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Experimental Investigation on Electrochemical Grinding of Inconel 718

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Abstract

Electrochemical grinding (ECG) is a variation of electrochemical machining (ECM), in which material is removed from the workpiece by simultaneous electrochemical reaction and mechanically abrasive action. It offers a number of advantages over conventional grinding, such as low induced stress, large depths of cut, and increased wheel life. It has been reported that ECG was employed in machining stainless steel 304, metal-ceramic hard alloy of WC-Co groups, and Tungsten carbide. Inconel 718 is used extensively in aerospace because of their excellent combination of high specific strength (strength-to-weight ratio) which is maintained their fracture resistant characteristics, and their exceptional resistance to corrosion at elevated temperature. The machinability of Inconel 718 is generally considered to be poor owing to several inherent properties of the materials. Poor thermal conductivity, chemically reactivity and low elastic modulus are the common problems.
In this paper, ECG is employed to process Inconel 718. To prolong the wheel life, the brazed diamond wheel is introduced to be a tool instead of the electrodeposited diamond wheel. Experiments illustrated that the tool durability has been improved from 15 hours to 50 hours when a brazed diamond wheel was employed to replace an electrodeposited diamond wheel. In addition, a proper high applied voltage and electrolyte temperature was verified to be conductive to improve the maximum electrode feed rate and material removal rate. A electrode feed rate of 6.6 mm min^{-1} was obtained at 30 V and 36 ℃, respectively.

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Keywords: Electrochemical grinding; Inconel 718; brazed diamond wheel; hybrid machining

1. Introduction

Developments of aero-engine are in great demand for super alloys with high specific strength to fatigue resistance and exceptional resistance to corrosion at elevated temperature. Because of its excellent inherent characteristics, Inconel 718 has been increasingly applied in key components of aero engine such as blade, blisk and cartridge receiver [1]. However, the machinability of Inconel 718 is generally considered to be poor owing to several inherent material properties including poor thermal conductivity, chemically reactivity and low elastic modulus. Electrochemical grinding (ECG) is a hybrid process combining electrochemical machining (ECM) and conventional grinding, in which material is removed from the workpiece by simultaneous electrochemical reaction and mechanically abrasive action [2-3]. It offers a number of advantages over conventional grinding, such as low induced stress, large depths of cut, and increased wheel life.

ECG has been well applied in machining stainless steel 304, metal-ceramic hard alloy of WC-Co groups, and Tungsten carbide for improving the surface integrity [4-6]. Recently, more interests have been focused on increasing the material removal rate, improving the machining accuracy and enhancing the tool life. Atkinson J. [7] found that pulsed voltage with a low duty cycle was effective in diminishing the overcut while the wheel grit type has no specific influence on it. Zaborski S. [8] have studied different forms of cathode wear in ECG and presented the crucial factors influencing on their wear. It was found that cathodes having diamond embankment are considerably more durable than others. Joshi S.S. [9] has analyzed the electrolytic flow effects in micro ECG. Roy S. [10] studied the effect of voltage on surface texture in ECG.

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Nevertheless, few investigations on electrochemical grinding Inconel 718 were reported. In this paper, ECG is employed to process Inconel 718. Experiments were conducted to verify the feasibility of the brazed diamond wheel instead of the electrodeposited diamond wheel to prolong the wheel life. In addition, the effects of electrode feed rate, applied voltage and electrolyte temperature on material removal rate (MRR) were experimentally investigated.

2. Experimental procedures

Fig. 1 shows a schematic diagram of electrochemical grinding. The diamond wheel is attached to a high-speed spindle and fed along the programmed tool trajectory. When a voltage is applied, the rotary wheel is fed perpendicular to the workpiece surface. Afterwards, the wheel is fed along the workpiece surface. In this paper, a brazed diamond wheel and an electrodeposited wheel were used to evaluate the tool durability.

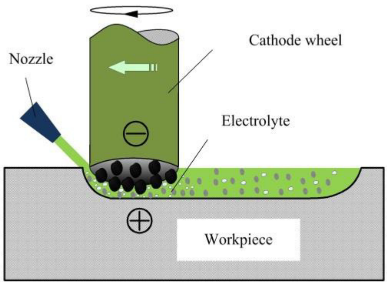

Fig. 1. Schematic diagram of electrochemical grinding

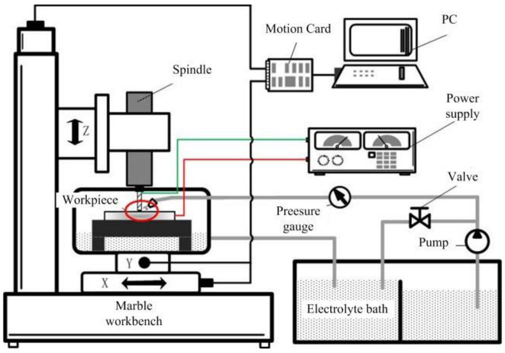

Fig. 2. Experimental setup for electrochemical grinding

Fig. 2 shows a schematic diagram of the experimental setup for ECG. This system comprises an X–Y–Z–C movement stage, an electrolyte recycling system, a real-time detection system, and some accessories. The wheel is fed along the programmed trajectory via X-Y-Z linear motion. Rotation of the wheel is accomplished via an air-bearing spindle installed on the Z-axis. The electrical energy is supplied by a DC power and the machining current is detected in real time by a Hall sensor.

Material removal rate (MRR) is one of the most important criterions determining the machining efficiency and is defined as follows:

$$MRR = m/t \tag{1}$$

Where m is the mass removed in the ECG process, and t is the machining time.

Samples of Inconel 718 with dimensions of 80 mm × 60 mm × 5 mm were ultrasonically cleaned and weighted by analytical balance (AE240, Mettler, China) before and after the experiments. Based on pre-trials of the machining stability, the machining conditions were chosen and listed in Table 1. The electrolyte temperature was controlled and measured at the electrolyte bath. Its range were set from 30 ℃ to 36 ℃ and equally divided to 4 intervals. When the electrolyte temperature is under 30 ℃, the electrolyte conductivity is too low to support a stable efficient material removal process. When the electrolyte temperature is above 36 ℃, it is easy to boil in the machining zone. The applied voltage was ranged from 6 V to 30 V and equally divided to 5 intervals. When the voltage is under 6 V, the ratio of electrochemical material removal is so small that material is almost removed by mechanical abrasion. When the applied voltage is above 30 V, the machining gap is so large that the tool could touch the workpiece surface and the mechanical abrasive action will not take place.

Table 1. Machining Conditions

Parameter	Value
Electrolyte	120 g L^{-1} $NaNO_3$
Electrolyte temperature /℃	30, 32, 34, 36
Electrode feed rate /mm min^{-1}	0.5-7
Applied voltage /V	6, 12, 18, 24, 30
Spindle speed /rpm	1500
Machined depth /mm	0.5
Machining length /mm	10

3. Results and discussion

3.1. Comparison of tool durability between a brazed diamond wheel and an electrodeposited wheel

In industrial production, tool cost has a major percent of the processing cost. Thus, improving the tool durability is important in cost reduction. Electrodeposited Diamond wheels have been proven to be durable in ECG. However, the diamond grains are easily brushed off during machining Inconel 718 and the tool durability was too short. To prolong the wheel life, the brazed diamond wheel is introduced to be a tool instead of electrodeposited diamond wheel. Experiments have been carried out to compare the tool durability of these two kind wheels. In this set of experiments, the applied voltage was 18 V, the electrode feed rate was 1 mm min^{-1} and the electrolyte temperature was 30 ℃. The diamond grain size of the electrodeposited diamond wheel and the brazed diamond wheel is about 100 μm.

The durability results were listed in table 2. The tool durability has been improved from 15 hours to 50 hours when a brazed diamond wheel was employed. Thus, in the following experiments brazed diamond wheels were used to investigate the parametric effects on material removal rate and maximum feed rate.

Table 2. Tool durability of different kinds of wheels

Wheel	Time (H)
Electrodeposited diamond	15
Brazed diamond	50

Fig. 3 presents the wheels which have been used for 15 hours. As shown in fig. 3(a), few electrodeposited diamonds were left and stood out the substrate metal. While, most of the brazed diamonds remained intact with only several in the center dropped. It was obvious that the wear of electrodeposited diamonds is much serious than the brazed.

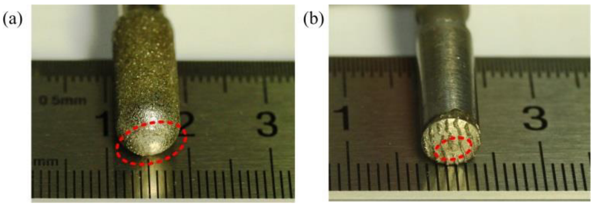

Fig. 3. Wheels after machining with 15 hours. (a) electrodeposited diamond wheel, (b) brazed diamond wheel

3.2. Effects of electrode feedrate on ECG

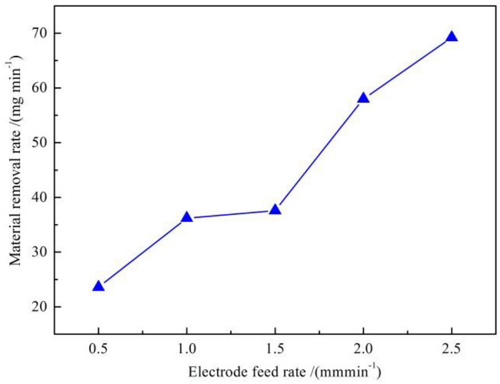

Fig. 4. Variations of material removal rate with electrode feed rate

Fig. 4 shows the variation of material removal rate with the electrode feed rate. In this set of experiments, the applied voltage is 18 V and the electrolyte temperature is 30 ℃. When the electrode feed rate was 0.5 mm min^{-1}, the material removal rate was 23.6 mg min^{-1}. The material removal rate increased with the increase of the electrode feed rate. When the electrode feed rate was 2.5 mm min^{-1}, the material removal rate has been improved to 69.2 mg min^{-1}. When the feed rate is too slow, the material is mostly removed by the electrochemical dissolution reaction rather than the mechanically abrasive action. When the feed rate is too fast, the material is mostly removed by the mechanically abrasive action and short circuits occur frequently. Thus, the tool durability drops quickly. The results illustrated that the electrode feed rate had an important influence on ECG. The material removal rate and machining efficiency could be improved a lot when a proper high electrode feed rate is applied.

3.3. Effects of applied voltage on ECG

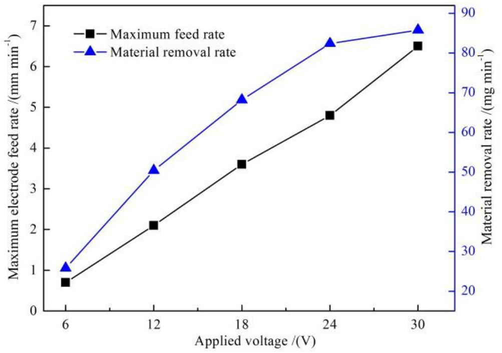

Fig. 5. Variations of maximum feed rate and MRR with applied voltage

Fig. 5 illustrates the variation of the maximum electrode feed rate with applied voltage. In this set of experiments, the electrolyte temperature is 30 ℃. As the applied voltage increased from 6 V to 30 V, the achievable maximum feed rate increased from 0.7 mm min^{-1} to 6.5 mm min^{-1} and the material removal rate increase from 25.8 mg min^{-1} to 85.8 mg min^{-1}. Inconel 718 is a kind of nickel-base super alloy in which nickel is easily passivated. A high applied voltage helps nickel activated more quickly and the machining efficiency is improved. When the applied voltage is too low, the material is mostly removed by the mechanically abrasive action and short circuits occur frequently. When the applied voltage is too high, the material is mostly removed by the electrochemical dissolution reaction. Massive electrolysis products would block the wheel and the machining gap, and deteriorates the machining stability. The results illustrated that the material removal rate and machining efficiency could be improved a lot when a proper high applied voltage is applied.

3.4. Effects of electrolyte temperature on ECG

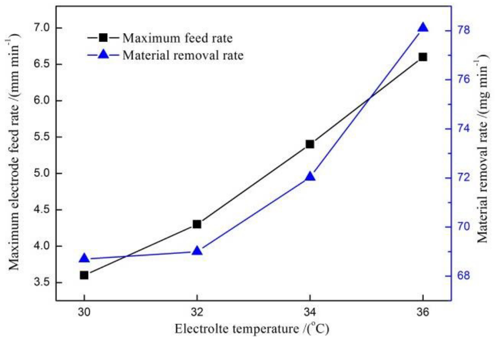

Fig. 6. Variations of maximum feed rate and MRR with electrolyte temperature

Fig. 6 shows the variation of the maximum electrode feed rate with electrolyte temperature. In this set of experiments, the applied voltage is 18 V. The maximum electrode feed rate increased rapidly with the increase in electrolyte temperature. As the electrolyte temperature increased, the electrolyte electrical conductivity and the current density increased. Thus, material removed by the electrochemical dissolution reaction increased as well as the machining gap. As a result, the achievable maximum electrode feed rate is improved. In addition, it was found that when the electrolyte temperature kept increasing, the electrolyte in the machining was boiled by joule heat and grinding heat. This phenomenon is trying to avoid in ECM. So it could be concluded that the material removal rate and machining efficiency could be improved a lot when a proper high electrolyte temperature is applied.

4. Conclusions

In this paper, electrochemical grinding is employed to machine Inconel 718. Conclusions could be summarized as follows:

- The tool durability has been improved from 15 hours to 50 hours when a brazed diamond wheel was employed to replace a electrodeposited diamond wheel.
- The electrode feed rate had an important influence on ECG. The material removal rate and machining efficiency could be improved a lot when a proper high electrode feed rate is applied.
- A proper high applied voltage and electrolyte temperature is conductive to improve the maximum electrode feed rate and material removal rate. In this paper, the recommended parametric combination is an electrode feed rate of 6.6 mm min^{-1} obtained at the applied voltage of 30 V and the electrolyte temperature of 36 ℃.

Acknowledgements

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