Characterization of smearing patterns in ball nose end milling process

Biondani, F.; Bissacco, G.; Hansen, H. N.

Publication date: 2017

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Characterization of smearing patterns in ball nose end milling process.

F. Biondani, G. Bissacco, H. N. Hansen

1Department of Mechanical Engineering, Technical University of Denmark
frgbio@mek.dtu.dk

Abstract
Very shallow depth of cut are used in ball end milling finishing operation in order to minimize the chip thickness, therefore reducing the surface roughness. When the chip dimension reaches a certain thickness threshold (the minimum uncut chip thickness), the cutting dynamic switches from effective material removal to ploughing and smearing. Smearing effects can significantly enhance the surface roughness. Another important factor is the choice of the appropriate tool path, which strongly affect the tool engagement condition and surface roughness. In this work, smearing pattern produced on mould steel by cBN ball end mill, are characterized by means of SEM analysis. The results show that the location of the smearing pattern is strictly connected with the relative direction of cutting speed and feed and step over direction. Furthermore, a comparison with the theoretical chip thickness distribution confirms that the smearing of the material occurs in the area in which the chip thickness approaches to zero.

Machining, smearing, surface topology

1. Introduction

The Interaction between tool and workpiece determines the topology of the generated surface and, in turn, the resulting roughness. Low surface roughness is required in several applications such as mould manufacturing industry. In order to target this need a low depth of cut is used while machining for finishing operations. The cutting edge radius of the ball end mill plays a key role in this. While it can be considered infinitely sharp in a roughing operation, the dullness of the cutting edge must be considered when the chip thickness is reduced more and more [1]. Once a certain local thickness is reached, called minimum uncut chip thickness (MUCT) [2], the tool is not able to remove material, that is therefore deformed and smeared over the surface [3]. In this work, smearing patterns produced by machining steel surfaces using a ball end mill were characterized by means of SEM analysis. The tool engagement conditions were varied and the developed smearing pattern is discussed.

2. Experimental work

The test part consists in a steel flat surface with approximately 52–54 HRc hardness. The surface was machined using a cBN ball end mill with two flutes and a ball radius of 0.5 mm. The machining strategy, in terms of tool path and cutting parameters, were varied during the tests, Figure 1. In this way it is possible to observe and characterize the surface topology produced in different cutting configurations. The four tool paths studied in this work are represented in Figure 1 and here called tool path A, B, C and D. Every configuration has a different relative orientation with respect to the cutting velocity, feed direction and step over direction. Several tracks were produced over the surface of the test part maintaining an inclination of 40° between the tool and workpiece to avoid the zero cutting speed part of the tool edge. Two sets of cutting parameters were used: depth of cut, step over, feed per tooth and rotational speed were respectively 15 µm, 50 µm, 15 µm and 13000 RPM for the first set and 25µm, 100µm, 25 µm and 1300 RPM for the second set. Surfaces were characterized by means of SEM analysis.

Figure 1. Different tool paths. The white solid arrow indicates the feed direction, the dashed white arrow the step over while the black arrow the cutting speed direction.

3. SEM characterization

Similar smearing patterns are observed for both sets of cutting parameters, even though for the second set the smearing phenomena is more evident. In tool path A (Figure 2 left), the cutting speed matches the step over direction. The feed marks left by the teeth are clearly visible and a clean cut separates every tool pass. At the end of the cutting edge engagement a wave-like structure is visible protruding in the opposite direction to the feed. In tool path C (Figure 2 right), the direction of the cutting speed is the opposite of the step over direction. The wave-like structures are still visible but material is piled up between subsequent tool passages.

In tool path B and D (Figure 3 left and right), the cutting speed is now parallel to the feed direction, concordant in B and discordant in D. Piling up of material is present in D where the cutting speed points toward the freshly generated surface, while the wave-like structures are localized along two subsequent tool passes in both cases.
squeezed material flows orthogonally to the cutting speed direction where the deformation is easier because of the missing material. This generates a characteristic side flow visible as protruding wave-like structures on the surface, Figure 5 right. The theoretical local chip thickness is quantitatively shown in Figure 6. It can be noticed that the smearing phenomena are always localized where the chip thickness decreases.

5. Conclusion

Two different smearing phenomena occur in ball end milling where the chip thickness decreases below the MUCT: side flow and ironing. The tool path influences the relative direction of cutting velocity, feed direction and step over direction that, in turn, determines where the smearing will occur. Knowledge of the development and position of the smearing pattern can help in the selection of optimal cutting parameters and in modelling the surface generation process.

References