A Study on the effect of different proportion of B4C and Al powders on the strengthened layer of TC4 by EDM

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Abstract: The surface of TC4 titanium alloy was strengthened by powder-mixed near-dry EDM with different proportion of B4C and Al powder. The microstructure, wear resistance and strengthening time were analyzed and studied. The results show that the microstructure and strengthening time of the strengthened layer are affected by different proportion of powder. With the increase of B4C content, the thickness of strengthening layer increases, and with the increase of Al content, the strengthening time decreases. When the proportion of B4C to Al powder is 2:1, the microstructure appearance is the best, the petal structure is compact and the cracks are few, the thickness of strengthening layer is the largest, and the wear resistance of the strengthened layer is about 3.8 times as much as that of the substrate.

1. Introduction

Since the powder-mixed near-dry EDM surface strengthening technology has been proposed, it has always been a hot spot and focus in the research field of surface strengthening technology. In this field, there are many studies on the influence of the optimization of discharge parameters, the selection of tool electrodes and the type of powder-mixed selection on surface strengthening [1-4]. However, there is a lack of research in this field of different proportion of powder-mixed, especially in the influence of the proportion of powder-mixed on the thickness, wear resistance and time of the obtained strengthening layer. Therefore, it is necessary to study the effect of different proportion of powder-mixed on TC4 strengthening by near-dry EDM, which can provide more suitable reference standards for the proportion of powder-mixed.

The addition of powder-mixed types plays a key role in the improvement of surface strengthening technology. Under the same sliding condition, the wear resistance of TC4 alloy can be significantly improved by adding powders of different proportions [5]. Adding some strengthening powders, such as B4C powders, can improve the hardness and wear resistance of the cladding layer, and the surface is relatively flat without cracks [6,7].

In recent years, in the research field of powder-mixed EDM, most of the researches focus on the influence of different media processing on the microstructure of the surface strengthening layer, as well as the statistics and analysis of crack initiation and propagation on the strengthening layer [8,9]. For the study of powder processing mechanism, the powder medium can increase the discharge gap, effectively release pulse energy. A relatively flat etch pit structure is formed on the strengthening layer to improve the flatness of the strengthening surface [10,11]. Within a certain range of discharge parameters, the greater the relative density of B4C powders in the EDM medium, the lower the thickness of the reinforcement layer [12].
In this paper, the microstructure, wear resistance, thickness and strengthening time of TC4 titanium alloy surface strengthened by powder-mixed near-dry EDM were studied. The best proportion of powder-mixed for the formation of better microstructure of strengthening layer was obtained, it can provide a reference for the determination of powder mixing proportion in EDM.

2. Test materials and methods
The surface of TC4 titanium alloy plate was strengthened by using powder mixed quasi dry EDM and af1100 EDM. Titanium alloy plate size: 20mm x 20mm x 3.5mm. Graphite electrode is selected as the working electrode. B4C powder particles and Al powder particles with different proportion of strengthening medium and deionized water are mixed into 0.3g/L solution. The size of both powder particles is 7μm. The mass proportion of B4C powders and C powders is 1:1, 1:2, 2:1 respectively. The peak current, pulse width, pulse gap and processing depth are 8.2A, 100μs, 100μs and 0.1mm respectively.

The strengthened layer was observed and analyzed by tescan Vega TS 5136XM scanning electron microscope, and the thickness and wear resistance of the strengthened layer were measured by high temperature friction tester, and compared with the surface of the base material.

3. Test results and analysis

3.1. Effect of powder-mixed proportion on Microstructure of strengthened layer

(a) B4C:Al=1:1, low power

(b) B4C:Al=1:1, local amplification

(c) B4C:Al=2:1, low power

(d) B4C:Al=2:1, local amplification
It can be seen in Figure 1 that petal like and etched pit structures are formed on the strengthening layer, but many petal like structures are irregular. Under the condition of different proportion of B4C powders and Al powders, the overall morphology of the upper surface of the strengthening layer is also different. As a whole, after high-temperature melting, the splashing molten phase and solidified cladding phase are mutually stacked and formed, and form at the discharge center Pitting structure. This is due to the fact that the pulse discharge is completed in a very short period of time and the energy is concentrated on the discharge point on the surface of the base material in the discharge machining of graphite tool electrode under the condition of different proportion of mixed powder. In each discharge process, the proportion of the reinforced powders entering the discharge channel is different, and the phase formed after the high temperature melting of the base material is also different.

From (a) and (b) in Figure 1, it can be found that there are dense petal like microstructures on the strengthening layer. For the locally enlarged image, it can be seen that the pits on the strengthening layer are large and deep, and there are short microcracks on the petal tissues around the pits. In (c) and (d) diagrams, it can be found that the density of petal like structure on the strengthening layer is smaller than that in (a) and (b), the pit structure is smaller and deeper, and the petal like microstructure around is coarser and less microcracks exist. In the (e) and (f) diagrams, it can be seen that the petal like microstructure on the strengthening layer is obviously reduced, and the etch pit structure is not obvious, and there are many pieces of unformed fragments. The main reason is that the melting point of Al powder is low and the breakdown voltage energy required is lower than that of B4C under different proportion of B4C and Al powders, so the melting and re solidification can be carried out quickly. With the increase of the specific gravity content of Al powder, there will be more molten liquid on the strengthening layer and the melting combination of the base material.

3.2. Thickness of strengthened layer

| B4C:Al | position1 | position2 | position3 | position4 | position5 | average value |
|--------|-----------|-----------|-----------|-----------|-----------|---------------|
| 1:1    | 18.32     | 17.65     | 15.79     | 19.03     | 18.92     | 17.94         |
| 2:1    | 19.71     | 19.31     | 19.49     | 20.56     | 19.83     | 19.68         |
| 1:2    | 17.82     | 18.15     | 15.33     | 18.62     | 18.45     | 17.67         |
It can be seen from Table 1 that when the proportion of B4C powders and Al powders is 1:1, the maximum thickness of the strengthening layer is 19.03μm, the minimum thickness of the strengthening layer is 15.79μm, and the thickness range is 3.24μm, which is the largest in all powder-mixed processing with different proportions, but the average thickness is not the smallest. When the proportion of B4C powders and Al powders is 2:1, it can be seen that the thickness difference at different positions is very small, and the average thickness is the largest. When the proportion of B4C powders and Al powders is 1:2, the average thickness of strengthening layer is the smallest. This is because the melting point of B4C powder is much higher than that of aluminum powder. When EDM is carried out under the same conditions, aluminum powder needs less energy and melts more rapidly. In addition, aluminum powder is lighter in weight and has better suspension in the working medium, so it is not easy to be melted to the surface by EDM. In Figure 2, when the aluminum powder proportion is smaller, the thickness of the strengthening layer is more uniform. When the B4C powder proportion is increased, the thickness of the strengthening layer is increased.

3.3. 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| 8.3145                     | 8.2729                    | 0.0416      |
| 1:1              | 8.2954                     | 8.2758                    | 0.0196      |
| 2:1              | 8.2772                     | 8.2663                    | 0.0109      |
| 1:2              | 8.2551                     | 8.2364                    | 0.0187      |

(1) It can be seen from Table 2 that the wear resistance of the strengthened layer is higher than that of the surface of the base material under the condition of EDM with different proportion of mixed powder. When the proportion of B4C powder and Al powder is 2:1, the wear resistance of the strengthened layer is about 3.8 times as much as that of the substrate. This is due to the formation of petal shape and pitting like microstructure on the surface of the strengthening layer. There are TiC, boron titanium compounds and titanium aluminum compounds in these microstructures, which can effectively improve the wear resistance of the strengthening layer\(^{[13]}\). When the proportion of B4C
powder increased, the petal like structure increased, the pit structure became deep and small, and the morphology of these structures was also conducive to the improvement of wear resistance. The wear resistance of the strengthened layer is affected by different proportion of mixed powder, which is due to the different content of B4C and Al, and the content entering the discharge channel is also different. When the proportion of B4C powder is large, the high melting point of B4C powder leads to the increase of energy consumption required for discharge breakdown, the weakening of the effect of discharge bombardment on the substrate surface, and the growth of the surface microstructure is stable. When the proportion of Al powder is large, the lower melting point of Al powder leads to the decrease of energy consumption required for discharge breakdown, the stronger bombardment effect on the surface of the substrate, and the faster and unstable growth of microstructure on the strengthening layer. Therefore, there are some elastic materials in the processed surface structure.

3.4. Strengthened time

| B4C: Al | time1 | time2 | time3 | average time |
|--------|-------|-------|-------|-------------|
| 1:1    | 1’23” | 1’36” | 1’28” | 1’29”       |
| 2:1    | 1’40” | 1’56” | 1’39” | 1’45”       |
| 1:2    | 1’12” | 1’26” | 1’13” | 1’17”       |

It can be seen from table 3 that in the three experimental schemes, when the proportion of mixed powder is 2:1, the strengthening time is the longest; when the proportion of mixed powder is 1:2, the strengthening time is the shortest. Compared with traditional EDM, for example, in kerosene medium and air medium, the strengthening time of powder-mixed near-dry EDM is significantly shorter. When the proportion of B4C powder is large, due to the high melting point of B4C, the discharge process is not easy to be broken down, the material erosion rate is small, the processing efficiency is low, and the strengthening time is increased. On the contrary, when the proportion of Al powder is large, due to the small ionization energy of aluminum powder, the amount of aluminum powder entering into the discharge channel increases, the energy needed in the discharge process is small, the breakdown rate is fast, the material removal rate is large, the processing efficiency is high, and the strengthening time is reduced.

4. Conclusion:
(1) The surface morphology of strengthening layer is different under the condition of B4C powders and Al powders with different proportion. When the proportion of B4C powders is 2 times of that of Al powders, the microstructure of B4C is the best, and the petal structure is dense with few cracks.
(2) When the proportion of B4C powders increases, the thickness difference is no longer obvious, and the average thickness increases. On the contrary, when the proportion of Al powders increases, the thickness difference is obvious and the average thickness decreases.
(3) When the proportion of B4C powders to Al powders is 2:1, the wear resistance of the strengthened layer is about 3.8 times as much as that of the substrate.
(4) The time needed to strengthen the surface is affected by the different proportion of powders, but the overall processing time is not very different. The strengthening time mainly depends on the influence of different powder powders on the process of discharge breakdown.

Reference:
[1] Liu Shijie, Cai lanrong, Li Min, et al. Effect of structure and performance of TC4 strengthening layer on electrode quasi dry EDM surface [J]. Machine tool and hydraulics, 2019, 47 (19): 32-35.
[2] Muttamara A and Mesee J. Effect of TiN powder mixed in Electrical Discharge Machining. [J]. Mater. Sci. Eng.2016.157, 012-021.
[3] Li Min, Wang Hongwei, Cai lanrong. Microstructure and properties of TC4 titanium alloy surface
strengthened by EDM [J]. Aerospace materials technology, 2013, (3): 95-99.
[4] Bai Xue. Study on the mechanism and technology of powder mixed quasi dry EDM [D]. Shandong: Shandong University, 2014.
[5] Guo Menglei, Chen Wei, Jiang Wei, Wang Shuqi. Effect of different proportion of nano powders on Wear Behavior of TC4 alloy [J]. Material protection, 2019, 52 (10): 50-54.
[6] Wang Xinshuai, Jing Fengyu, Zhang Xidong, Zhao Jingyu, sun Yufu. Study on the structure and wear resistance of plasma cladding injection B4C iron base cladding [J]. Surface technology, 2014, 43 (5): 42-46.
[7] Gu Zhenjie, Lei Jianbo, Zhao Dongmei, Guo Jinbo, Zhou Shengfeng. Properties of laser cladding layer of Ni based alloy reinforced by B4C ceramic powders [J]. Journal of material heat treatment, 2016, 37 (11): 147-151.
[8] Li Min, Cai lanrong. Microstructure and properties of TC4 titanium alloy strengthened layer by mixed powder quasi dry EDM [J]. Special casting and nonferrous alloy, 2017, 37 (9): 1014-1017.
[9] Liu Shijie, Cai lanrong, Li Min, Zhao Junling. Study on microcracks in TC4 strengthened layer by quasi dry EDM [J]. Manufacturing technology and machine tool, 2019, 03: 1005-2402.
[10] Zhao Fuling, LV Zhanzhu, Wang Hui, et al. Study on the mechanism of powder particles in EDM [J]. Journal of Dalian University of technology, 2005, 45 (5): 1000-8608.
[11] Su Hongzhi, Zhao Fuling, Wang Yuanang. Action mechanism of powder on liquid-solid mixed working fluid of powder mixed EDM [J]. Mechanical design and manufacturing, 2010 (05): 113-115.
[12] Murahari Kolli, Adepu Kumar. Assessing the Influence of Surfactant and B4C powder Mixed in Dielectric Fluid on EDM of Titanium Alloy [J]. Silicon, 2019, (11): 1731-1743.
[13] Zhao Lin, Li Li, Liu Yun, et al. Study on surface strengthening of Ti-6Al-4V titanium alloy by powder mixed EDM [J]. Mechanical design and manufacturing, 2018, (3): 1001-3997.