Surface Characteristics of Titanium Alloy by Electrical Discharge Machining

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Abstract. Ti-6Al-4V has many applications because of its excellent properties. However, it also has its own defects such as poor wear resistance, which limits its application. In order to improve its hardness, electrical discharge machining (EDM) method is introduced in this study. Scanning electron microscope (SEM) and X-ray diffraction (XRD) were used to analyze the structural features and chemical composition. The effects of pulse on time and pulse current on the EDMed surface are analyzed. Microhardness was measured by microhardness tester. Experiment indicates that the continuous hardening layer is formed in the electrical discharge machining process. Due to the new formed TiC phase on the surface layer, the hardness of the surface layer was improved significantly. Thickness of the strengthened layer improves with the increase of pulse width.

Introduction

Ti-6Al-4V alloy is widely used in many applications because of its excellent properties [1, 2]. However, titanium alloy has poor wear resistance and low hardness which makes it hard to process with traditional processing technology. Electrical discharge machining (EDM) can process any conductive material regardless of their hardness [3, 4]. Therefore, titanium can be machined by EDM. To further improve the properties of the machined surface, researchers have attempted various methods including adding different powders to the medium fluid [5, 6]. Dr. Kumar studied the effect of the added powder in the medium fluid on the surface roughness and found that the conductivity and concentration have an important influence [7, 8]. In order to further reduce the surface roughness of electrical discharge machining, Dr. Zhang did mixed-powder EDM compound machining experiments, a certain concentration of powder is added in the kerosene liquid, and the electrode vibrates under the driving of the ultrasonic vibration system. Results show that the surface roughness is reduced with the aid of micro cutting of the abrasive (12, 13).

In the paper carbon powder is chosen as the abrasive particle to improve the machining quality by powder mixed EDM. Fig. 1 shows the mechanism of action. It is expected that carbon element decomposed by liquid kerosene and the added carbon powder can be transferred to the surface of the workpiece and react with the surface material during the electrical discharge.

![Figure 1. Principle of abrasive mixed EDM.](image)
Materials and Methods

Experiments were carried out on DM71 series precision EDM machine. Based on the previous experiments, the mixed abrasive concentration of 10g/L was selected. In order to make the C particle suspension in the working fluid evenly, the powder is stirred with a magnetic stirrer. The effect of C abrasive on the machined characteristics of Ti-6Al-4V is studied and the EDM parameters are shown in table 1.

Table 1. EDM parameters.

| Current (A) | Pulse on time (us) | Pulse off time (us) | Voltage (V) |
|------------|-------------------|-------------------|-------------|
| 3.5        | 8                 | 7                 | 65          |
| 3.5        | 15                | 7                 | 65          |
| 3.5        | 30                | 7                 | 65          |
| 9          | 45                | 7                 | 65          |
| 16         | 45                | 7                 | 65          |

Table 2. Materials’ properties.

| Material    | Density (g/cm³) | Melting point (℃) | Thermal coefficient (W.m⁻¹.k⁻¹) | Heat capacity (J.kg⁻¹.℃⁻¹) |
|-------------|-----------------|-------------------|-------------------------------|-----------------------------|
| Copper      | 8.95            | 1081.2            | 381.3                         | 412                         |
| Ti-6Al-4V   | 4.4             | 1662.3            | 7.95                          | 0.51                        |

Ti-6Al-4V alloy is chosen as workpiece material, the size is 8 × 8 × 3mm, and the electrode material is copper.

The surface morphology of the EDMed surfaces was analyzed by SEM. The phase of the material surface was studied by D8 Advance polycrystalline X-ray diffraction. In order to observe the microhardness of the cross-section, the samples were washed by epoxy resin, mild polishing and ultrasonic wave, and etched with 5 ml HF, 10ml HNO₃ and 35 ml water. The microhardness was measured by using FM800 hardness tester. The test load was 45gf and the loading time was 15s.

Results and Discussion

Surface Micrograph Analysis

Fig. 2 (a) (b) is the surface micrograph of titanium alloy produced by abrasive mixed EDM and traditional EDM. The results show that the boundary of the erosion crater obtained by abrasive mixed EDM is clear and the surface is smooth. This is due to the existence of conductive C abrasive which leads to the discharge gap increase. Therefore, due to the increase of plasma channel, the discharge point tends to be uniform and produces large pits. Thus, the surface roughness is reduced.

![Figure 2. The surface topography of EDMed sample.](image-url)
XRD Analysis

XRD analysis result is shown in Fig. 3. Fig. 3 shows that the hard phase of TiC was formed on the processed surface, which shows that in the process of sample preparation, working medium in the process of powder mixed EDM of carbon powder under the action of high temperature reaction happened and artifacts.

Micro Hardness Analysis

Micro hardness has a great influence on the surface performance. Fig. 4 shows the microhardness distribution curve on the cross section under different pulse discharge energy. The hardness below the surface of 20um is about twice that of the bulk due to the hard phase of TiC on the surface.

The peak current and pulse on time have an important effect on microhardness. When the peak current increases from 3.5 A to 9 A, the hardness also increases obviously.

Conclusions

(1) The boundary of the erosion crater formed by abrasive mixed EDM is clear and the surface is smooth.

(2) The result of X-ray diffraction shows that the hard phase of TiC is formed on the strengthened layer, thus micro hardness is improved.
(3) The hardness of surface obtained from powder mixed EDM is 2 times that of the bulk material.

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