Effect of tool edge radius on the microscale milling of ultrafine-grained steels at high-performance machining

C.L.F. Assis, A.M. Rigatti, R.G. Jasinevicius, A.R. Rodrigues, R.T. Coelho
Escola de Engenharia de São Carlos - Universidade de São Paulo, Brazil

fazolocla@usp.br

Abstract

The effect of tool cutting edge radius (r_e) and feed per tooth (f_t) on roughness and specific cutting energy in end milling of ultrafine-grained steel has been quantified. Stylus profilometer measurements showed that workpiece roughness is minimum when feed per tooth is close to the cutting edge radius, i.e., when $f_t \approx r_e$. Specific cutting energy, obtained by measuring the cutting forces, was higher for smaller feeds and decreased significantly for $f_t > r_e$.

1 Introduction

Miniaturization has become a global phenomenon that affects significantly in many fields, including telecommunications, electronics and biomedical among others [1,2]. Micromachining technologies play a fundamental role in the manufacturing of micromolds for the replication of small components. However, cutting tool/material interaction in the microscale presents some problems related to material deformation which limits the generation of fine, burr-free edges. Since polycrystalline materials present non-uniform response to mechanical work due to anisotropy which may affect surface integrity [3-5]. Based upon this, it would be interesting to suit the microstructure of the workpiece material to the scale of the cutting parameters. In addition, very little has been investigated on how a metallurgically modified material responds to microcutting. This paper presents the effect of tool cutting edge radius and feed per tooth upon surface roughness and specific cutting energy in end milling of ultrafine grain low carbon steel.

2 Experimental procedure

End milling was carried out in a Hermle C800U CNC machining centre. The cutting parameters adopted were cutting speed 700 m/min, depth of cut 500 μm, width of cut

2 mm, and feed per tooth varying from 10 to 100 μm/tooth (ten feeds equally spaced). A carbide endmill tool coated with PVD-TiNAl layer (code R390-11 T308-PL 1030) and 24.404 ± 0.848 μm edge radius was used in machining in a down milling, dry operation. The cutting edge radius was measured on an Olympus OLS4000 3D Laser Microscope. A 0.16%C steel thermo-mechanically processed for grain refinement with 216.0 ± 4.0 HV hardness and 0.7 ± 0.06 μm grain size (ASTM E112-96) was used.

The cutting force was measured by a Kistler 9257BA piezoelectric 3-component dynamometer and a Kistler 5233A signal conditioner. To calculate the specific cutting energy [J/mm^3] the cutting force was integrated numerically by the trapeze method along the cutting time and multiplied by the ratio between cutting speed and removed material volume. The quantitative and visual surface finish was characterized by Taylor Hobson Talysurf 50 2D Profilometer and Zeiss LEO 440 Scanning Electron Microscopy. Figure 1 shows data of the workpiece and cutting tool.

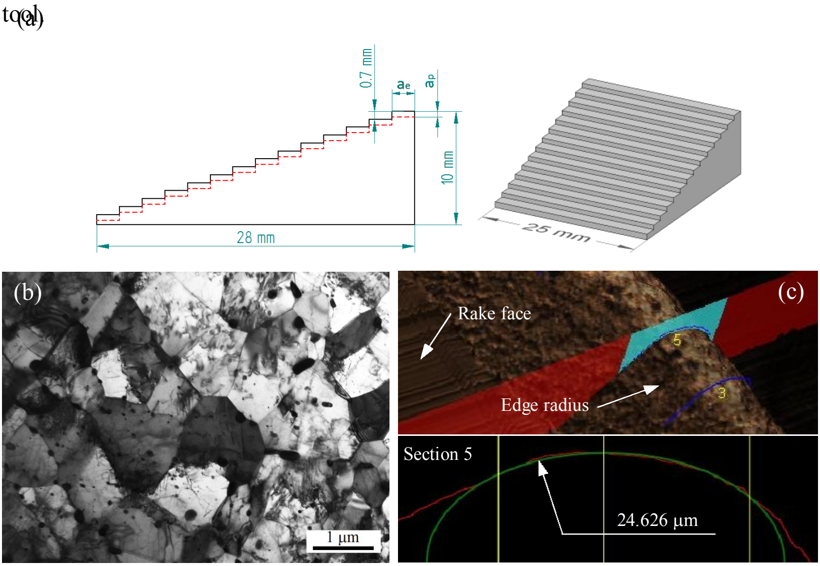

Figure 1: (a) specimen dimensions, (b) TEM bright field image of the workpiece microstructure and (c) endmill cutting edge radius measurement results from Olympus OLS4000 3D Laser Microscope.

3 Results and discussion

Figure 2 presents a graph of the surface roughness and specific cutting energy as a function of the feed per tooth to cutting edge radius ratio. The graph shows the positive parabolic curve of the surface roughness (Center Line Average - CLA) and asymptotic behavior of the specific cutting energy (SCE).

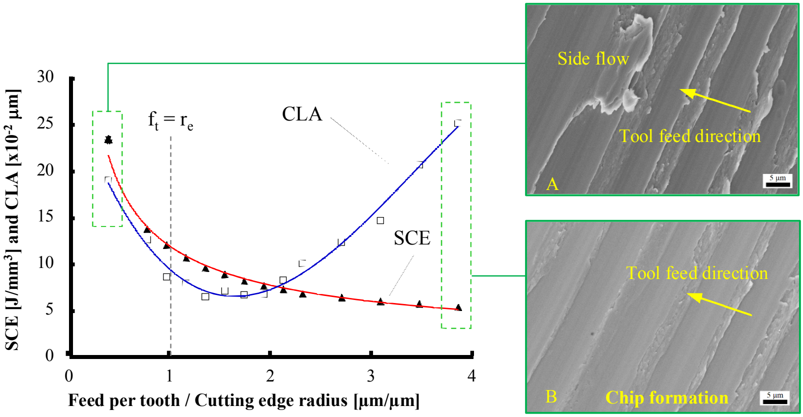

Figure 2: Variation of roughness (CLA) and specific cutting energy (SCE) as function of the feed per tooth to cutting edge radius ratio.

Surface roughness is minimum for feed per tooth values close to the cutting edge radius. SEM photomicrograph A in Fig. 2 shows that side flow is the prominent mechanism of surface formation where chip formation is precluded due to feed per tooth being smaller than the cutting edge radius. Side flow may be responsible for the increase of surface roughness for lower feeds per tooth and lower material removal rate. When the feed per tooth is maximum (image B), i.e., the uncut chip thickness is much larger than the tool cutting edge, the specific cutting energy decreases and the surface roughness increases as expected, and a higher material removal rate is achieved. Fig. 2 also shows that the surface roughness curve presents an inflexion point when feed per tooth is next to the cutting edge radius ($f_t/r_e = 1$). Below this point, the prominent mechanism is side flow; and above it, the prominent mechanism is chip formation, i.e., the minimum chip thickness reaches a similar value as the tool cutting edge radius.

4 Conclusions

In summary, this paper showed that the mechanism of material removal is directly affected by the chip thickness and tool cutting edge radius. Depending on the value of feed per tooth and especially its combination with the tool cutting edge radius, the chip may or not be completely formed, affecting the machined surface (roughness) and the cutting process performance (specific cutting energy). The results show that the surface roughness measurement may be useful to monitor the cutting tool performance in terms of effective material removal mechanism and surface formation. Surface roughness shows its minimum values when the feed per tooth is only slightly larger than the tool cutting edge radius ($f_t \approx r_e$). The side flow seems to be the mechanism responsible for increasing in surface roughness for values of feed per tooth smaller than the cutting edge radius. Further work will be carried out in order to investigate in deep how this phenomenon affects machined surface generation.

Acknowledgements

To FAPESP for grants 2011/10659-4 and 2010/06140-0. Special thank are addressed to AROTEC for the use of the Olympus OLS4000 3D Laser Microscope.

References:

[1] CHAE, J.; PARK, S. S.; FREIHET, T. Investigation of micro-cutting operations. **International Journal of Machine Tools & Manufacture**, 46, 2006, p. 313-332.

[2] MASUZAWA, T. State of the art of micromachining. **CIRP Annals - Manufacturing Technology**, 49, 2000, p. 473-488.

[3] LAI, X. et al. Modelling and analysis of micro scale milling considering size effect, micro cutter edge radius and minimum chip thickness. **International Journal of Machine Tools & Manufacture**, 48, 2008, p. 1-14.

[4] KIM, C.; MAYOR, J. R.; NI, J. A static model of chip formation in microscale milling. **Transactions of the ASME**, 126, 2004, p.710-718.

[5] DORNFELD, D.; MIN, S.; TAKEUCHI, Y. Recent advances in mechanical micromachining. **CIRP Annals - Manufacturing Technology**, 55, 2006, p. 745-768.