Effect of ELID Grinding on Conductive Rubber-Bond Wheel

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Abstract:

We developed a conductive rubber-bond grinding wheel for ELID grinding. The grinding wheel is composed of rubber, carbon, and abrasives, and was designed to demonstrate ELID effects (continuous grinding ability) by the excellent finishing effects of rubber and conductivity ensured by carbon. The prototyped grinding wheel was a #1200 conductive rubber-bond grinding wheel using Al_2O_3 abrasives. Grinding experiments of mono-crystalline silicon were carried out using this grinding wheel, and it was found that stable grinding without loading could be realized by adding ELID grinding.

Key words: ELID grinding, Conductive rubber-bond wheel, Grinding characteristics, Mirror surface

1. Introduction

Lapping and polishing processes using free abrasives are applied to the finishing of machine parts, such as molding dies. However, in these processing methods, skill is required, work environment is soiled, and process efficiency is low. Moreover, these have the fault that the automatic mechanization for reacting to price war in recent years is difficult. In order to solve these problems, the grinding process by fixed abrasive grain is proposed as a finishing process, and the research is done actively⁽¹⁾. We are also advancing examination aiming at realization of a finishing process of the machine part by grinding process used ELID method⁽²⁾⁻⁽⁵⁾. Recently, we developed the conductive rubber-bond wheel for ELID grinding realizes polishing process of machine parts using the elastic deformation of rubber. This report discusses about the electrical dressing characteristics, the friction and wear characteristics, and the grinding characteristic of the conductive rubber-bond wheel for ELID grinding.

2. Production process of the conductive rubber bond wheel for ELID grinding

Figure 1 shows a schematic illustration of the production process for a conductive rubber-bond wheel for ELID grinding. First, carbon is mixed with rubber (styrene butadiene rubber) for conductivity of the rubber wheel. Next, alumina (WA) abrasives (#1200 in mesh size, about 10 micrometers of particle diameter) were mixed with this conductive rubber.

And the conductive rubber containing abrasives was molded and is sintered at a temperature of 170 °C. A prototype wheel has a resistance value of 2.7kΩ, and hardness 90Hs JIS A. This wheel aims at the finishing process of machine parts including corner or form, because this wheel can use elastic deformation ability peculiar to rubber.

Fig.1: Schematic illustration of production process of conductive rubber-bond wheel for ELID grinding

3. Electrical dressing characteristics

In order to investigate the suitability about ELID grinding of a prototyped wheel, the electrolysis dressing experiment was conducted by the electrical dressing system shown in **Figure 2**. In this system, the wheel was connected to the anode of the power supply, and the electrode was connected to the cathode. The gap between the wheel and electrode was 0.5mm. Grinding fluid was supplied to this gap. It is the weak conductive grinding fluid for ELID grinding, and it is diluted by 50 times with purified water. Moreover, electrolytic current is supplied to this gap and electrolytic layer generates on the wheel surface. In the experiment, the effects of the wheel in electrical dressing were investigated.

Table 1 shows the specifications of the electrical dressing system. **Figure 3** shows the electrical behavior during electrical dressing. With progress of dressing time, the working-current value decreased nonlinear and the working-voltage value increased, these were stabilized in about 10 minutes. It is thought that the wheel surface became non-conducting by electrolysis.

(a) Photograph of test piece

(b) External view of system

(c) Schematic diagram of system

Fig.2: Electrical dressing system

Table 1: Specifications of electrical dressing system

Power supply	High Frequency pulse power supply for ELID (ED930)		
Grinding wheel	Conductive rubber-bond wheel, Grain: #1200 alumina (WA)		
Electrolytic conditions	Open voltage	E_o	60V
	Maximum current	I_p	10A
	Pulse on/off time	τ	2/2μsec
Electrolytic fluid	Weak conductive grinding fluid (CG7), Diluted by 50 times with purified water		

Figure 4 shows the optical micrographs of wheel surface before and after electrical dressing. The electric resistance value on the wheel surface changed to 58MΩ (after electrical dressing) from 2.7kΩ (before electrical dressing). It was found that the electrolysis layer of the wheel surface is non-conducting. The wheel surface before electrical dressing has a clear boundary between the abrasive grain and the rubber-bond, and the wheel surface after electrical dressing has the layer changed in quality by the electrolysis. It is thought that the ingredient of grinding fluid deposited to wheel surface. (6)-(7).

Fig.3: Electrical behavior during electrical dressing

(a) Before electrical dressing

(b) After electrical dressing

Fig.4: Optical micrographs of wheel surface before and after electrical dressing

4. Friction and wear characteristics

The non-conducting coating of the wheel surface generated by the electrical dressing phenomenon can be considered to have a big influence on the grinding characteristic. Therefore, the friction and wear characteristics (friction coefficient and specific wear rate) on the wheel surface were investigated. **Figure 5** shows the external view of friction and wear testing machine. **Table 2** shows the specifications of the friction and wear test system.

Figure 6 shows the comparison of the friction coefficient on the wheel surface before and after electrical dressing. The friction coefficient before electrical dressing is about 0.24, and that after electrical dressing is high with about 0.32 due to the effects of the non-conducting layer. Due to the resistance of friction between the work and the wheel increases by adding ELID, the stable process without slip is expectable.

Fig.5: External view of friction and wear testing machine

Table 2: Specifications of friction and wear test system

Testing machine	Friction and wear testing machine (HHS-2000)		
Lubrication condition	Ball specimen: Alumina	R	5mm
	Normal load	W	0.49N 0.98N
	Stroke	L	5mm
	Speed	S	2mm/s
	Number of repeat cycles	N	250 cycles
Lubricating fluid	Weak conductive grinding fluid (CG7), Diluted by 50 times using purified water		

Figure 7 shows a comparison of the specific wear rate on wheel surface of before and after electrical dressing. The specific wear rates of the wheel surface after electrical dressing is increasing about 2 times to that before electrical dressing. Due to wear of the electrolysis layer, the stable process without loading is expectable.

Fig.6: Comparison of friction coefficient on wheel surface of before and after electrical dressing

Fig.7: Comparison of specific wear rate on wheel surface of before and after electrical dressing

5. Grinding characteristics

It was found that the prototyped wheel generates an electrolysis layer by electrical dressing, and the layer has a friction coefficient and a high specific wear rate. Accordingly, the efficient process without loading is expectable. Therefore, the grinding experiment by constant-pressure process system was conducted for the purpose of investigating the grinding characteristics in ELID lap grinding.

Figure 8 shows the produced cup type conductivity rubber bond wheel. **Figure 9** shows the schematic illustration of grinding system. **Figure 10** shows the close-up view of grinding system during process. **Table 3** shows the specifications of the ELID lap grinding system. After truing the wheel, the initial electrical dressing was performed on the wheel for 10 minutes, and mono-crystalline silicon was processed.

Fig.8: External view of the cup type wheel

Fig. 9: Schematic illustration of grinding system

Fig.10: Close-up view of grinding system

Figure 11 shows the electrical behavior during initial electrical dressing. From immediately after electrical dressing start, the working-current value decreased and the working-voltage value increased, and these were stabilized in about 10 minutes. The electric resistance value on the wheel surface changed to $15\text{M}\Omega$ (after electrical dressing) from $4.62\text{k}\Omega$ (before electrical dressing). It was found that the electrolysis layer of wheel surface is non-conducting.

Table 3: Specifications of ELID lap grinding system

Grinding machine	Single side lapping machine (MG773B)		
Grinding wheel	Conductive rubber-bond wheel, Grain: #1200 alumina (WA)		
Grinding conditions	Wheel speed	100min ⁻¹	
	Work speed	100min ⁻¹	
	Pressure	66.5kPa	
Power supply	High Frequency pulse power supply for ELID (ED630)		
Electrolytic conditions	Open voltage Eo	60V	
	Maximum current Ip	10A	
	Pulse on/off time τ	2/2μsec	
Electrolytic fluid	Weak conductive grinding fluid (CG7), Diluted by 50 times with purified water		
Workpiece	Mono-crystalline silicon (φ75)

Fig.11: Electrical behavior during initial electrical dressing

Fig.12: Comparison of stock removal with and without ELID

Figure 12 shows the comparison of stock removal with and without ELID. When ELID was added, it was found that the stable process without loading occurred because the stock removal was increased in most proportion to the grinding time. When ELID was not added, it was found that the process of a loading occurred, because the stock removal was not increased after 15 minutes.

Fig.13: Comparison of surface roughness with and without ELID

(a) Before ELID grinding

(b) After ELID grinding

Fig.14: Photographs of workpiece before and after ELID grinding (Mono-crystalline Silicon)

Figure 13 shows the comparison of the surface roughness with and without ELID. In order to investigate the stable process in ELID grinding, the grinding process for 120 minutes was performed further.

When ELID was added, the surface roughness improved with progress of grinding time, and it was 6.2nmRa. It is thought that surface roughness improved due to the electrolysis layer by electrolysis.

When ELID is not added, surface roughness was 27.2nmRa. It is thought that surface roughness is improving due to the polishing effect of the rubber wheel.

Figure 14 shows photographs of workpiece before and after ELID grinding. Compared with the surface with 43.2nmRa before ELID grinding, the ground surface with 6.2nmRa after ELID grinding is a very smooth mirror surface.

Figure 15 shows the SEM image of the ground surface after ELID grinding. Although there are grinding marks in part, it is the surface smooth on the whole.

Figure 16 shows the comparison of amounts of wear on wheel with and without ELID. The amount of wear of a wheel increases by addition of ELID because it is tended to wear an electrolysis layer as explained above. From now on, bond material will need to be inquired towards utilization.

Fig.15: SEM image of ground surface

Fig.16: Comparison of amount of wear on wheel after ELID grinding with and without ELID

6. Conclusions

Aiming at the wheel for finishing by ELID grinding, we developed the conductive rubber-bond wheel for ELID grinding, and investigated the electrical dressing characteristics, friction and wear characteristics and grinding characteristic, and obtained the following results.

- 1) By electrical dressing to prototyped conductive rubber-bond wheel, the non-conducting layer is generated on wheel surface and has high electric resistance value compared to wheel surface before electrical dressing.
- 2) The non-conducting layer generated by the electrical dressing has high friction coefficient and specific wear rate compared to matrix.
- 3) By electrical dressing to cup-typed conductive rubber-bond wheel, the non-conducting layer is generated on wheel surface and has high electric resistance value compared to wheel surface before electrical dressing.
- 4) In the grinding experiment of the mono-crystalline silicon by ELID lap grinding, the wheel realized stable processing without loading, and surface roughness of silicon was 6.2nmRa.

7. References

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