Mirror Surface Grinding for Brittle Materials with In-Process Electrolytic Dressing

J.-D. Kim and Y.-J. Lee

Use of a diamond wheel with superabrasive is required for mirror-like surface grinding of brittle materials. However, conventional dressing methods cannot apply to the diamond wheel with superabrasive. Recently, an electrolytic dressing method was developed for use with a cast iron-bonded diamond wheel and superabrasive. This technique can replace lapping and polishing. Using electrolytic dressing, surface roughness of the workpiece was improved significantly, and the grinding force was very low and the continuity of the grinding force was also improved. The purpose of this study was to achieve mirror-like surface grinding of ferrite with electrolytic dressing of a metal-bonded diamond wheel. For application of ultraprecision grinding for brittle material, superabrasive, air spindle, and in-process electrolytic dressings were used. Additionally, the effects of pick current and pulse width on ground surface were investigated, and suitable dressing conditions for ferrite were determined.

Keywords

brittle material, cast iron fiber-bonded wheel, electrolytic dressing, ferrite, mirror-like surface grinding, superabrasive diamond wheel

1. Introduction

RECENTLY, mirror-like surface grinding of brittle materials such as silicon, ferrite, and ceramics has become necessary for use in the semiconductor and optical industries. In particular, ferrite is indispensable as the material of choice for magnetic heads, and cracking and chipping are likely to occur.[1] Lapping and polishing are used to produce mirror-like surfaces on these materials, but work on superprecision grinding to replace polishing and lapping is being actively pursued.[2] Because superabrasive diamond and Cubic Boron Nitride (CBN) wheel are economical, brittle materials such as ferrite, ceramic, silicon, and optical lens are suitable for grinding, but mirror-like surface grinding in which surface roughness (*Ra*) must be less than 200 nm is possible using a superabrasive wheel (greater than No. 1000).[3] Dressing of the superabrasive wheel is difficult due to loading and glazing.[4]

A new dressing method based on the use of electrolysis for the superabrasive wheel has been developed.[5] Conventional dressing is based on mechanical removal, and electrodischarge is based on electric removal, but the new electrolytic dressing method is based on an electric/chemical principle.[6] In this study, the electrolytic dressing system was constructed. To obtain mirror-like surface grinding of ferrite, the effects of electrolytic fluid, pick current, and pulse width and the relationship between electrolytic dressing and brittle fracture were studied.

2. Experimental Setup and Method

Figure 1 illustrates the electrolytic dressing system. The electrode is made of copper of 99% purity, and the gap distance between the electrode and the wheel surface is 0.1 mm. A surface grinding machine was used with an air spindle, and the electrode and electrolytic dressing unit were attached to the machine. Power source output was DC pulsed, and τ_{on}, τ_{off} is 5, 50, 100, and 200 μs. A voltmeter and ampmeter were at-

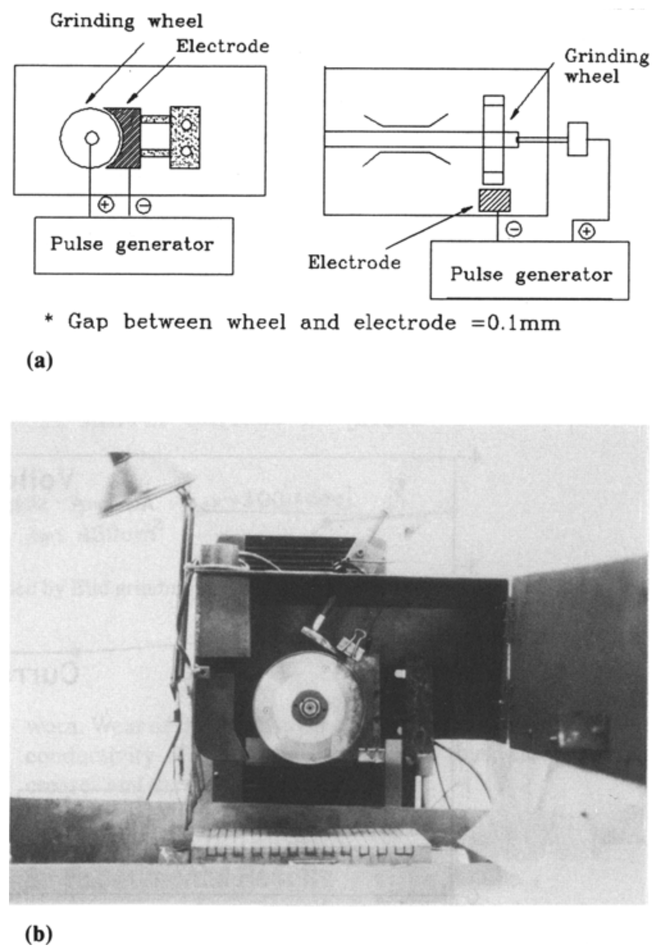

Fig. 1 Experimental grinding apparatus with in-process electrolytic dressing system.

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tached to the power source. The air dryer was a Hankinson Air Dryer 8010 (Hankinson Company, USA). The electrolytic fluid for Elid-grinding (Electrolytic In-process Dressing) was a solution type. Truing was accomplished with a brake-truing instrument with a green carborundom (GC) wheel. For measuring grinding force, a tool dynamometer, A/D converter, and personal computer were used. For measuring surface roughness, a

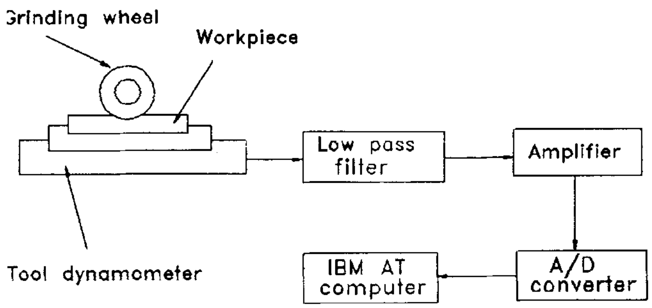


Fig. 2 Schematic of force measurement system.

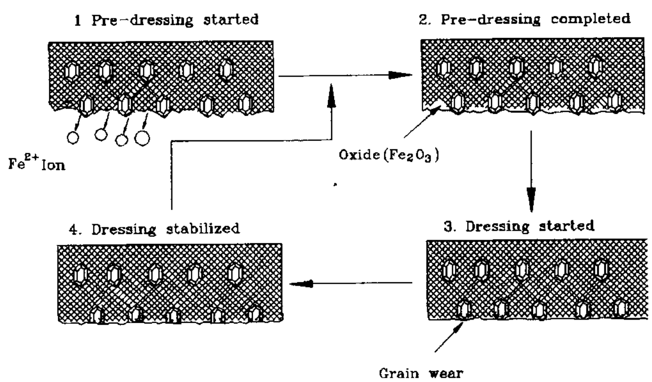


Fig. 3 Schematic of electrolytic dressing mechanism.

Table 1 Experimental grinding conditions

Grinding machine	Surface grinding machine (KGS-600H)
Wheel	SD8000, SD4000
Wheel for truing	GC60K7VG
Workpiece	Ferrite
Power source	EPD-3A (I_p = 5 to 20 A, τ_{on} = 5 to 200 μs)
Electrode	Overlapped area; one third of the wheel Material: pure copper
Electrolytic fluid	Solution type 3
Surface roughness tester	Noncontact surface roughness measurement system WYKO

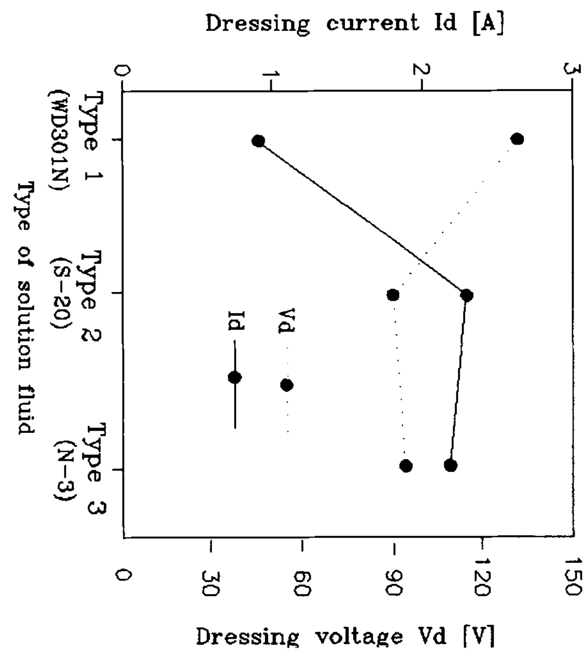


Fig. 4 Relationship between dressing current and voltage in electrolytic fluid. Depth of grinding, 5 μm; pick current, 20 A.

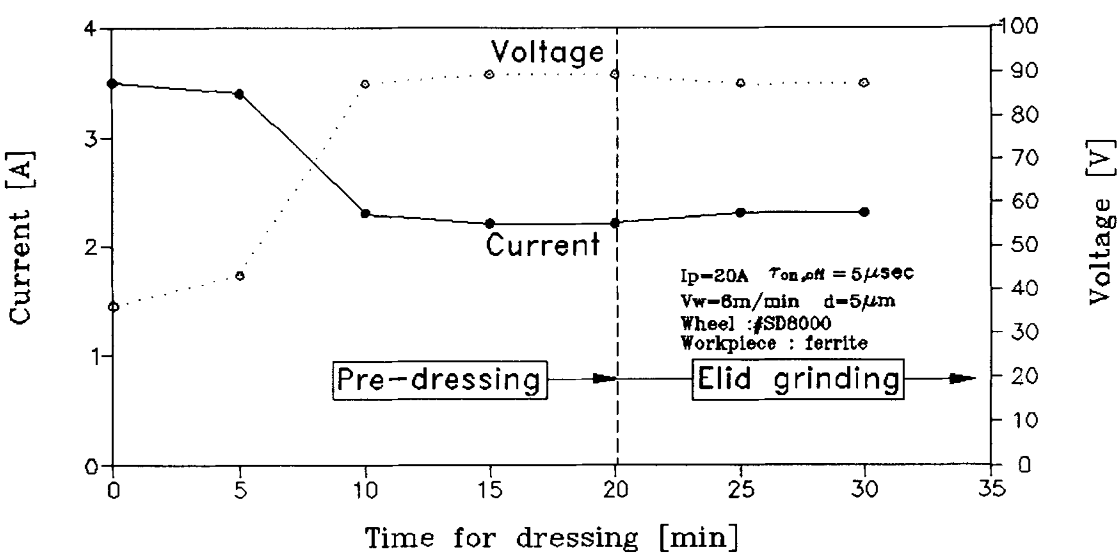
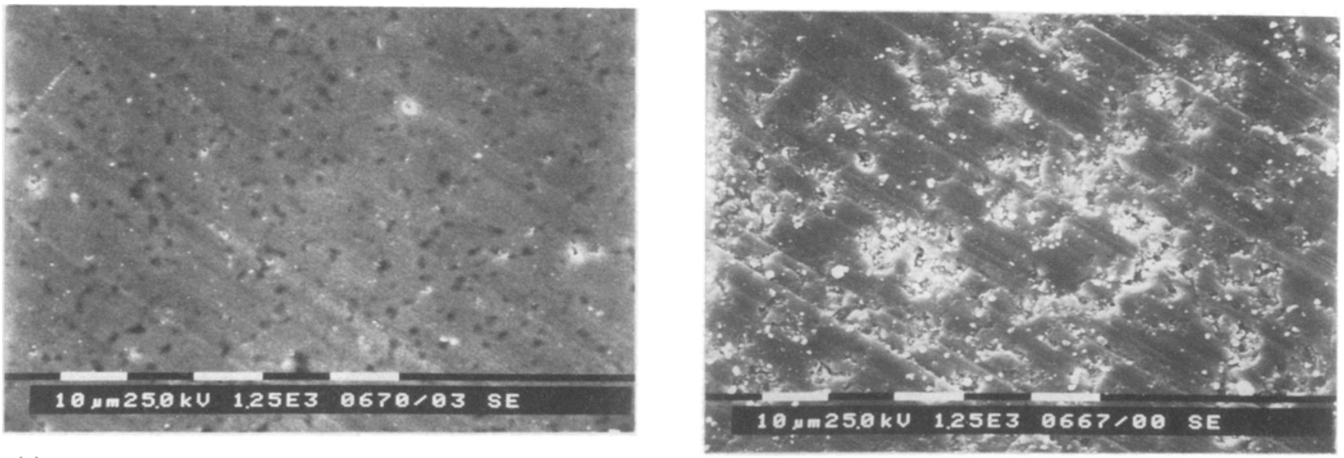


Fig. 5 Electrical behavior of the electrolytic dressing.



(a) (b)

Fig. 6 SEM photograph of ground ferrite surface produced by No. SD8000 wheel.

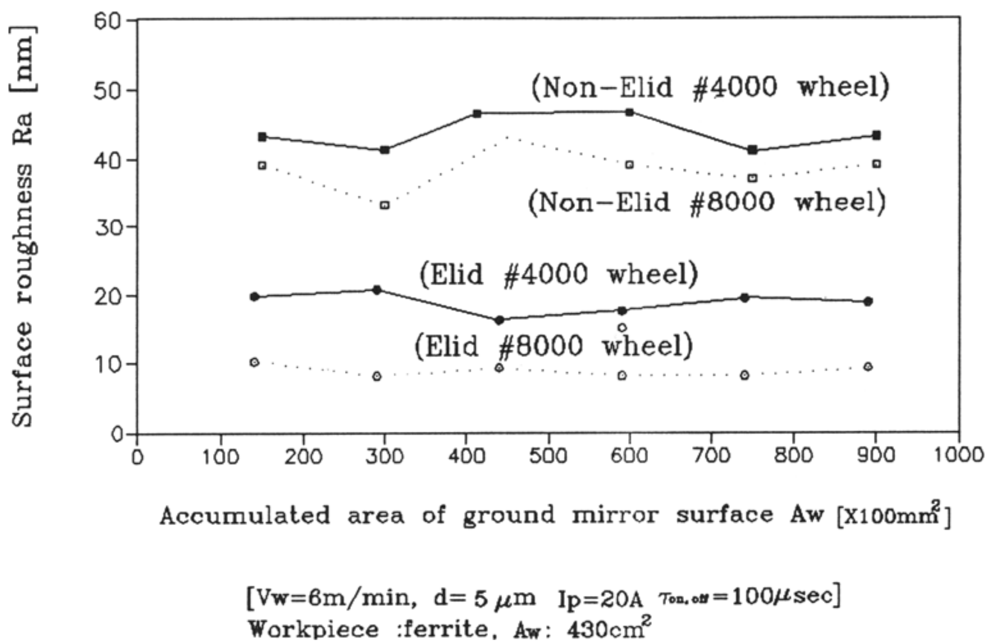


Fig. 7 Surface roughness of ground mirror-like surface of ferrite obtained by Elid grinding. Vw = 6 m/min; d = 5 μm; I_p = 20A; τ_{on}, τ_{off} = 100 μs. Workpiece: ferrite; Aw: 430 cm^2.

noncontact surface roughness measurement system (WYKO) was used. Figure 2 illustrates the measurement system.

Specifications of the machine tools used for the experiments are shown in Table 1. Figure 3 shows a schematic diagram of the electrolytic dressing system. The wheel is the + pole, and the electrode was fixed below the – pole. At a small clearance, electrolysis occurs by supply of an electrical current, and a cast iron bond is ionized in Fe^{2+}. The ionized iron is changed into Fe_2O_3 oxide by electrolysis of water; electrolysis does not occur due to the occurrence of oxide substances. Accordingly, grinding starts at the same time the oxide layer also becomes worn. Wear of the oxide layer causes an increase in the electroconductivity of the wheel surface, and thus, electrolysis increases and the oxide layer is recovered.

3. Experimental Results

3.1 *Effect of Electrolysis Fluid*

Figure 4 shows the results of dressing voltage and current measurement in using solution Type 1 (WD-301N), solution

Type 2 (S-20), and solution Type 3 (N-3) as the electrolysis fluid. Grinding conditions are as follows: depth of cut, 5 μm and pick current, 20 A. In Fig. 4, the dressing voltage is highest at 125 V and dressing current is lowest at 0.9 A in solution Type 1. Therefore, electrical resistance is highest in solution Type 1, and the dressing current and voltage in solution Type 1 and 2 are similar.

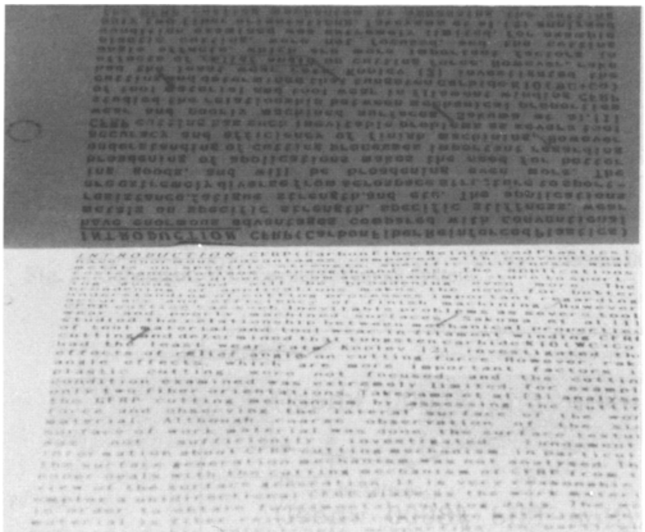


Fig. 8 Ground mirror-like surface of ferrite obtained by using No. SD8000 wheel and the electrolytic dressing.

High electrical resistance causes a large consumption of electrode,[6] and requires a large power source. Therefore, the appropriate electrolysis fluid is solution Type 2 or 3.

3.2 *Electrical Behavior during Electrolytic Dressing*

Figure 5 illustrates the electrical behavior during electrolytic dressing. When predressing starts, the surface-trued wheel exhibits good electroconductivity. Therefore, the current is high and voltage is low. After several minutes have passed, the bond material is removed by electrolysis. The ionized iron makes a hydroxide substance. Next, this substance changes into an oxide substance, and the electroconductivity of the surface of the wheel is reduced in accordance with the growth of the insulating oxide. Consequently, the current decreases, and the voltage becomes high. Accordingly, grinding starts at the same time the oxide layer also becomes worn. Wear of the oxide layer causes an increase in the electroconductivity of the wheel surface, and the electrolysis thus increases and the oxide layer is recovered.

3.3 *Improvement and Stability of Surface Roughness*

Figure 6(a) shows a scanning electron micrograph (SEM) of a ground mirror surface by Electrolytic In-process Dressing (Elid). Figure 6(b) shows the SEM photograph of a ground surface after the ground volume is 430 cm^2 not using Elid. In Fig. 6(a), a mirror-like surface is generated. In Fig. 6(b), brittle fracture occurred on the entire surface. This difference is caused by the following. When grinding starts, the tip of the grain is flattened by attritious wear, and the flattened area increases. The grinding force thus increases in accordance with the growth of the flattened area.[7] The beginning of the crack increases in

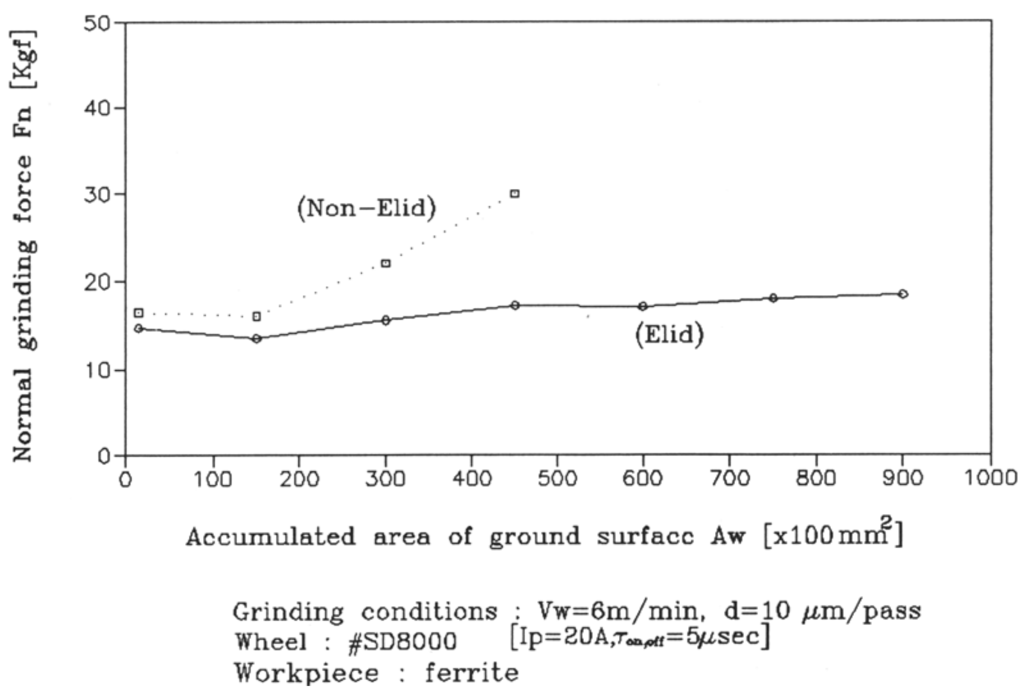
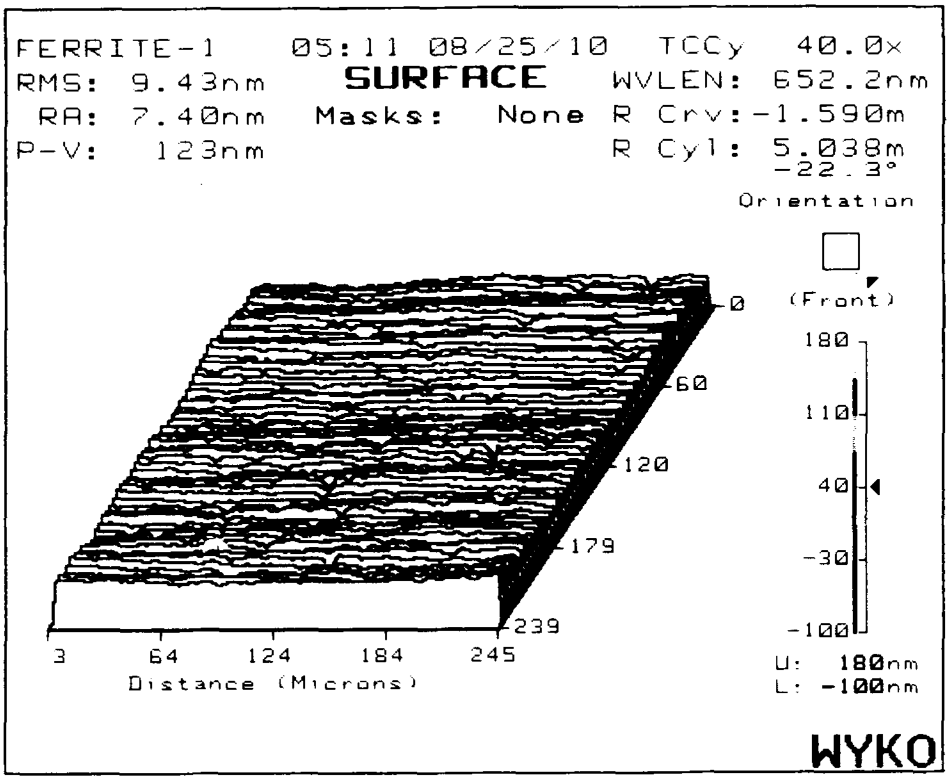
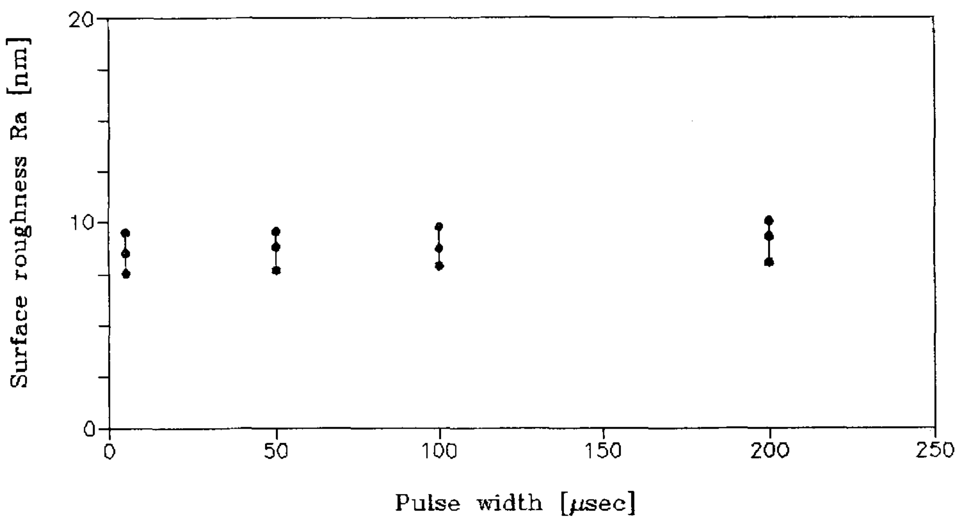


Fig. 9 Results of normal grinding force by Elid grinding. Grinding conditions: Vw = 6 m/min; d = 10 μm/pass; wheel, No. SD8000; I_p = 20 A; $\tau_{on,off}$= 5 μs; workpiece, ferrite.



(a) Example of non-contact surface roughness measurement

(a)



(b) Result of non-contact surface roughness measurement

[Vw=6m/min, d=5μm, Ip=20A]
Wheel : #SD8000

(b)

Fig. 10 Effect of pulse width on surface roughness. (a) Noncontact surface roughness measurement. (b) Noncontact surface roughness measurement.

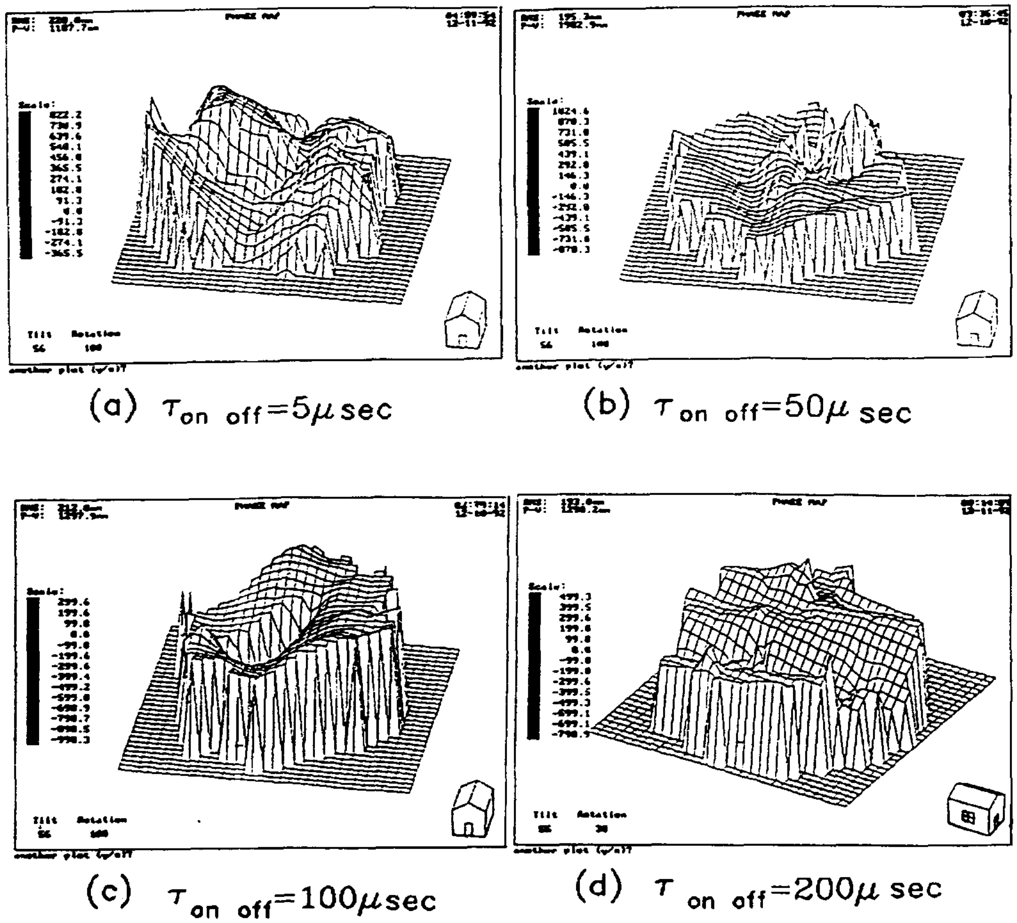


Fig. 11 Effect of pulse width on flatness. No. SD8000 wheel; I_p = 20 A.

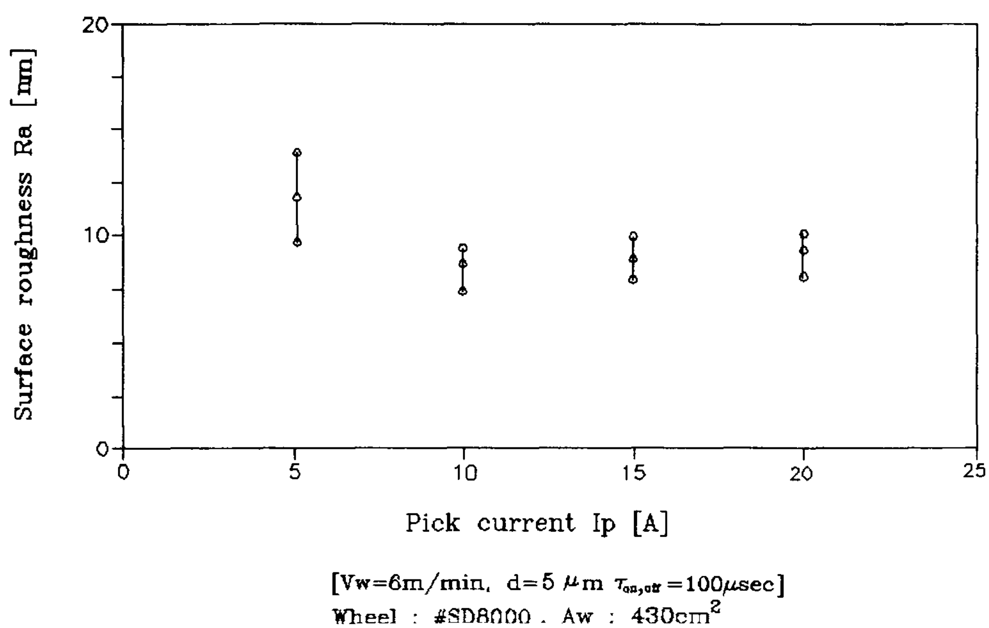


Fig. 12 Effect of pick current on surface roughness (ferrite). Vw = 6 m/min; d = 5 μm; $\tau_{on,off}$ = 100 μs; wheel: No. SD8000; Aw = 430 cm^2

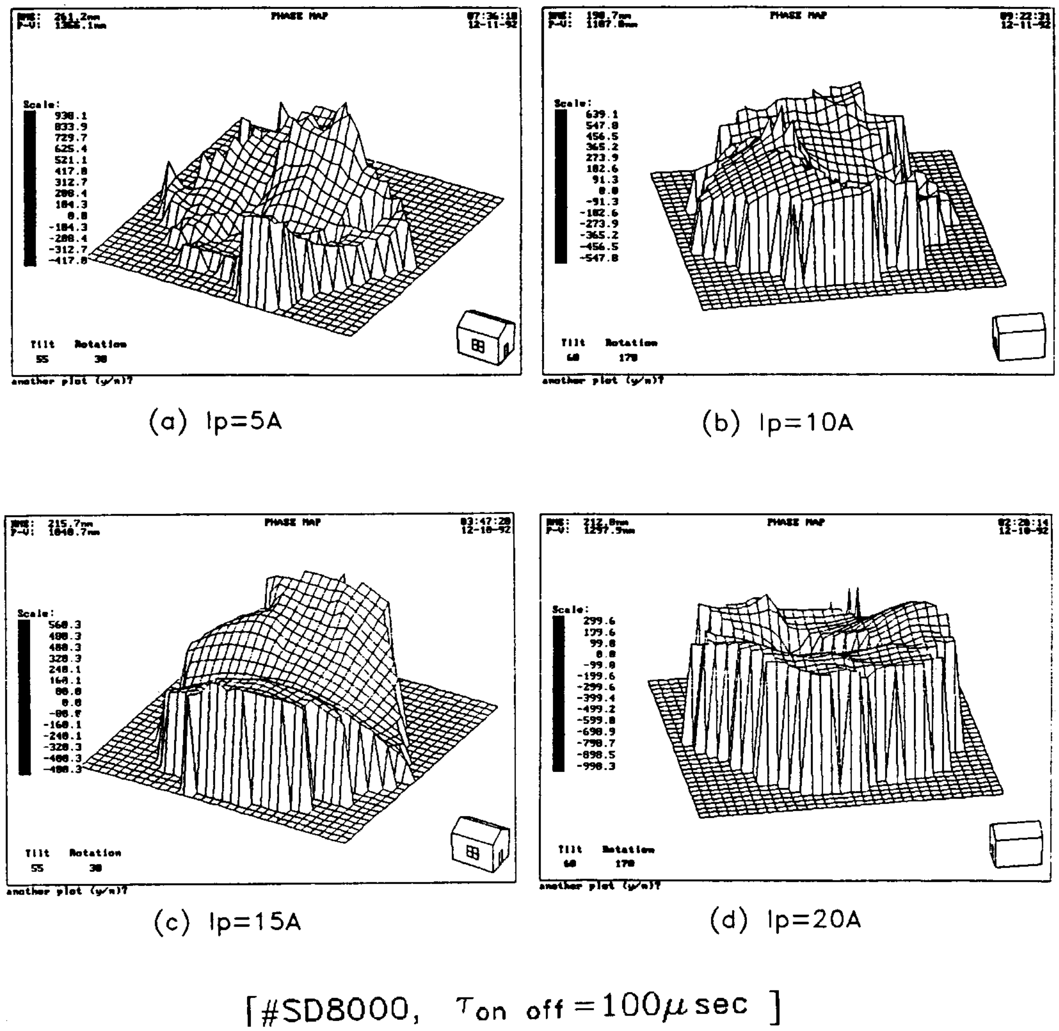


Fig. 13 Effect of pick current on flatness. No. SD8000; $\tau_{on,off}$= 100 µs.

proportion to the grinding force and the hardness of the material.[8] Consequently, cracking occurs on the surface interfacing with the flattened grain. In conventional dressing, cracking and chipping occur largely because the number of grains with flattened areas due to attritious wear is great. However, when electrolysis starts in Elid, the depth of bond supporting the grain decreases, and the force supporting the grain decreases; thus, the flattened grain easily falls off when the grinding force approaches a critical force, and grains with over-flattened areas do not occur. By using Elid, the grinding force is less than the critical force required to initiate cracking, and brittle fracture does not occur. Consequently, grinding is performed in a ductile mode.

Figure 7 shows the stability of a ground surface obtained by Elid grinding when the ground volume is 430 cm^2. The grinding surface roughness in Elid grinding is less than that in non-Elid grinding, and the variation in surface roughness in Elid is minimal, although the ground volume increases. In the case of Elid, due to the effect of the protrusion of micrograins, the surface was ground to a mirror-like condition. Grinding conditions included a table speed of Vw = 6 m/min and depth of cut of d = 5 µm. The surface roughness of ground ferrite using No. SD4000 wheel was 18 nm and 7 nm using a No. SD8000 wheel. Figure 8 shows the ground mirror-like surface of the ferrite.

3.4 *Grinding Force*

Figure 9 shows the effect of electrolytic dressing on grinding force. When ground volume (Aw) approaches 430 cm^2 in non-Elid grinding, the grinding force increases abruptly and is twice as high as the grinding force in Elid grinding. The increase in grinding force in non-Elid grinding is caused by glazing and loading. The grinding force in Elid grinding is less than that in non-Elid grinding because of the appropriate protrusion of the micrograins and the chip removal effect of the oxide layer.

3.5 *Effect of Dressing Conditions on Ground Surface*

3.5.1 Effect of Pulse Width

Figure 10 shows the effect of pulse width on surface roughness, and Fig. 11 shows the result of flatness measurements

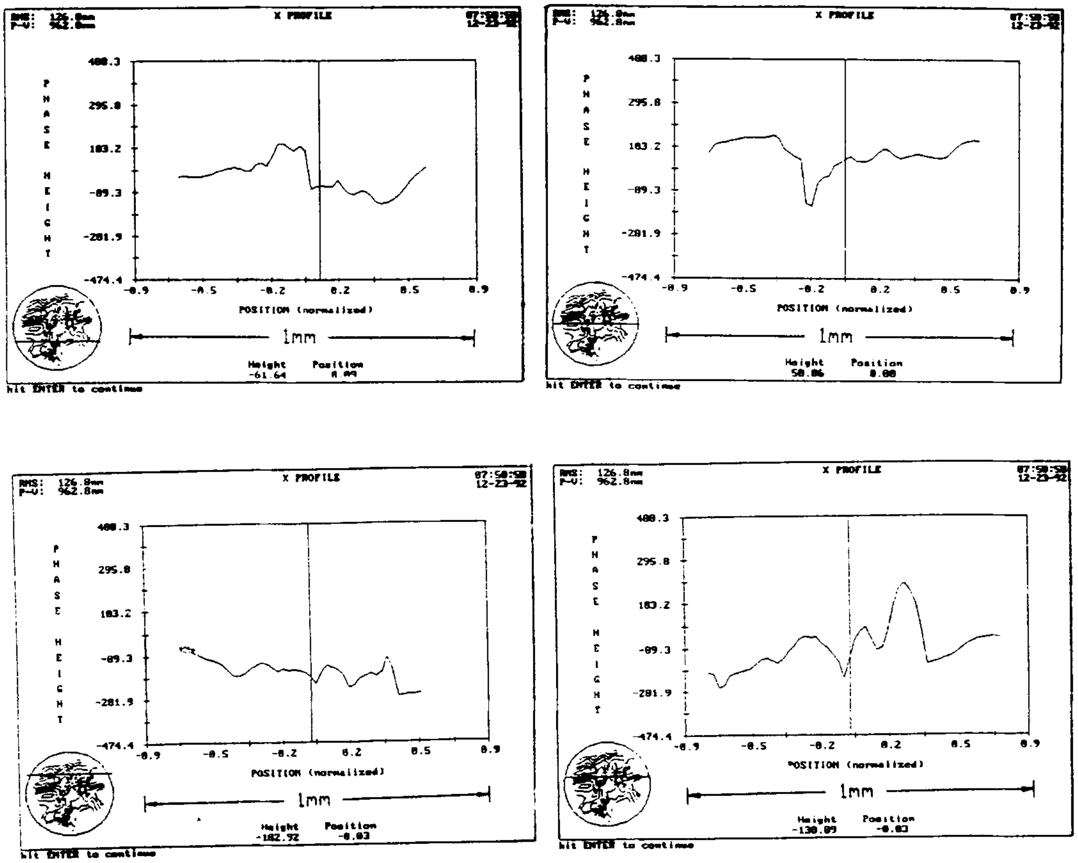


Fig. 14 Flatness of grinding surface perpendicular to grinding direction.

made by a laser interferometer. Using a superabrasive wheel (No. SD8000), the surface roughness (*Ra*) ranged from 7.4 to 10.5 nm, and the flatness measured by the laser interferometer ranged from 193 to 228.8 nm in RMS. Ignoring measurement variances and errors, the pulse width had little influence on surface roughness. The present results are in accord with the results of Suzuki.[6] When τ_{on} and τ_{off} are the same, even though pulse width varies, the ionized volume[9] is the same, even though determined by Eq 1, because the dressing current is the same. Consequently, the pulse width has little effect on the electrolytic dressing:

$$M = k \cdot I_d \cdot t \qquad [1]$$

where M is the ionized volume of the wheel; k is the ion value; I_d is the dressing current; and t is dressing time.

3.5.2 Effect of Peak Current (I_p)

Figure 12 shows the effect of pick current on surface roughness, and Fig. 13 shows the result of flatness measurements made by a laser interferometer on respective pick current. Surface roughness (*Ra*) is greatest at 9 to 14 nm and the flatness Root Mean Square (RMS) is also greatest at 261.2 nm for 5 Amps. Surface roughness ranged from 7.4 to 10 nm, and the flatness RMS ranged from 190.7 to 215.7 nm for 10, 15, and 20 A. Ignoring variances and error measurement, the change of surface roughness was very small for 5A. In the case of I_p>10 A, excessive electrolysis was encountered without improvement in surface roughness. Consequently, the appropriate pick current for ferrite is 10 to 15 A. Figures 14 and 15 show the flatness of the ground surface in the grinding direction and perpendicular to the grinding direction. This result illustrates the ductile mode of grinding ferrite.

4. Conclusion

In this study, the following results were obtained. Mirror-like surface grinding of ferrite can be achieved by using an in-process electrolytic dressing technique. Low grinding force is maintained in grinding ferrite using an in-process electrolytic dressing technique because of satisfactory protrusion of the grains. Brittle fracture does not occur due to use of this low grinding force. The pulse width has little effect on surface roughness of ferrite because in general pulse width has little effect on ionized volume. The appropriate pick current for ferrite is 10 to 15 A. Using an in-process electrolytic dressing and a cast iron bonded diamond wheel (No. 8000) for ferrite, surface roughness is 7.4 nm and flatness RMS is 190.7 nm. The appropriate electrolysis fluid for ferrite is solution Type 1 and Type 2.

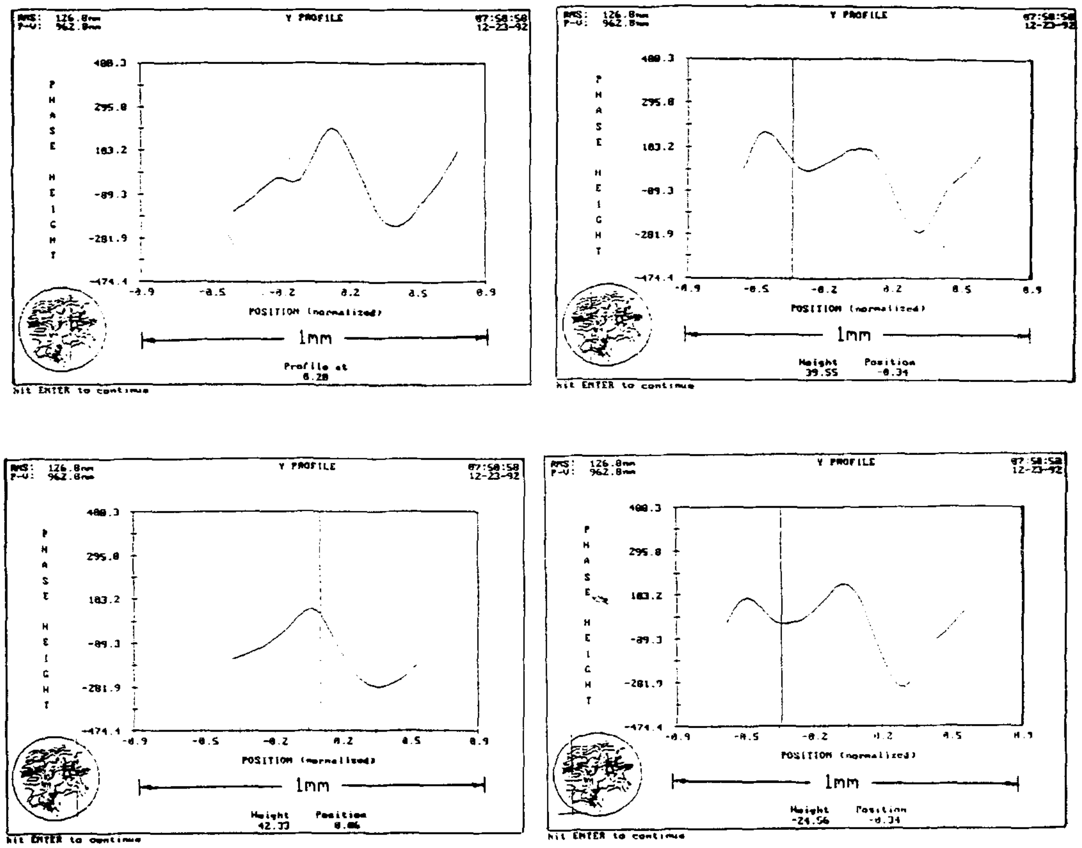


Fig. 15 Flatness of grinding surface versus grinding direction.

References

1. A.B. Groenou and J.D.B. Veldkamp, Grinding Brittle Materials, *Phil. Tech. Rev.*, Vol 38, 1979, p 131-144
2. H. Ohmori, "Elid Mirror Surface Grinding Technology with Electrolytic In-Process Dressing," Elid Grinding Research Group, RIKEN, 1991, p 8-31
3. "N.N. The Trend and Future of Mirror Like Grinding," Material Fabrication Laboratory, 1991, p 147-148
4. R. Komanduri and W.R. Reed, A New Technique of Dressing and Conditioning Resin Bonded Superabrasive Grinding Wheel, *Ann. CIRP*, Vol 29, 1980, p 239-243
5. H. Ohmori and T. Nakagawa, Mirror Surface Grinding on Silicon Wafers with Electrolytic In-Process Dressing, *Ann. CIRP*, Vol 39, 1990, p 329-332
6. K. Suzuki and T. Uematsu, Development of a Simplified Electrochemical Dressing Method with Twin Electrodes, *Ann. CIRP*, Vol 40, 1991, p 363-366
7. S. Malkin, The Wear of Grinding Wheels Part 1. Attritious Wear, *Trans. ASME, J. of Eng. for Ind.*, Vol 93, 1971, p 1120-1128
8. T.G. Bifano, "Ductile-Regime Grinding of Brittle Materials," Precision Engineering Center, North Carolina State University, NG 27695-7918, 1984, p 325-338
9. K. Okano and C. Tsutsumi, Machining of Ceramics. Part 2, *J. Mech. Eng. Lab., Vol 142 (No. 3), 1988, p 239-243*