In-Process Measurement of ELID Grinding Status
- Thickness of Insulating layer -

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To successfully establish the ELID-grinding, it is important to properly select the electrolytic condition according to grinding conditions. Currently, the selection of electrolytic condition is mainly dependent on the operator's experience, which is one of difficulties preventing the successful application of ELID technique. In this study, an in-process measurement system of the insulating layer using two gap sensors-a capacitance type and an eddy current type-are developed and the change of the thickness of insulating layer during ELID grinding is detected. Evaluation experiments show the possibility to control the electrolytic condition through the in-process measurement of the layer status.

Key Words : ELID Grinding, In-Process Measurement, Insulating Layer Thickness, Eddy Current Gap Sensor, Capacitance Gap Sensor

1. Introduction

ELID grinding is widely used as a high-productivity and super-precision grinding method for hard and brittle materials such as ceramics and quartz because it continues to grind stably with no loading even on the surface of metal bonded diamond wheel due to its in-process dressing (Ohmori and Nakagawa, 1995; Kim and Ohmori, 1997). The high quality surface ground by ELID grinding which is highly dependent on the combination of grinding conditions and electrolytic conditions is difficult to obtain because their settings are up to operator's experience so far (Ohmori and Takahashi, 1994). To do that, in general, it is known that the wear rate of the abrasive and the removal rate of the metal bond of the grinding wheel should be balanced to maintain the depth of the insulating surface layer to an appropriate level.

In order to accomplish the high quality ELID grinding it is necessary to measure the depth of the insulating layer in real-time and then to control the electrolytic conditions to keep the depth to a certain level. However, the in-process layer measurement has not been conducted yet because no appropriate sensors are developed and ELID grinding system generates so much electrical noise.

In this study, an in-process measurement system of the insulating layer using two gap sensors-

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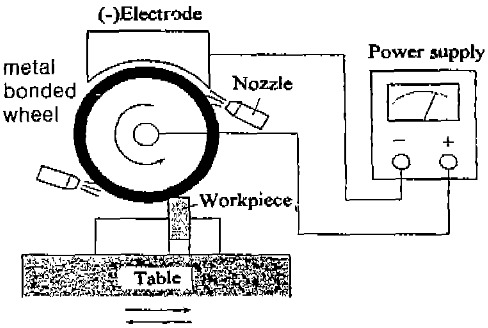


Fig. 1 Principle of ELID grinding

a capacitance type and an eddy current type-was developed and the change of the status of the insulating layer during ELID grinding is detected.

2. Mechanism of ELID grinding

Figure 1 shows the principle of ELID grinding (Ohmori, 1993; Lee, Je and Ohmori, 2000). A metal bonded diamond wheel is put electrically positive, an electrode located above the wheel surface is negative. With as small clearance as around 0.1mm between the negative and the positive poles, electrolysis occurs on suppling electrically conductive fluid and a pulsetype direct current. This process enables to maintain the protrudent grains during the grinding operations. Figure 2 shows the in-process dressing mechanism in ELID grinding. At the beginning of ELID process much current, up to the possible maximum value, flows so that the electrolysis occurs actively because the surface of a newly dressed wheel has high electrical conductivity.

A few minutes later, the metal bond of the wheel begin to fall out by electrolysis and some insulating layer of Fe_2O_3 begins to cover the surface of the wheel. In about 30 minutes when the insulating layer reaches to a certain level of thickness, the flowing current rapidly decreases and the pre-dressing comes to an end. In ELID grinding following pre-dressing as the protrudent grains grind the workpiece, the grains and the insulating layer wear down. As the electrical conductivity of the wheel surface increases due to the wear of the insulating layer, the electrolysis increases so that the insulating layer recovers.

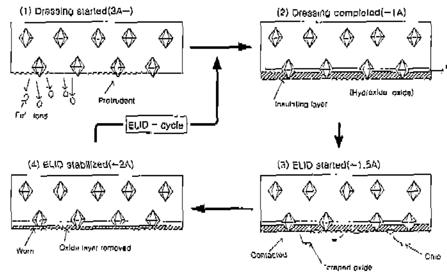
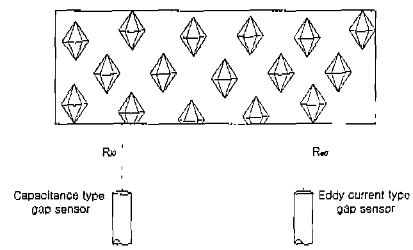
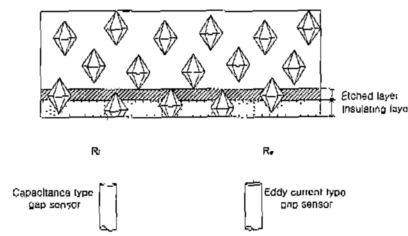


Fig. 2 In-Process dressing mechanism



(a) After truing



(b) ELID grinding

Fig. 3 Measurement principle of insulating layer

This process is then repeated. In Fig. 2, the etched layer is a corroded layer made by the falling out of the metal bond, which cases the abrasives protrude.

3. Principle of Insulating Layer Measurement

Figure 3 shows a principle for the measurement of the insulating layer considering the generation mechanism of the insulating layer in ELID grinding. The depth of the insulating layer, t_i, is theoretically expressed as follows:

$$t_i = R_i - R_e$$

where, R_i is the radius of the insulating layer surface, R_e is the radius of the etched layer surface.

Table 1 Specifications of experimental equipments

Machine tool	Reciprocating surface grinder EPG52S : [Nagase Co.]
Grinding wheel	#4000 cast iron bonded CBN wheel(grit size 5μm)
Workpiece	SKD11
Power supply	FUJI ELIDER ED910 [Fuji Dies Co.]
Fluid	AFG-M+tap water (1.28% dilution of water)
Gap sensors	Eddy current type : AEC-5706PS, Resolution max. 0.02μm Capacitance type : VE133[Ono Sokki Co.], Resolution max. 1μm
	Surftest SV501 [Mitutoyo Co.]

Table 2 Grinding/electrolytic conditions of experiments

Grinding conditions	Spindle speed(rpm) : 2000 Depth of cut(μm/pass) : 0.1
Electrolytic conditions	Condition① : Eo 100V, Ip 10A, τ on/off=5μs Condition② : Eo 50V, Ip 5A, τ on/off=5μs Condition③ : Eo 30V, Ip 2A, τ on/off=5μs

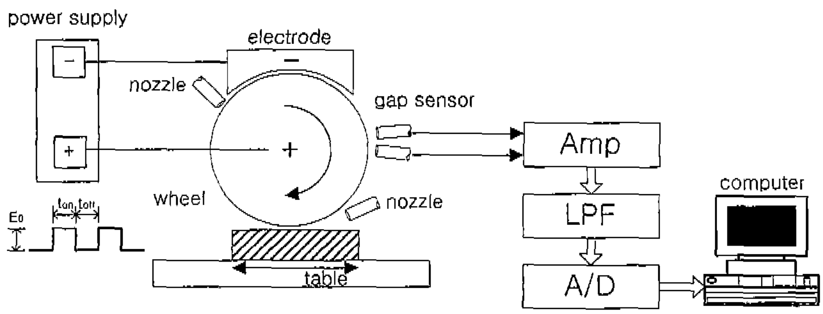


Fig. 4 Schematic diagram of experimental setup

In this study, a capacitance type and an eddy current type gap sensors are used to measure R_i and R_e, respectively. In order to remove the capacitor effect of grinding fluid, a special unit with compressed air is devised to remove the fluid between the wheel and the capacitance type gap sensor.

4. Experimental Setup and Method

Figure 4 shows a schematic diagram of the experimental apparatus. Two kinds of gap signals are filtered through low-pass filters at a sampling rate of 1kHz into a PC. Table 1 shows the specifications of the experimental equipment. Table 2 shows the grinding/electrolytic conditions of the experiments.

The effect of the electrolytic conditions to the thickness of the insulating layer is investigated for three conditions ①, ② and ③ under the same grinding conditions. In any case, pre-dressing of at least 30 min should be done to make sure that the insulating layer covers enough the whole wheel surface prior to ELID grinding.

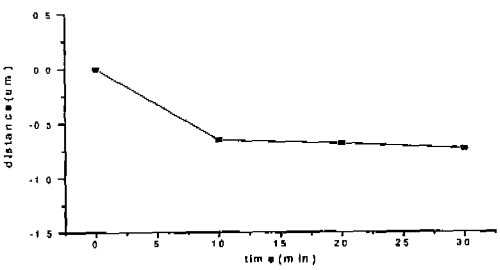
5. Experimental Results and Discussion

Figure 5 show the variation of the wheel surface at the electrolytic condition ①.

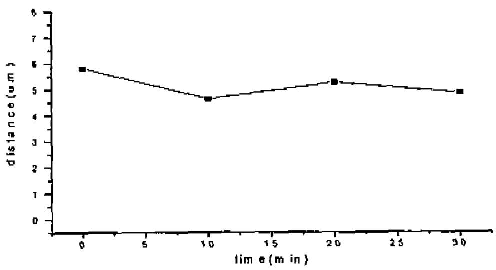
Figure 5(a), (b) show the radius measurements of the etched layer surface and the insulating layer surface respectively. The former represents the removal amount of the bonding metal by ele-

Table 3 The variations of average value during grinding

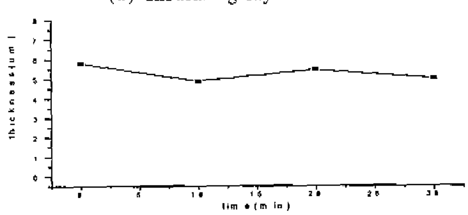
Electrolytic conditions	① 100V 10A	② 50V 5A	③ 30V 2A
Decrease of etched layer surface	1.4μm	0.4μm	1.2μm
Decrease of insulating layer surface	1.0μm	0.9μm	0.6μm
The estimated thickness of insulating layer	5μm	4μm	3.6μm



(a) Etched layer surface

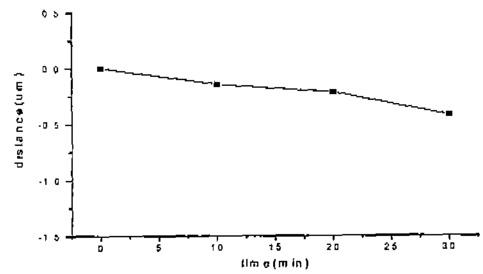


(b) Insulating layer surface

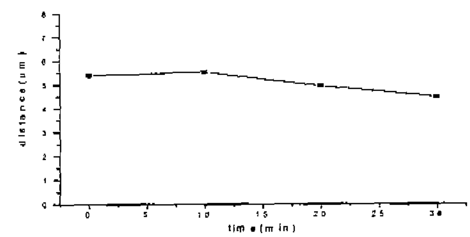


(c) Estimated thickness of insulating layer from (a), (b)

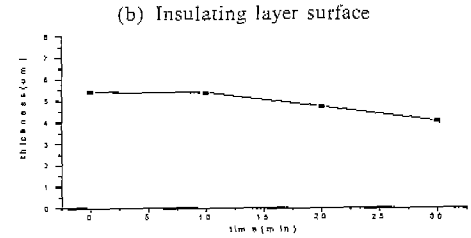
Fig. 5 In-process measurements of the layer surfaces during ELID grinding (electrolytic condition ①)



(a) Etched layer surface



(b) Insulating layer surface



(c) Estimated thickness of insulating layer from (a), (b)

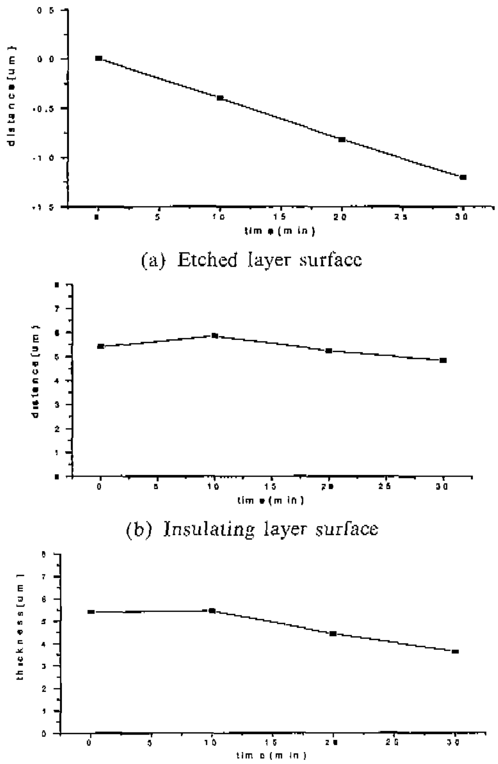
Fig. 6 In-process measurements of the layer surfaces during ELID grinding (electrolytic condition ②)

ctrolysis, the latter represents the wear amount of wheel by mechanical contact between wheel and workpiece.

Figure 5(c) is the estimated thickness of the insulating layer based on the two radius measurements - (a), (b). In the same way, the results for the electrolytic condition ② and ③ are shown in Fig. 6 and Fig. 7. The signals were acquired for 10 msec just after every 5 minutes ELID-grinding and then were averged. As shown in Fig. 5(a) and Fig. 6(a), the decrease amount of the etched layer surface for the condition ① is greater than that of condition ②. This fact implies that the electrolytic condition is stronger and that the removal amount of bonding metal is greater, Therefore, it is desirable to select the electrolytic condition as weak as possible to prevent the

Table 4 Surface roughness of the ground surface

Electrolytic condition	Ra	Rmax
① 100V 10A	10.7 nm	72 nm
② 50V 5A	9.4 nm	67 nm
③ 30V 2A	20 nm	200 nm



(a) Etched layer surface

(b) Insulating layer surface

(c) Estimated thickness of insulating layer from (a), (b)

Fig. 7 In-Process Measurements of the Layer Surfaces during ELID Grinding (electrolytic condition③)

excessive wear of wheel. The thickness of insulating layer is also almost uniformly kept about 5μm and 4μm, respectively. These result show that the balance between the removal rate of the bonding metal by electrolysis and the wear rate of diamond grains are sustained during ELID-grinding.

As shown in Fig. 5(a) and Fig. 7(a), the thickness of insulating layer for condition ① is unformly kept along with ELID-grinding, while that of condition ③ is continuously decreased along with ELID-grinding.

In case of condition ③, due to the weak electrolytic condition compared with the grinding condition, the ELID-grinding is being carried out which the insulating layer is not fully recovered.

Table 3 summarizes the average value of each data for the three conditions. Even under the same grinding condition, due to stronger electrolytic condition, the insulating layer for condition ① is thicker than that for condition② and ③.

For the same reason, the wheel wear due to the removal of the bonding metal becomes about 1.4 μm for the condition ①, which is larger than 0.4 μm for condition ② and 1.2μm for condition ③.

Although the condition ③ is weaker than the condition ②, the wheel wear for condition ③ is larger than that of condition ② because of a poor recovery of the insulating layer.

Table 4 shows the surface roughness of the ground surface. The surface roughness for condition ② is the best, while the surface roughness for condition ③ is the worst. Despite of the same grinding condition, this difference of surface roughness was caused by the variation of thickness of insulating layer during ELID-grinding.

For stably efficient grinding in ELID with micro-grain sized wheel, it is desirable that the thickness of insulating layer is somewhat small kept than the grain size of wheel.

In case of electrolytic condition ②, ELID-grinding is being carried out with the grain of wheel is protruded about 1μm, while, in case of condition ③, the protrudent amount of abrasive grain is too large. Because of excessive contact of the bonding metal and workpiece, the quality of ground surface for condition ③ becomes coarse.

Therefore, in order to get a high quality surface, the proper control of thickness of insulating layer according to the grinding condition is very important.

Theses results show the possibility to keep the thickness of insulating layer to a certain level of the grain size to get the high quality surface by controlling the electrolytic conditions through in-process measurement of the layer status.

6. Conclusion

In the study, an in-process measurement system for the insulating layer in ELID grinding was developed and its performance was evaluated through experiments. The summarizing remarks are as follows:

(1) Thickness of the insulating layer in ELID grinding was estimated based on the measurements of both insulating layer surface and etched layer surface by a capacitance type gap sensor and an eddy current one.

(2) In-process measurement of the insulating layer verified the fact that the stronger electrolytic condition the thicker of insulating layer and the more wheel wear.

(3) The feasibility to be able to develop a real-time electrolytic condition control system using the in-process measurement of the insulating layer was suggested.

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