Experimental Study on AE from Precision Diamond Machining

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Acoustic emission (AE) has been studied extensively as a technique for monitoring machining processes. In this study, relationships between the RMS AE signals and the cutting parameters in precision diamond turning are investigated experimentally. To build such experimental relationships, each measured RMS AE signal is seperated into two components, the one associated with the chip formation and the other one resulting from the rubbing friction at the tool flank-workpiece interface. The responses of these components to variations in cutting parameters are then explained. The experimental data suggest that the AE is generated predominantly by the chip formation in diamond turning, whereas the rubbing friction is one of the primary sources of AE in the conventional turning.

Key Words: Acoustic Emission, Rubbing Friction, Chip Formation

1. Introduction

The productivity of turning operations depends heavily on the level of process automation and the development of automation technique is often directed to maintain a satisfactory situation or to optimize a specific performance index. In case of turning operations, a great deal of effort has been devoted to achieving the high precision and the accurate control of the machine tools. Toward this goal, development of the intelligent monitoring systems appears to be a crictical factor.

Traditionally, force and displacement information is used for such systems. Researchers in recent years, however, have found that the acoustic emission (hereafter, AE) generated in turning contains rich informations about the cutting process. The effectiveness of AE-based machine tool condition monitoring and process analysis has been established accordingly (Teti and Dornfeld, 1989). For example, in an effort to establish a basic tool for the analysis of the cutting process, a model of the AE signal properties as a function of cutting parameters has been proposed for orthogonal cutting (Kannatey-Asibu Jr. and Dornfeld, 1981). The model has been limitedly successful in predicting the AE characteristics in the conventional turning. Here, the word "conventional" was used in contrast to more "ideal" diamond turning.

In diamond turning, however, the cutting edge is sharp and well defined, chip-tool interaction along the tool rake is minimal and the continuous chip is produced in most cases. As the cutting state becomes closer to such ideal conditions, AE-based process analysis becomes more realizable (Teti and Dornfeld, 1989). In all cases, however, no attempt has ever been made to estimate the AE generated by the rubbing friction at the tool flank-workpiece interface.

The main objective of this study is to experimentally investigate the AE generation and to identify the principal sources of AE in precision diamond turning. In particular, the measured RMS AE signal is seperated into two components, the one associated with the chip formation and the other one resulting from the rubbing

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friction at the tool flank-workpiece interface. The responses of these components to variations in cutting parameters are then explained and their origins are identified in diamond turning. The conventional turning experiments are also performed for comparison purpose.

2. AE Generated in Turning

Figure 1 depicts the zones of AE in turning, i. e., the primary shear zone, the secondary zone and the tertiary zone. Intensive plastic deformation takes place in the primary shear zone, both plastic deformation and sliding friction are present in the secondary zone, and rubbing friction takes place at the tool flank-workpiece interface in the tertiary zone. The AE signal is sensitive to material, tool geometry, and tool abnormalities such as tool wear and tool breakage. As for the cutting parameters, only the strong effect of cutting speed (or strain rate) has been confirmed by many investigators (Teti and Dornfeld, 1989; Kannatey-Asibu Jr. and Dornfeld, 1981; Lee et al. 1987). The AE signal typically shows little, if any, sensitivity to changes in depth of cut and feed.

In general, a power function model is assumed to describe the relationship between the RMS AE voltage and the cutting parameters, and is given by

$$AE_{RMS}=KV_w^a t_1^b f^c+C \qquad (1)$$

where K, a, b and c are constants, V_w is cutting speed, t_1 is depth of cut, f is feed, and C is the offset value. It is well understood that the intensity of AE signal from machining low strength metals, carbon steels and low alloy steels shows little or no dependence on the depth of cut, but these parameters become significant for machining of high strength alloys such as SAE 4340 (Lee et al., 1987). Furthermore, in the practical ranges of cutting parameters, $c\approx 0$ in conventional turning, whereas c has a small but nonzero value in diamond turning.

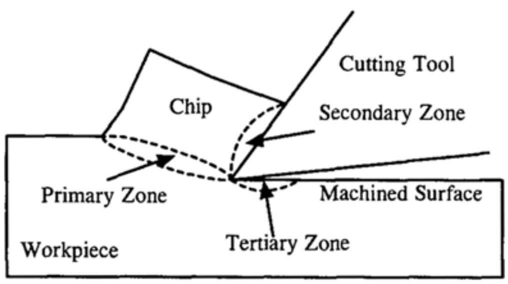

Fig. 1 Zone of acoustic emission generation in turning

3. Experiments

A series of turning experiments were conducted on a lathe. The workpieces used were Al6061-T6 round bar of 101.6 mm diameter in diamond turning and mild steel round bar of 50.8 mm diameter in conventional turning. Tools used were Korea Tungsten KT300 (DNMG-15-0608) insert (conventional turning) and Kennametal Compax TPG-321 diamond insert (diamond turning). The experimental setup shown in Fig. 2. is composed of a lathe, PAC-WD wide band piezoelectric transducer, PAC 1220-A preamplifier, PAC 1200-A amplifier, PAC band pass filter (pass band: 100 kHz~1200 kHz), National Instrument's DAQ-1200 data aquisition module and a PC. The signal was picked up by the AE transducer mounted on the tool shank and passed through preamplifier and amplifier which transformed the raw current from the transducer to the output voltage. The amplifier gains were 60 dB and 3 dB, respectively. The amplified signal was

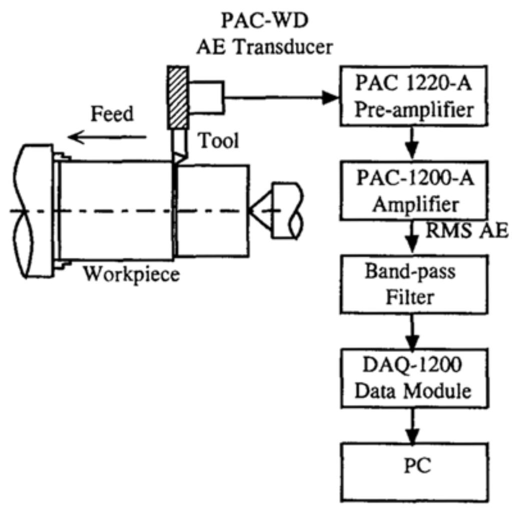

Fig. 2 Experimental setup used in this study

Table 1 Experimetal conditions used in this study

		Conventional Turning	Diamond Turning
Workpiece (Round Bar)		Mild Steel	Al6061-T6
Workpiece Diameter, mm		101.6	101.6
Tool	Model	Korea Tungsten KT300 (DNMG-15-0608)	Kennametal TPG321 K68
	Nose Radius, mm	0.8	0.4
	Shape	Diamond	Triangle
Cutting Speed, m/sec		1.86~5.85	1.86~5.85
Depth of Cut, mm		0.101~0.406	0.051~0.203
Feed, mm/rev		0.051~0.203	0.051~0.203

then sampled in real-time and stored in a PC. The sampling rate was 1024 Hz. Detailed experimental conditions are summarized in Table 1.

In order to decompose the signals generated by rubbing friction in the tertiary zone from the raw AE signal, the following experiments were executed: The in-feed of tool was abruptly stopped and remained in contact with the workpiece as the spindle continues to turn (Drescher and Dow, 1990). Then, the residual RMS AE signal was measured after it stabilized to steady state. This residual AE signal represents the contribution from rubbing friction.

4. Results and Discussion

Figures 3 and 4 show the typical residual RMS AE signal obtained in conventional and diamond turning, respectively. Feed was stopped at about the mid-point of the signal in each figure so that the second half represents the residual AE signal. In all cases, continuous chip was produced during the normal operation (i. e., the first half of the signal in Figs. 3 and 4). Decrease in the RMS AE voltage in the second half is clearly seen in the figures. This indicates that the residual AE signal is successfully isolated.

Changing cutting speed certainly changes the condition of rubbibg friction and, therefore, affects the level of AE produced, Fig. 5. The RMS AE voltage increases linearly with cutting speed for other conditions in Table 1. The residual AE

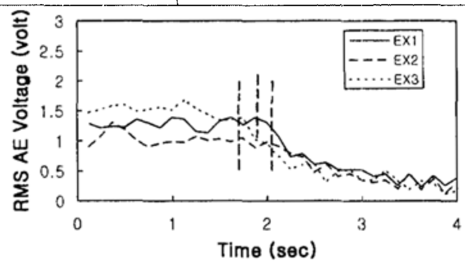

Fig. 3 Residual RMS AE signal obtained in conventional turning. Dashed line indicates the point where the feed of tool was stopped
EX1: $t_1=0.2$ mm, $f=0.1$ mm/rev, $V_w=3.98$ m/sec
EX2: $t_1=0.3$ mm, $f=0.1$ mm/rev, $V_w=2.92$ m/sec
EX3: $t_1=0.2$ mm, $f=0.15$ mm/rev, $V_w=2.92$ m/sec

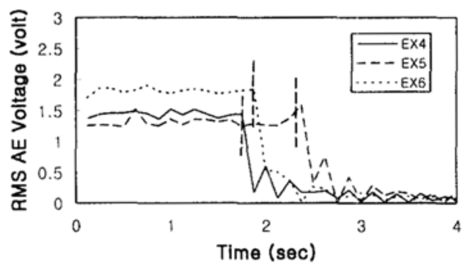

Fig. 4 Residual RMS AE signal obtained in diamond turning. Dashed line indicates the point where the feed of tool was stopped
EX4: $t_1=0.1$ mm, $f=0.1$ mm/rev, $V_w=3.98$ m/sec
EX5: $t_1=0.15$ mm, $f=0.1$ mm/rev, $V_w=2.92$ m/sec
EX6: $t_1=0.1$ mm, $f=0.15$ mm/rev, $V_w=2.92$ m/sec

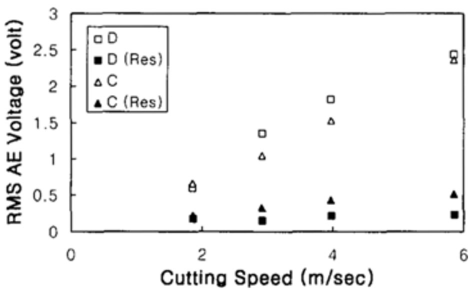

Fig. 5 Variation of the RMS AE voltage with cutting speed. $t_1=0.2$ mm for conventional turning and $t=0.1$ mm for diamond turning. $f=0.1$ mm/rev. C: Conventional Turning. D: Diamond turning.

signal in conventional turning shows little sensitivity to variation in cutting speed. No effeect of cutting speed on the residual AE signal was seen in diamond turning.

Figures 6 and 7 show the variation of the RMS AE voltage with depth of cut and feed, respectively, for cutting conditions indicated. As expected, the AE signal shows little sensitivity to these cutting parameters. Such a low sensitivity of AE signal can be attributed to the strong influence of chip formation on the AE generation. Namely, the chip-tool contact condition is influenced by the changes in depth of cut and feed, which in turn changes the AE signal. The RMS AE voltage increases slightly with depth of cut but, in general, depends strongly on work materials. Variation in RMS AE voltage with depth of cut for a variety of work materials has been previously reported elsewhere (Lucca, et al. 1991; Lan et al. 1985; Heiple et al. 1990, 1991). Increased feed is not expected to significantly affect the rubbing friction at the tool flank-workpiece interface and, therefore, the similar levels of AE are produced.

To account for the residual AE signal Eq. (1) is now decomposed into two parts, i.e.,

$$\begin{aligned} AE_S &= (AE_S)_c + (AE_S)_t + C \\ &= K_c V_w^{a_c} t_1^{b_c} f^{c_c} + K_t V_w^{a_t} t_1^{b_t} f^{c_t} + C \end{aligned} \quad (2)$$

where a_c, b_c and c_c signify the effect of chip formation in the primary and the secondary zone on AE generation. a_t, b_t and c_t relate the additional AE generated in the tertiary zone with the cutting parameters. Table 2 summarizes the values

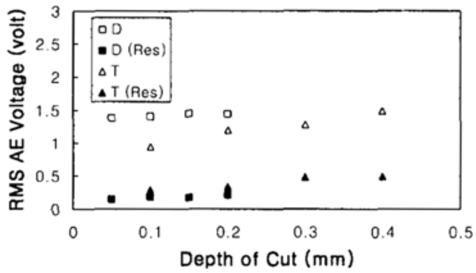

Fig. 6 Variation of the RMS AE voltage with depth of cut. $f=0.1$ mm/sec and $V_w=2.92$ m/sec

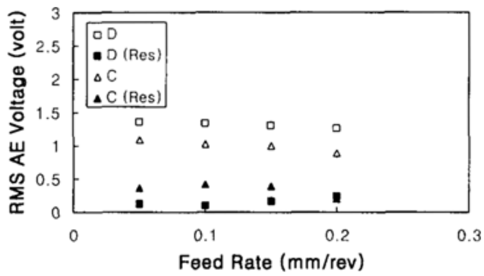

Fig. 7 Variation of the RMS AE voltage with feed. $t_1=0.2$ mm for conventional turning and $t_1=0.1$ mm for diamond turning. $V_w=2.92$ m/sec

of these constants observed in this study.

The residual AE energy is up to 40 % of total energy in conventional turning. It may be reasoned that intensive rubbing action takes place at the tool flank-workpiece interface, which can be considered as one of the principal sources of AE. This result supports the works by Heiple et al (Heiple et al. 1990, 1991) in the sense that the AE resulting from the rubbing friction is no more negligible. It is also noted that more AE energy is generated as a result of chip formation in conventional turning. Shearing in the primary zone and friction in the secondary zone are unable to account for the observed total energy since the dissipation of mechanical energy due to rubbing friction is not responsible for material removal in turning. Any change in the ratio of energy consumed to overcome the rubbing friction to total energy will alter the overall force system. It is not known how changes in tool forces (or forces/unit contact area of tool flank) alter the generation of AE by sliding friction.

The level of residual AE energy is much lower

Table 2 Constants experimentally observed in this study

Constants	Conventional turning	Diamond Turning
a	$a\approx 1,\ a_c\approx 1,\ a_t\approx 1$	$a\approx 1,\ a_c\approx 1,\ a_t\approx 0$
b	$b\neq 0,\ b_c\approx 0,\ b_t\neq 0$	$b\approx 0,\ b_c\approx 0,\ b_t\approx 0$
c	$c\neq 0,\ c_c\neq 0,\ c_t\approx 0$	$c\approx 0,\ c_c\approx 0,\ c_t\approx 0$

in diamond turning compared with that in conventional turning. Only 10 % of total AE energy is attributed to the contribution from the rubbing friction. In diamond turning, specific cutting energy (energy per unit volume) was found to increase as depth of cut decreases for a given tool geometry (edge radius) (Lucca et al. 1991). The extreme hardness of diamond, however, permits the fabrication of very sharp cutting edge and the low friction at the tool-chip and the tool flank-workpiece interfaces makes the chip formation under eased stress conditions possible in diamond turning. It is unlikely that severe sticking friction takes place at the tool flank-workpiece interface under these conditions. Reduced emission activity at the tool flank contact is understandable in those respects. Apparently, rubbing friction is not a principal source of AE in diamond turning and friction-based theory does not apply in this case (Heiple et al. 1990, 1991).

The basic assumption in deformartion-based theory is that the portions of plastic work of deformation that go into producing AE and generating more dislocations are always in the same ratio. If this is true, a relationship holds such that (Kannatey-Asibu Jr. and Dornfeld, 1981)

$$AE^2_{RMS} \propto \dot{W} \quad (3)$$

where $\dot{W}$ is the energy source for AE that is generated from plastic deformation. However, the experimental results discussed so far suggest that the rate of deformation energy for a variety of combinations of cutting parameters in both conventional and diamond turning does not vary in proportion to the square of the RMS AE energy. Therefore, the deformation-based approach in modeling AE generation in metal cutting is believed to be invalid.

Another interesting observation is that more total AE energy was recorded in diamond turning than in conventional turning. This may be attributed to the sensitivity of AE to work material-tool combinations.

5. Conclusions

In this study, generation of AE in turning was experimentally investigated. In particular, AE generated by rubbing friction was successfully isolated and the experimental relationships between the characteristics of residual AE signal and the cutting parameters were established. Based on the experimental results the following conclusions can be drawn:

(1) More AE energy is recorded in diamond turning than that expected in conventional turning. The residual AE energy is, however, higher in conventional turning. The ratio of residual AE energy to total AE energy is also higher in conventional turning.

(2) Rubbing friction at the tool flank contact is one of principal sources of AE in conventional turning. It must also be noted that more AE is generated by the chip formation in the primary and the secondary zones.

(3) More than 90 % of AE is generated by the chip formation in diamond turning, which is not in accordance with the friction-based theory.

(4) The experimental results suggest that the deformation-based theory is not valid in modeling AE generation in metal cutting.

The inherent limit of this study lies in the fact that only mild steel and Al6061-T6 were used as work material. More works need to be performed for a variety of work material-tool combinations in the future.

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