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Turning-form electrode in ultrasonic-aided electrochemical finishing

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ABSTRACT

Purpose: The ultrasonic-aided electrochemical finishing following traditional turning by a turning-form electrode for several die materials is demonstrated.

Design/methodology/approach: A guide line for the design process is followed a scientific method including the design requirement, design development, detail design, and experimental analysis is adopted in the current study. The proposed design of turning-form electrode combined with the ultrasonic-aided electrochemical finishing is presented.

Findings: Smaller end radius and smaller declination angle are associated with higher current density and provides larger discharge space and better polishing effect. The plate-shape electrode with small end radius and decreasing the surface area of top-view performs the best. The ultrasonic assistance can avoid the difficulty of dreg discharge in the electrochemical finishing, thus increasing the finishing effect.

Research limitations/implications: The potential for electrode design and using ultrasonic energy transmitted to the electrolyte to assist discharging dregs out of electrode gap during the electrochemical finishing is yet to be explored.

Practical implications: This process can be used for various turning operations including end turning, form turning, and flute and thread cutting. Through simple equipment attachment, the electrochemical finishing can follow the cutting on the same machine and chuck.

Originality/value: It is a great contribution that the ultrasonic-aided electrochemical finishing after turning process just needs quite short time than manual or machine finishing to make the surface of workpiece smooth and bright. An effective and low-cost finishing method after turning process is presented.

Keywords: Surface treatment; Turning-form electrode; Ultrasonic-aided; Electrochemical finishing, Die material; Turning process; Low-cost finishing

1. Introduction

Electrochemical machining (ECM) is suitable for high-strength and high-melting point alloy. More industrial applications were realized throughout the decades, such as electrochemical drilling, electrochemical grinding, electrochemical deburring, and electropolishing [1]. Shen used $NaNO_3$ as the electrolyte to proceed the electropolishing on die surface. The result showed that the surface roughness of workpieces decreases with the increase of current density, flow rate and concentration of electrolyte. Moreover, polishing with pulsed direct current is found to be better than continuous direct current [2]. The gap width between electrode and workpiece directly influences the electrical current condition and the dreg discharge [3]. In ultrasonic cleaning, the ultrasonic energy is transmitted to the medium of liquid, and the object is put into the washing tank via soaking to execute the cleaning function. The ultrasonic cleaning usually uses high-frequency vibrations (the range of frequency is between 20-50 kHZ) in the cleaning liquid to remove the filth rapidly and to achieve the function of cleaning. In comparison with the traditional cleaning methods, it not only shortens the cleaning time, but also has an excellent capability of erasing pollution [4]. For electropolishing of external and internal cylindrical surface, various types of electrodes were also developed, including the disc-form and borer-shape [5,6]. Good surface quality of the workpiece was obtained through the arrangement of the experimental conditions. In ECM, when the machining depth increases, structures taper. A disc-type electrode is introduced to reduce the taper [7]. Electrochemical machining process is still being under-utilized because of the lack of understanding of the mechanism of metal removal and the use of inefficient tool design methodology. Even for simple cases, it is not possible to predict work profiles accurately [8]. The electropolishing is a surface finish process [18], in which the major difficulty faced is the cost and the compensation design of tool electrode.

Surface crack and micro-voids are often induced and reduced the service life. Electropolishing can efficiently produce workpieces free of the above-mentioned shortcomings [9]. author conducted electrochemical finishing with a design turning-form electrode in a cylindrical surface when turning process can not achieve the desired fine surface finish for some die materials. The potential for using ultrasonic energy transmitted to the electrolyte to assist discharging dregs out of electrode gap during the electrochemical finishing is yet to be explored. Further enhancement is obtained through the ultrasonic aided. For the purpose of further improving the application of electrochemical finishing, the performance assessment of design turning-form in ultrasonic-aided electrochemical finishing of the workpiece surface is investigated.

2. Design process

A guide line for the design process is followed a scientific method [10]. The finishing effects are identified in the experiment. The development of an effective design of turning-form electrode and the ultrasonic aid in electrochemical finishing of workpiece surface is based on the following considerations:

1. Effective discharge of electrolytic product
2. Reduction of secondary machining
3. Increase of electric current density
4. Low-cost consideration
5. Effect of ultrasonic aid
6. Economic-size power supply

The the geometry of the turning-form electrode is shown in Fig. 1.

3. Experimental set-up

The system schematics and configuration of tool and workpiece of experiment set-up are illustrated in Fig. 2. The materials of workpiece: AISI H13, AISI D2, AISI P21, and AISI 4340. The chemical compositions are shown in table 1. The amount of the reduction of diameter after electrochemical finishing is 0.2mm. The main parameters include the geometry of electrode, die material, the rotational speed of workpiece, the frequency and power of ultrasonic, and the electrode feed rate. The electrolyte is $NaNO_3$ of 25%wt. The flow rate of electrolyte is 6 l/min.

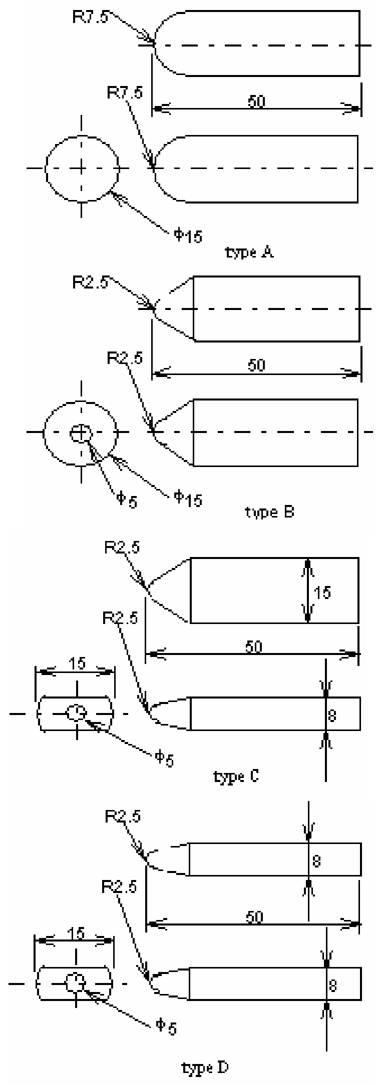

Fig. 1. Design of turning-form electrode

The temperature of the machining is maintained at 25±5□. The gap width between electrode and workpiece is set 0.3mm. The current rating is 10A. The rotational speed of workpiece is 200, 400, 600, 800, 1000, 1200, and 1400rpm. The axial feed rate of the electrode ranges from 0.5 to 4.0mm/min. The frequency and power of ultrasonic is 46KHZ/50W, 46KHZ/80W, 120KHZ/80W, 120KHZ/150W.

Table 1.
Chemical composition of workpieces (Wt %)

	Fe	C	Si	Mn	P	S	Cr	Mo	Al	V	Cu	Ni
AISI H13	90.7	0.4	1	0.4	0.3	0	5.3	1.1	/	0.8	/	/
AISI D2	88.65	1.4	0.4	0.3	0	0	8.2	0.8	/	0.2	/	/
AISI P21	92.06	0.1	0.6	1.5	/	/	/	0.3	1.1	/	1.2	3.1
AISI 4340	96.48	0.4	0.3	0.9	0	0	0.8	0.3	/	/	0	2

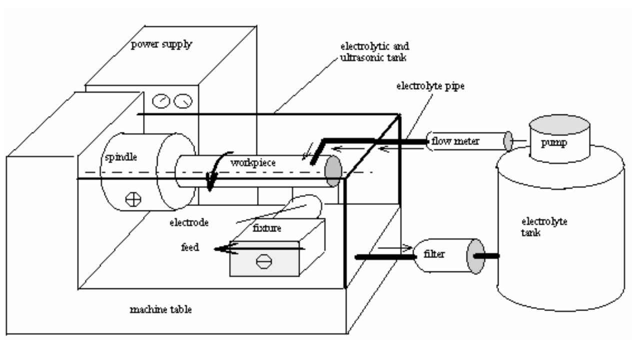

Fig. 2. Experimental set-up

4. Results and discussion

Fig. 3 suggests an adequate range of feed rate of turning-form electrode in electrochemical finishing. High feed rates produce insufficient finishing, while low feed rates worsen the surface finish by excessive material removal. The same good finishing can be achieved by adequate combination of current rating and electrode feed rate, such as 5A and 1mm/min, 10A and 2mm/min, 15A and 3mm/min, and 20A and 4mm/min. Fig. 4 suggests the operation at the current rating of 10A and feed rate of 2mm/min for the electrode in the present case. Figure 4 shows the amount of diameter reduction is inversely proportional to the feed rate for all the tested materials. Small feed rates provide large amount of energy input per unit length of the electrode travel, leading to deep removal of material. Hence the diameter control of the workpiece has to be done by knowledge of this relationship.

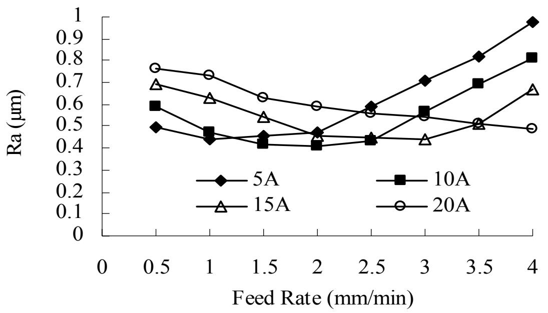

Fig. 3. Electrochemical finishing at different feed rate and current rating(Type A, AlSiH13, $NaNO_3$, 25%wt, 6l/min, continous DC, workpiece 600rpm)

Fig. 5 compares the electrochemical finishing of AISI H13 through different design turning-form electrodes, the results show that among the four types of electrode, the electrode D gives the best surface finish. Various design electrodes show different finishing effect in the electrochemical finishing process. Type A is the simplest half-global form providing the mediocre effect. Type B reduced the end radius on the edge of the cylinder can be eliminated the secondary machining effectively, more space for dreg discharge is also obtained, thus the finishing effect is better than type A. Type C is designed change to a plate shape which has small end radius on the edge of the plate can actually provides more open space of dregs discharge than the other electrodes. Type D of the plate-shape decreased the surface area of top-view is associated with larger electrolyte flowing and discharge space. In the meantime, the electrolytic products and heat can be brought away more rapidly. Thus the finishing effect is better than the electrode C. The effects of reducing the end radius, design change to the plate shape, and decreasing the surface area of top-view in electrochemical finishing are summarized in Fig. 6.

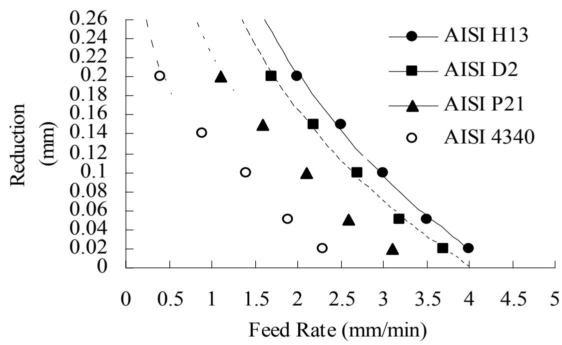

Fig. 4. Correlation between diameter reduction and feed rate (Type A, $NaNO_3$, 25%wt, 6l/min, 10A, workpiece 600rpm)

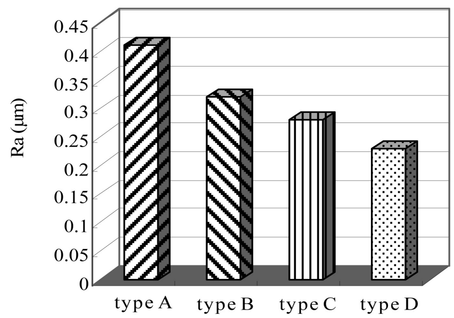

Fig. 5. Electrochemical finishing with different types of electrode (AlSiH13, 6l/min, 10A, 2mm/min, workpiece 600rpm)

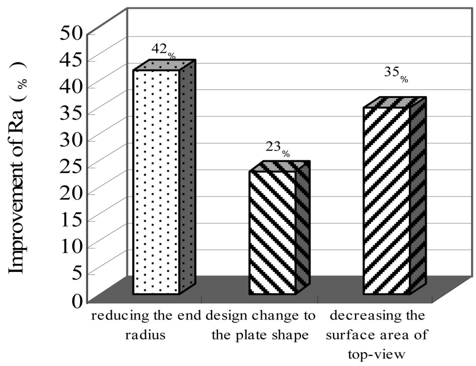

Fig. 6. The average contribution of surface finish improvement (Type D, AlSiH13, 6 l/min, 10A, 2mm/min)

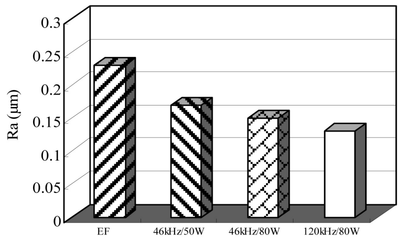

Fig. 7. Effect of frequency and power of ultrasonics (Type D, AlSiH13, 6 l/min, 10A, 2mm/min, workpiece 600rpm)

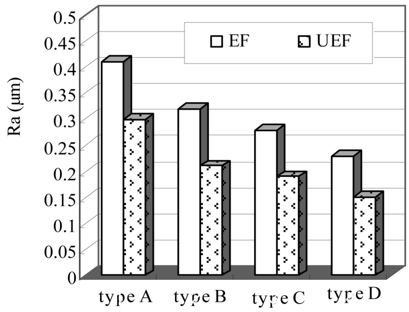

Fig. 8. Effects of Design Electrodes (AlSiH13, 6 lmin, 10A, 2mm/min, 46khz/80W)

The improvement is calculated by the reduction of surface roughness in variation with the considered design parameter divided by the best value in that experiment. Based on the above results, the author finds the contribution of surface finish improvement obtained by type D through the design of reducing the end radius is more significant (42%) than design change to the plate-hape (23%), and decreasing the surface area of top-view (35%). It shows that reducing the end radius is the most potential design factor to be considered, followed by design change to the plate shape, and decreasing the surface area of top-view. Fig. 7 shows that the method of ultrasonic-aided electrochemical finishing improves the finishing quality. The higher the frequency or the power is, the better is the finishing. One believes the reason is that the electrolyte with ultrasonic vibration energy has the capability of discharging dregs effectively out of the tight machining gap. In the current process, the frequency and power level of ultrasonics of 46Kz/80W is used. Fig. 8 shows the finishing effects of electrochemical finishing and ultrasonic-aided electrochemical finishing. It remains the same finishing sequence for different electrodes with or without the ultrasonic aided, but the surface roughness is further reduced than without the ultrasonic aided. The ultrasonic power (46kHz/80W) being applied to type D can improve the roughness by 0.08µm (from 0.23µm to 0.15µm), and the surface finishing with the design change of electrode from type A to type D is from 0.41µm to 0.23µm. The use of ultrasonics provides an effective method to assist the design of electrode. From the experimental results, the average contribution of ultrasonic-aided The ultraelectrochemical finishing of surface finish improvement obtained by type D through the use of ultrasonics (44%), and the electrode geometry (56%). In summary, the ultrasonic-aided in electrochemical finishing is worth to be recommended following the turning process. As to the incorporation of ultrasonic aided electrochemical finishing elevates the finishing effect and the machining time is not increased, thus the ultrasonics definitely promotes the effect of the electrode design. Even if the design of electrode remains the most influential parameter in this study, however, both adopted electrode design and ultrasonic aided are efficiency and low-cost means.

5. Conclusions

The ultrasonic-aided electrochemical finishing following traditional turning by a turning-form electrode for several die materials is demonstrated. Smaller end radius and smaller declination angle are associated with higher current density and provides larger discharge space and better polishing effect. The plate-shape electrode with small end radius and decreasing the surface area of top-view performs the best. The higher current density with ultrasonic aid will overcome the problem of dreg discharge and reduce the finishing time. The proposed design of turning-form electrode combined with the ultrasonic-aided electrochemical finishing which followed by the turning process require a shorter time to make the workpiece surface smooth and bright.

Acknowledgements

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