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Design of continuity processes of electrochemical finishing and grinding following turning[†]

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Abstract

A newly designed finishing process utilizing an effective electrode and a grinding tool to execute the continuous electrochemical finishing and grinding processes following turning is described in this paper. The proposed process can be used for a variety of turning operations. Electrochemical finishing and grinding can be performed following the finishing process on the same machine by using a simple attachment. The factors affecting electrochemical finishing, grinding performance, and electrochemical finishing are discussed. The electrode was tested with both continuous and pulsed direct current. A higher work piece rotational speed produced a better finish. Changing the electrode design from a semicircle to a wedge form with a small end radius caused the electrolytic products and heat to dissipate more rapidly and provided the best finishing. Pulsed direct current finishing was slightly better than using continuous direct current finishing. However, the use of pulsed current would increase machining time and cost.

Keywords: Continuity processes; Grinding; Electrochemical finishing; Turning; Design; Finishing tool

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1. Introduction

Grinding is the finishing process in mould and die manufacturing. Surface quality plays a very important role in the performance of machined parts [1]. Variations in position, velocity, and force trajectories in the grinding process affect component quality by changing the surface finish, geometry, and process material removal rate. Thus, controlling the position, velocity, and force is critical to achieving a high quality product from the grinding process [2, 3]. In continuous grinding operations, the grinding efficiency of vitrified grinding wheels deteriorates as the sharp cutting edge becomes blunt from the formation of wear flats. Dressing during the sharpening operation addresses this problem by generating a specific topography on the grinding wheel's cutting face [4].

Electropolishing is used for difficult-to-machine materials, such as ceramic and cermet. Ceramic and cermet materials are used for die components, plastic or press dies, wire-drawing dies, and optical units. Electropolishing can also be applied to electrolytic components (silicon chips, VLSI/ULSI chips). Electrochemical machining (ECM) was originally described by Faraday in the eighteenth century who used electric energy and chemical processes to remove materials [5]. The main difficulty in the complicated process of metal removal is the design of the tool electrode. The electrochemical hole machining process improves hole precision by controlling machining conditions and electrode geometry [6]. The gap width between the electrode and work piece directly influences the current condition and the dreg discharge of the electrolyte [7]. The quality of the machined surface will be influenced by current density, electrolyte flow rate, and the gap width in

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electrochemical machining [8]. When $NaNO_3$ is used as the electrolyte for die surface electropolishing, the surface roughness decreases with increased current density, flow rate and electrolyte concentration [9]. It has been shown that machining resolution can be reduced to a few micrometers by applying ultra short pulses with a duration of a nanosecond for micro structures produced by ECM [10].

Varies types of electrodes were developed for electropolishing, including the disc-form electrode [11, 12]. In ECM, good work piece surface quality was obtained by careful selection of experimental conditions [13]. However, the major difficulty of electrochemical finishing is the cost and the effort required to design the finishing tool. The design of the finishing tool plays a major role in electrochemical finishing [14]. Grinding assistance for electrochemical finishing and the design of the finishing tool are crucial steps for the finishing process of turning. In the current study, the most effective finishing process is discussed, and the advantage of using low cost equipment with continuous electrochemical finishing and grinding following turning is presented.

2. Experimental setup and processes parameters

The development of an effective design for continuous electrochemical finishing and grinding following turning is illustrated in Fig. 1. The process utilizes a scientific design method that includes analysis of design considerations, development, and details and experimental analysis to construct the final design results [15]. The system schematics and configuration of the finishing tool and work piece are illustrated in Fig. 2. The type and configuration of the finishing tool and work piece are shown in Fig. 3. The work piece material was composed of ASTM D2. The chemical composition is shown in Table 1. The work piece dimensions after fine turning were 30.02 mm (diameter) and 150 mm (length). The reduction in diameter after electrochemical finishing and grinding was 0.02 mm. The grinding tool that was used was the GC2000H6V. The average surface roughness of the work piece after precise turning was about 3.5 μm. The $NaNO_3$ electrolyte concentration was 15 %wt. The machining temperature was maintained at 40±5 ℃. The gap width between the electrode and work piece was 1.0, 2.0, 3.0, 4.0 or 5.0 mm. The electrolyte flow rate was 4, 6, 8, 10, or 12 L/min. The work piece rotational speed was varied from 200 to 1400 rpm. The current rating was 15, 20, 25, 30, 35, or 40A. The finishing tool feed rate ranged from 20 to 120 mm/min. The pulsed period (on/off time) was 100 ms/100 ms, 100 ms/200 ms, 100 ms/300 ms, 100 ms/400 ms or 100 ms/500 ms. The experiments examined a range of design finishing tools and different finishing processes, including electrochemical finishing (EF), pulsed electroche-

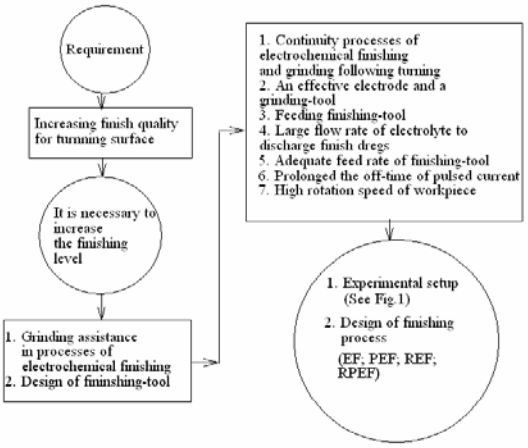


Fig. 1. Design process with a basis of analysis [15].

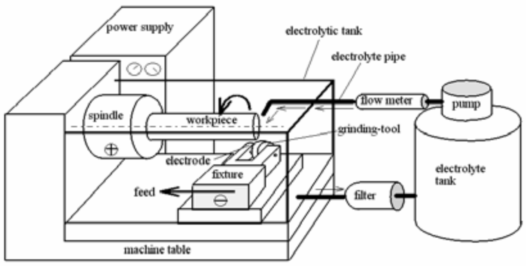
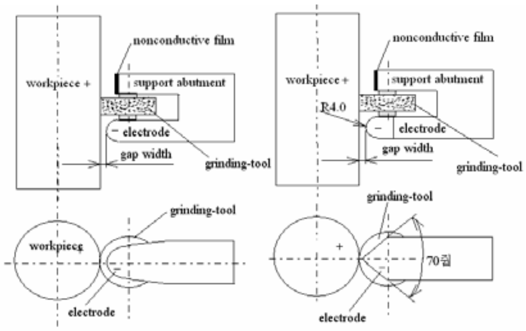


Fig. 2. Experimental setup.



(a) Type A (b) Type B

Fig. 3. Configuration of finishing tool and workpiece.

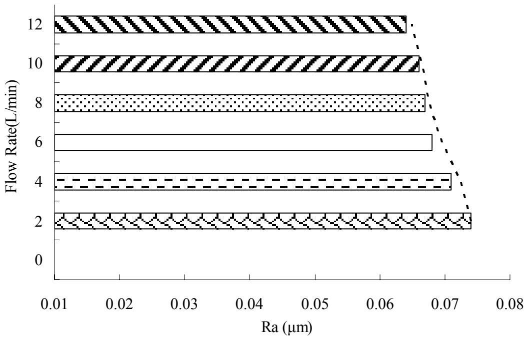


Fig. 4. Continous processes of electrochemical finising and grinding at different electrolyte flow rates (ASTM D2, $NaNo_3$, 15 %wt, 40 ℃, gap width 3 mm, continuous DC 40A, 120 mm/min, type A, workpiece.

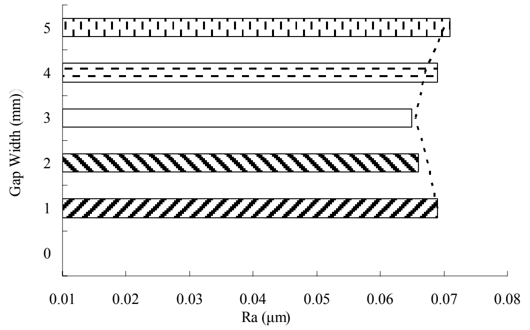


Fig. 5. Continous processes of electrochemical finising and grinding at different electrolyte and work piece gap width (ASTM D2, $NaNo_3$, 15 %wt, 40 ℃, continuous DC 40A, 120 mm/min, type A, workpiece 1000 rpm).

mical finishing (PEF), continuous electrochemical finishing and grinding (GEF), and compound processes of pulsed electrochemical finishing and grinding (GPEF). The range of experimental parameters is shown in Table 2. Three specimens were analyzed. After electrochemical smoothing, the surface roughness of work pieces was measured with the Hommel T500 instrument, the accuracy of which is within a range of ±5 % after standard correction. The surface roughness is characterized by Ra, where the length of cut-off is 0.8 mm and the measuring direction is perpendicular to the tooth mark. The measurements were performed at a minimum of two different locations.

3. Results and discussion

Fig. 4 shows that, as the flow rate increased, electrolytic depositions and heat removal occurred more rapidly and the surface roughness of the work piece was improved. Therefore, the use of a large electrolytic flow rate is preferred. Fig. 5 shows that an adequate gap width between the electrode and work piece produced a better finish. A small gap width takes a shorter time for material removal, but the discharge of electrolytic depositions from the gap is more difficult; hence, the effect of finishing is reduced. A large gap width takes a longer time for material removal since the effect of electrochemical finishing is reduced [14]. For the stable operation of electrochemical finishing and grinding, a gap width of 3 mm was more effective, so it was used for the next-stage test.

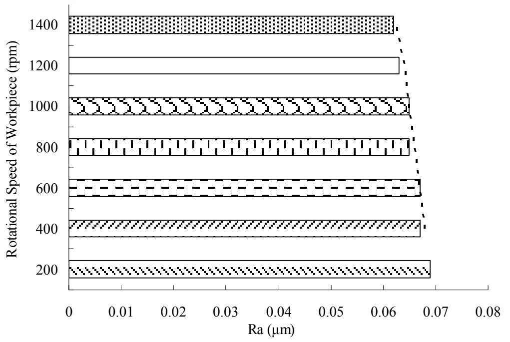


Fig. 6. Continous processes of electrochemical finising and grinding at different finishing tool rotational speeds (ASTM D2, $NaNo_3$, 15 %wt, 10 L/min, 40 ℃, gap with 3 mm, continous DC 40 A, 120 mm/min, type A)

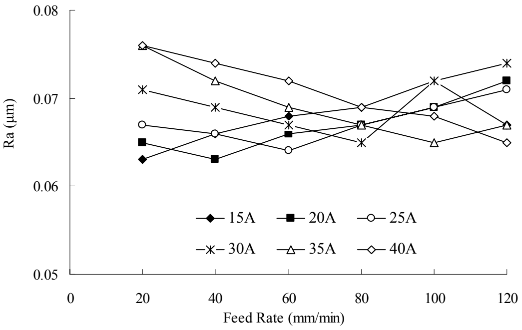


Fig. 7. Continous processes of electrochemical finising and grinding varying the finishing tool feed rate with different current ratings (ASTM D2, $NaNo_3$, 15 %wt, 10 L/min, 40 ℃, gap width 3 mm, continuous DC, type A, workpiece 1000 rpm).

The rotation effect of the work piece is shown in Fig. 6. A work piece rotational speed greater than 1000 rpm is suggested. Over 1000 rpm, the rotation effect contributed to effective flushing, with high-speed rotation producing a better effect on electrochemical finishing and grinding. Fig. 7 shows that, for the continuous processes of electrochemical finishing and grinding (GEF), a good finish was achieved by properly setting the current rating and feed rate of the finishing tool. A fast feed reduces the power delivered to a unit area of the work piece surface, and a slow feed increases it. The former cannot supply sufficient electrochemical power, whereas the latter leads to the problem of dreg discharge. In order to achieve the same 0.02 mm removal of ASTM D2 from electrochemical finishing and grinding compound processes, the following settings are suggested: 15 A and 20 mm/min, 20 A and 40 mm/min, 25 A and 60 mm/min, 30 A and 80 mm/min, 35 A and 100 mm/min, and 40 A and 120 mm/min for the finishing process. According to the formula, derived from Faraday's Law [5], the theoretical removal on an alloy is expressed as:

$$W = \frac{\eta \times I \times t}{F \times (\frac{n_A}{M_A} a_A + \frac{n_B}{M_B} a_B + ...)} \tag{1}$$

where η is the efficiency of current, I is the current, t is electrochemical finishing time, F is the Faraday constant, n_i is the atom number, a_i is the proportion of composition, and M_i is the atomic mass.

$$\text{Let } M_R = W/A \tag{2}$$

$$M_R = \frac{\eta \times I \times t}{F \times A \times (\frac{n_A}{M_A} a_A + \frac{n_B}{M_B} a_B + ...)} \tag{3}$$

$$= \frac{\eta \times I_A \times t}{F \times (\frac{n_A}{M_A} a_A + \frac{n_B}{M_B} a_B + ...)} \tag{4}$$

where M_R is the theoretical material removal in the longitudinal direction, A is the relative area of the electrochemical finishing, and I_A is the current density.

From the above formula, M_R is directly proportional to the electrochemical finishing time (t). The theoretical machining time (t) for identical material removal (M_R) can be calculated (where η and F are regarded as constants for the material). The experimental results show that the material removal is directly proportional to the current density (I_A). This agrees with the theoretical prediction.

Fig. 8 shows that the performance results for electrochemical finishing (EF), pulsed electrochemical finishing (PEF), continuous processes of electrochemical finishing and grinding (GEF), and compound processes of pulsed electrochemical finishing and grinding (GPEF) using different finishing tools (Types A and B). Type B gave the best surface finish. Changing the design of the electrode from a semicircle (type A) to a wedge form with a small end radius (type B) provided more open space for dreg discharge. This allowed the electrolytic products and heat to discharge more rapidly, which improved the entire finishing effect [12, 14]. Off-time with longer pulse was slightly better because of the more complete discharge of electrochemical finishing dregs during the off-time, but the machining time and cost increased. Surface roughness was further reduced without the assistance of grinding. Electrochemical finishing (EF) using grinding was superior to the use

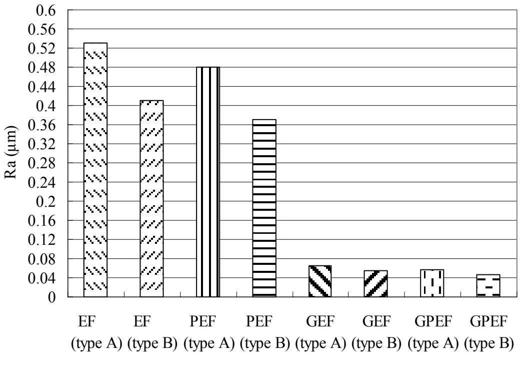


Fig. 8. Evaluation of the finising effect of four processes (ASTM D2, NaNo₃, 15 %wt, 12 L/min, 40 ℃, gap width 3 mm, 40 A, 120 mm/min, 100 ms/500 ms, workpiece 1000 rpm).

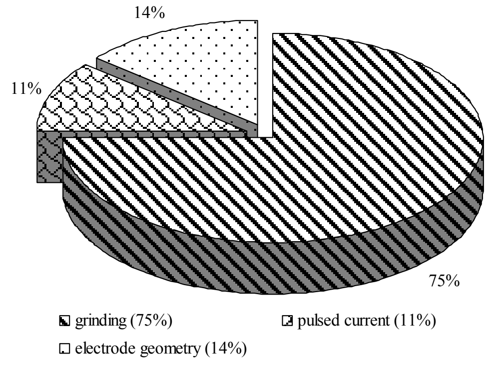


Fig. 9. Contribution to the improvement of surface finish for the design's finishing tool (ASTM D2, Type B, NaNo₃, 15 %wt, 12 L/min, 40 ℃, gap width 3 mm, 40 A, 120 mm/min, 100 ms/500 ms, workpiece 1000 rpm).

of pulsed direct current. As shown in Fig. 8, the surface of the work piece had an average surface roughness from 0.41 μm (from Type B) to 0.53 μm (from Type A) after EF and an average surface roughness from 0.37 μm (from Type B) to 0.48 μm (from Type A) after PEF. With grinding only, an average surface roughness of 0.093 μm was produced. When grinding was performed simultaneously with electrochemical finishing (GEF), the surface roughness was reduced from 0.054 μm (from Type B) to 0.065 μm (from Type A). Therefore, continuous electrochemical finishing and grinding following turning improves the two individual processes and rapidly and efficiently achieves a superior surface finish. Fig. 9 shows that the average contributions of continuous pulsed electrochemical finishing and grinding (GPEF) to the improvement of surface finish were 11 % for pulsed current, 75 % for grinding, and 14 % for electrode geometry. The improvement is expressed as the percent reduction in surface roughness values obtained with each design parameter. In summary, the design of the continuous processes for grinding produced the greatest improvement. The compound process of electrochemical finishing and grinding (GEF) without pulsed current is also recommended. The use of pulsed current is of limited value, especially if the increased finishing time and increased cost of pulsed-power supply equipment is considered.

4. Conclusions

The continuous processes of electrochemical finishing and grinding following turning by the design's finishing tool require a shorter time to produce a smooth and bright workpiece surface. The design's finishing tool with an effective electrode and a grinding tool provides the optimum value for higher current density, and it provides larger discharge space, thereby producing a smoother surface. The use of a higher electrolytic flow rate and a high work piece rotational speed produces a better finish. The finishing effect is better with longer off-time because of the improved discharge of the finishing dregs. Changing the design of the electrode from a semicircle to a wedge form with a small end radius causes the electrolytic products and heat to discharge more rapidly and produces the best finishing. Grinding following electrochemical finishing improves the finishing effect and uses low cost equipment in the turning process.

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