WORKPIECE MICROSTRUCTURE AND MICROMILLING PARAMETERS AFFECT THE MICROCHANNELS FEATURES

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ABSTRACT

Machining parameters should be properly specified not only regarding the tool edge radius, but also considering the piece grain size. This paper demonstrates that microchannels quality is affected by cutting parameters even when milling ultrafine-grained workpieces. Aluminum, low-carbon steel and stainless steel (grain size < 1 µm) were micromilled with ball-nose endmill of 0.75 mm diameter and 2.24 ± 0.5 µm edge radius at 50 m/min cutting speed, 50 and 80 µm depth of cut, and feeds per tooth from 0.25 to 3.5 times the tool edge radius (r_e). Laser 3D microscopy qualified the channels burr formation, bottom deformation and geometrical deviations. The greater the depth of cut is, the higher the aluminum 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. Therefore, the suitable adjustment between machining parameters and workpiece microstructure is crucial to ensure micromilled channels quality and accuracy.

Key-words: microchannels quality, homogeneous microstructure, milling parameters, burr formation, geometrical deviations.

INTRODUCTION

Microparts have been a good improvement to chemical microreactions, medical microanalisys and heat microsinks. By this way, 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)]. The increases in the contact area of roughened surfaces lead on capillary condensation, but the adhesion forces are minimized when decreasing the contact area[(3)]. Thereby, the surface feature depends on the applications and specific needs of microfluidic devices[(4)].

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[(5)]. During microcutting the tool cross the microstructure cutting a grain of a hardness phase and next a soft phase grain, producing a variation of microchannels roughness[(6)]. This non homogenous roughness provide a surface where the microfluid flow suffer behavior changes that can interfere on expected results[(7)].

With respect to microchannels fabrication, 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[(8)]. By micromilling process is possible to fabricate new designs of microfluidic devices, applied mainly on pharmaceutical industry to produce medicines and genetic studies[(9)]. Microdevices with higher aspect ratio also can be fabricate by this machining process, ensuring a better control of volumes during chemical microreactions[(10)].

The main milling process advantages 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 geometry when fabricated by micromilling process, considering ultrafine-grained metals as workpiece material and machining parameters.

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).

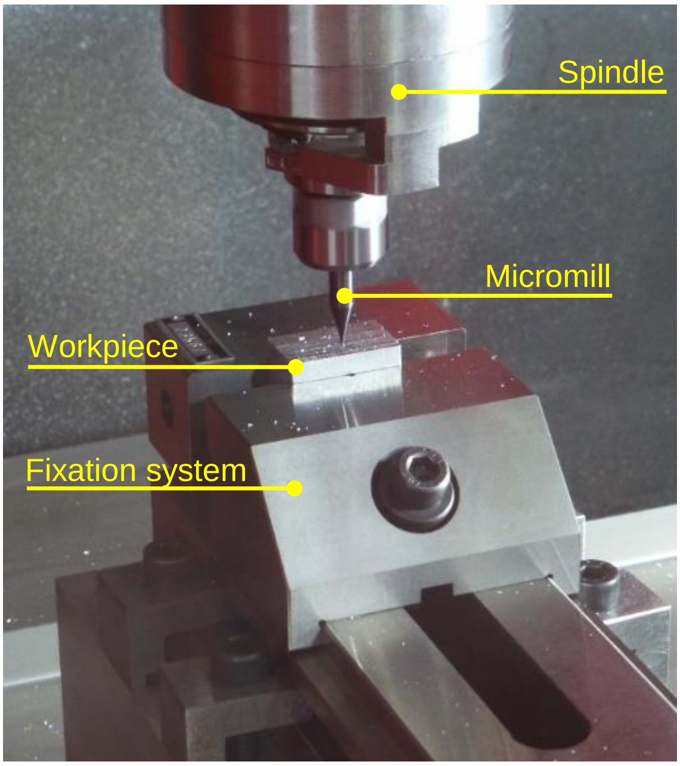

Figure 1. Experimental setup for micromilling of channels in ultrafine-grained workpieces.

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. Figure 2 presents an image of tool edge radius and the technique to measure edge radius. Eight measurements were made and a mean was calculated, considering the standard deviation as well.

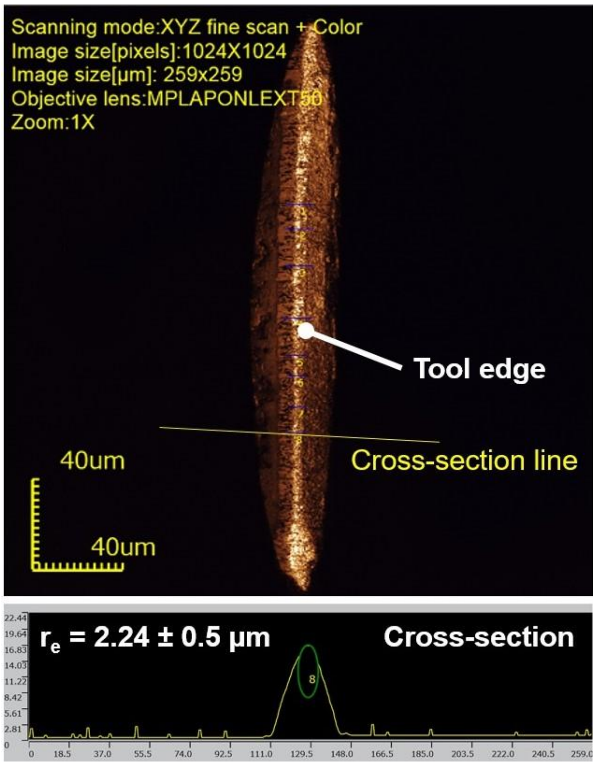

Figure 2. Edge radius measurement by 3D laser microscopy.

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.

All the microchannels section areas to evaluated geometrical deviations were also measured by using 3D laser microscope aided by image analysis software (Figure 3). 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.

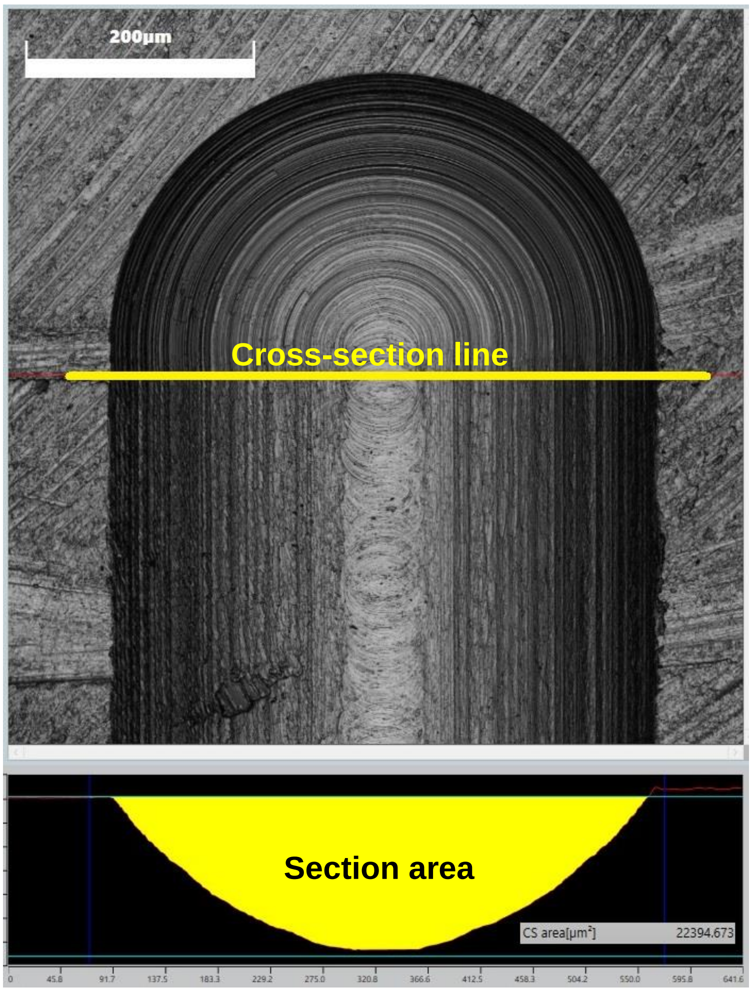

Figure 3. Microchannels section area measurement by 3D laser microscopy.

RESULTS AND DISCUSSION

Figure 4 and Figure 5 shows the micromilled channels with 50 and 80 µm depth of cut, respectively. Each column represents the materials with ultrafine grains and each line shows the ratio between the feed per tooth and the tool edge radius. Only three conditions are showed to simplify the representations. 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.

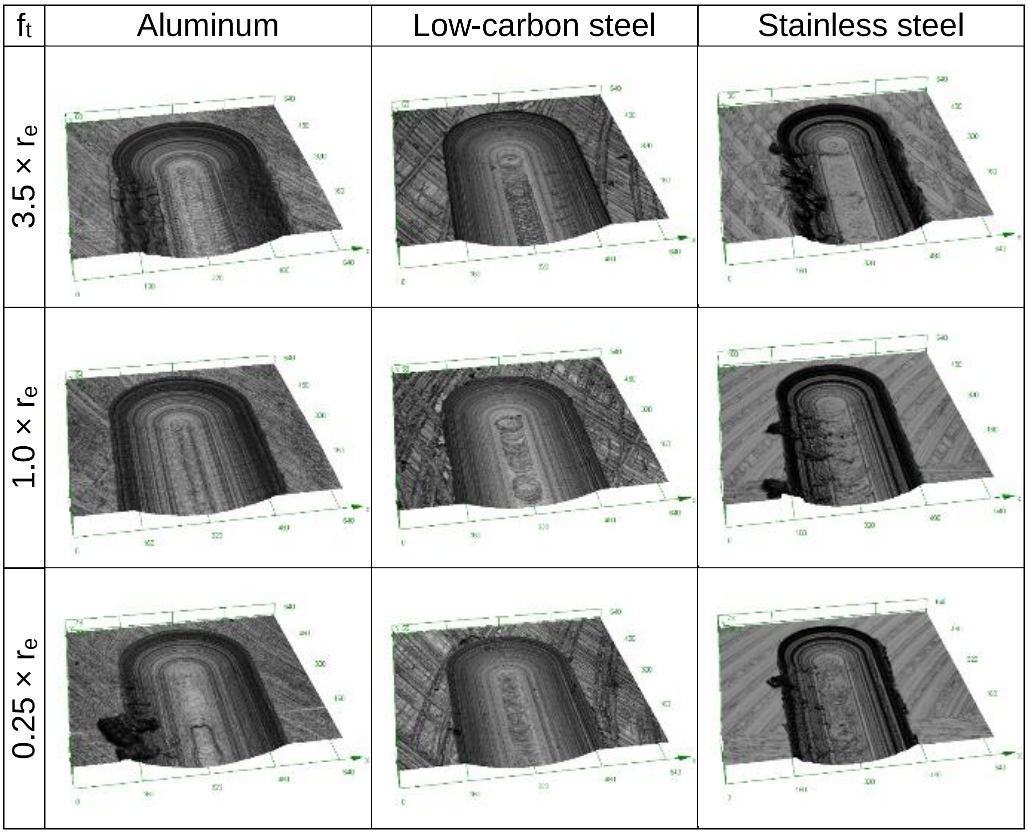

Figure 4. Microchannels with 50 µm depth of cut. Image size [µm]: 642x642.

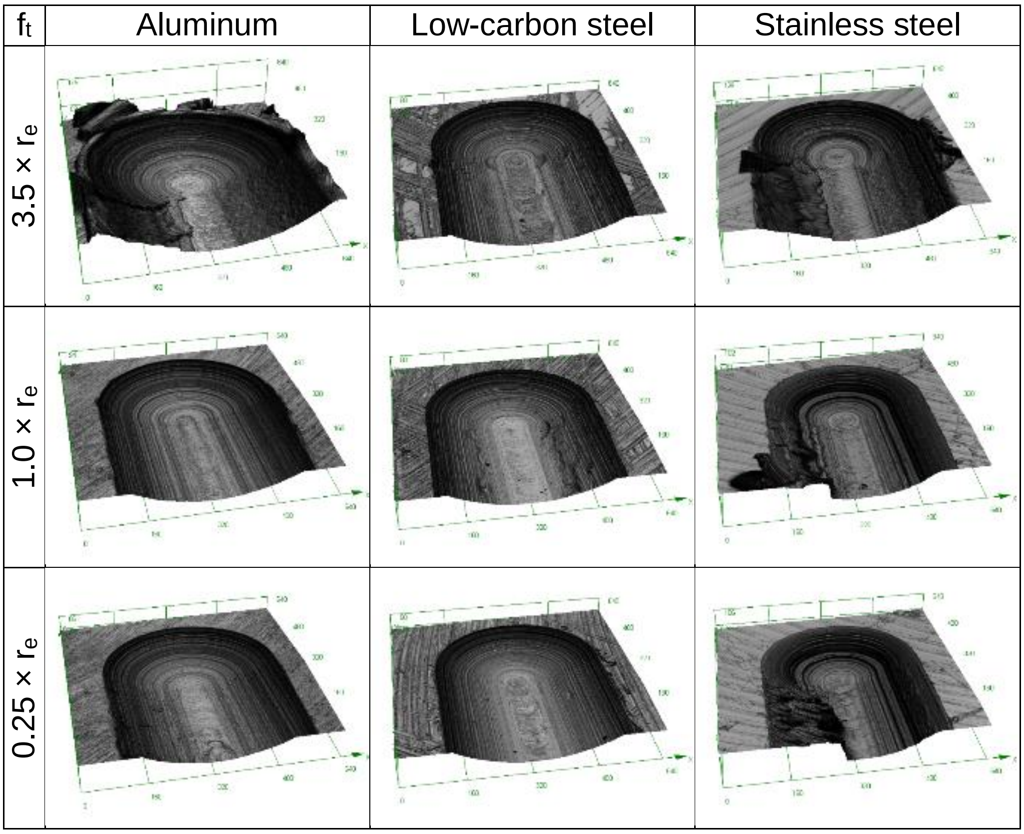

Figure 5. Microchannels with 80 µm depth of cut. Image size [µm]: 642x642.

Figure 6 presents the main effects plot for channel cross-section area to workpiece materials. 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 behavior was observed to stainless steel and aluminum 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[8]. 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.

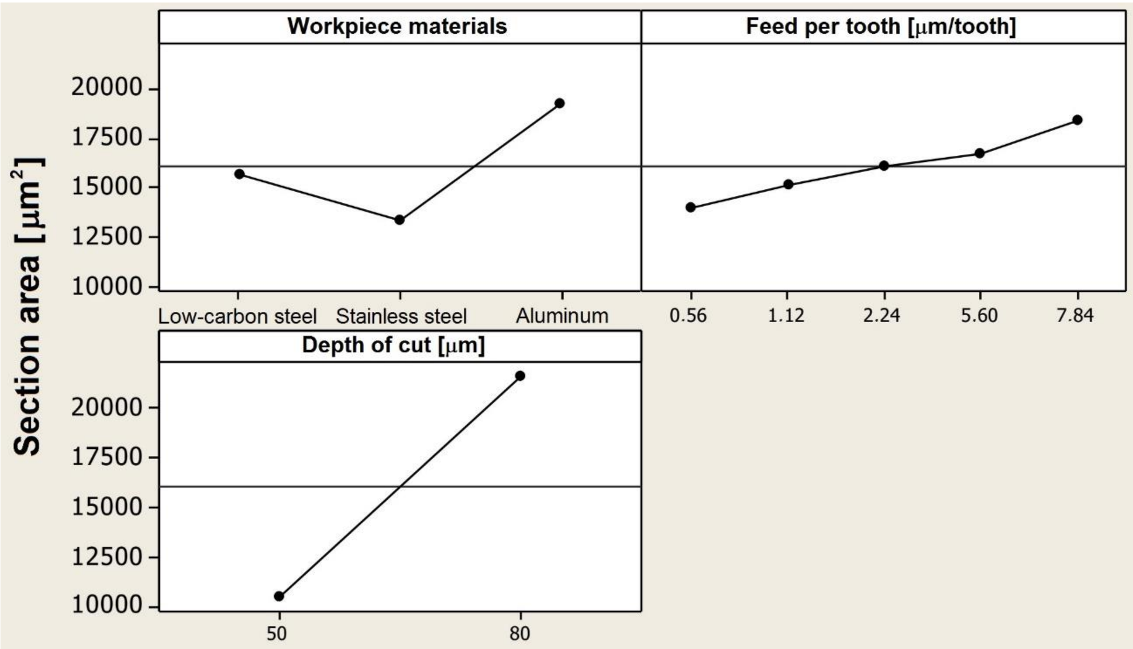

Figure 6. Main effects plot for section area to workpiece materials and micromilling parameters.

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). Aluminum 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 aluminum, with statistical significance $\beta<5\%$. 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 aluminum (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 aluminum. 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.

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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