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초지립 지석에 의한 금형강 경면연삭시 최적 연속 전해드레싱의 영향

이 은 상*

The Effect of Optimum In-process Electrolytic Dressing in the Mirror-like Grinding of Die Steel by Superfine Abrasive Wheel

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Abstract

In recent years, grinding techniques for precision machining of brittle materials used in die, mold and optical parts have been improved by using superfine abrasive wheel and precision grinding machine.

The completion of optimum dressing of superfine abrasive wheel makes possible the effective precision grinding of die steel (STD-11).

In this study, a new system and the grinding mechanism of optimum in-process electrolytic dressing were proposed. This method can carry out optimum in-process electrolytic dressing of superfine abrasive wheel. Therefore, the optimum in-process electrolytic dressing is a good method to obtain the efficiency and mirror-like grinding of STD-11.

Key Words : Superfine abrasive wheel (초지립 지석), Optimum in-process electrolytic dressing (최적 연속 전해드레싱), Die steel (금형강), Insulating layer (절연층)

1. Introduction

In recent years developments in the metallic mold and electronics industry have brought a rapid increase in the use of brittle materials such as hardened steel, ferrite and sintered carbide. Die steel (STD-11; D2, American Iron and Steel Institute) is widely used in materials of blanking die, punching die and forming die, because this steel has the properties of high hardness, high compressive strength and low wear. But, because of high hardness and strength, nitriding STD-11 is particularly difficult to machine. Polishing has been used for mirror-like surface generation in this material but research on high-precision grinding for the replacement of this process has also been actively developed. Superfine abrasive diamond and CBN wheels are able to produce mirror-like surfaces in these brittle materi-

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als economically using superfine abrasive wheels of more than 1000.⁽¹⁾ The dressing of the superfine abrasive wheel is difficult due to loading and glazing.⁽²⁾ Using an in-process electro-discharge dressing system⁽³⁻⁴⁾ the surface roughness of brittle material was improved. In-process dressing using electrolysis⁽⁵⁻⁷⁾, which has been developed in recent years has achieved an effective ductile grinding mode, but introduces the problem of dressing current change owing to the unstable dressing conditions and insulating layer. The diminution of the electrolytic dressing effect is a small for the initial dressing, but with the increase of in-process dressing and grinding time, the dressing current changes unstably and dressing effect reduces.⁽⁸⁾

In this study, an optimum system of in-process electrolytic dressing⁽⁹⁾ that is controlled by a computer was developed for reducing the above defects, which can maintain optimum dressing condition at all times. An optimum in-process electrolytic dressing system was constructed and the characteristics of mirror-like grinding of STD-11 with it were studied.

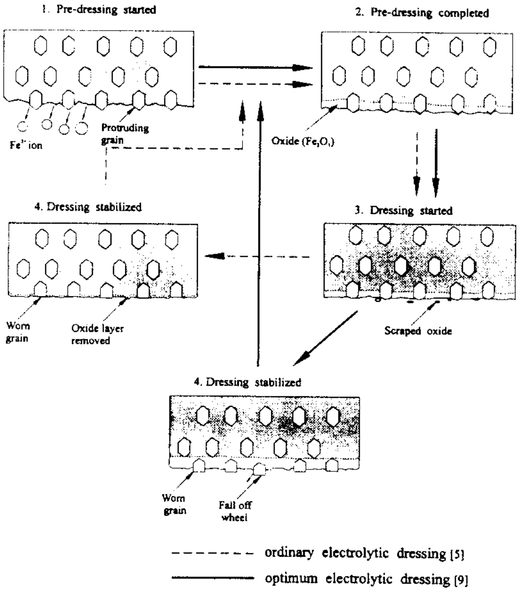


Fig. 1 Schematic diagram of the mechanism of in-process electrolytic dressing

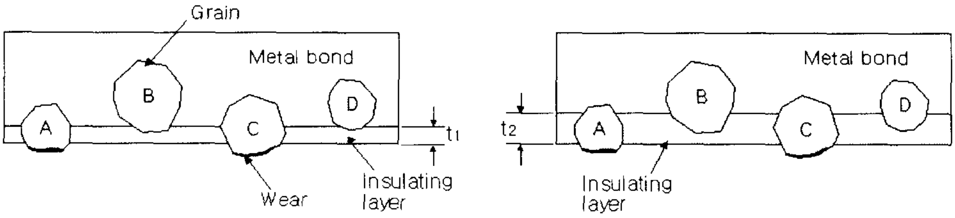
2. Grinding mechanism of optimum in-process electrolytic dressing

In-process electrolytic dressing is the method using the electrolysis, and the worn abrasive grains are removed and new grains are protruded from the wheel surface in the grinding with in-process dressing. Since it is possible to be grinded by grains, which are not worn, the machined surface with good quality is obtained. The bond material of grinding wheel consists of cast iron which has electric conductivity. Supplying power to metal bond, connecting electrode with cathode, and providing electrolyte between anode and cathode, the electrolysis occurs at the gap between the metal bond and electrode, and the metal bond is removed. It is mostly ionized into Fe^{2+}.

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2 \tag{1}$$

At the cathode, the electrochemical reactions are the generation of hydrogen gas and the production of hydroxyl ions. The ionized Fe forms hydroxides, $Fe(OH)_2$ or $Fe(OH)_3$. At the anode, these substances change into oxide substances such as Fe_2O_3. After these reactions occur, the electric conductivity of the wheel surface is reduced with the growth of the insulating layer.

Fig. 1 shows a schematic diagram of the mechanism of in-process electrolytic dressing. The dotted line is shown the mechanism of general electrolytic dressing and the solid line is shown that of optimum electrolytic dressing. The cases of general and optimum are almost same from 1 to 3 step, but there is the difference at 4 step which is the stable condition of dressing. In the case of general dressing without dressing control, the oxide layer is removed and the wear of abrasive grain increases. In the condition of the bad effect on the surface, the removal of grinding wheel bond is not achieved for the fall of worn grains. So, it has a bad effect on the grinding force and the improvement of surface quality. In the case of applied optimum in-process electrolytic dressing, the worn grains are fallen rapidly and the new grains are protruded. And it doesn't have a bad influence upon the workpiece surface. It's due to be weakened the fixing force of grinding grains by bond machining as continuous constant electrolytic dressing, and to fall easily



(a) ordinary electolytic dressing (without dressing control)

(b) optimum electrolytic dressing (without dressing control)

Fig. 2 Schematic of wheel conditions with in-process electrolytic dressing

worn grains by acting force of grinding. The mass w dissolved from metal bond by a current I passed for in-process electrolytic dressing time t is as follows:

$$It = wnF/M$$
$$w = MIt/nF \qquad (2)$$

where n is valency, F is Faraday's constant and M is atomic weight.

The theoretical removal volume of metal bond V_0 is

$$V_o = MIt/nFp = V_s It \qquad (3)$$

where $V_s (= M/nFp)$ is specific volume of machining and p is density of metal bond. Considering the current efficiency (η), the actual removal volume V_r is as follows:

$$V_r = \eta V_o = \eta MIt/nFp = \eta V_s It \qquad (4)$$

And, the volumetric removal rate for unit time v is

$$v = dV_r/dt = \eta MI/nFp = \eta V_s I \qquad (5)$$

With the electrolytic dressing, the volumetric removal rate of metal bond is influenced by the atomic weight, the current efficiency and the current value of inter-electrode. Assuming that the specific volume of machining is constant in electrolytic dressing, the volumetric removal rate is only influenced by the change of current value. The dressing rate is changed by the control of dressing current value. And the dressing current is controlled by constructed dressing system for the optimum in-process electrolytic dressing.

Fig. 2 shows the schematic of wheel condition with in-process electrolytic dressing. It is the comparison of wheel condition with and without dressing current control. It shows the difference of each the thickness of insulating layer. Among the grinding grains, grain A and C are worn grains in the grinding. In the case of without dressing control, the worn grain is tightly fixed with metal bond because the oxide layer is formed thinner. But, the oxide layer is formed thicker with dressing control for the fall of worn grain A and C which is prevented the bad effect on the workpiece. In the case of without dressing control, the dressing efficiency is decreased by an unstable change of dressing current and inter-electrode gap. The thickness of oxide layer is able to maintain uniformly with dressing current control, the new grains which aren't worn protrude on the grinding wheel surface. The performance of dressing is distinguished that the worn grains are protruded on the grinding wheel surface and not protruded. The worn grain causes the increase of grinding force and has a bad effect on grinding surface.

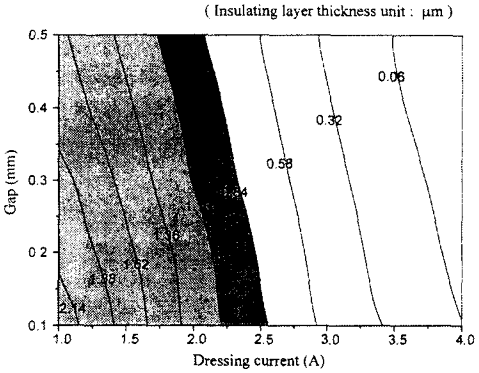
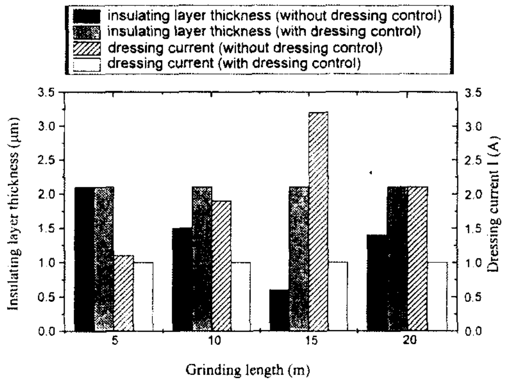


Fig. 3 Insulating layer thickness contour according to gap

Fig. 3 shows the insulating layer thickness contour



wheel speed 3400 rpm electrolytic dressing : τ on/off = 5 μsec

Fig. 4 Change of insulating layer and dressing current

according to the dressing current and the gap between wheel surface and electrode. The thickness of insulating layer decreases according to the increase of the gap. Accordingly, the effect of in-process dressing is dropped off as the removal rate of worn grains is decreased remarkably. For the constant dressing effect, it is necessary to increase adequately the thickness of insulating layer by the control of dressing current. The grinding force increases by worn grain in the grinding, has a bad effect on the grinding of workpiece.

Fig. 4 shows the change of insulating layer and dressing current according to grinding length. It is distinguished into the case with ordinary electrolytic dressing (without dressing control) and with optimum in-process electrolytic dressing (with dressing control). It is observed after grinding for 5, 10, 15 and 20 m in order to investigate the change of dressing current and insulating layer thickness. In the case of with dressing control, the dressing current and insulating layer thickness is maintained stably. In the case of without dressing control, the oxidic insulating layer is changed unstably, the worn grain is fixed by metal bond because the insulating layer is not generated sufficiently at 10, 15, and 20 m. In result, a lot of worn grains are protruded on the wheel surface without dressing control and the grinding force on the workpiece increases with the increase of the friction force. Therefore, the dressing current must be controlled constantly for the stable insulating layer.

3. Experimental procedure

The control mechanism of optimum in-process electrolytic dressing is beginning to be applied to dressing of superabrasive metal bond wheel for the keep of optimum dressing by computer control. Fig. 5 shows the optimum control mechanism of regular current for optimum in-process electrolytic dressing. For electrical power supply it is linked a metal bond wheel and the system anode, a copper electrode and cathode. The terminals for the current, the pulse duration, pulse pause and peak current are linked to the interface board which is connection A/D and DIO converter. The upper part of shown in dotted line is the optimum dressing control system. The lower part of shown in dotted line shows an electrical schematic of in-process electrolytic dressing controller. The rectifier in this controller converts AC 100V power into DC 150V power, and electrolysis is occurred between two electrodes by pulse generation control. Pulse current for reasonable electrolytic dressing is generated by the control circuit and stabilizer. There are DC 12V power supply circuit for the operation of timer, the control of pulse generation control and PC interface board for the control of electrolytic current, voltage. To obtain an optimum in-process electrolytic dressing, the system measures at first the gap and the dressing current using A/D converter. These measurements were taken to operate computer program by dressing condition, and control regular dressing current by using DIO converter. Table 1 represents the specification of optimum in-process electrolytic dressing system.(8-9) The band of peak current (Ip) is from 0A to 40A, pulse duration and pause from 0 to 999 μsec. Analog current and voltage meter are constructed for the measurement of dressing current and voltage. For the optimum control by the computer, the value of measured dressing current converts the digital signal from -5V to +5V for input value of computer by A/D converter. The peak current, pulse duration and pause signal for the control of optimum dressing are transmitted the dressing controller as the digital signal from 0V to 5V.

Fig. 6 shows the flow chart of optimum control of regular current for optimum dressing. The operation of computer program for automatic optimum dressing sets firstly the

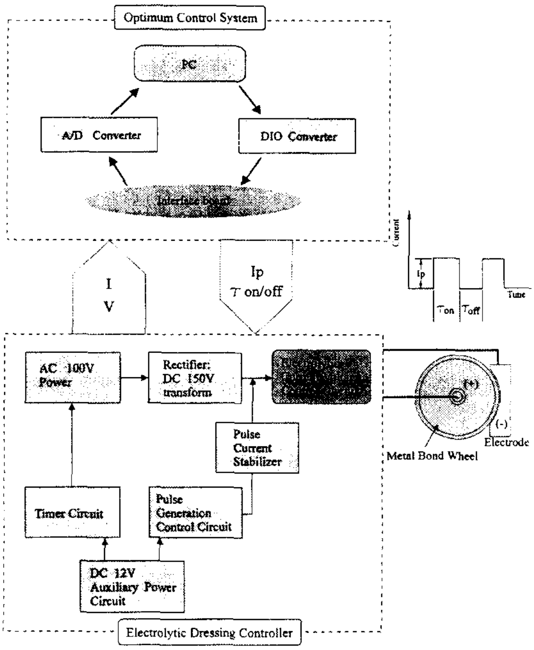


Fig. 5 Optimum control mechanism of regular current for in-process electrolytic dressing

Table 1 Specification of optimum in-process electrolytic dressing system

Peak Curren	0 ~ 40 A
Pulse Duration / Pause	τon/off = 0 ~ 999 μsec
Timer	0 ~ 120 min
Data for Control	Input : Current, Voltage, Gap Output : Ip, τon, τoff
Optimum Control Factor	Regular Current
Input/ Output Data Control Mode	A/D Converter, DIO

initial value of peak current, pulse duration and pulse pause, detects in-process electrolytic dressing condition such as gap and dressing current. The input control signal of in-process electrolytic dressing for optimum dressing changes continuously by the comparison of measured current with optimum regular current. Namely, the peak current, pulse duration and pulse pause according to dressing current change for the keep of optimum dressing. These conditions are preserved in the case of optimum regular current and

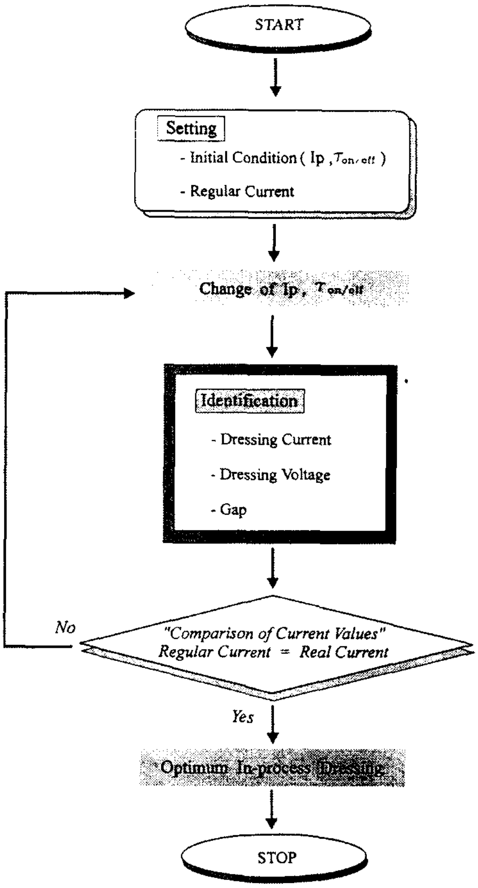


Fig. 6 Flow chart of control of regular current for optimum electrolytic dressing

are changed for the maintenance of optimum value according to the error of current.

Table 2 represents experimental conditions. The electrode, which is the cathode, is pure copper (purity 99%) and the metal bond of the wheel is the anode. Truing is done using a brake-trueing instrument with GC 180 wheel. For measuring the grinding force, a tool dynamometer (kistler, 9257B; piezo type), an A/D converter and a personal computer were used. A electrolyte is used as the solution type (50:1). The data of regular dressing current is obtained 100 data for 0.73 sec and is averaged for the reduction of noise effect. And a gap sensor (Model ST-3501) is attached to the side of the wheel for measuring the

Table 2 Experimental conditions

Grinding Machine	Surface Grinding Machine
Wheel	CBN12000(CBN12000N100M3)
Wheel Speed	3400 rpm
Dressing System	Optimum In-process Electrolytic Dressing system
Electrolytic Fluid	Solution type (50:1)
Power Source	Ip = 0 40 A τon/off=1 10 μsec
Electrode	Copper (1/4 of Wheel size)
Gap Sensor	ST-3501 (Capacitance type) Iwatsu electric Co.
Tool dynamometer	Kistler 3-Component Dynamometer Type. 9257B
Surface roughness teste	Rank Taylor Hobson Surtronics 3+

Table 3 Chemical composition of STD-11 (%)

Materials	Chemical composition (%)
Cr	11.0 ~ 13.0
C	1.4 ~ 1.6
Mo	0.8 ~ 1.2
Mn	0.6
Si	0.4
V	0.2 ~ 0.5
P	0.03
S	0.03

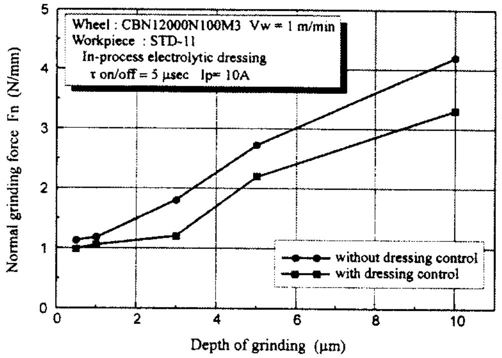


Fig. 7 **Relationship between normal grinding force and depth of grinding**

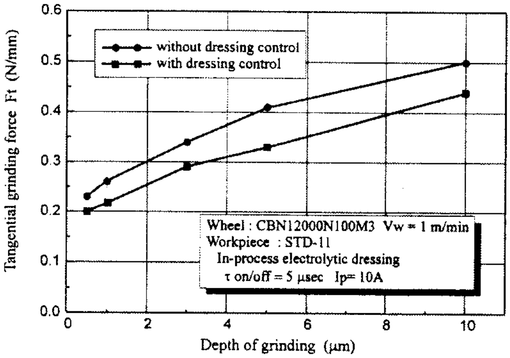


Fig. 8 **Relationship between tangential grinding force and depth of grinding**

wheel removal rate and the insulating layer thickness. The gap distance between the electrode and the metal bond surface is 0.1 mm at first. In this clearance, electrolysis occurs by means of the supply of an electrolytic energy. The workpiece of this experiment is a nitriding die steel (STD-11). Table 3 shows the chemical composition of die steel. And the surface generation and the situation regarding the effect of optimum in-process electrolytic dressing are observed and analysed using a scanning electron microscope.

4. Experimental results and discussion

Fig. 7 shows the change of normal grinding force was measured according to the depth of grinding in the grinding of STD-11 with a metal bonded (grain size 12000) CBN wheel. The normal grinding force decreases with the decrease of depth of grinding. Without control of the dressing current, the normal grinding force increases a little with grinding depth in comparison with the optimum control. Electrolytic dressing efficiency reduces without control of diminished dressing current, and the grinding force increases.

Fig. 8 shows the tangential grinding force for various depths of grinding of STD-11 with CBN wheel. The tangential grinding force with control of dressing current is smaller than that without control after grinding for 1 hours. A reduction in dressing efficiency results from the decrease and unstability of dressing current, and affects the loading and glazing of wheel. The variation of tangential grinding

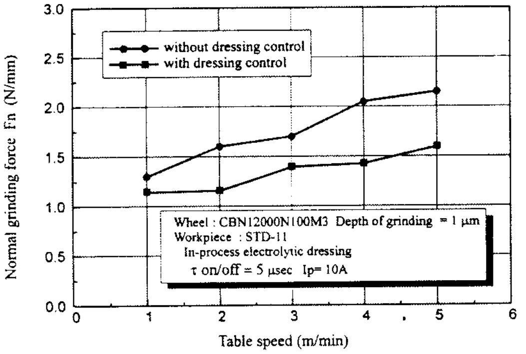


Fig. 9 Relationship between normal grinding force and table speed

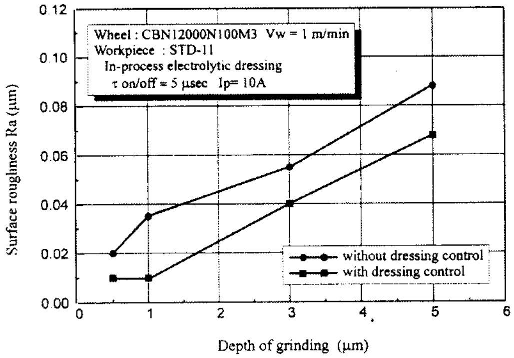


Fig. 11 Relationship between surface roughness and depth of grinding

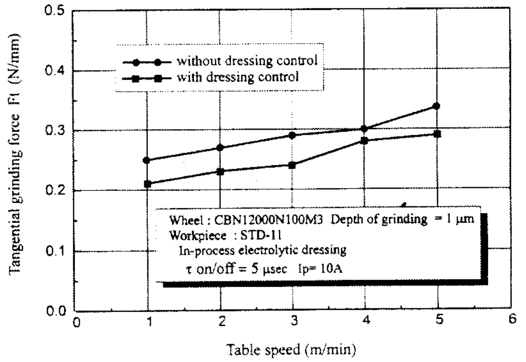


Fig. 10 Relationship between tangential grinding force and table speed

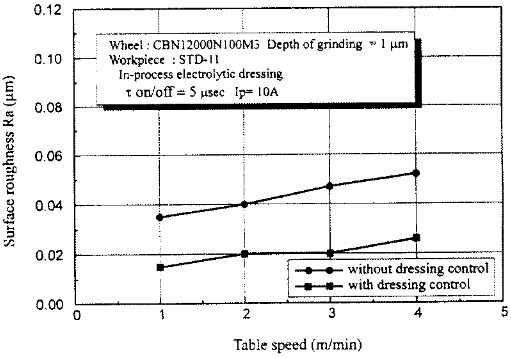


Fig. 12 Relationship between surface roughness and table of grinding

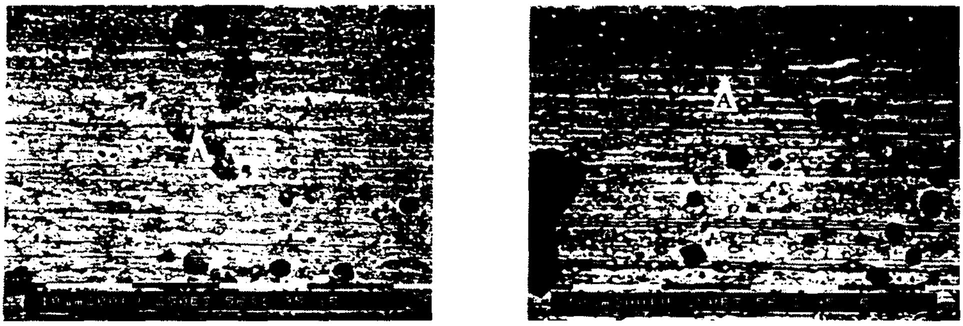
force has a large effect on surface generation in the grinding of STD-11. Therefore, the application of dressing current control has an effect on the small grinding force and mirror-like surface formation in the grinding of STD-11.

Fig. 9 shows the normal grinding force of grinding STD-11 according to table speed at a fixed 1 m depth of grinding. The normal grinding force decreases with the decrease of table speed, and shows the difference in normal grinding force with and without control of the dressing current with a CBN wheel.

Fig.10 shows that the relationship between the tangential grinding force and table speed. The tangential grinding force is smaller when applying dressing current control at all table speeds. Therefore, in the grinding of STD-11 the grinding force is reduced with the use of the optimum in-process electrolytic dressing system owing to the prevention of a glazing. With dressing current control the thickness of oxide layer is able to maintain uniformly, and the new grains which aren't worn protrude on the grinding wheel surface. The worn grain causes the increase of normal and tangential grinding force and has a bad effect on grinding surface.

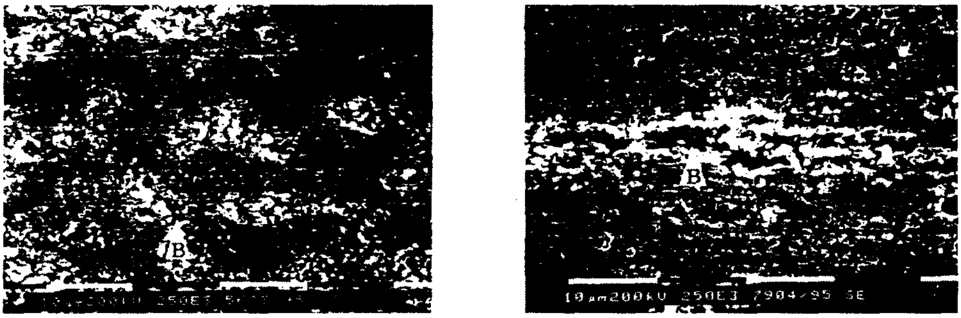
Fig. 11 shows the change of surface roughness according to the depth of grinding. It's observed the surface roughness decreases according to the decrease of depth of grinding. The surface roughness is Ra 0.01 μm at 1 μm depth of grinding. But, in the case of without electrolytic dressing control, the surface roughness value is maintained to Ra 0.02 μm level at 0.5 μm depth of grinding.

The surface roughness with dressing current control is



with dressing control **without dressing control**

(a) depth of grinding : 10 ㎛



with dressing control **without dressing control**

(b) depth of grinding : 20 ㎛

A : grinding mark B : surface breakage

Fig. 13 SEM Photographs of STD-11 according to depth of grinding; Wheel : CBN12000N100M3 Workpiece : STD-11

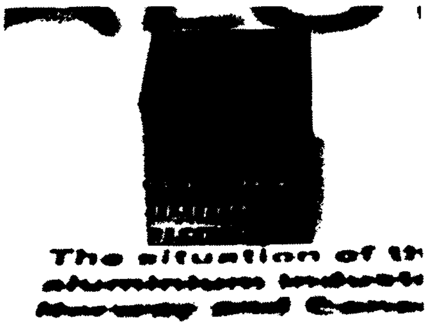
better than without control. Thus, in the grinding of STD-11 the application with dressing control by optimum dressing system is useful. This reason is that the application prevents the glazing phenomenon of grinding wheel.

Fig. 12 shows the change of surface roughness according to the change of table speed. In the case of dressing current control, the surface roughness is not affected largely with table speed and shown almost constant. In the case of without dressing control, the surface roughness increases according to the increase of table speed. Therefore, in the grinding of STD-11 the surface roughness with the use of dressing control is improved for the prevention of glazing phenomenon.

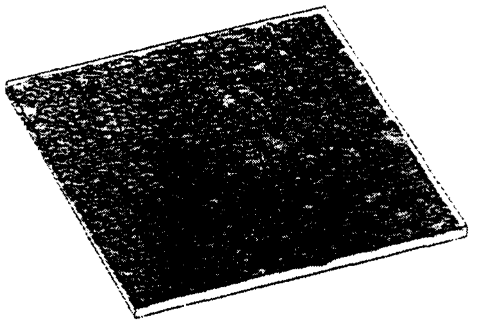
Fig. 13 shows a scanning electron microscope photograph of the STD-11 with metal bonded CBN wheel. (a) shows the ground surface at 10 ㎛ depth of grinding, (b) shows the ground surface at 20 ㎛ depth of grinding.

For 10 ㎛ depth of grinding the ground surface shows the grinding wheel marks (A), and in the case of without dressing control more large grinding marks is observed. In the case of 20 ㎛ depth of grinding, it is shown surface breakage (B) phenomenon on machining surface. In the case of without dressing control, large surface breakage is generated because of glazing phenomenon.

The important factors for the generation of a mirror-like



(a) Ground mirror-like surface



Ra 4 nm

(b) Surface roughness

Wheel : CBN12000N100M3 Vw=1.0 m/min
Depth of grinding : 0.3 mm Wheel speed : 3400 rpm
Workpiece : STD-11
Optimum in-process electrolytic dressing
τon/off=5 μsec

Fig. 14 View of ground mirror-like surface of STD-11

surface are small depth of grinding and very good dressing performance for the prevention of large grinding forces, glazing and loading phenomena.

Fig. 14 shows a view of ground mirror-like surfaces on STD-11 by using optimum in-process electrolytic dressing. Surface roughness is shown very good (Ra 4 nm). Here, a cast iron bonded wheel CBN 12000 is used. In the in-process electrolytic dressing condition the pulse duration/ pause is 5 μsec. Table speed is fixed at 1.0 m/min, and the depth of grinding is 0.3 μm.

5. Conclusions

In this study an optimum in-process electrolytic dressing system is proposed for mirror-like grinding of die steel (STD-11) with a metal bonded CBN wheel. This dressing system was developed and produced an effective control of regular electrolytic dressing current by computer control. By applying this system the grinding force and the surface roughness decreased in the grinding of die steel, and the wheel marks and breakage was reduced. Therefore, the mirror-like grinding of STD-11 is achieved by the application of the optimum in-process electrolytic dressing. And, the worn grains are protruded in the surface of the wheel in the case of without dressing current control, causes the increase of normal and tangential grinding force and has a bad effect on grinding surface.

Applying an optimum in-process electrolytic system, the worn grains are removed and it is possible to be grinded stably by new grains.

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