Cutting Parameters Impacting on Tool Wear in Micro End-milling of Tool Steel H13

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Abstract

In micro milling process, the quick wear and premature breakage of tools configure a problem that affects not only the process costs but also the manufacturing quality. This work investigates the influence of the cutting parameters on tool wear and surface roughness in a dry machining of a tool steel H13 workpiece (X40CrMoV5-1). Spindle speed was kept constant (27200 rpm) and two feeds per tooth were applied (1.5 and 3.0 µm) as depth of cut (25 and 30 µm), and variating cut length as well. The wear of the tool top area, tool diameter and nose radius were monitored during micro milling tests. Roughness was evaluated by using a Laser Confocal Microscope. The lower level of feed per tooth and depth of cut showed lower roughness, but a higher tool wear. A balance between cutting parameters and cutting length must be considered to ensure micromachining without severe tool wear and preserve microchannel features along its machined surface.

Keywords: Micro milling, cutting parameters, tool wear, roughness.

1. Introduction

Microcomponents are required for various industrial applications including electronics, optics, aerospace, medical, biotechnology, among others. The ability of micromachining, particularly micro milling, to work with a variety of materials and complex geometries makes this process one of the best in microscale production [1]. Micro milling is characterized by the use of tools with a diameter smaller than 1 mm. Micro milling differs in many aspects from conventional milling due to the presence of minimum chip thickness, size effect, elastic recovery and ploughing mechanism. And, due to very small diameter, the microtools are very fragile and can be easily broken due to excessive deflections, forces and vibrations [1]. Although the number of studies focused on micro milling tool wear is still limited, it is important to understand the interactions among wear, machining forces, tool deflections and roughness to maintain component quality requirements [2].

This work evaluates the influence of the parameters feed per tooth (f_z) and depth of cut (a_p) on the wear of micro tools with a diameter of 400 µm and on machined channels roughness in a tool steel workpiece H13 (X40CrMoV5-1).

2. Experimental Setup

Micro channels were machined using micro milling process performed by a KERN Evo® ultra precision center under dry condition. The cutting parameters evaluated were feed per tooth and depth of cut. The spindle speed was kept constant. Experiments were repeated three times for each tool. Table 1 shows the cutting parameters applied.

Cutting parameters	Tool A	Tool B
Spindle speed [rpm]	27200	27200
Feed per tooth [µm]	3.0	1.5
Depth of cut [µm]	30	25
Cutting length [mm]	316	316

Table 1. Cutting parameters applied to micro milling experiments.

The micromills used has two flutes and diameter of 400 µm, coated TiAlN, model AFH50526-004A TIA70 from ARNO®. A fresh end mill tool was used for each sample. The sample material is tool steel H13 (X40CrMoV5-1) and after the three repetitions the total cutting length performed per tool was 948 mm.

The tools were taken to a Scanning Electron Microscope model SEM JCM-6000 from Jeol® to collect images before the machining. Then the first machining of both samples were performed. The micro tools were cleaned with isopropyl alcohol and taken to the SEM to observe the tool wear after its use. The ImageJ® software was used to image processing. The procedure was repeated after each machining in order to obtain gradual wear with the cutting length.

Roughness was evaluated by using a Laser Confocal Microscope model LEXT OLS4100 from Olympus®. The arithmetical mean high of surface S_a was used. The values of S_a were collected using two strategies: (a) use a large area (437.5µm x 250µm) centralized in the channel and (b) use three smaller areas of 50µm x 437,5µm evaluated in three channel regions (center, down and up milling sides). The wavelength cut-off parameters λ_c and λ_s used were 80µm and 2.5µm, respectively, based on ISO 3274 and ISO 4288 [3][4].

3. Results and Discussion

3.1. Tool Wear Area

Fig. 1 presents SEM images of fresh (a) and worn (b) micromills. It is seen a wear area starting from the flute edge in direction to the micromills center. By this way, the wear evaluation was made based on the area lost in the tool top highlighted in white as shown in Fig.1-c and Fig.1-d.

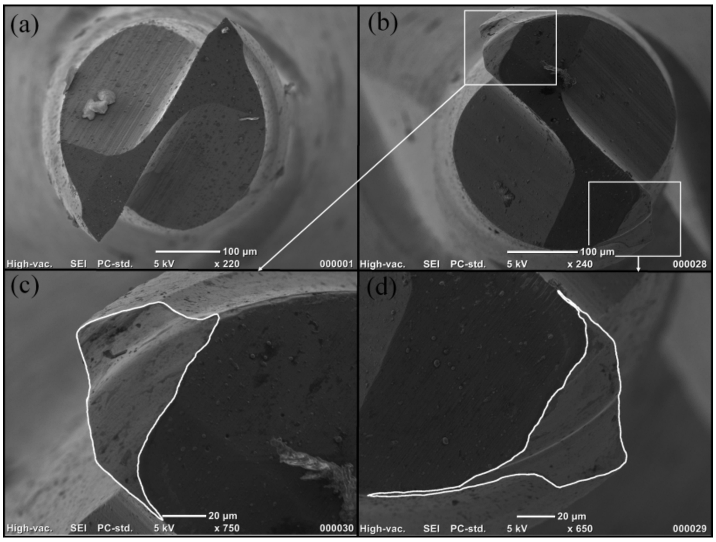

Fig. 1: (a) Fresh tool, (b) Worn tool, (c) and (d) Tool B wear area after machining 948 mm.

Table 2 presents the wear area in the micromills top after each machining for both flutes. During the increase of the cutting length a severe wear is observed to both tools. Under lower feed per tooth the Toll B wear was larger than Toll A.

	Tool area wear and standard deviation s (µm²)					
Length	**316 mm**		**632 mm**		**948 mm**	
	wear	s	**wear**	s	**wear**	s
Tool A	364	12	1268	8	1868	11
	478	12	1370	6	2645	12
Tool B	917	4	2656	7	3101	7
	542	7	1680	7	3009	7

Table 2: Evolution of wear area by cutting length.

3.2. Nose Radius Wear

Figure 2 shows the nose rounding after machining of all tests. The results indicate that nose radius increases, reducing the effective tool diameter [2]. Tool B also presented a deformation on its edge, this deformation was reflected in channel geometry, that presented rounded corners. The relative tool diameter reduction calculated was 23% for tool A and 33% for tool B using Equation 1 [2]. Fig. 3 presents the tool diameter evolution.

$$\frac{D_{up}-D_{worn}}{D_{up}}\times 100 \qquad [1]$$

The main mechanism detected on nose radius wear was friction. Friction wear can be defined as the cyclical adhesion of workpiece/chip material resulting in a removal of particles from the tool. [5]. The wear was more pronounced at lower feed rate and depth of cut in Tool B, which resulted in a more accelerated decrease in tool effective diameter.

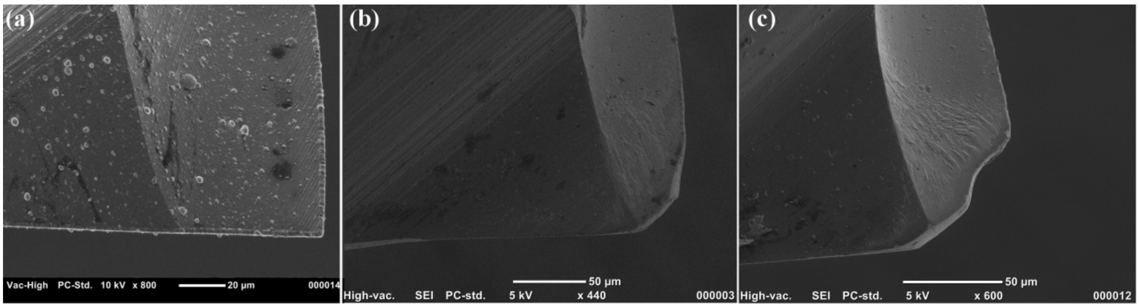

Figure 2: Tool nose wear: (a) example of a fresh tool, (b) tool A nose wear and (c) tool B nose wear.

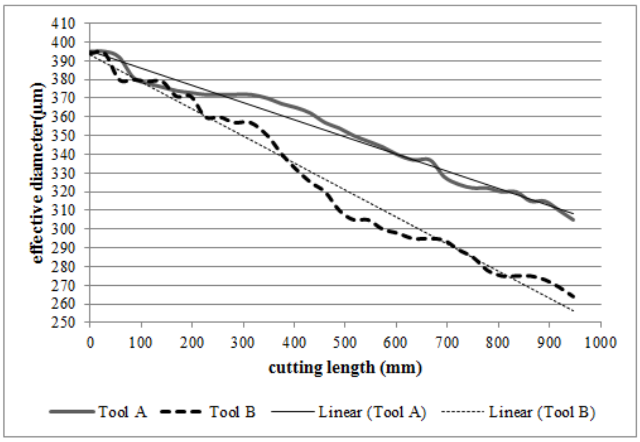

Figure 3: Effective tool diameter evolution.

The linear function adjusted to Tool A is presented by Equation 2 and for Tool B by Equation 3. Both functions have coefficient of determination R^2 above 0.97.

$$y=-0.0915x+395.21 \qquad [2]$$

$$y=-0.1446x+393.04 \qquad [3]$$

3.3. Roughness analysis

Table 3 shows the roughness S_a measured by laser confocal microscope. The roughness increased with increase of cutting length. In both samples the central region of the channel presented lower roughness when compared to the regions near the channel walls in up and down milling. Lower surface roughness were achieved for the smaller feed per tooth, presenting the same effect as conventional milling.

Mean S_a and standard deviation s (µm)												
	Sample A						Sample B					
Region/ cutting length (mm)	**316**	**s**	**632**	**s**	**948**	**s**	**316**	**s**	**632**	**s**	**948**	**s**
Center	0.172	0.076	0.333	0.053	0.293	0.128	0.177	0.057	0.244	0.026	0.258	0.057
Down milling	0.313	0.054	0.395	0.074	0.319	0.131	0.196	0.088	0.309	0.138	0.204	0.074
Up milling	0.234	0.147	0.219	0.033	0.390	0.035	0.216	0.059	0.290	0.048	0.303	0.052
Large area	0.506	0.256	0.739	0.286	0.777	0.205	0.485	0.132	0.703	0.080	0.604	0.129

Table 3: Mean surface roughness $\boldsymbol{S_a}$.

4. Conclusions

This paper presents a study on the influence of cutting parameters on tool wear in micro milling of tool steel H13. The conclusions follow:

- A smaller feed per tooth provides a lower roughness but increase tool wear;
- The difference in levels of depth of cut in this experiment was too low to allow make statements about its effect. However previous studies have confirmed that an increase in depth of cut increases the tool life by avoiding the occurrence of a chip clogging [6]. Future experiments will be developed to evaluate the effect of this parameter on tool wear;
- The nose radius increases by friction until tool geometry is deformed impacting on surface quality;
- A study combining different techniques such effective diameter monitoring, nose radius rounding, flank wear and the proposed approach of tool wear area can provide a complete scenario of tool condition. The next step of the research is to evaluate the effect of other cutting parameters as cutting speed to a complete compilation with statistical analysis.

5. Acknowledgments

The authors acknowledge the Coordination for the Improvement of Higher Education Personnel (Capes) for the support through the BRAGECRIM Project #028/14 Micro-O- Micro milling process optimization.
We would like to thank the team from IPT: Renato, Bruno and Jayson and the technicians from UFABC: Pedro, Eduardo, Daniel and Henriques and also professor Dr. Renato Antunes, professor Dr. Christian Baldo and MSc Leandro Antoli for the support with the experiments.

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