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Journal of Materials Processing Technology 62 (1996) 403–407

Journal of Materials Processing Technology

Effect of grinding parameters on acoustic emission signals while grinding ceramics

Javad Akbari[a], Yoshio Saito[b], Tadaaki Hanaoka[b], Shizuichi Higuchi[b], and Shinzo Enomoto[c]

[a]*Faculty of Mechanical Engineering, Sharif University of Technology, P.O. Box 11365-9567 Tehran, Iran*

[b]*Faculty of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263, Japan*

[c]*GINTIC Institute of Manufacturing Technology, Nanyang Technological University, Singapore*

Abstract

Grinding process of engineering ceramics is always accompanied by cracking. For automation of machining process it is necessary that a reliable sensing system be devised to detect the workpiece cracking during grinding. In this paper an acoustic emission (AE) sensor was examined for in-process detection of workpiece conditions. Different grinding conditions were performed for evaluation of sensitivity of AE and understanding the effect of each grinding parameter.on AE activities during grinding process of alumina ceramics. The results of experiments indicate that AE activities increase with increasing wheel depth of cut and table speed, however when the wheel speed increases, AE activities decrease. As a result, it is shown that AE is basically a function of abrasive grain depth of cut which is in turn, the main factor for determining the surface integrity of fine ceramics.

Keywords: Grinding, Acoustic Emission, Ceramics, Machining Damage, Grinding Mode

1. Introduction

Under certain controlled conditions it is now possible to grind brittle materials such as engineering ceramics so that material is removed by plastic flow, leaving crack-free surfaces [1].

Such a *damage-free grinding* occurs when the volume of materials stressed by each grit of the grinding wheel is small enough to yield rather than exhibit brittle fracture, i.e. cracking. In practice, this means maintaining the grain depth of cut (undeformed chip thickness) to below the ductile-brittle transition value.

In order to reduce the machining times and costs extremely, automatic machines and systems are applied. For automation of ductile-mode grinding of fine ceramics the machine tool must be equipped with sensors of enough sensitivity to ceramic part cracking.

Acoustic emission technology has a long history in studies relating to materials research, material evaluation, nondestructive testing and manufacturing processes. Using AE for inspection of machining process was intensified during the last decade. Wakada and Inasaki [2], for instance, used AE sensor to monitor chatter vibrations and wear of a CBN grinding wheel. Some workers such as Eda, et al. [3], Bifano and Yi [4] and Akbari, et al. [5] have used AE for monitoring the machining process of brittle materials. The results of our previous experiments [6, 7] indicate that AE is sensitive enough to detect surface damage of fine ceramics. It was also shown during grinding of fine ceramics that AE activities increase when the abrasive grain depth of cut, g , increases [8].

The objective of present article is to evaluate the sensitivity of AE to different grinding parameters such as wheel depth of cut, table speed and wheel speed. In this way the main factor which controls the AE activities in ceramic materials during grinding is determined.

In order to solve the problem of noises which is the most important precondition for using acoustic emission signal analysis, different strategies are introduced.

2. Experimental procedure

Experiments were carried out on a horizontal spindle surface grinder with variable wheel speed, table speed, and down feed control. Table 1 shows the grinding con-

PII 0924-0136(96)02443-0

Table 1
Grinding conditions and mechanical properties of workpiece

Grinding conditions		*Workpiece properties (WT% 99.7 Al_2O_3)*		
Grinding method	One-pass, up- and wet surface grinding	Bending strength	374	$MPam^{1/2}$
Grinding wheel	ASD200R100B, (NORTON)	Hardness	1590	$HV10$
Truer	Rotary type DD-205, (FSK)	Fracture toughness	4.5	$MPam^{1/2}$
Dresser	GC dressing stick, 360H, (FSK)			
Wheel speed, V, m/min	700, 900, 1100, 1300, 1500, 1700			
Table speed, v, m/min	0.06, 0.12, 0.18, 3, 6, 9			
Depth of cut, t, μ m	2.5, 5, 10, 15, 20, 25			

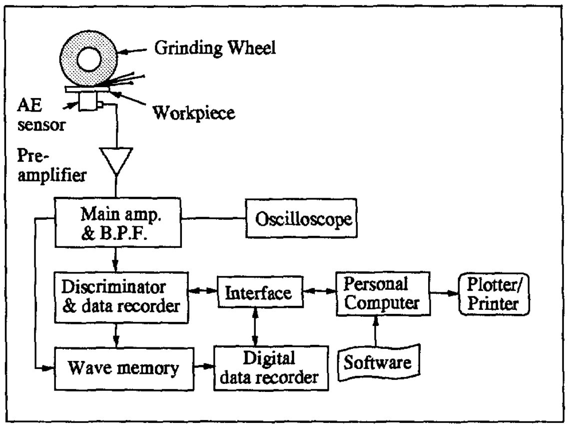

Fig. 1. Experimental setup for grinding tests

ditions and mechanical property of the normal sintered Al_2O_3 which served as test material.

The AE measurement apparatus and data processing system which is schematically shown in Figure 1 was used. Acoustic emission signal was detected using a piezoelectric transducer of 140 kHz resonance frequency which was attached to the opposite side of the grinding surface below the workpiece using a wax-type couplant. The detected signal then was passed through a low-noise preamplifier with 40 dB gain and the main amplifier to total gain of 60 dB. There are different sources of noise during grinding process. To determine the characteristics of each noise, the noise was generated separately or combined with other noises, then it was recorded and analyzed. The noises from grinding wheel and grinding fluid were the most serious noises. For filtering the noises, different filtering strategies were used in order to diminish the noise effect. Most of the noises generated by peripheral sources such as machine vibration and wheel rotation were easily omitted using high-pass filters with cut-off frequency of 200 kHz. Just before starting to record AE, the grinding fluid was stopped to avoid the high level fluid noise. This method was successful because the noise level decreased considerably and the workpiece and the wheel were enough wet for the short period of engagement. Each experiment was repeated 3 times.

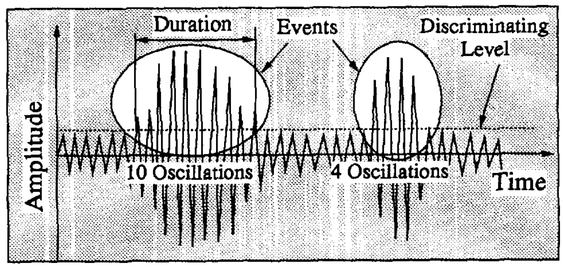

Fig. 2. Schematic of typical AE signal

The data analysis software let us to select the AE events within two predefined limits of amplitude, duration, rise time or oscillations. Figure 2 introduces some expressions of AE which are used in this work.

Discriminating level was set at 0.8-1.7 volts, depending on the background noise level; however, for data processing, an amplitude window of 2-5.1 volts was used. The data processing time window was 5 seconds for the data of all experiments. After the grinding process, grinding mode and surface damage were studied by SEM micrography.

3. Results and discussion

For analysis of acoustic emission signals different methods based on waveform power spectrum (FFT) and AE event counting were examined. As explained in previous works [6, 7], for quantitative comparison

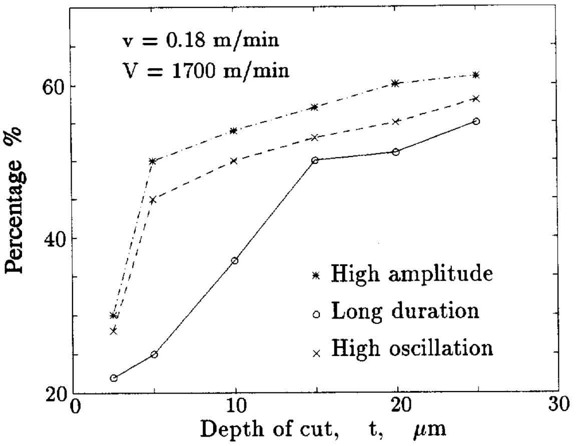

Fig. 3. Percentage of events of high amplitude, long duration, and high oscillation vs. wheel depth of cut.

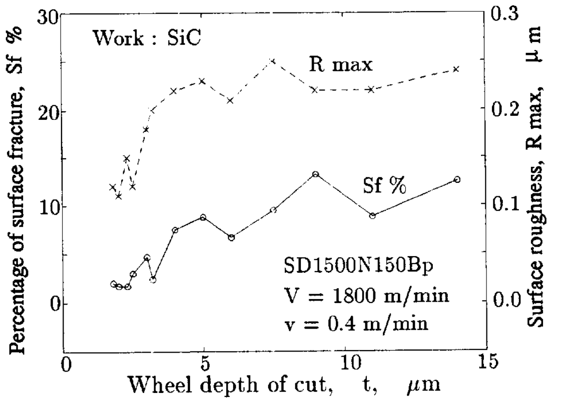

Fig. 4. Effects of actual wheel depth of cut on percentage of surface fracture and surface roughness of SiC. [1]

between the results of distribution plots such as amplitude distribution, duration distribution and oscillation distribution during each grinding experiment, it is suitable to choose a limit line on the graph and make a basis on the number of events on each side of this limit for evaluation as "higher" or "lower". The limit line is preferably determined using the experience for transition from ductile to brittle mode. Using this method, the percentage of events more or less than the threshold, give a unique value which can be plotted on a graph by one point. In grinding experiments, the threshold was decided 3 V for amplitude distribution, 20 μsec for duration distribution and 20 cycle/event for oscillation distribution. Thus, the values more than these limits were called *high amplitude*, *long duration* and *high oscillation.*

Figure 3 indicates that the percentage of events of high amplitude, long duration and high oscillation increase with increasing the wheel depth of cut, *t*. Generally, the results of previous studies showed that these parameters increase when the surface cracking and chipping increase. The increasing rate of high amplitude events at smaller depth of cut are more, but decreasing with increasing the depth. This may occur because of sinking the diamond abrasive grains into the resinoid bond of the wheel which is a controlling factor for the grain depth of cut.

It is interesting to compare this results with the results of grinding of SiC ceramic (Fig. 4) [1]. These data were obtained for quantitative evaluation of the finished surface of the ceramic workpiece, using the area percentage of fracture surface, S_f. For this purpose, an *image analyzing instrument* was used on a secondary electron image of a 2000 times magnified SEM photograph (The average of 10 times measurements was used as S_f for each sample). The percentage of surface fractures and surface roughness of ceramics increase with increasing wheel depth of cut.

In this case also it is possible to suggest a threshold for transition from ductile to brittle mode. Moreover, the results of previous works especially in scratching tests [6] confirm that with decreasing depth of cut, we will have a condition of ductile mode material removal. Thus AE can be used in place of microscopic observation for in-process monitoring of grinding mode of ceramics.

Similarly, the percentage of high-amplitude, long-duration and high-oscillation AE events can be plotted against table speed, v, (Fig. 5) and peripheral wheel speed, V, (Fig. 6).

From Fig. 5 it can be seen that these AE parameters are much sensitive to table speed when grinding is performing in creep feed mode, while in normal speed grinding this sensitivity decreases. In Fig. 6, however, all of the percentages decrease with increasing the wheel speed. Investigation reports that increasing the table speed or decreasing the wheel speed would increase the surface fracture and machining damages of ceramic materials [1]. Based on these facts, Fig. 5 and Fig. 6 indicate that increasing damages are accompanied by events of longer life, higher amplitude and more oscillations. This fact was also confirmed previously in scratching tests.

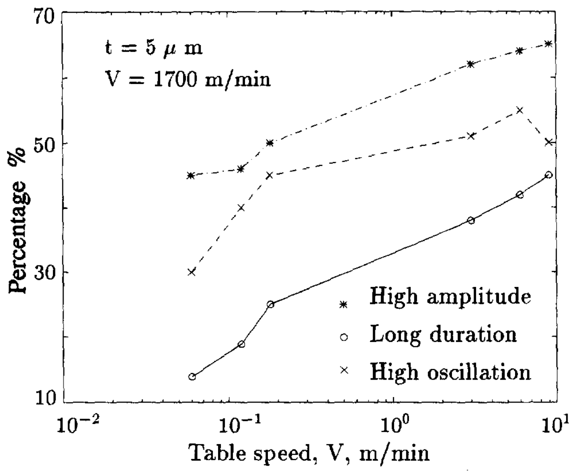

Fig. 5. Percentage of events of high amplitude, long duration and high oscillation vs. table speed.

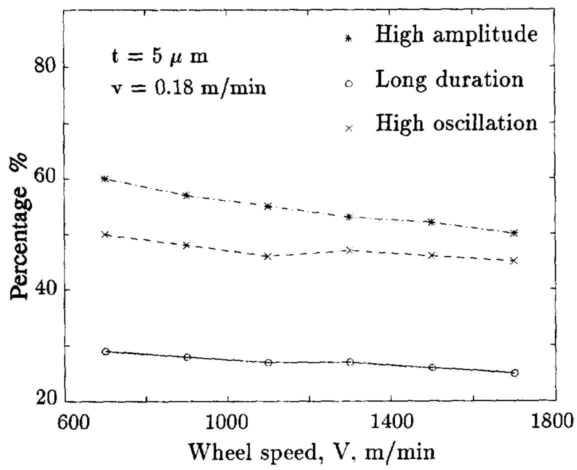

Fig. 6. Percentage of events of high amplitude, long duration and high oscillation vs. wheel speed

4. Effect of the coefficient of grain depth of cut on AE

The effects of grinding parameters on AE activities indicate that AE signals can be characterized by another basic parameter which is the coefficient of grain depth of cut, ϕ_g (Eq. 1). ϕ_g in Eq. 1 is a dimensionless value derived from grinding conditions. This factor which mainly controls the mode of grinding process, can be expressed by following equation:

$$\phi_g = v/V(\ t/D\ )^{1/2} \tag{1}$$

where:

ϕ_g = coefficient of grain depth of cut
t = wheel depth of cut
D = wheel diameter
v = table speed
V = wheel speed

The results of our previous research [9] indicate that we can use ϕ_g (Eq. 1) as a dimensionless parameter for evaluation of grinding mode of fine ceramics. For a constant grinding wheel, ϕ_g is only a function of the grain depth of cut (undeformed chip thickness), g. Therefore the amount of ϕ_g was calculated for each experiment and Fig. 7 was plotted. The plot confirms that with increasing ϕ_g which is accompanied by surface damage [9], the percentage of AE events of high amplitude, high oscillation, and long duration increase. There is a critical grain depth of cut for transition from ductile to brittle mode. These critical conditions can be evaluated by SEM observation.

Finally, at different wheel speeds, the table speeds were calculated and set so that ϕ_g was fixed and didn't change during the experiments. The results in Fig. 8 show that the amount of AE activities don't change when the grain depth of cut doesn't change. This fact indicates that AE activities are only a function of ϕ_g. Therefore, confirming the relationship between AE and ϕ_g will let us to use AE for grinding mode monitoring of fine ceramics.

5. Conclusions

1. The percentage of events of high amplitude, long duration and more oscillation which indicate surface cracking increase with increasing depth of cut and table speed but decrease as the wheel speed increases.

2. AE parameters also show good correlation with the coefficient of grain depth of cut, ϕ_g. When ϕ_g is kept constant, the AE activities don't change at different grinding conditions.

3. Confirming the relationship between AE and ϕ_g will let us to use AE for monitoring the grinding mode of fine ceramics.

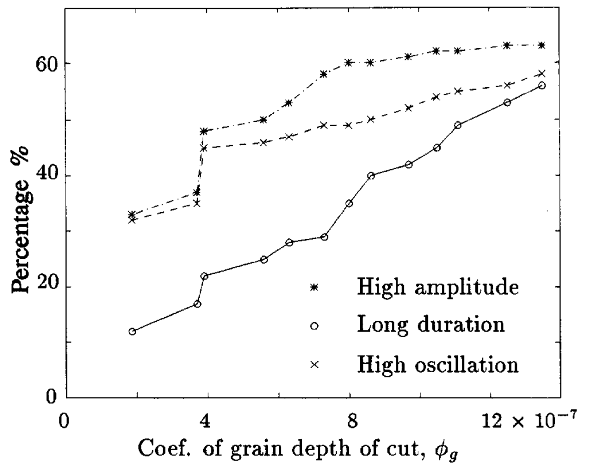

Fig. 7. Percentage of events of high amplitude, long duration and high oscillation vs. coefficient of grain depth of cut.

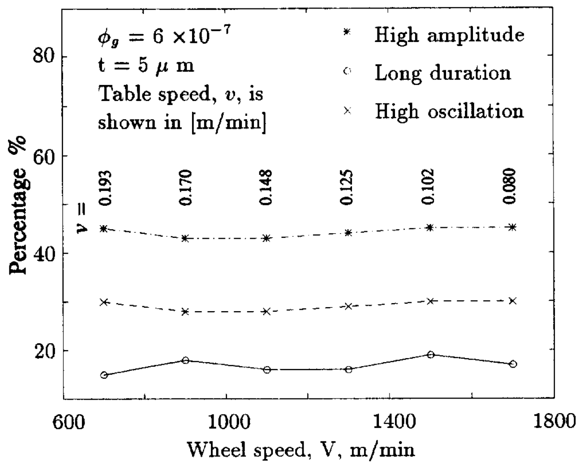

Fig. 8. Percentage of AE parameters at constant coefficient of grain depth of cut

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