interaction. Analysis of the slots was carried out by means of a laser 3D microscope. A 0.75 mm diameter cemented carbide ball-nose mill was used. The cutting edge radii of the cutting tools were evaluated and presented an average value of 2.24 µm. A 50 m/min cutting speed, 50 and 80 µm depth of cut, and 390 and 580 µm width of cut were applied to all materials. The feeds per tooth adopted around the edge radius value ranged from 0.6 to 8.0 µm. S_z roughness variation was more sensitive for the stainless steel, and dependent on the depth of cut. The variation was caused by damage on the machined surface at all feed per tooth conditions. On the other hand, better behaviour was achieved during the cutting of aluminium and low carbon steel. The machined surface showed minor cratering with the larger volume of material removed (80 µm depth of cut). Burrs increased in the aluminium when feed per tooth was larger than edge radius, while minor burrs were found in the low carbon steel at all conditions. The results showed that a micropart quality with the micromilling process, considering a workpiece with homogenous microstructure and ultrafine grains, had good agreement when aluminium and low carbon steel were applied, indicating that material hardness also affects the microcutting process.

Burrs. Edge radius. Micromilling. Ultrafine-grained materials.

1. Introduction

For over 25 years, micromachining has been applied for the fabrication of microfluidic systems using various materials types, and microchannels are an essential part of these microdevices [1]. MEMS devices (electromechanical systems) have required the development of structures with increased thickness, often with high aspect ratios [2]. These structures have resulted in the production of new components for a variety of applications including micromixers, microelectrophoresis chips, micropumps and lab-on-chip devices for microfluidic systems [3]. At the macroscale, the machining process is very versatile and able to generate features and three-dimensional structures. The adoption of this process at a micro scale can lead to rapid and direct manufacture of micromolds and masks to aid the development of microcomponents [4]. The burrs are a problem when microcutting with tools of defined geometry. To resolve this problem, ultrafine grained materials could be a good solution [5]. This work aims at investigating burr formation during micromilling of ultrafine grained metals. 3D intensity images were used for the analysis.

2. Experimental procedure

Micro end-milling tests were carried out on a machining centre. Dry conditions were used. The cutting parameters adopted were speed cutting 50 m/min, depth of cut 50 and 80 µm, width of channels 390 and 580 µm, and feed per tooth varying from 0.6 to 8 µm/tooth (five feeds equally spaced). A carbide ball-nose tool TiN coated with diameter 750 µm, lateral radius 0.4 and edge radius (2.24 ± 0.5) µm was used. The cutting edge radius was measured on an Olympus OLS4000 3D Laser Microscope as well as intensity images of the channels. Three ultrafine grained metals were used during the tests. These were 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. The cutting process was interrupted to allow the evaluation of the burrs caused by micromilling.

3. Results and discussion

To simplify the presentation of results, only three feed per tooth images of burrs and machined surface were considered. They are minimum, middle and maximum feed per tooth values applied to the tests.

Figure 1 and Figure 2 shows the micromilled channels with 50 and 80 µm depth of cut, respectively. Each column represents the materials with ultrafine grains and each line the feed per tooth. Low carbon steel showed less burrs than other materials on each depth of cut and all feeds per tooth. Aluminium had an increased burr formation when larger depths of cut and feeds per tooth were used, but less than when an edge radius was applied. Stainless steel showed irregularities on the channels in the side of up milling to feed per tooth less than the edge radius and with an increased depth of cut.

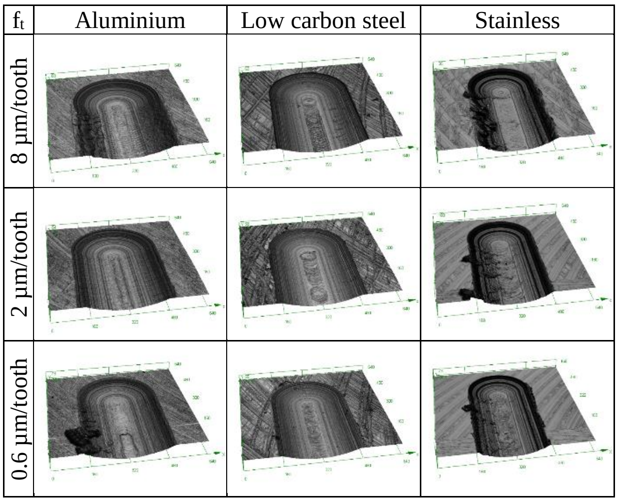

Figure 1. Micromilled channels with 50 µm depth of cut.

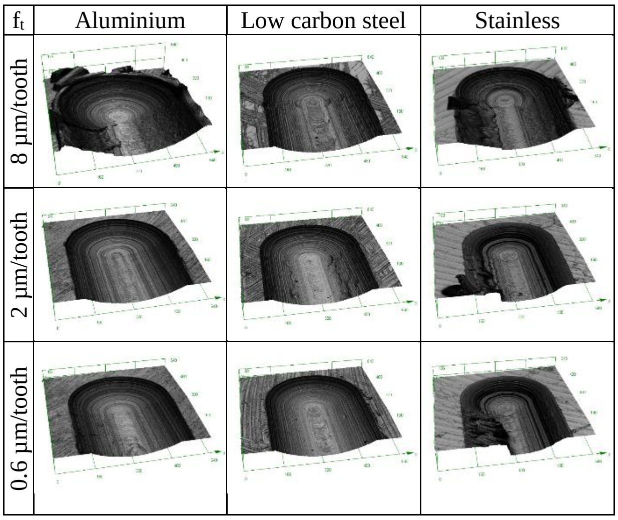

Figure 2. Micromilled channels with 80 µm depth of cut.

Figure 3 and Figure 4 shows the micromilled channel surfaces with a 50 and 80 µm depth of cut, respectively. A qualitative analysis reveals a better finish with feed per tooth around or less than edge radius. Furthermore, an increase in depth of cut showed good agreement with low carbon steel and aluminium finishing. Stainless steel showed cratering and the other materials to a feed per tooth less than edge radius.

A reduction of burr formation can be made by reducing the grain size, but when different materials were considered, a distinct behaviour of burrs under different cutting conditions was seen. The increase of material removal volume affected only aluminium under lower feeds per tooth, revealing a compression of the material towards the tool, caused by negative rank angle (edge radius effect). This resulted in more deformation than cutting of the material. Low carbon steel showed good agreement with the cutting conditions as indicated in previous literature [5].

When using stainless steel, an up milling side of the channel, a large material deformation was observed, while in down milling, the surface showed a good result of feed marks with less damage. Apparently, when the tool penetrates the workpiece material, until the minimum cutting thickness is reached, the deformation prevails and the surface formation is badly affected. The workpiece material properties such as hardness could be responsible for this difference among the materials during cutting, and more investigations will be necessary.

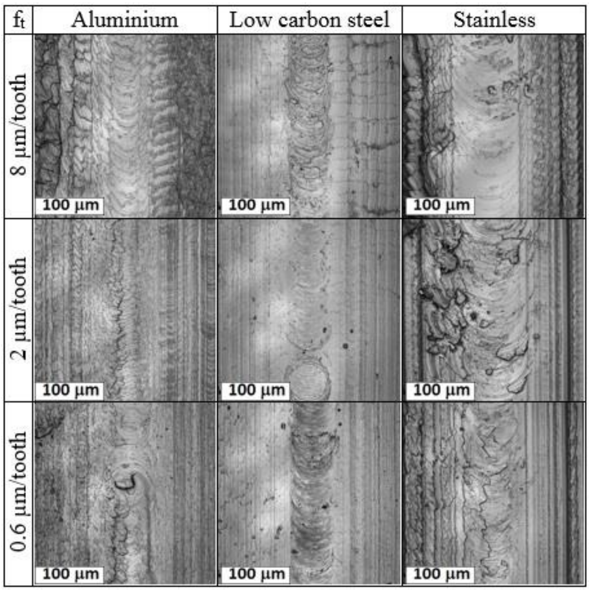

Figure 3. Micromilled channels surface with 50 µm depth of cut.

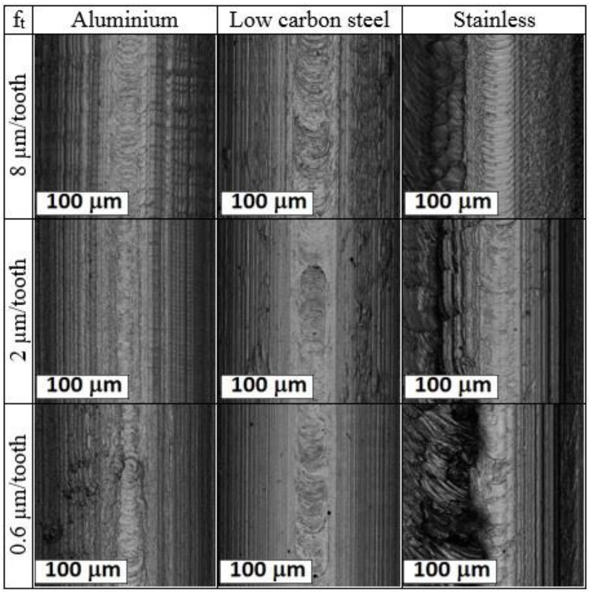

Figure 4. Micromilled channels surface with 80 µm depth of cut.

4. Conclusions

The present investigation showed that the mechanism of materials removal could be affected by workpiece alloy used and their hardness. The use of ultrafine grained materials represented an improvement to reduce burr formation. However, when different alloys were evaluated, low carbon steel showed better behaviour during cutting. Further work will be carried out in order to investigate this phenomenon.

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