Monitoring single point diamond turning through acoustic emission

H.A.T.Silva,[1] J.G.Duduch,[1] R.G.Jasinevicius,[1] A.E.Gee [2]
[1]Department of Mechanical Engineering, University of São Paulo, São Carlos-SP, Av. Dr. Carlos Botelho 1465, CEP:13560-250, Brazil
email:helderts@sc.usp.br
[2]School of Industrial and Manufacturing Science, Cranfield University, Building 50, Cranfield Bedford MK 43 OAL UK
email:a.e.gee@cranfield.ac.uk

Abstract

The machining of brittle glassy, ceramic and crystalline materials is assuming increasing importance in the manufacture of optics, opto-electronics and components for other areas of industry. A restricted range of ductile mode machining can be obtained with controlled cutting parameters (cut-depth and feedrate). The need to improve the control of such cutting parameters makes the use of acoustic emission (AE) sensors a potentially viable technique.
An investigation into ultraprecision diamond turning monitoring by measuring AE during the cutting process and studying its correlation with the cutting mode. It was shown that AE is a viable monitoring technique for controlling the micromachining of brittle materials in the ductile regime.

1 Introduction

There is increasing interest in forming and fabrication technologies for components in brittle materials. Demands for semiconductor crystals, optical glasses and durable ceramics stem from their special optical, opto-electronic and mechanical attributes. However, their hardness and brittleness are constraints in economically machining these materials [1,2]. Earlier research has shown that, when certain basic restrictions in terms of thickness of cut and cutting depth are respected [3], ductile regime machining is achievable.

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For shop floor applications, there is an important need to monitor the process since the cutting conditions and tool dimensions in ultraprecision machining are required to be precisely controlled to within sub-μm levels. For this purpose, it is necessary to identify specific features from the cutting process, that is, the ductile, ductile-brittle and brittle material removal regime characteristics. Acoustic emission (AE) can be considered capable of precisely identifying these cutting modes.

The acoustic emission (AE) generated during the machining process involves information which can be correlated with the efficiency of the process [4]. AE is referred to as elastic tension waves generated resultant from the rapid liberation of deformation energy in the material due to the rearrangement of its internal structure. The main source-locations of AE generation in machining processes are the primary zone (e.g. shear zone), secondary zone (chip-tool interface) and tertiary zone (friction between the clearance face and the newly-formed surface).

The viability of AE application to the monitoring of single point diamond turning process has been proposed and studied for non-ferrous metals such as aluminium [5,6]. The results have demonstrated that AE may be considered as a feasible monitoring technique.

This work intends to present, for the first time, AE signals obtained from single point diamond turning of monocrystalline silicon in three distinct cutting regimes: *Ductile, Brittle-Ductile and totally Brittle.* The AE technique was used to identify particular features in the cutting signals obtained in the different cutting modes. The signal generated was used to correlate the primary material removal mode and the AE_{RMS} (V) level.

2 Experimental method

A silicon single crystal sample was diamond face-turned parallel with its (100) surface using a Rank Pneumo (now Taylor Hobson Pneumo, of Keene NH, USA and Leicester UK) type ASG 2500 surface generator. A diamond tool with rake angle –2.5°, nose radius R = 0.776mm and clearance angle of 12° was used in all tests. Feedrates were set to 1.0 , 2.5 and 7.5 μm/rev and the nominal depth of cut was set at 10 μm. Coolant fluid was continuously sprayed onto the workpiece surface during machining. These cutting conditions provide the ductile, brittle-ductile and brittle modes during machining, respectively with surfaces of mirror-like and opaque quality generated. The spindle speed was kept constant at 1000 rpm. Using a piezoelectric pick-up transducer mounted on the tool post, the AE signal obtained was amplified and high-pass filtered (2.5kHz). A National Instruments acquisition module DAQ Card 700 was employed in conjunction with a Personal Computer. The RMS value of the AE signal was employed as an indicator for monitoring the diamond cutting process as it provided a direct measure of the energy content of the signal.

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3 Results and discussion

The large number of AE data related to indentation and scratching of brittle materials available in the literature and the resemblance of indentators and single point diamond tools show that the monitoring of brittle materials machining is possible. AE was first used in the indentation and scratching of glass and ceramics, for example [7,8]. In the indentation of glass, it was possible to identify the initiation of medium, lateral and radial cracks during loading and unloading cycles. During scratching tests in alumina, it was possible to correlate different types of signals with microscopic observations, in order to identify plastic deformation and brittle fracture. There seems to be an increase in AE levels with the increase of brittle fracture. High amplitudes and energy levels indicate a process where brittle fracture prevails.

Figures 1, 2 and 3 show AE signals obtained from three different material removal regimes: ductile, ductile-brittle and brittle, respectively. It can be seen that there is an increase in signal amplitude with the initiation of the brittle regime. The $AE_{(RMS)}$ signal level for the ductile regime shown in Figure 1 does not reach values greater than 0.8V and its amplitude is 0.2V. This amplitude is also observed in the ductile/brittle regime (2.5μm/rev, d_c=10μm), shown in Figure 2. However, the $AE_{(RMS)}$ signal is increased, reaching 1.0V. This increase in the $AE_{(RMS)}$ level might be the contribution of the material removal that occurs partially in the brittle regime due to the generation and propagation of microcracks. This tendency corroborates well with the signal of the material removal in the brittle mode (7.5μm/rev, d_c=10μm) as in Figure 3. This shows the $AE_{(RMS)}$ signal reaching levels as high as 10.0V with the signal amplitude 1.5V. It is appropriate to mention that, in this cutting condition, the machined surface presents spalling damage and cracks.

Using this sensor, this system not only acquires AE signals but also other noises. These noises are generated by moving parts of the machine tool, hydraulic pumps, pneumatic circuitry, cooling fluid etc. The noise level detected in the cutting tests was 0.4V as can be observed in the initial part of the graphs.

4 Concluding remarks

An investigation into single point diamond turning using AE has been carried out. Three material removal regimes were analysed: ductile ductile/brittle and brittle. A correlation between AE level and material removal mode was obtained in order to investigate the feasibility of using AE to routinely monitor single point diamond turning of brittle materials.

The AE graphs obtained show the emitted signal increasing with increase of volume removal rate into the brittle mode (generating cracks). The signal levels for each of the three removal modes can be clearly distinguished and, for either extreme of condition (pure ductile and pure brittle) there is a marked difference in signal level (0.8V and 10.0V, respectively). This indicates that the material removal mode may be easily detected This increase in the $AE_{(RMS)}$ signal

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amplitude is probably related to the phenomenon of brittle fracture with high levels of energy indicating a prevalence of microcracking. AE, therefore, seems to be a viable technique for the monitoring of diamond turning of brittle materials, and further investigation is justified.

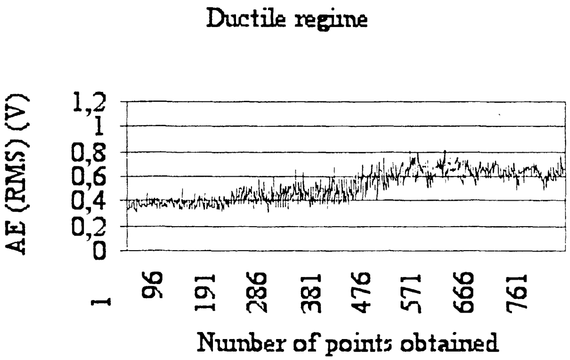

Figure 1: AE in the ductile regime.

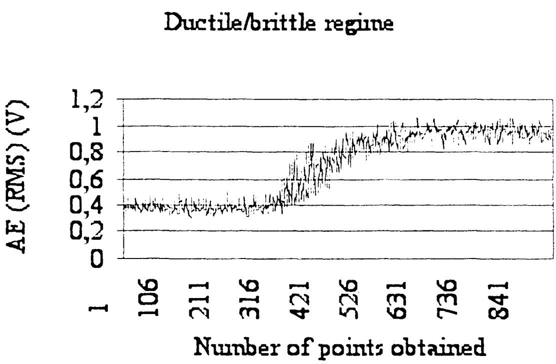

Figure 2: AE in the Ductile/Brittle regime.

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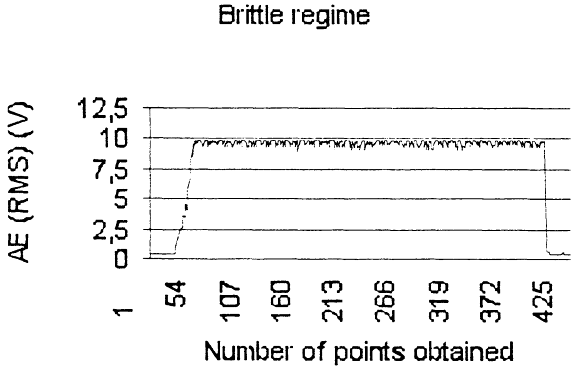

Figure 3: AE in the Brittle regime.

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