euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Ball-nose micro end-milling of ultrafine-grained steels

Cleiton Lazaro Fazolo de Assis[1], Alessandro Roger Rodrigues[2]

[1]*Federal Institute of Sao Paulo, Campus Votuporanga – Brazil*
[2]*University of Sao Paulo - Brazil*

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

Abstract
In micromilling the most studies considers flat micro end-mill and workpiece "as-received" grain size to analyse surface quality, burr and chip formation, size effect, cutting force and so on. Investigations concerning part finer grains and ball-nose micro end-mill are scarce in literature due to the chip-tool interaction complexity. Thus, this paper determines the relationship between piece grain size and ball-end micromill with long neck length on part roughness and geometrical deviation. Micro channels were machined in low-carbon steels with 0.7 µm (ferrite) and 11 µm (pearlite-ferrite) grain sizes by using 400, 600 and 800 µm tool diameters; 15, 20 and 30 krpm spindle rotation; 20, 40, and 60 µm depth of cut, and 0.5, 2 and 5 µm/tooth tool feed. Analysis of Variance (ANOVA) showed the effect of main parameters (workpiece material, milling type and tool feed) on finishing. The results indicated rougher machined surface for up-milling in both materials and ultrafine-grained workpiece machined with smaller tools' diameter. Parameter R_z was more sensitive to changes on microcutting with ball-end mills and R_{sm} to ultrafine-grained workpiece with larger tools' diameter. Geometrical deviations was notice during machining with 600 µm tool diameter. The application of a homogeneous microstructure showed better performance to some machining conditions and smaller tools' diameter.

Micromilling. Ball-end mill. Workpiece grain size. Finishing. Geometrical deviations.

1. Introduction

Micromilling cutting tools have a significant influence on the quality of parts [1]. Geometry of the microchannels, machined surface and burrs formation are heavily affected by tools geometry and cutting parameters [2]. Using ball-end milling, a minimum surface roughness depends on cutting parameters feed per tooth (f_t) and width of cut (a_e) when milling steels [3]. Then, investigations regarding feed per tooth and surface roughness are relevant as for maximum and minimum feed acceleration to machine free-forms surfaces in conventional milling and more significant during micromilling due to effects of workpiece microstructure and cutting parameters [4].

The effect of the workpiece microstructure has been studied by several researchers [5-7]. The results of those studies showed that the ultrafine grain material presents improved machinability at conventional and microscale cutting conditions using flat-end mills overcoming conventional problems due to the differences between parameters and microstructure scale. Regarding ball-end milling at microscale, the compreehension of the workpiece-tool interaction during milling of homogeneous microstructure can be considered a scientific and technological gap needed to be investigated and improved.

In this study, ball-end mills performed microchannels in dual phase and ultrafine-grained steels. Different cutting conditions were considered in micro-endmilling operations to evaluate the interation of tool diameter, mill feed and workpiece material upon geometrical deviations and roughness R_z, R_a, R_{sm} and $R_{\Delta q}$.

2. Experimental procedure

Micro-endmilling operations were carry out using a vertical CNC machining center Kern model D-824118 (maximum rotational speed of 50 000 rpm) with dry cutting condition. Each machining test was performed four times. Carbide ball-end mills of 400, 600 and 800 µm diameters produced microgrooves in a 0.16 %C steel orinally received with a microstructure dual phase (ferrite-perlite) and grain size of 11 µm, and a version processed thermo-mechanically to reach finner grain (ferrite only) of 0.7 µm grain size. Experimental matrix for micromilling tests is summarized in Table 1.

Table 1. Cutting conditions to the micro-endmilling operations.

Group	Parameter	Ball-end mill diameter		
		400	**600**	**800**
Micromilling process	Spindle rotation/rpm	15 000	20 000	30 000
	Feed/µm/tooth	0.5; 2 and 5		
	Length of cut/mm	2.5		
	Depth of cut/µm	35	50	80
	Width of cut/µm	175	300	420
Cutting tool	Edge radius/µm	1.5		
	Neck length/mm	2	8	6

Workpieces were machined as a sandwich with dual phase (DPh) and ultrafine-grained (UFG) materials. This setup was applied to be sure that the same cutting tool perfomed the machining conditions on both materials. Figure 1 shows 3D view of the schematic workpiece. Roughness data and microchannels profile were assessed by using a Olympus 3D Measuring Laser Microscopy OLS4100. Analysis of Variance (ANOVA) by considering 0.05 significance level was employed to determine the contributions of the workpiece materials, milling type (up- and down-milling) and tool feed on roughness parameters R_z, R_a, R_{sm} and $R_{\Delta q}$.

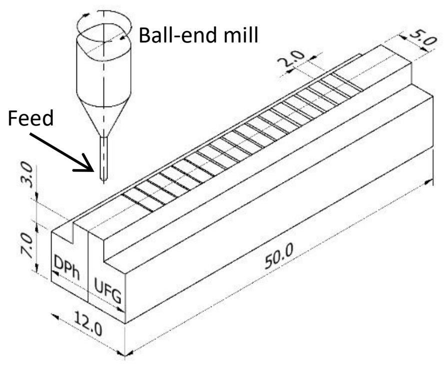

Figure 1. 3D view of the workpiece and ball-end mill (in mm).

3. Results and discussion

Aiming to simplify the terminology, ball-end mill sizes will be indicated as D400 (400 µm), D600 (600 µm) and D800 (800 µm). Figure 2 presents the microgrooves profile analysis made for D600 tool. Regular line is the tool profile and irregular line is the channel one. Analysis indicates a tool deflection upon channels millled with tool feed of 2 and 5 µm/tooth for both materials. For these machining conditions the volume of material removed is increasead, resulting in channels geometry deviation. No geometrical deviations of the profile were observed to other tools' sizes. Due to complexity of the machining forces analysis with ball-end mills, this presented study can be a good indicative for qualifying the feed force behaviour.

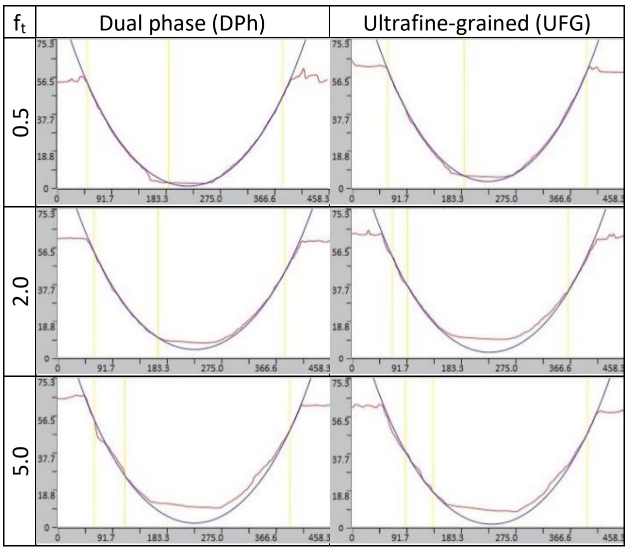

Figure 2. Microchannels' profiles for D600 tool (in µm).

Roughness parameters R_a, R_z, $R_{\Delta q}$ e R_{sm} measured on micromilled surfaces were submitted to Analysis of Variance (Table 2). Ball-end mill diameter was not included as source or control factor due to different levels of cutting speed and depth of cut used to each tool size. Therefore, a statistical analysis was done for each one.

Material microstructure affected parameters R_a, R_z and $R_{\Delta q}$ during milling with D400 tool and parameter R_{sm} with D800 one. Milling type revealed statistical significance on R_a, R_z and $R_{\Delta q}$ for all tool diameters and on R_{sm} only for D600 tool. All roughness parameters were sensitive to tool feed regardless of mill diameter. The effect of microstructure grain refinement showed be more sensitive during micromilling with smaller tool size. In general, the behaviour between up- or down-milling and feed per tooth demonstrated be important during micromilling with ball-end mills.

Table 2. Analysis of variance for roughness parameters.

Source	Parameter	P-Value		
		400	600	800
Material	R_a	0.005	0.804	0.096
	R_z	0.005	0.807	0.176
	$R_{\Delta q}$	0.010	0.767	0.119
	R_{sm}	0.465	0.412	0.011
Milling type	R_a	0.000	0.000	0.000
	R_z	0.000	0.000	0.000
	$R_{\Delta q}$	0.000	0.000	0.000
	R_{sm}	0.381	0.000	0.150
Feed	R_a	0.000	0.030	0.001
	R_z	0.000	0.008	0.000
	$R_{\Delta q}$	0.000	0.012	0.002
	R_{sm}	0.000	0.000	0.000

Finner part microstructure increased the amplitude and slope of the roughness when D400 tool was used. A rougher surface was formed having the parameters R_a, R_z and $R_{\Delta q}$ increased about 38 %, 43 % and 35 %, respectively. Down-milling demonstrates a smoother surface for both part materials. The difference of roughness between up- and down-milling considering the same microgroove is about 35 %, 40 % and 50 % for D400, D600 and D800 tools. Parameter R_a and R_z indicated a smoother surface when the smallest tool diameter was applied. Tool feed close to edge radius value resulted lower roughness for D800 tool. Parameter $R_{\Delta q}$ showed similar values for D600 and D800 tools when machining with 0.5 and 2 µm/tooth feed. Parameter R_{sm} was coincident to feed per tooth value for channels machined with 2 µm/tooth and D400 and D800 tools.

4. Conclusions

This study proposed a micro ball-end milling in materials with different metallurgical conditions. Geometrical deviations and roughness were analysed. Slots geometry are affected by tool size and feed. A good agreement between smaller ball-end mill diameters and cutting parameters (low feed) was noticed for both workpiece materials. Tool deflections is more pronounced for D600 tool and 2 and 5 µm/tooth feed. Parameter R_z was more sensitive than R_a to identify changes on slots' topography. UFG part material machined with D400 tool increased the roughness about 40 % greater than DPh (parameters R_a, R_z and $R_{\Delta q}$). Down-milling produced smother surface for both materials and cutting conditions.

Acknowledgments

To the Technological Research Institute of Sao Paulo (IPT) for technical support and Mitsubishi Materials for providing micromills.

References

[1] Biondani F G and Bissacco G 2019 *CIRP annals* **68** 571-74
[2] Oliaei S N B, Karpat Y, Davim J P and Perveen A 2018 *J. Manuf. Proc.* **36** 496-19
[3] Zhang J, Zhang S, Jiang D, Wang J and Lu S 2020 *Int. J. Adv. Manuf. Technol.* **106** 3975-84
[4] Herraz M, Redonnet J M, Mongeau M and Sbihi M 2020 *Int. J. Adv. Manuf. Technol.* **111** 1425-43
[5] Mian A J, Driver N and Mativenga P T 2010 *Int. J. Adv. Manuf. Technol.* **50** 163-74
[6] Rodrigues A R, Balancin O, Gallego J, Assis C L F, Matsumoto H, Oliveira F B D and Silva Neto O V D 2012 *Mat. Res.* **15** 125-30
[7] De Assis C L, Jasinevicius R G, Rodrigues A R 2015 *Int. J. Adv. Manuf. Technol.* **77** 1155-65