Title
Analysis of Tool and Workpiece Interaction in Diamond Turning using Graphical Analysis of Acoustic Emission

Authors
Valente, Carlos M
Dornfeld, David

Publication Date
2003-06-01

Analysis of Tool and Workpiece Interaction in Diamond Turning Using Graphical Analysis of Acoustic Emission

C.M.O. Valente
Sponsored by Industry Affiliates of the LMA

Abstract— The surface quality obtained in diamond turning operations Is highly influenced by the interaction between the tool and workpiece. These influences include changes in cutting forces, chip formation phenomena, microstructure of workpiece, and others. Local changes in the depth of cut and material properties lead to variable cutting forces that may result in unacceptable form errors. This research proposes an innovative approach for mapping the AE RMS generated during diamond turning able to graphically represent several features of the interaction between tool and workpiece related to instant depth of cut distribution, grain boundaries, and grain orientation.

Keywords: acoustic emission, metal cutting, precision machining, micro machining, microstructure, grain orientation, grain boundary, diamond turning, depth of cut.

1. Introduction

Ultraprecision micro-cutting operations have been used to manufacture a wide variety of precision components such as spherical lenses, high-precision reflecting mirrors, hard disk drive head assemblies, and other optics and semiconductor applications. However, in ultraprecision machining, the undeformed chip thickness can reach the order of a few microns or less. At such scales, surface finish and chip formation are much more intimately affected by the material properties of the workpiece, such as ductile/brittle behavior and micro topographic characteristics. Thus, while cutting polycrystalline materials with extremely small undeformed chip thicknesses, the material removal mechanism can be highly influenced by individual grains and their orientation. Hence, unlike conventional metal cutting, previous research has shown that at the microscale, micro-topographical characteristics or machined surfaces and the chip formation process itself are dependent on the crystallographic orientation of the machined material [1].

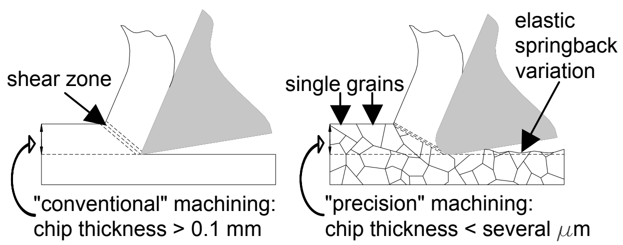


Figure 1. Relative scale comparison of conventional vs. ultraprecision cutting processes.

Polycrystalline materials consist of individual grains misaligned with respect to one another; each having a particular crystallographic orientation and separated by grain boundaries. At this scale, where tool/chip interaction can take place entirely within an individual grain, the effect of cutting direction with respect to the crystallographic orientation of the machined grain on both chip formation and machined surface finish has been demonstrated [2].

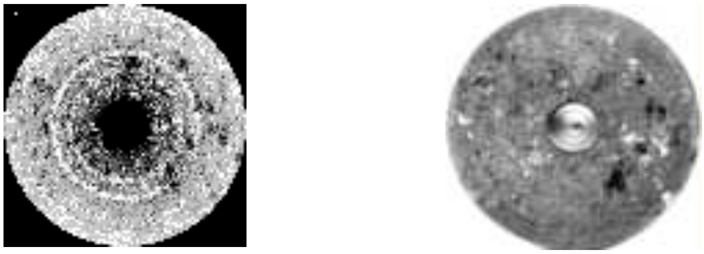
Acoustic emission (AE) has been shown to be generated by a number of different mechanisms and can be sensitive to local variations in the tool and workpiece interactions at the microscale, particularly to those variations induced by grain orientation [3]. Compared to other sensing technologies, e.g. force measurement, AE sensing may offer better sensitivity to the underlying deformation mechanisms in ultraprecision machining. That is, AE is particularly well suited because of its ability to detect micro scale deformation mechanisms within a relatively ‘noisy’ machining environment. The purpose of this work is to investigate the sensitivity of AE to variations in the ultraprecision machining process due to variations in the microstructure of both single-crystal and polycrystalline workpieces.

2. Experimental setup

The polycrystalline workpieces used for the experiment were 63.5 mm diameter OFHC Cu disks that were cold worked at 60% and subsequently recrystallized at 830° C. The workpieces were recrystallized for different time durations (20-60 min.), resulting in a variation in recrystallized grain size from approximately 0.1 mm to 4 mm in average grain diameter. Bridgman-grown single-crystal Cu workpieces rated at 5N purity with crystallographic orientations of [100] and [111] were used for the single-crystal tests. The workpieces were machined on a Rank Pneumo MSG-326 precision lathe equipped with an air bearing spindle and precision lays. A constant rotational speed of 1000 RPM was used, corresponding to a maximum cutting velocity of about 6.6 m/sec on the outer circumference of the workpiece. The AE signal was filtered through a high-pass filter with a 50 kHz cutoff, and subsequently amplified by 40 dB. The AE RMS signal was integrated with a time constant of 20 microseconds and acquired at a sampling rate of 160 kHz. Finally, the data was arranged in data arrays corresponding to a full rotation of the workpiece. Data collection was synchronized using an encoder mounted on the work spindle.

3. **Results/future work**

For the polycrystalline workpiece experiments, the workpiece was machined to an optical quality surface finish of 58 nm Ra at 1000 RPM with a 0.274 mm nose radius diamond tool (0 deg. rake, 10 deg. clearance), DOC of 2 microns, and feed rate of 13.2 μm/rev. No macro-scale surface defects could be observed with the naked eye. Figure 2 shows an intensity-based polar mapping of the AE RMS signal next to a macrograph of the actual OFHC Cu workpiece after etching with an ammonium hydroxide etch for 30 seconds to



(a) (b)

Figure 2. Comparison between the microstructure presented in the polar AE map and the actual workpiece.

remove the process-induced strain hardened layer of material. Regions of relatively high AE RMS signal are represented as light gray, whereas areas of relatively low AE RMS signal correspond to the dark regions. A good correlation can be made between the large individual grains on the workpiece and the large dark regions on the AE polar map. For the single-crystal cutting experiments, the [100] and [111] orientation workpieces were diamond-turned in a facing operation in the (100) and (111) planes, respectively.

The obtained polar maps (Figure 3) demonstrate a continuous variation of the AE RMS signal as a function of workpiece rotation angle, and hence the crystallographic orientation of the machined workpiece. Assuming that AE RMS is approximately proportional to cutting force, this confirms the force-based crystallographic orientation data for similar materials machined in similar directions. Since it has been previously established that surface finish is a function of grain orientation in ultraprecision machining [4], the homogeneity of the polar map can also serve to represent overall homogeneity in the surface finish.

(a) (b)

Figure 3. Influence of the grain orientation in the AE level during turning of single crystal Cu: (a) [100] orientation; (b) [111] orientation.

Future work includes machining of [110] orientation single-crystal Cu workpieces, and a comparison of data between surface finish measurements and the corresponding AE RMS signal obtained during machining to evaluate the potential of using the AE signal as a means of evaluating surface finish.

References

[1] Yean, Z., Lee, W., Yao, Y., Zhou, M., “Effect of Crystallographic Orientations on Cutting Forces and Surface Quality in Diamond Cutting of Single Crystal,” *CIRP Annals*, 43/1, 1994, pp. 39-42.

[2] Ueda, K., Iwata, K., “Chip Formation Mechanism in Single Crystal Cutting of β Brass,” *CIRP Annals*, 29/1, 1980, pp. 41-46.

[3] Lee, Y., Monitoring and Planning for Open Architecture Manufacturing of Precision Machining Using Acoustic Emission, Ph.D. Thesis, University of California, Berkeley, 2000.

[4] Brinksmeier, E., Schmutz, J., “Generation and Texture of Surfaces In Ultraprecision Cutting of Copper”, *Machining Science and Technology*, Vol. 1, No. 2, 1997, pp. 185-193.