ELID 를 이용한 초미립 숫돌의 원통내면연삭

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Internal Cylindrical Grinding with Super Abrasive Wheel and Electrolytic In-Process Dressing

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ABSTRACT

전해 인프로세스 드레싱(ELID)의 응용기술로써 간헐적 드레싱(ELIDⅡ) 및 무전극 드레싱(ELIDⅢ)이 원통내면 마무리 연삭에 이용되고 있다. 주철본드(CIB-D) 및 메탈레진본드 다이야몬드 숫돌(MRB-D)이 이 방식들에 사용되고 있다. 경면 가공에 있어서 이 두방식은 미립의 숫돌이용으로 일반연삭기에 정밀부속장치의 보완없이 이용될 수 있다. ELIDⅡ연삭에서 CIB-D숫돌은 파이프 형상의 전극에 의하여 간헐적으로 드레싱되고, 반면에 MRB-D 숫돌은 인프로세스 드레싱 되며 전극은 필요로 하지 않는다. 본 연구에서는 ELIDⅡ 및 ELIDⅢ 방식에 있어서, 연삭조건 및 연삭입자크기에 대한 연삭특성을 비교검토 하였다. 그 결과, ELIDⅡ, Ⅲ방식 공히 대단히 작은 표면거칠기를 갖는 경면이 얻어짐을 확인하였다.

Key Words : Precision grinding(정밀연삭), Internal Cylindrical grinding(원통내면연삭), Electrolytic in-process dressing(ELID, 전해 인프로세스 드레싱), Metallic bond wheel(메탈본드숫돌), Metal-resin-bond wheel(메탈-레진본드숫돌), Electrolytic in-process dressing(ELIDⅡ, 간헐식 인프로세스 드레싱), Electrodeless in-process dressing(ELIDⅢ, 무전극 인프로세스 드레싱)

1. Introduction

Electrolytic in-process dressing(ELID), as the most successful dressing method for metal-bond wheels so far, has been devised and applied successfully in precision surface grinding of various hard and brittle materials [1~4]. However, in the case of internal cylindrical grinding, especially when the diameter of the workpiece is just slightly larger than that of the grinding wheel, it becomes very difficult and sometimes even impossible to fix a dressing electrode mounted parallel to the wheel as in the common ELID system. Moreover, there could be electrolytic corrosion on the ground surface when the workpiece is conductive, since there will be electrolysis occured between the dressing electrode and the workpiece.

To cope with these problems, an electrolytic interval dressing(ELIDⅡ) technique with pipe-type dressing electrode has been developed on an ordinary grinding machine. Some preliminary experiments have been carried out and mirror surfaces have been obtained on

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both metallic and ceramics materials. However, it is still very difficult to ensure sufficient dressing when grinding long workpiece to mirror surface. Furthermore, sacrifice of machining efficiency is inevitable since additional dressing time is necessary. this means that extra movement of grinding wheel is needed to dress the wheel. Correspondingly, the wheel mandrel in this method must be longer because the additional space is necessary for dressing electrode (Fig. 1). Thus a new kind of grinding wheel has been developed and used in the internal cylindrical grinding in the experiment for the first time. Applying metal-resin bond wheel, the dressing electrode is removed and the workpiece acts as the dressing electrode. This method is called Electrodeless in-process dressing(ELIDⅢ). SKD11, SKH51 and bearing steel have been ground to mirror finish using this technology.

The principle of both ELIDⅡ and ELIDⅢ will be explicated in this paper and the grinding results of different materials with different mesh size wheels will be also reported.

2. Experimental system

2.1 Experimental system and principle

The experiments were conducted on an ordinary cylindrical grinder with an internal grinding attachment. As shown in Fig. 1 and Fig. 2, the essential elements of the ELIDⅡ and ELIDⅢ systems are:1)a metal/metal-resin bond wheel, 2)a DC-pulse electric power source and 3)chemical-solution-type electrolytic coolant. In ELIDⅡ grinding, a pipe-type dressing electrode is necessary and no electrode is used in ELIDⅢ grinding.

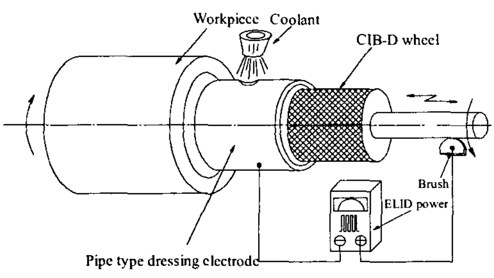


Fig. 1 Schema of electrolytic interval dressing

As shown in Fig. 1, the metallic bond wheel, which is electrically conductive, is connected to the positive terminal of a DC-pulse power supply with a smooth brush contact. And a fixed electrode is made negative. A proper clearance of approximately 0.1mm is originally set between the positive pole (wheel) and the negative one(dressing electrode).

In ELIDⅢ grinding, the metal-resin bond wheel is connected to the positive terminal of a power supply, while the metallic workpiece is linked to the power supply's another pole with a smooth brush contact. To isolate the metallic workpiece from the chuck, which has the same electrical potential as the grinding wheel, insulating material (ceramic chuck) is utilized to isolate the workpiece in the ELIDⅢ experiment.

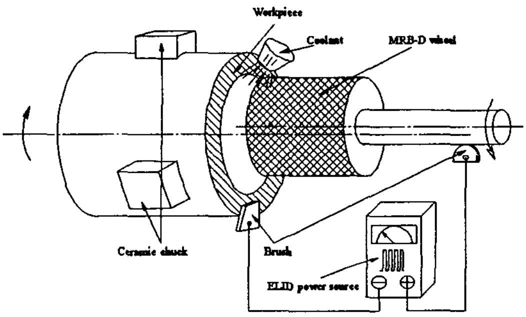


Fig. 2 Sketch of ELIDⅢ grinding system

Due to electrolysis between the wheel and the cathode, the grinding wheel will be dressed and this occurs upon the supply of current from the power source and electrically conductive fluid. Fig. 3 shows the schema of the ELIDⅢ grinding method. In the case that the metallic bonding material is bronze, the bronze particles will be dissolved into ion copper and the abrasive of the wheel remains protrudent.

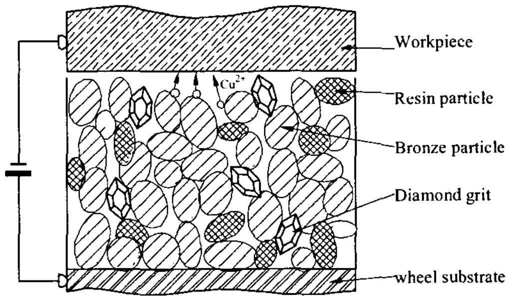


Fig. 3 Dressing mechanism in ELIDⅢ

The electrolytic reaction on the grinding wheel (anode) can be explicated by the following equations:

$$Cu - 2e \longrightarrow Cu^{+2}$$

$$H_2O \longrightarrow H^+ + OH^-$$

$$Cu^{+2} + 2OH^- \longrightarrow Cu(OH)_2 \downarrow$$

2.2 Experimental procedure and method

Usually, ELID grinding consists of the following steps: 1) Truing : Truing is required to reduce the initial eccentricity of the wheel, especially when a new wheel is used for the first time. It is difficult to apply conventional truing methods, such as brake dresser, to metallic bond wheels due to the high bond strength. In this investigation the cast iron bond wheel was trued by the electrical discharge truing (EDT) process. 2) ELID dressing also known as pre-dressing by electrolysis, prevailingly performed at a much lower wheel rotation speed and higher electric settings, and 3) Grinding : ELID grinding. The conditions of electrolysis, during the last two steps, differ due to change in the wheel state and grinding conditions.

ED-truing : It is well-known that truing of metallic bond wheel is not easy with ordinary mechanical methods, especially in the case of internal cylindrical grinding where the rigidity of the wheel quill is poor because of the large ratio of length to diameter. To true the cast iron bond diamond wheel at high speed and with high precision, an electrical discharge truing (ED-truing) method was used in this study. Fig. 4 shows the details of this method. A special ED-truing wheel, made of high temperature alloy and insulated from its central shaft, was mounted on the three-jaw chuck of the grinding tool. The ED-truing wheel was connected to the negative pole of an ELID power source originated from ordinary ED power supply, while the grinding wheel was linked to the positive pole. Both the ED-truing wheel and the grinding wheel, especially the latter, rotated at a fairly low speed and the ED truing wheel reciprocated along the machine's saddle. Little and sometimes even no coolant was supplied to the working area to prevent electrolysis to the full and to pursue high truing precision.

Pre-dressing : Following the ED-truing, pre-dressing was carried out before starting ELID grinding. When the pre-dressing began, the surface of the trued wheel showed a good electrical conductivity. Therefore, the current would be very high and the voltage between the wheel and electrode would be low, varying in accordance with the wheel size and dressing settings. After several minutes, the cast iron bond material, which is mostly ionized into Fe^{+2} , is dissolved by electrolysis. The ionized Fe^{+2} will react to nonconductive ferrous hydroxides and oxides to form a layer on the wheel periphery. This insulating oxide layer would grow on the wheel surface, whereby its electrical conductivity would be reduced. Consequently, the current would decrease and the working voltage would remain pretty high (90V, in case that the originally set open voltage is 100V) after 20 minutes. The color of the wheel changed to dark pink, due to the formation of ferrous oxide.

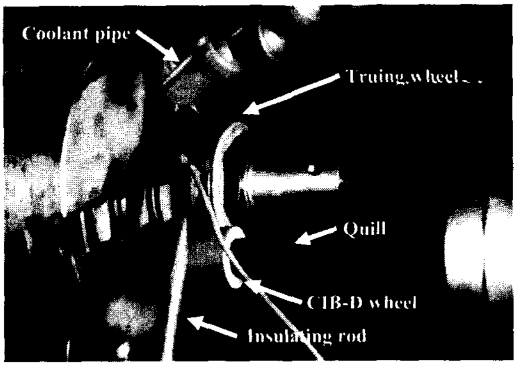


Fig. 4 View of ED-truing setup

Interval ELID-Grinding : During the grinding process, the protrudent grains grind the workpiece and as a result, the grains and the oxide layer wear down. The wheel's electrical conductivity increases, due to the wear of the oxide layer. The current in the circuit increases, accelerating the electrolysis, making the abrasive grains more protrudent and forming an insulating layer. In the case of internal cylindrical grinding, the metallic bond wheel is dressed at intervals-that is, the wheel is dressed when it departs away from the workpiece. When very fine grit size abrasive wheel is used and the infeed rate is very low, the insulating layer and the abrasive can finish the work surface in a way similar with lapping, achieving super smooth surface. In the case of ELIDⅢ grinding, the ELID power source, the conductive workpiece, the coolant and the metallic bond particles in the MRB-D wheel constitute a loop circuit, so electrolysis occurs between the wheel and the workpiece through coolant, whereby the metallic bond is dissolved and the wheel remains protruding.

Table 1 Experimental specifications

Machine tool	Mug27/30-22 Mitsui Seiki Kogyo Co. Ltd.
Grinding wheel	CIB-D straight wheel, ϕ 30 × L20, #325,#1200,#4000 MRB-D straight wheel, ϕ 30/ ϕ 20 × L20, #1200,#2000,#4000
ELID power	SUE-87(peak value:150V, 30 A)
Coolant	2% dilution of chemical coolant AFM-G
Workpiece	SKD11, SKH51, ϕ 36 × L30 / ϕ 26 × L60 WC-Co, ϕ 26 × L60 Bearing steel , ϕ 36 × L15mm Aluminum ceramic, ϕ 36 × L30mm
Measuring instruments	MITUTOYO Surftest 701

Preliminary experiments were carried out on an ordinary grinder and Table 1 lists some of the experimental details. ELID II grinding was firstly carried out and to verify the validity of ELID II grinding, a coarse grit size grinding wheel of mesh size #170(80 micra mesh size) was first used to grind alumina ceramic, and two types of dressing electrodes, a pipe- type and an arc-type electrode were used. The grinding results of these dressing electrodes and those without interval ELID dressing were also evaluated. With the same wheel, effects of grinding parameters were investigated so as to optimize parameter combination. Then three wheels of different grit sizes, #325, #1200(12 macra) and #4000(4 micra) respectively, were utilized to grind bearing steel rings. All three bearing rings were ground with a #325 wheel and then two were ground with #1200 and #4000 wheels respectively. Next, mirror surface ELID II grinding of SKD11, SKH51, bearing steel and alumina ceramic was performed through two steps : rough grinding with a #325 wheel and precision grinding with a #4000 wheel. Finally, ELID III grinding was performed. Various workpieces were firstly ground by a #325 wheel, then a #1200 wheel and finally finished by a #2000 or a #4000 MRB-D wheel.

3. Results and discussions

3.1 ED-truing of CIB-D wheel

To start the experiment, a new CIB-D wheel of #325 mesh size was installed on the quill of the internal grinding setup. The run-out of the new grinding wheel, before ED-truing, was around 40 micra, so ED-truing was conducted as stated in the previous section. Fig. 5 shows the result of ED-truing, denoting the change of wheel run-out versus truing time. Through both the eccentricity and roundness of the new wheel contribute to the run-out of the wheel, the former, obviously, is the major cause of wheel run-out and need to be removed by electrical discharging. At the beginning of ED-truing, the material volume to be removed for reducing the unit of run-out was small and the wheel run-out decreased relatively quickly. As it went on, the removal volume increased and thus the run-out diminution rate slowed down.

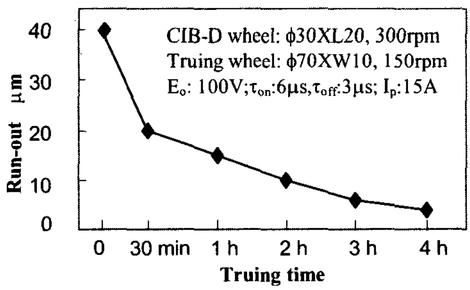
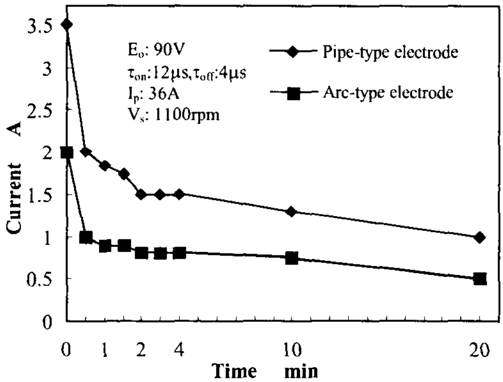


Fig. 5 Wheel run-out change in ED-truing

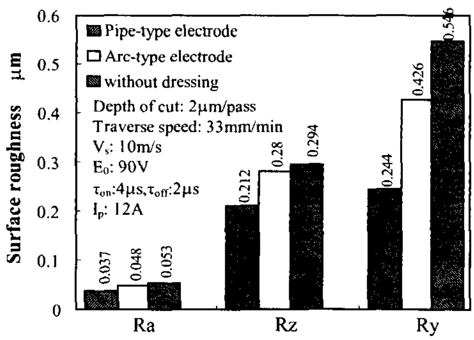
In practice, when a large electrical discharging specification was chosen, the wheel run-out in some positions even more increased slightly than that before ED-truing. This is due to the electrical discharging characteristic that the melt material scatters over the wheel surface and solidifies on it. Thus the wheel surface becomes rough and run-out increases. However, these protrudent points are very easy to be demolished by electrolysis and almost have no effect on ELID grinding. After ELID grinding of one workpiece, the measured wheel run-out was 4 micra.

3.2 Comparison of pipe and arc electrodes

In the internal cylindrical grinding, usually a small-diameter grinding wheel is utilized and therefore abrasive wear occurs considerably faster. Two types of dressing electrodes, arc and pipe-type electrodes were used in the experiment. Compared with the arc-type electrode, the pipe-type electrode possesses a larger dressing area along the wheel periphery. Hence its pre-dressing current is higher than the arc-type electrode (Fig. 6 (a)). It also implies that the dressing effect of the pipe-type electrode is better than the arc-type electrode and thus better surface can be expected (Fig. 6 (b)). The pipe-type electrode was therefore applied to the following experiments for the sake of providing sufficient dressing.



(a) Current difference in pre-dressing under same electrical settings



(b) Ground surface roughness with same wheel

Fig. 6 Comparison of pipe type and arc type electrode

different grinding settings.

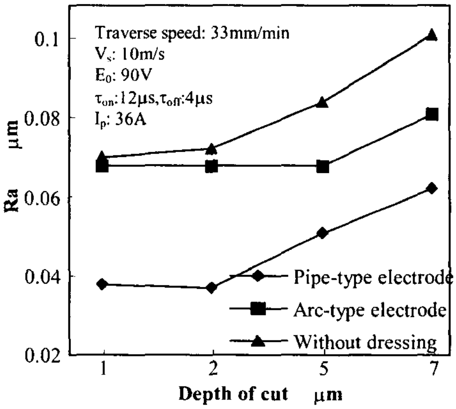


Fig. 7 Influence of depth of cut on Ra

Fig. 7 depicts that the surface roughness increases when the depth of cut per path increases under each condition. However, with the pipe-type electrode the best surface roughness Ra can be obtained under the same grinding settings.

Fig. 8 elucidates the influence of traverse speed on the ground surface roughness. It can be discerned that the ground surface quality remains almost constant up to a traverse speed of 33 millimeters per minute. So the lower the traverse speed is, the better the surface is available. It also seems that the optimal traverse speed is around 40mm/min.

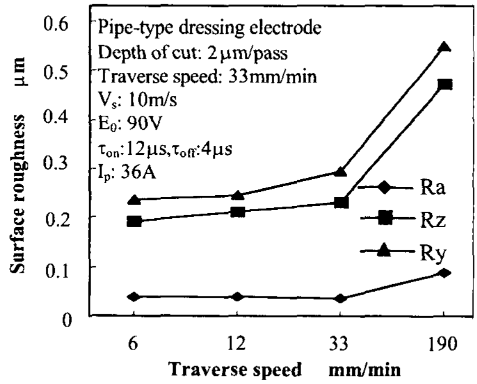


Fig. 8 Influence of traverse speed

3.3 Effects of grinding parameters

To optimize grinding parameters for ELID II grinding, several grinding tests were carried out with

Due to the limitation of the wheel diameter, the wheel speed therefore could be adjusted within a small range and the effect of wheel speed in this scope is not very notable. Fig. 9 shows the ground surface roughness at different wheel speeds V_s in this investigation. The Ra more or less shows the same value in the accessible speed compass. In whichever case, the higher the wheel speed is, the better the ground surface is.

Based on these empirical results, it can be concluded that the effects of grinding parameters in interval ELID grinding are just the same as ordinary internal grinding and the results coincide with the common grinding principle, while with ELID a better surface can be reckoned on.

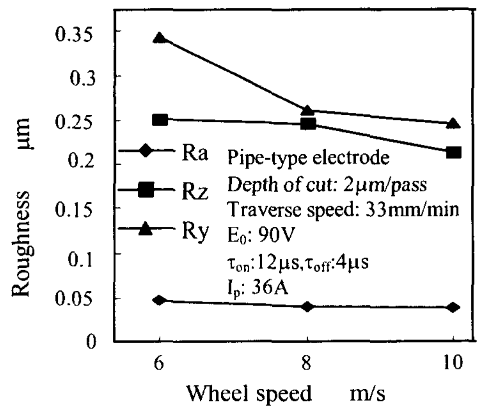


Fig. 9 Influence of wheel speed on surface roughness

3.4 Influence of grit size on surface roughness

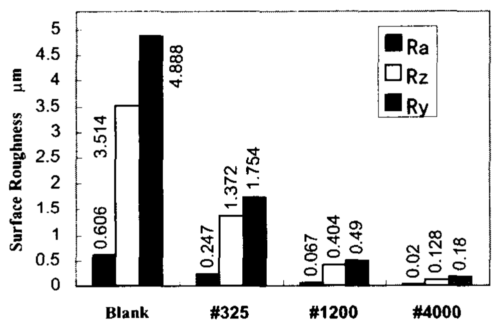


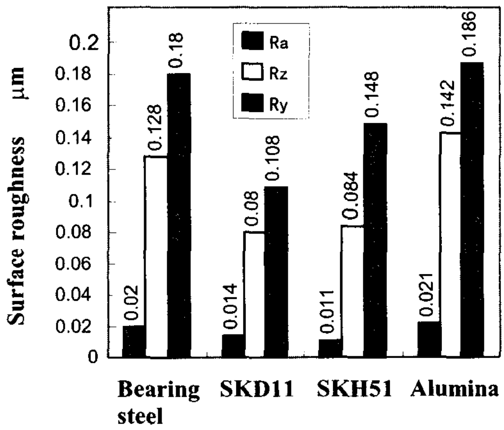
Fig. 10 Bearing steel surface roughness ground by wheels of different grit sizes

Fig. 10 shows the comparison of ground surface roughness of bearing steel rings by wheels of different grit sizes. The grinding conditions were : wheel speed 10m/s, workpiece rotation 150 rpm, traverse speed 40mm/min, in-feed 1μm/pass. The #325 mesh size wheel was used as rough grinding wheel. Then #1200 and #4000 mesh size grinding wheels were used to conduct finish grinding.

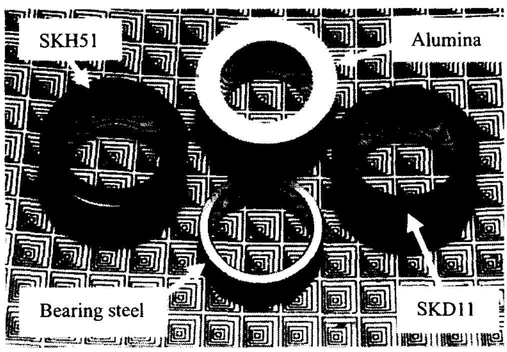
It is obvious that the ground surface quality increases along with the wheel mesh size. The advantage of this method is that very fine abrasive can be used and sufficient dressing for continuous grinding is possible. Thus very smooth surface can be fabricated.

3.5 Mirror surface grinding of different materials by ELID II

Fig. 11 shows the ground surface results of four materials, bearing steel, SKD11, SKH51 and alumina. These materials were all ground by a #325 wheel and then finished by a #4000 wheel.



(a) Surface roughness of different materials

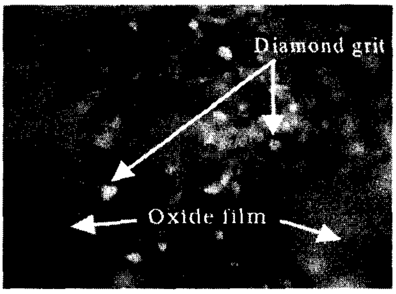


(b) View of ground workpieces

Fig. 11 Samples finished with #4000 CIB-D wheel

3.6 Wheel topography in ELID III grinding

A CIB-D wheel was replaced by a MRB-D wheel to carry out ELIDⅢ grinding. The MRB-D wheel possesses good conductivity on the wheel surface and therefore predressing is necessary and very important in this case. Fig. 12 (a) and (b) show the wheel topography before and after ELIDⅢ grinding. It can be seen that oxide layer is formed on the wheel surface after predressing.



(a) After pre-dressing

(b) After grinding

Fig. 12 Wheel topography in ELIDⅢ

Theoretically, the metallic bond is mostly removed by electrolysis in ELIDⅢ grinding, but experiments show that electrical discharge is inevitable and that account measures should be taken to diminish its negative effects. Research also shows that insulating film contributes to inducing electrical spark in a similar working situation[5], and it also can be anticipated that the conductive grinding chips will cause sparks in the process. Fig. 6 (b) shows the wheel topography after ELIDⅢ grinding. The cavities on the wheel surface are supposed to be fabricated by both electrolysis and electric discharging. It was observed that when high electric parameters were used in the experiment, obvious discharging marks were formed on the workpiece surface and the grinding process was not able to continue. On the contrary, mirror grinding with fine abrasive wheel was achievable if proper parameters were chosen.

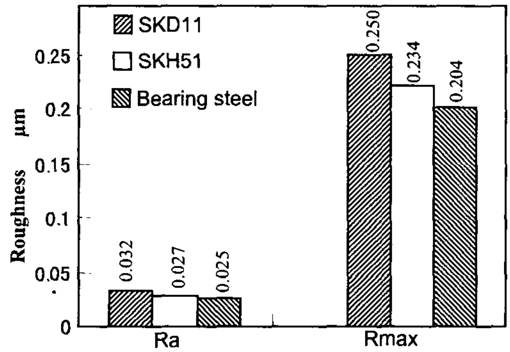


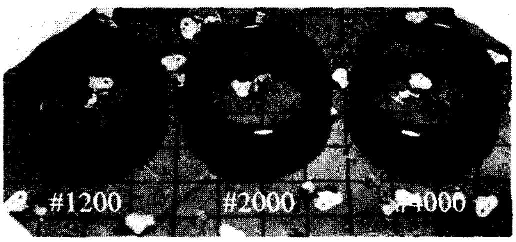
Fig. 13 Comparison of surface roughness

To prevent electrical discharge , the following measures should be adopted: (1) low open voltage, (2) low peak current value, (3) low duty factor of pulse amplitude and (4) small infeed rate to prevent grinding chips from causing spark.

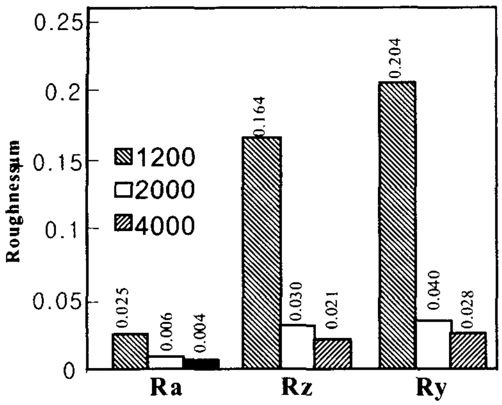
3.7 Mirror surface grinding with ELIDⅢ

Specimens of different materials were ground with a #325 MRB-D wheel and finished by #1200, #2000, and #4000 wheels. The finish grinding conditions are as follows: wheel speed V_s: 7m/s; workpiece rotary speed V_w: 150rpm; traverse speed: 30mm/min; depth of cut: 1μm/pass. When low electric parameters were chosen, experiment went on smoothly and mirror surfaces were achieved.

Fig. 13 shows the surface roughness of three materials finished by a #1200 mesh size MRB-D wheel. Both SKD11 and SKH51 were not hardened and the bearing ring was hardened. It seems that the harder the material is, the better the surface could be achieved.



(a) View of ground bearing ring samples



(b) Surface roughness versus mesh size

Fig. 14 Surface roughness versus mesh size

Three bearing rings were finished by wheels of different grit sizes and Fig. 14 illustrates the effects of grit sizes on surface roughness. Mirror surface can be readily achieved by these wheels and it can be seen that the roughness deviation between surface ground by #2000 and #4000 wheels is very small. This may be due to the effect of resin in the MRB-D wheels.

In the case of grinding of long workpiece, ELID Ⅱ and ELIDⅢ were combined. Since the wheel strength of MRB-D wheel is not as good as that of CIB-D wheel, its wheel wear is relatively high. So it is better to conduct rough and middle finish grinding by ELID Ⅱ and finish the workpiece by ELIDⅢ. Fig. 15 shows the SKD11 sample (¢40×t10). It was ground by a #1200 CIB-D wheel (ELID Ⅱ) and finished by a #2000 MRB-D wheel (ELIDⅢ). The surface roughness are Ra: 0.0086μm, Rz: 0.044 μm and Ry: 0.067μ m.

4. Conclusions

Both ELID Ⅱ grinding and ELID Ⅲ grinding have been successfully achieved on a common grinder with an attached internal grinding head. Based on the results obtained in the experiments, some issues can be concluded as follows:

Pipe-type electrode is superior to electrodes of other shapes in the case of ELID Ⅱ grinding. In ELID Ⅱ grinding, the grinding conditions have just the same tendency as ordinary internal cylindrical grinding in grinding qualities. Internal mirror surface grinding is practicable on ordinary grinding machine using CIB-D wheels with electrolytic interval dressing (ELID II).

Electrical parameters are critical in ELID Ⅲ grinding, and lower level electric parameters should be selected to reduce the effect of electrical sparks. Mirror finish can be achieved when appropriate grinding parameters as well as electrical parameters are chosen. The surface roughness obtained using #2000 is the same order as that of ELID grinding using a #4000 CIB-D wheel.

Since the wheel wear increase due to the relatively weakened strength of bond material, ELID Ⅲ grinding is suggested to be combined with ELID II grinding and utilized for finishing process.

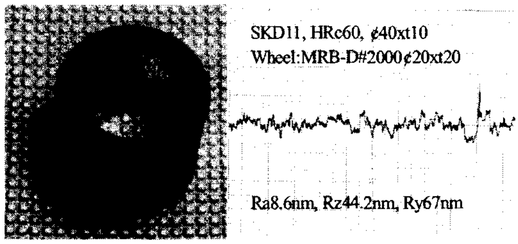


Fig. 15 View of SKD11

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