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Influence of tool neck length on tool deflections during micromilling of an ultrafine grained low-carbon steel

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Abstract

The technological development enabled the miniaturization of devices applied in medicine, chemical, mechanical and electrical fields. In this scenario, micromilling appears as an alternative for the device reduction with complex geometry. The very small tools diameters used in micromilling are subject to deflection mechanisms due to machining forces during cutting. When micromills need to reach deep pockets, it is necessary apply tools with longer neck length and the effects of tool deflections can be increased under this machining condition. This work aims to evaluate the influence of neck length during micro-endmilling of a low-carbon steel presenting a dual phase microstructure (ferrite and perlite) and a modified version with grain refinement (ultrafine ferrite). Microchannels were cut at once using a vertical CNC machining center. Machining tests were made applying ball-nose micromills with 400, 600 and 800 µm diameter with 200, 800 and 600 µm neck length, respectively. Cutting parameters adopted were 8, 20 and 40 m/min cutting speed, 0.5, 2.0 and 5.0 µm/tooth tool feed and 40, 60 and 90 µm depth of cut. The effect of tool deflections was evaluated using 3D laser microscopy, considering the relation between theoretical depth of cut and real microchannels depth. Results indicated that both workpiece materials showed similar behaviors of tool deflections. Higher tool feed reduced microchannels depth due to tool deflection to 400 µm micromills diameter (30% lesser) and the opposite effect was noticed to 800 µm micromills diameter (0,6%). When machining with 600 µm micromills diameter, tool deflections were relatively stable to all tool feed conditions, with reduction of microchannels depth around 13%. In spite of the finishing homogeneity favored by the microstructure grain refining, reported in the literature, tool deflection should be considered a phenomenon present during microcutting of ultrafine grained workpieces, which may cause geometry deviations in machined microchannels.

Micro-Endmilling. Ball-Nose Micromill. Micromill Deflections. Microstructure Refinement.

1. Introduction

The demand for reduced dimensions components has increased in the most diverse fields, especially in areas such as medical and mechanical, with the requirement of high precision components [1]. Thus micromachining presents itself as a good way to this miniaturization.

The adaptation of the conventional processes of material removal to micrometric scales, especially milling processes, is a viable alternative of microdevices production [2]. In spite of several similarities with the conventional milling process, some specific difficulties arise with the reduction of the dimensions involved in the micromilling operations, such as i.e. the micromills deflection [3]. The cutting tool deflection, mainly when using flexible tools such as micromills with long neck length, results in lesser depth of cut than original parameter [4].

In this study, the tool deflections influence in the micromilling operations was performed. Different micromills diameters and feed per tooth were considered during micromilling tests to evaluate the relation between real microchannels depth and depth of cut set in machining center.

2. Experimental procedure

Micromilling operations were performed 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 (R_a roughness parameter used as reference).

A 0.16%C steel with different metallurgical conditions was applied, a dual-phase material (ferrite-perlite) with 11 µm grain size and a homogeneous ultrafine grained material (ferrite) lesser than 1 µm grain size, named DP and UFG, respectively. Instructions for material grain refinement used in micromilling operations can be found in the Brazilian patent registration number PI 1107247-4 granted on October 10, 2018 [5].

The effect of tool deflections were evaluated using a Olympus OLS4000 3D Laser Microscope, considering the relation between microchannels depth and depth of cut set to the micromilling operations. It was measured the deeper of microchannels machined with two-flute carbide ball-nose end micromills MITSUBISHI MS2XLB. Three measurements of each channel were made (considering three replicates per cutting condition and workpiece material). Cutting parameters and tool specifications are presented in Table 1.

Table 1. Cutting parameters and micromills specifications.

Tool diameter [µm]	Neck lengh [µm]	Cutting speed [m/min]	Tool feed [µm/tooth]	Depth of cut [µm]
400	200	8	0.5, 2 and 5	40
600	800	20		60
800	600	40		90

3. Results and discussion

Table 2 presents the depth of machined microchannels with diferente micromills diameters and tool feed conditions, considering the workpieces materials applied to the tests. The means statistical deviations were calculated for a confidence interval of 95%. When are analised microchannels produced by microcutting with micromills of 400 and 600 µm diameter and 0.5 µm/tooth, the effect of tool deflection is more sensitive during machining of ultrafine grained material (UFG). This could be explained due to increase of yield strength after grain refinement, 510 MPa against 474 MPa of dual phase material (DP). However, higher tool feed equalize the effect of mechanical properties of the materials.

The increase of removed material volume caused reduction of microchannels depth at 2 and 5 µm/tooth during machining with 400 µm tool diameter in both materials. Small tool diameters tend to cause dimension error due to micromilling forces. Although no data on forces were obtained in this work, this affirmation is supported by the literature [3, 6].

Table 2. Depth of microchannels measured by laser microscopy.

Tool diameter [µm]	Tool feed [µm/tooth]	Depth of microchannels [µm]	
		DP	UFG
400	**0.5**	36.85 ± 0.6	34.42 ± 0.3
	2.0	31.36 ± 0.5	30.78 ± 0.3
	5.0	27.85 ± 0.6	28.70 ± 0.3
600	**0.5**	54.13 ± 0.1	52.90 ± 0.1
	2.0	51.20 ± 0.1	51.96 ± 0.1
	5.0	52.44 ± 0.2	52.23 ± 0.2
800	**0.5**	75.07 ± 0.1	74.91 ± 0.6
	2.0	87.09 ± 0.1	87.15 ± 0.1
	5.0	89.46 ± 0.3	89.13 ± 1.0

Figure 1 presents the percentage of microchannels depth reduction when compared to the value set in the machining center. As seen previously, rigidity of micromills is favoured by larger tool diameter and during microcromilling at 2 and 5 µm/tooth. Applying 800 µm tool diameter, only lower tool feed affects the microchannels depth with reduction of 17% for both workpiece materials. Small micromills showed a difference of microchannels depth of ~10% and ~30% at 0.5 and 5 µm/tooth, respectively. Homogenous behaviour was showed by 600 µm tool diameter with reduction of ~13% after tool deflection effect.

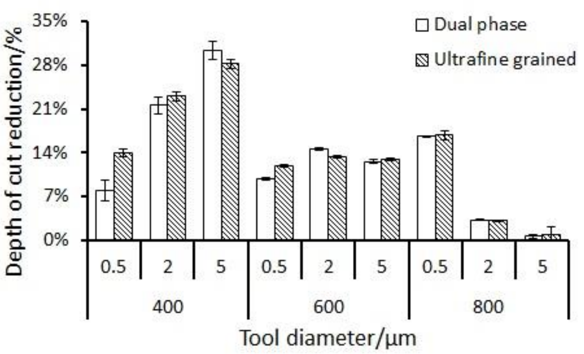

Figure 1. Depth of cut reduction presented as percentage. Tool feed is presented as µm/tooth (0.5, 2 and 5) in a relation with each tool diameter.

Figure 2 presents machined microchannels laser images at 0.5, 2 and 5 µm/tooth, and 600 µm tool diameter. Images revel some deviations of toolpath along the microchannels, in special during micromilling of ultrafine grained material. Comparing the micromills diameters applied to the tests, the larger neck lengh (800 µm) is related to this micromill (Table 1). That feature caused instability during cutting, with intense tool deformation. Dual phase material showed better results, without apparent deviations along machined microchannels.

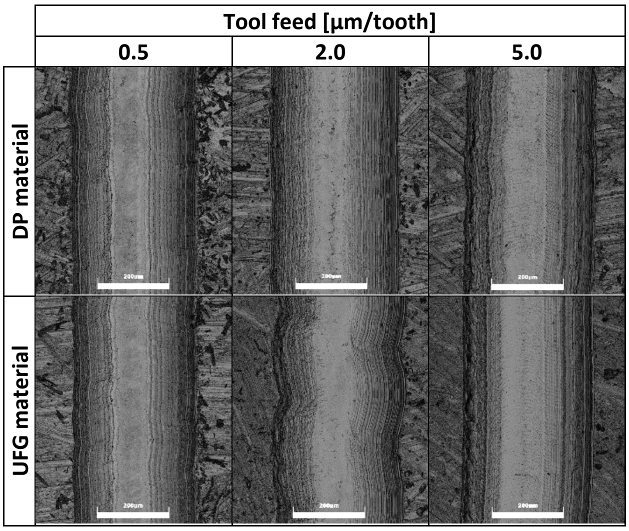

Figure 2. Machined microchannels images of DP and UFG materials with 600 µm tool diameter (scale is 200 µm).

4. Conclusions

Results indicated some effect of tool deflection during micromilling of workpieces with different microstructure morphology. Small micromills were sensitive to the tool feed while larger micromills under higher tool feed showed lesser tool deformation. Neck length affected geometry deviations and it is necessary consider this feature to selection of micromills. Tool deflection is sensitive to mechanical properties of workpieces materials, mainly under lower tool feed conditons and small micromills. The future of this work is research some relation between tool defletion and workpiece metallurgical condiction on roughness along the machined surface of microchannels.

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