Surface formation during micromilling of ultrafine grained low carbon steel

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Abstract

The objective of this paper is to investigate the behaviour of metallurgically modified low carbon steel with ultra fine grain (with 0.7 µm grain size) concerning surface formation and material/tool interaction during micro-endmilling. The effect of tool cutting edge radius (r_e), feed per tooth (f_t) and tool diameter upon surface quality and roughness were considered. Results showed that surface roughness reached its lower values when the feed rate condition is of the same order of magnitude as the cutting edge radius ($f_t \approx r$). The machined grooves presented uniform tool feed marks without side flow, delamination or cratering. Results showed that the ultrafine grain material presents improved machinability at microscale cutting conditions overcoming conventional problems due to the difference between parameters and microstructure scale.

1. Introduction

Surface generation and material removal mechanism are strongly influenced by the relationship between the cutting edge microgeometry and material when small scale machining is carried out [1]. Under small scale cutting conditions, the cutting edge/material interaction is mainly affected by the effective rake angle formed at the cutting edge roundness, similar to the material response observed when highly negative rake angle tool is used under conventional machining conditions [2]. This aspect may have strong influence upon surface roughness formation and residual stress after machining. In order to overcome these problems, a microstructure with ultrafine grains may have a positive effect in terms of homogeneous material behaviour under small cutting conditions in the micrometer range [3]. The reduction of the machining scale leads to the manifestation of size effects related to the limited scalability of the work material microstructure and of the tool geometry and topography [3]. The objective of this paper is to investigate the effect of metallurgically modified low carbon steel with ultra fine grain to meet machining condition scale in the surface formation and material/tool interaction during micromilling.

2. Experimental procedure

End milling was carried out on a machining centre. Down-milling and dry condition were considered. The cutting parameters adopted were 54000 rpm spindle rotation, 32 μm depth of cut, 132 μm width of cut, and feed per tooth of 5 μm (close to edge radius value) and 18 μm (larger than edge radius value). A carbide endmill tool coated with PVD-TiN layer (code 76808 EX-TIN-EDS) with 5.1 ± 1 µm edge radius was used. The cutting edge radius was measured by Olympus OLS4000 3D Laser Microscope. A 0.16%C steel processed thermo-mechanically for grain refinement with 216.0 ± 4.0 HV hardness and 0.7 ± 0.06 μm grain size (ASTM E112-96) was used. Machined surface and indentations 3D images were made by Veeco optic perfilometer, model Wyko NT1100. Nanohardness were measured on a CSM Instrument, model TTX-NHT. Berkovich diamond indenter was used and max load values of 25.0, 50.0, 100.0, 250.0 and 500.0 mN were considered. The elastic recover was calculated considering the geometric volume of the theoretical indenter and the real volume of the indentation measured by indentations 3D images and Vision 4.20 Copyright©2002-2008 Veeco Instruments, Inc., a piece of software for surface and volume analysis.

3. Results and discussion

During low loading size effect would be expected, making measured hardness to be larger than the nominal hardness of the material. When a solid mass is deformed, a part of the energy is absolved and kept in the material (known as plastic component or permanent deformation), and part of the energy involved in the deformation corresponds to the elastic component. Figure 1a shows that elastic deformation increases with loading, which is not compatible with ‘size effect’ where the hardness increases with decreasing load, or energy storage for the solid mass is most effective when the dimensions of the indentation is reduced. Figure 1b presents the Young´s modulus to hardness ratio variation with loading. It can be seen that the size effect becomes evident since E/H ratio diminishes with loading.

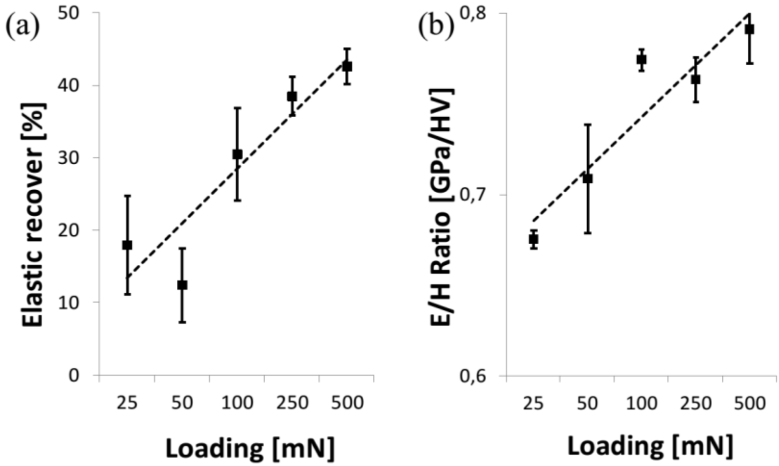

Figure 1: Material behavior to the indentation testing with Bekovich indenter. (a) Elastic recover and (b) E/H ratio.

The material response to machining in microscale may be considered similar to its behavior in indentation testing, insofar as reducing the feed per tooth may cause the same effect as reducing the loading. The different aspect is that in indentation testing the loading is quasi-static while in micromachining experiments a dynamic mechanism prevails. Figure 2 presents 3D images of micromilled surfaces cut under different cutting conditions. For all conditions it is seen uniform tool feed marks without apparent side flow, delamination or cratering along the micromilled surface. Reducing the tool diameter to machine ultrafine grained steel, the material presents an increase of plastic component, favoring the shear and reducing the elastic deformation particularly when the feed per tooth is close to the edge radius value.

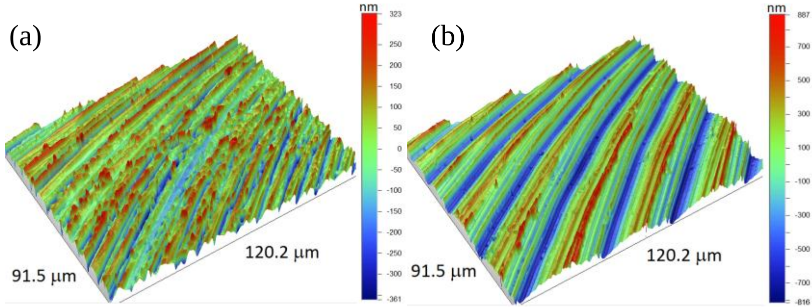

Figure 2: Micromilled surface 3D images at 5 µm/tooth in (a) and 18 µm/tooth in (b).

4. Conclusions

In summary, this paper showed that the scale of machining directly affects the mechanism of material removal. Reducing the tool diameter the elastic recover is lesser, favoring the shear mechanism during cutting of ultrafine grained low carbon steels. These results still need to be considered with caution; future work will be carried out in order to investigate in deep how this phenomenon affects machined surface generation.

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