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ELID 연삭에 의한 고경도 재료의 미소형상가공

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Fabrication of Micro Shapes for Advanced Materials by ELID Grinding

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ABSTRACT

세라믹, 다이야몬드등과 같은 고경질재료에 대한 미소형상의 가공은 대단히 어렵고 일반적인 방법으로는 상당한 시간을 요구한다. 이러한 재료의 고능률 가공을 실현하기 위하여, 메탈본드 다이야몬드휠에 전해 인프로세스 드레싱(Electrolytic In-Process Dressing)을 적용한 연삭을 머시닝센타에서 시도하였다. 본 연구에서, 메탈본드 다이야몬드휠은 전기방전에 의하여 고능률로 트루잉(truing)되었다. 알루미나 세라믹의 핀선단(φ50μm)과 로커웰 경도측정기의 다이야몬드 압입자(indenter)(φ400μm)를 ELID 연삭에 의하여 창성하였다. 그 결과를 본 논문에서 보고한다.

Key Words : Electrolytic In-Process Dressing(ELID, 전해인프로세스드레싱), Mist Electrical Discharge Truing(MEDT, 연무식 방전 트루잉), Cast-Iron-bond Diamond Wheel(주철본드 다이아몬드 숫돌)

1. Introduction

Interests in advanced materials, such as ceramics and diamond, have been increasing significantly in recent years due to their unique physical, chemical and mechanical properties [1]. For instance, the diamond material, one of the hardest materials on the earth, has been utilized in various industrial areas because of its high hardness. The application of diamonds in industry has been proven in the manufacturing extra hard cutting tools [2]. Similarly, aluminum oxide ceramic has well been used to manufacture special components in industries such as the chemical, petroleum, marine, medical and precision machinery industries. However, 3-dimensional processing of such advanced materials by traditional methods such as the loose abrasive lapping process has proven to be very difficult, and has reduced machining efficiency [3].

Many research attempts have been put forward to conduct micro machining along with the progressive advancement of micro-machines and micro-machining [4]. Micro-EDM is capable of fabricating 3-D parts using metallic materials [5,6], but its relatively poor productivity and applicability to conductive materials limit its applications. Though high energy beams such as laser beams and ion beam are also capable of 3-D machining [7,8], expensive and complicated equipment is necessary. Furthermore, surface integrity is not satisfactory using these techniques[9]. Micro turning has been applied to fabricating micro screw and aspherical surfaces [10,11], but it is impossible to use this method to machine ceramics

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and diamonds.

Grinding, the predominant method for machining advanced materials, has also been utilized to manufacture micro parts [12] and micro ceramics shafts have been ground with a specially designed compact size NC grinder using an electro-plated diamond wheel [13]. Grinding using metallic bond grinding wheel is a promising alternative for high efficiency grinding, although it also needs high efficiency dressing. Electrolytic in-process dressing (ELID)-grinding, which has been applied successfully to precision surface grinding with cast-iron-bond super abrasive wheels [14], is a promising process for micro-machining. In the study, the fabrication of micro ceramics pin with a round tip as well as a segment of arc on a diamond indenter tip for a ROCKWELL hardness tester have been attempted on a vertical machining center employing a CIB-D wheel applying electrolytic in-process dressing (ELID). The experimental methods and results are presented in the following sections.

2. Experimental method and procedure

2.1 Experimental method

In our experiments, the desired workpiece shapes of both diamond and alumina are axis-symmetrical, so they can be fabricated by the envelope method. In the course of the grinding process, the workpiece rotates and the relative movement between the diamond indenter tip and the grinding wheel is set by NC program, which can be prepared according to the desired radius of the diamond indenter tip. Considering the high grinding wear due to the high hardness of workpiece, the grinding wheel is set to move helically in order to distribute the wheel wear on the whole surface. To complete such a movement, the concurrent feed function of the machining center is utilized. When the wheel starts circular movement in the XY plane, it moves vertically (Z direction) at the same time. Fig. 1 shows the trajectory of the spindle center.

To evaluate the wear of the grinding wheel, the radius of the grinding wheel is measured at intervals and the NC route is adjusted.

The ELID grinding in this experiment consists of the following steps : i) Truing ; Truing is required to

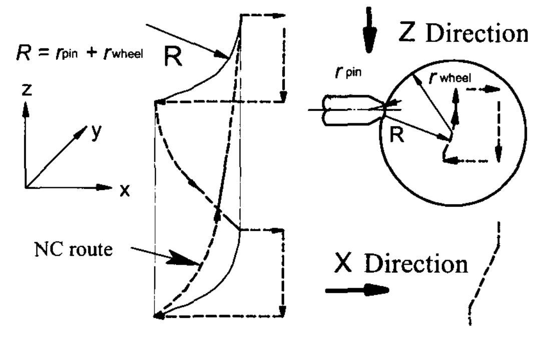
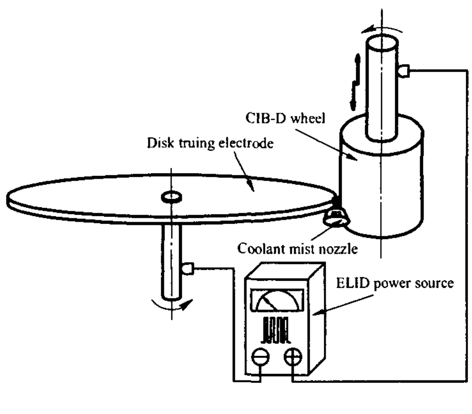


Fig. 1 NC route of grinding wheel

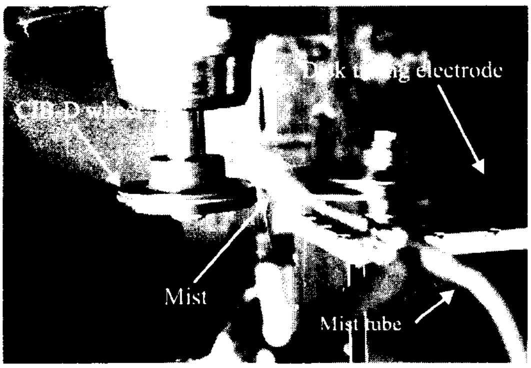
reduce the initial eccentricity of the wheel and to improve wheel straightness, especially when a new wheel is used for the first time. In this investigation, the cast-iron bond wheel is trued by a high-efficiency mist electrical discharge method. ii) ELID dressing (also known as pre-dressing by electrolysis); This is usually performed at a much lower wheel rotation speed and higher electric settings, and iii) Interval ELID grinding; The conditions of electrolysis, during the last two steps, differ according to the changes in the wheel state and grinding conditions.

Mist Electrical Discharge Truing (MEDT) ; It is difficult to apply conventional truing methods, such as brake dresser, to metallic bond wheels due to the high bond strength. To true cast-iron-bond diamond wheels at high speed and with high precision, the mist electrical discharge truing method was used in this study.

Fig. 2 shows the details of this method. A special MEDT unit, whose truing wheel is made of high temperature copper alloy and insulated from the main body of the machining center, is mounted on the saddle of the machining center. The MEDT wheel is connected to the negative pole of an ELID power source originating from ordinary ELID power supply, and the grinding wheel is linked to the positive pole. Both the MEDT wheel and the grinding wheel, especially the latter, are rotated at a fairly low speed and the truing wheel is reciprocated along with the spindle of the machining center. To pursue high efficiency truing, coolant is not poured into the machining gap but sprayed into the gap mixed with compressed air.



(a) Sketch of MEDT system



(b) View of MEDT unit

Fig. 2 Mist electrical discharge truing unit

When the mist is sprayed in the gap, a considerably strong electrical discharge occurs and high erosion speed can be obtained. According to the spark phenomena in the gap, material is mainly removed by arcing rather than ordinary electrical spark.

Pre-dressing ; Following the mist electrical discharge truing, pre-dressing is carried out before starting ELID grinding. When pre-dressing is initiated, the surface of the trued wheel shows a good electrical conductivity. Therefore, the current is very high and the voltage between the wheel and electrode is low, varying in accordance with the wheel size and dressing conditions. After several minutes, the cast-iron bond material, which is mostly ionized into Fe^{+2} is dissolved by electrolysis.

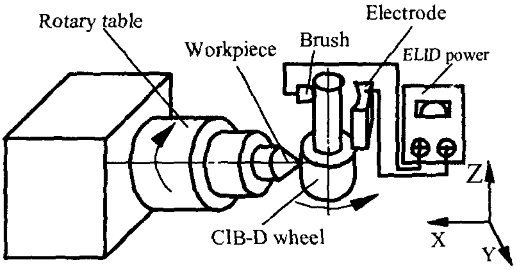
The ionized Fe^{+2} reacts to nonconductive ferrous hydroxides and oxides to form a layer on the wheel periphery. This insulating oxide layer grows on the wheel surface, which reduces electrical conductivity. Consequently, the current decreases and the working voltage remain notably high (90V, when the originally set open voltage is 100V) after 20 minutes. The color of the wheel is found to change to dark pink, due to the formation of ferrous oxide.

ELID-Grinding ; During the grinding process, the protruding 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 protruding and forming an insulating layer. In the case of internal cylindrical grinding, the metallic bond grinding wheel is dressed at intervals, which means that the wheel is not dressed in-process but it is dressed when it has lost its cutting ability. The interval time depends on the grit size of the grinding wheel, material of the workpiece, dressing and grinding conditions. When a 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 to lapping, a process that achieves super smooth surfaces. However, in this investigation, a relatively coarse grit diamond wheel was used.

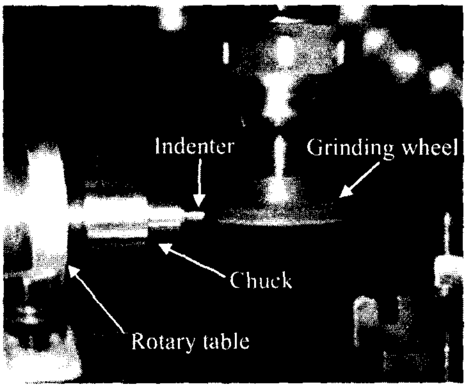
2.2 Experimental system

Preliminary experiments were conducted on a machining center (MAZAK VQC-15/40) and Fig. 3 illustrates the principle of the experimental system. A cast-iron-bond diamond wheel is mounted on the spindle of the machining center and connected to the positive pole of the ELID power supply through a smooth brush contact. The dressing electrode is fixed on the machine body, and it is linked to the minus pole of the ELID power source. The workpiece is installed on a rotary table, which is firmly fixed on the saddle of the machining center.

In the experiment, different wheels were utilized to grind different workpieces. A CIB-D wheel of #140 in grit size (105~88 μm mean mesh diameter distribution) was used for the diamond tip and a #325 wheel for the alumina pin tip. Table 1 demonstrates the details of the experimental system.



(a) Sketch of ELID grinding system



(b) Experimental setup

Fig. 3 ELID grinding system

Table 1 Experimental system

Equipment	Machining center MAZAK VQC-15/40
Wheels	CIB-D wheel, #140,ϕ70; #325,ϕ20
Dressing power	ELID power source ED-1560
Dressing conditions	Eo: 100V; τ_{on}:4μs, τ_{off}:2μs; Ip: 5A
Coolant	2% water dilution of AFG-M
Work piece	Al_2O_3-pin(ϕ4); Hardness: HV1296 Diamond indenter

3. Results and discussions

3.1 MEDT of CIB-D wheel

To start the experiment, a CIB-D wheel of #140 in mesh size was installed on the spindle of the machining center and the MEDT setup was also fixed. In order to evaluate the efficiency of this MEDT, truing of the grinding wheel in other conditions was also conducted, namely electrical discharge in air, in the air by an air jet, with coolant and with mist. Fig. 4 shows the removal rates under these conditions. It can be seen that electrical discharge with mist can achieve the highest removal rate. When the coolant is supplied, electrolysis may also take place on the wheel surface and a relatively higher removal rate can be expected.

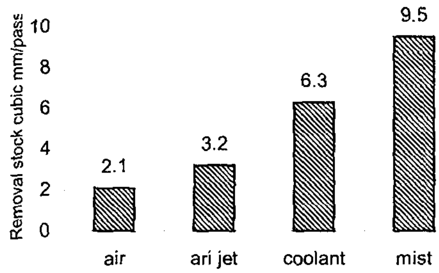


Fig. 4 Comparison of truing efficiency

The straightness of the grinding wheel is measured, by using a dial gauge and reciprocating the grinding wheel vertically. The value before MEDT was around 20 microns. Then, MEDT was applied as described in the previous section. Fig. 5 shows the result of ED-truing, denoting the change of wheel straightness versus truing time. Though both the eccentricity and roundness of the new wheel contribute to the straightness of the wheel, the former, obviously, is the major cause of wheel straightness and needs to be removed by electrical discharging. At the beginning of MEDT, the material volume to be removed for reducing the unit of

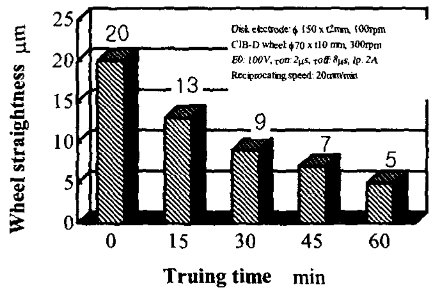


Fig. 5 Verticality of wheel versus truing time

straightness is small and the wheel straightness decreased relatively quickly. As EDT progressed, the removal volume increased and thus the straightness diminution rate slowed down.

3.2 ELID grinding of diamond indenter tip

3.2.1 Wheel wear

The wear of the abrasive wheel is supposed to be inevitable in grinding process, especially in our experiment, in which the workpiece is made from advanced materials. Therefore, to evaluate the wear of the grinding wheel and to adjust the NC route accordingly, the radius of the grinding wheel was measured at intervals in the course of grinding.

The grinding conditions are as follows: grinding wheel rotation: 4000rpm, workpiece rotation: 150rpm, feed rate: 20mm/min, and infeed speed: 1μm/pass.

Fig. 6 shows the change of wheel radius along with the infeed value. This is due to the run-out and straightness error of the grinding wheel, where only part of the wheel takes part in grinding at first and wears off quickly. When the whole wheel surface is ground, the wear of the wheel slows down.

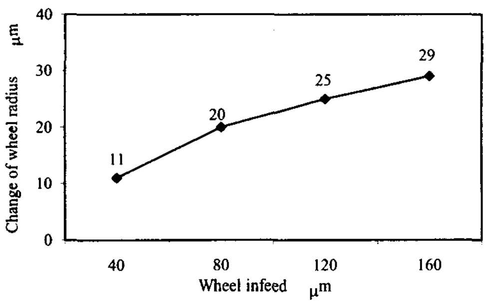


Fig. 6 Change of wheel radius versus infeed

3.2.2 Tip shape and error analysis

The shape of the fabricated diamond tip was measured with a 3-D laser microscope (MITAKA Optics Co. Ltd.). Fig. 7 shows the shape of the ground indenter tip and the calculated radius is 0.223mm, which is slightly greater than the theoretical value(0.2mm). The difference, 23μm, is almost same as the measured value of wheel wear, 29μm. Considering the measuring error, it could be calculated that radius error is caused by wheel wear.

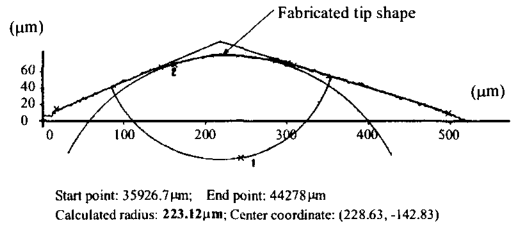


Fig. 7 Measured shape of diamond tip

Fig. 8 schematically shows the wheel wear that contributes to the increase of the formed shape size. Assuming the wheel wear to be δ, the curve equation can be written as:

$$x^2 + y^2 = (R_P - \delta)^2 \quad (1)$$

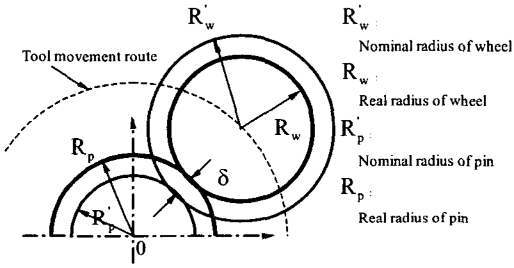


Fig. 8 Effects of wheel wear

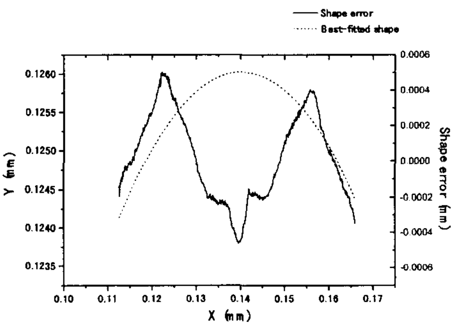
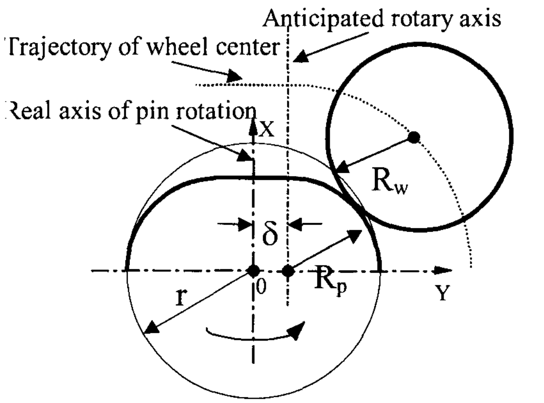


Fig. 9 Best-fitted tip shape and shape error

Based on the those measured data, the tip shape was regenerated using best-fit method. Fig.9 shows the regenerated tip shape and corresponding shape errors.

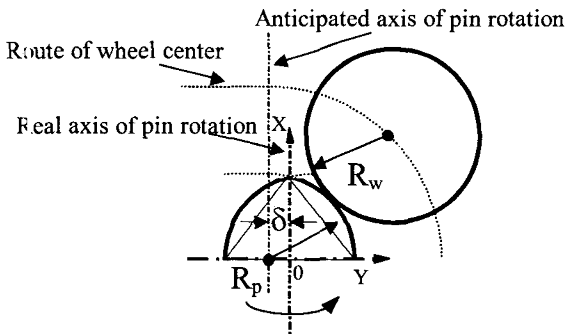
In our experiment, the workpiece was mounted on a rotary table, and the rotary table was fixed on the saddle of the machining center. The center of this rotary table is determined by the trial-and-error method; thus, the off-centering of the anticipated rotating center from the actual one is unavoidable.

Fig. 10(a) and (b) schematically show the influence of the off-centering on the formed shape. The head of the formed shape can be blunt or sharp in response to the off-centering.



$$\begin{cases} x^2 + (y - \delta)^2 = R_p^{\ 2} & , y \geq \delta \\ x = R_p & , 0 < y < \delta \end{cases} \quad (2)$$

(a)



In this case, the curve equation is:

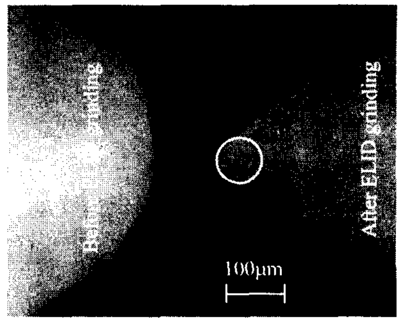
$$x^2 + (y + \delta)^2 = R_p^{\ 2} \quad (3)$$

(b)

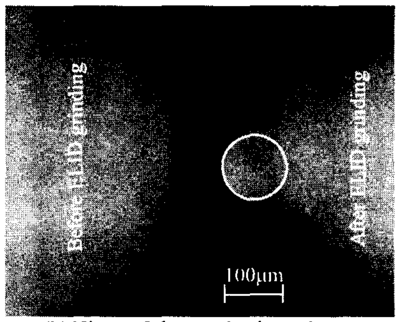
Fig. 10 Effects of off-centering

3.3 ELID grinding of alumina pin tip

ELID grinding of alumina pin tip was conducted on the same MC with the same method. Fig. 11 (a) and (b) are color-video-copy pictures of the pin tips before and after ELID grinding. It can be seen that the pin tip before machining is virtually flat (about 300μm).



(a) View of pin-point before and after ELID grinding



(b)View of the tenth pin-point

Fig. 11 View of specimens

In the grinding process, relative movement between the pin and the grinding wheel is controlled by the NC program, which is prepared according to the desired radius of the pin-points, and electrolytic in-process dressing is performed for continuous protrusion of diamond abrasive grains. A straight grinding wheel of small diameter(ϕ 20mm) is used and the grinding conditions are: grinding wheel rotation: 5000rpm, workpiece rotation: 100rpm and feed rate: 10mm/min.

Fig. 10 (a) shows the first fabricated pin tip and (b) shows the tenth pin tip without concurrent infeed. It is clear that the radius of the pin tip has increased, which could be explained same as that in section 3.2.2. Particularly, When the wheel reciprocated vertically, the wheel wear problem was solved to some extent and pin tips of 50μm in radius can be produced steadily.

4. Conclusions

In this investigation, fabrication of micro diamond indenter tip and alumina pin tip by ELID grinding were successfully conducted on a machining center.

The calculated radius of the ground diamond indenter tip was 0.223mm, and this value was a slightly larger than the desired value, 200μm. Preliminary error analysis was carried out and the radius error is mainly due to the wheel wear.

In the case of fabricating an aluminum oxide micro pin tip with ELID grinding, stable machining can be maintained when the concurrent infeed mode is applied to resolve the wheel wear problem. It can also be concluded that diamond micro tips can be produced by ELID grinding.

To achieve better and more stable grinding, in-process or on-machine measurement of wheel conditions and workpiece dimension is necessary.

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