A Study on the Microstructure Strengthening Phase of the TC4 strengthened Layer by powder-mixed near-dry EDM

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Abstract: The surface of TC4 titanium alloy was strengthened by powder-mixed near-dry EDM. In the research, the experimental investigation analyzed the influence of pulse on time and electrode polarity on strengthened layer microstructure of TC4 titanium alloy. The wear of the substrate surface and the strengthened layer was measured. The results showed that the number of corrosion pits and petal-like tissues of the strengthening layer increases first and then decreases with the increase of pulse on time. The more petals and pit tissues were obtained by negative electrode than positive electrode. When the pulse on time is 100μs and the electrode polarity is negative, it is beneficial to produce the petal-like and pit-like tissues. The petal-like strengthening phase is the key factor affecting the wear resistance of the strengthened layer. The experimental revealed that the wear resistance of the strengthened layer is about 3.5 times as much as that of the substrate.

1. Introduction
After the introduction of powder-mixed near-dry EDM technology, a lot of research and innovation have been made, especially in the field of discharge parameters, strengthening medium and the effect of electrode on machining quality[1]. Such as the generated special pit and petal-like tissues directly affect the strengthening quality[2]. However, there are few studies on the effect of discharge parameters on the size and quantity of special microstructure generated on the strengthened layer. Therefore, it is necessary to study the amount of special structure of microstructure, especially the influence of the size of the discharge parameters on the strengthened layer is an important topic. The size and quantity of special microstructure on the strengthened layer can be analyzed as the basis for judging the performance index of the strengthened layer.

In the field of strengthening layer microstructure, the main influence on the formation of surface pit tissue is the peak current[3]. The research on the surface of micromorphology strengthening layer is mainly explained by the existence or non existence of cracks[4,5]. However, the effect of the number, shape and characteristics of pits and petal like strengthening phases on their properties has not been studied and verified.

In recent years, a lot of researches have been made on the principle of the action of discharge parameters on the surface of the substrate during the strengthening process. For example, in single pulse EDM, it is found that charged particles bombard the surface of the substrate very fast in the discharge channel, which can melt the center of the discharge point on the surface of the substrate instantly[6,7]. The average depth of etch pit increases with the increase of single discharge energy, and the pulse energy increases with the increase of peak current. Through the size of pulse width, which
can analyze the effective use efficiency of pulse energy\cite{8,9}.

The purpose of this paper is to explore the influence of different pulse on time and electrode polarity on the special microstructure of the strengthened layer, which analyze and count the characteristics and quantity of the special microstructure, and measure the wear resistance of the strengthened layer under different discharge parameters. Finally, the performance of the strengthening layer is verified by the number of pits, petal like strengthening phases and the wear resistance.

2. Test Materials and Methods

In this experiment, the parameters of pulse on time and electrode polarity are mainly used as the research elements. In the test, the titanium alloy plate is used as the material to strengthen, and the tool electrode is graphite. The B4C particles and C particles were adjusted to a concentration of 0.3 L/g medium at 1:1. When the pulse interval is 100μs, the pulse on time $t_{on}$ is 80μs, 100μs and 120μs. The size of titanium alloy plate is 20 x20x4mm, the strengthening layer is machined under the condition of powder-mixed near-dry EDM, and the machining thickness is 0.1 mm.

This experiment is mainly to study the corrosion pit and petal microstructure of the strengthened layer after powder-mixed near-dry EDM, statistics and analyzes by electron scanning microscopy in 200x200μm regions. The wear tests of Samples under different parameters and without strengthening were carried out by high temperature friction testing machine, it has a travel of 100 meters and a load of 400 grams. The mass of the samples before and after three groups test was recorded and the wear loss was calculated, and the average value was obtained.

Through the statistics and calculation of the number of pit tissues and petal tissues on the surface strengthening layer, the following table 1 is obtained.

| pulse on time($t_{on}$)/μs | Electrode polarity | Average number of pits | Average pit density (1/μm²) | Average number of petals | Average petal density (1/μm²) |
|---------------------------|-------------------|------------------------|----------------------------|-------------------------|----------------------------|
| 80                        | -                 | 12                     | 3.00x10⁻⁴                  | 32                      | 8.00x10⁻⁴                  |
| 100                       | +                 | 14                     | 3.50x10⁻⁴                  | 42                      | 1.05x10⁻³                  |
| 120                       |                   | 11                     | 2.75x10⁻⁴                  | 34                      | 8.50x10⁻⁴                  |
|                           |                   |                        | 2.50x10⁻⁴                  | 30                      | 7.50x10⁻⁴                  |
|                           |                   |                        | 2.00x10⁻⁴                  | 23                      | 5.75x10⁻⁴                  |

3. Experimental results and analysis

3.1. Effect of Pulse on time on Microstructure of strengthened Layer
Figure 1. Microstructure and morphology of strengthening layer under different pulse on time

In figure 1, it can be seen that the pitting and petal-like strengthening phases different under the different of pulse on time. In Figure 1(a), the pits are small and there is less melts around it, the petals are thin, short and rough, and there are void holes in the surface of strengthening layer. In Figure 1(b), there is no significant increase in the number of pits, but the distribution of pit is more uniform, the petal-like strengthening phase is increased. In figure 1(c), the melt cladding is broad around the pit. The petal-like strengthening phase is closely connected with the pit, and it is more uniform around the pit. This is due to the process of EDM, the time of continuous discharge will affect the radius of liquid filling around the explosion point. During a continuous machining process of an EDM discharge, at a certain pulse on time value, the molten metal liquid around numerous explosion points is plasticized around the center of explosion point. The petal-like strengthening phase grows in situ around the explosion point. Different plastic filling radius directly affects the size of the pit and the size and shape of the petals. When the pulse on time is small, the radius of plastic filling will be small. The pit around the pit produced by the explosion point can not be filled, the molten metal can not be fully plasticized in a short period of time. With the increase of pulse on time, the radius of plastic filling increases, and the liquid around the pit is more fully plasticized and grown in situ. The void holes decrease, the size of the pit is gradually uniform, and the size of the petal-like strengthening phase increases, but the quantity decreases.

As can be seen from figure 1, with the increase of pulse on time, the corrosion pit gradually increases slightly, and the number of petals increases first, then decreases. The petals tissue grows fully and the void holes decrease. The size of the pit also changed from shallow flat to deep, while the petals changed from slender to thick and short.
3.2. Effect of electrode polarity on microstructure of strengthened layer

![Effect of electrode polarity on microstructure of strengthened layer](image1)

Figure 2. Microstructure of strengthened layer with different electrode polarity

Figure 2(a) shows that the pit is large and deep, the petals are mostly coarse length. In the figure 2(b), the pit is shallow and flat, the petals are mostly independent and small. This is caused by the movement of positive and negative ions, when the tool electrode is negative, the substrate surface is positive, when the tool electrode is positive, the substrate surface is negative. The temperature of the discharge point on the positive substrate surface is higher than that on the negative substrate surface. Therefore, the ions move fully towards the surface of the positive substrate, and produced intense bombardment on the substrate surface. On the surface of the positive substrate, the petal tissue growth sufficient, and the number of petals is large, the pit is large and deep. While on the surface of the negative substrate, the petal tissue growth insufficient, the petal is small and short, and the pit is small and shallow.

As can be seen in Figure 2, large and deep corrosion pits and large number of petal-like tissues are prone to be produced when the negative electrode is processed. The shallow and small corrosion pits and petal-like tissue prone to short and small When the positive electrode is processed.

3.3. Effects of discharge parameters on the number of pit tissues and petal tissues

![Effects of discharge parameters on the number of pit tissues and petal tissues](image2)

Figure 3. Number of pit tissues and petal-like tissues in strengthening layer under different discharge parameters.

In the figure 3(a), with the increase of pulse on time, the number of pitting and petal-like strengthening
phases increased first and then decreased. In the figure 3(b), when the tool electrode is negative, the number of corrosion pits and petal tissue on the strengthened layer is more than when the tool electrode is positive.

3.4. Wear resistance of strengthened layer

Table 2. Wear mass losses of different strengthened samples and TC4 base material

| Samples            | Mass before experimental/g | Mass after experimental/g | Mass loss/g |
|--------------------|-----------------------------|---------------------------|-------------|
| TC4 base material  | 7.2032                      | 7.1591                    | 0.0441      |
| t_{on}/μs 80       | 7.1963                      | 7.1746                    | 0.0217      |
| 100                | 7.1972                      | 7.1818                    | 0.0134      |
| 120                | 7.1751                      | 7.1547                    | 0.0204      |
| Electrode polarity| -                           | 7.1834                    | 0.0142      |
| +                  | 7.1859                      | 7.1692                    | 0.0196      |

From the analysis of the test data in the table2, it can be seen that the wear resistance of the strengthened layer formed by the powder-mixed near-dry EDM strengthening TC4 will be increased about 3.5 times as much as that of the substrate. This is due to the formation of corrosion pits and petal-like strengthening phases on the strengthening layer, which enhances the wear resistance of the substrate surface. With the increase of pulse on time, the wear resistance of the strengthened layer is increase, then decrease. The wear resistance of negative strengthened layer is higher than positive strengthened. This is due to the TiC and TiB phase is generated in the process of EDM, which can improve the surface wear resistance. These strengthening phases exist in the pit tissues and petal-like tissues can improve the surface wear resistance.

4. Conclusion:

(1) During the process of powder-mixed near-dry EDM of TC4, when pulse on time at 80μs-120μs, with the increase of pulse on time, the number of corrosion pits and petal-like tissues increases first and then decreases. When the negative electrode is processed, the petal-like tissue is large and the number is large, and the pit is deep. The shallow and small corrosion pits and petal-like tissue prone to short and small when the positive electrode is processed.

(2) When the pulse on time t_{on}=100μs and electrode polarity is negative, the microstructure of the strengthened layer is better, the size of the pit is uniform and the quantity is moderate, the number of petal-like tissues is many and uniform and dense.

(3) The wear resistance of strengthened layer formed by powder-mixed near-dry EDM of TC4 is about 3.5 times as much as that of the substrate. When the corrosion pit is small and deep, it is not conducive to the improvement of wear resistance. Petal tissue is the key factor affecting the wear resistance of the strengthened layer.

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