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Adequacy of roughness parameters to micro-endmilled channels surface evaluation

Cleiton Assis[1], Rayssa Azevedo[1], Rayane Azevedo[1], Reginaldo Coelho[2]

[1]*Federal Intitute of Sao Paulo - Brazil*
[2]*University of Sao Paulo - Brazil*

[1]*fazolocla@ifsp.edu.br*

Abstract

During micromachining, the contact between cutting tool and workpiece material affects the resulted surface integrity and roughness. Their control is important for microfluids flow and micromolds for injection applications. The application of homogeneous microstructure metals could reduce the roughness variation. However, some conventional roughness parameters adopted to evaluate surface finishing, such as R_a, may show no distinction when using different cutting conditions. A more complete analize could be achieved by using different roughness parameters, or a combination of a few. This work aims at evaluate the machined surface in microchannels made by micro-endmilling, considering several roughness parameters, including workpiece metallurgical condition and machining parameters. Three materials were used: aluminium, low-carbon steel and stainless steel. Ball-nose micromills with 800 µm diameter, 400 µm corner radius and ~2.24 µm edge radius to machine the microchannels in one cut. The cutting speed was set to 50 m/min, two depth of cut values (50 and 80 µm) and five feed per tooth (between 0.56 and 7.84 µm/tooth) were applied. The roughness was assessed by using a 3D Laser Microscope and Analisys of Variance (ANOVA). The results indicated that, when combinated, the parameters R_z, R_p, R_v, R_{sm}, $R_{\Delta q}$, R_{sk} and R_{ku} revealed some particular features formed during microcutting related with the workpiece material behaviour. Aluminium and low-carbon steel presented uniform surface finishing on both sides of the slots, which were up and down milling. In contrast, stainless steel showed uniform roughness only on the up milling side for all cutting conditions. The approach herby used for roughness analizes has showed to be a much more adequate evaluation for micromilled surfaces when using different workpiece materials and cutting conditions. It was capable to detect details not seen before.

Microchannels Finishing. Roughness Parameters. Homogeneous Microstructure Workpiece. Micro-endmilling.

1. Introduction

Micromachined surfaces are formed by interaction between tool microgeometry and workpiece material [1]. Microfluids flow and micromolds for injection depends of a controled finishing to provide microdevice efficience and quality [2]. In metallic materials, effects as ploughing and cutting edge radius are capable of causing damages to the microstructured surfaces, modifying important features of the workpiece [3]. Roughness are geometric irregularities on the surface, seen in micro or nanometric scale [4]. Machined surface evaluation is usually made using standard roughness parameters. Correlation among roughness parameters can be a good approach to surface analisys. Some applications on tribological surfaces behaviour in microscale have applied such combination with success [5]. Microdevice fabrication need a similar approach to ensure a constant finishing along the micromachined surfaces and a complete characterization of its features. This research aimed at evaluating microchannel surfaces, using several roughness parameters. Further investigations was also madeed to find relations with the surface formation during micromilling.

2. Experimental procedure

Micro-endmilled channels were cutat once using a vertical machining center CNC Kern model D-824118 with maximum of 50k rpm spindle rotation speed and achievable finishing quality <0.1 µm, according to the manufacturer (R_a roughness parameter used as reference). Three ultrafine-grained metals (lesser than 1 µm grain size) were machined: aluminum (177 HV), low-carbon steel (216 HV) and stainless steel (470 HV). The cutting parameters were 50 m/min speed cutting for all cuts, 50 and 80 µm depth of cut, and five feed per tooth variating from 0.56 to 7.84 µm. All cuts used dry conditions. Carbide ball-nose micromills TiN coated with 800 µm diameter, 400 µm corner radius and ~2.24 µm edge radius were used. The depth of the channels were 50 and 80 µm. The cutting edge radius and microchannels roughness were measured by Olympus OLS4000 3D Laser Microscope.

Five 3D images of each channel were made (considering two replicates per cutting condition and workpiece material), and roughness parameters R_z, R_p, R_v, R_{sm}, $R_{\Delta q}$, R_{sk} and R_{ku} were measured in three sections of the machined surface as shown in Figure 1. Cutting parameters and material effects on finishing were evaluated by using Analisys of Variance (ANOVA) and statistical significance with β=5%.

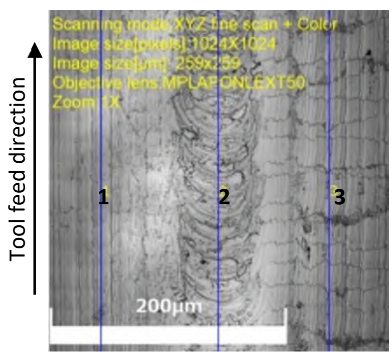

Figure 1. View from the top of the channel. Roughness measured in (1) up milling side, (2) center and (3) down milling side of microchannels surface.

3. Results and discussion

As presented in a previous study [6], the effect of cutting parameters upon material deformation at the bottom of the channel revealed different features observed during micro-endmilling of ultrafine-grained metals. Stainless steel showed material deformation in up milling side. Alumium and low-carbon steel showed the conventional relation with cutting parameters producing better surface finishing. Roughness analisys, in Figure 2 presents graphs of roughness parameters for 50 µm depth of cut, which is very similar to those using 80 µm. In all graphs feed per tooth is shown as a proportion of edge radius (r_e).

Looking at Figure 2 and also supported by ANOVA results it is possible to infer that R_p, R_v and R_z are affected by the point in the section where they are measured, workpiece material (β≈0%) and depth of cut (β≈0%). The variation of R_z shows changes of cutting mechanisms between up and down milling sides. Larger R_p in up milling side indicate the presence of high peaks, what is confirmed by R_{sk}. However, R_{ku} shows that the increase of feed per tooth tends to form sharp peaks to aluminum and low-carbon steel (R_{ku}<3), while indented peaks are formed to stainless steel (R_{ku}>3) in all cutting conditions.

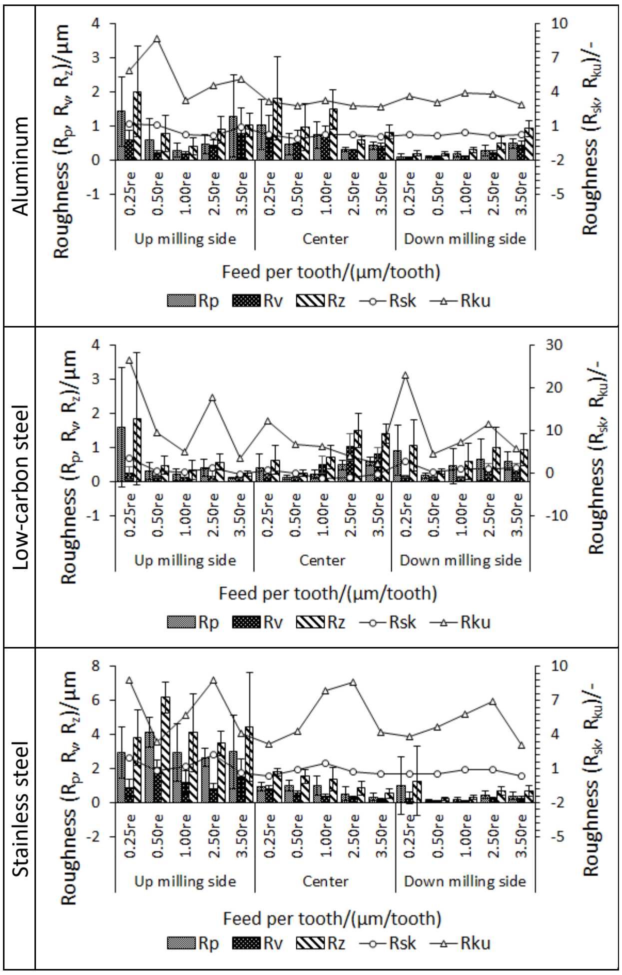

Figure 2. R_p, R_v, R_z, R_{sk} and R_{ku} parameters graphs to 50 µm depth of cut.

Figure 3 presents R_{sm} for 50 µm depth of cut. ANOVA identified effect of measurements section, workpiece material (β=2,3%) and depth of cut (β≈0%) on the roughness parameter. Error bars decrease with large feed per tooth, what reveals uniform waves along the machined surface. Stainless steel shows larger wave-length. However, this feature is associated to material deformation towards the tool during machining, and it is not related to feed marks.

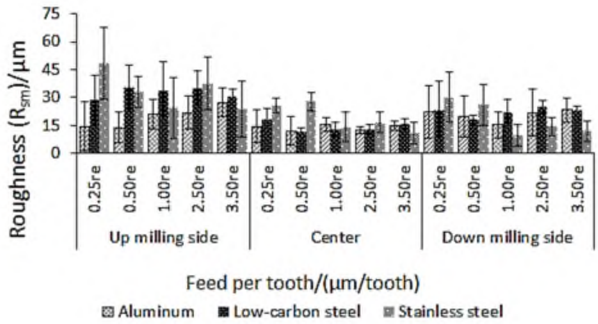

Figure 3. R_{sm} parameter graph to 50 µm depth of cut.

Figure 4 presents $R_{\Delta q}$ for 50 µm depth of cut. ANOVA identified effect of measurements section, workpiece material (β≈0%) and depth of cut (β≈0%) on the roughness parameter. Low-carbon steel shows less $R_{\Delta q}$ variation when compared to other workpiece materials. This effect is associated to less burr formation and machined surface uniformity in both sides of the channels [6].

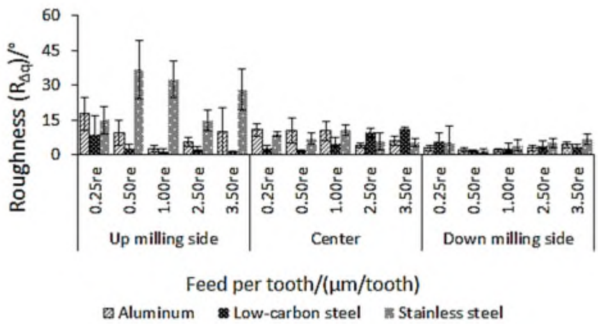

Figure 4. $R_{\Delta q}$ parameter graph to 50 µm depth of cut.

4. Conclusions

Deep analysis of Micromilled using several roughness parameters contributed to a more comprehensive understanding of the effects and relation between different workpiece and cutting conditions. Parameters, such as, R_p, R_v, R_z, R_{sk} and R_{ku} were a good approach to evaluate geometrical features in micromilled surfaces, while R_{sm} and $R_{\Delta q}$ identified features such as feed marks or material deformation during micromachining. Future works will concentrate on a statistical analisys and the possibilities of further improvements on the relations found so far.

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