The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)

Surface properties of SiCp/Al composite by powder-mixed EDM

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Abstract

This paper uses a kind of moderate volume fraction (40%) of SiC particle reinforced Al matrix composites (SiCp/Al) to research how the surface properties are affected in conventional EDM (EDM) and powder-mixed EDM (PMEDM). By means of environment scanning electron microscope (ESEM) and HIT friction and wear tester, surface micro-topography, elements and wear resistance were analyzed. Experiments and researches indicate that compared with EDM, the surface properties machined by using PMEDM are improved greatly. The PMEDM surface roughness decreases about 31.5%; corrosion resistance is better too; and wear resistance is twice of EDM. Powder-mixed EDM has promising applications in metal matrix composites machining field.

Keywords: SiCp/Al composite; Powder-mixed EDM; Surface properties

1. Introduction

SiC particle reinforced Al matrix composites is one of the most competitive metal matrix composites. It has excellent comprehensive properties: lower density, better anti-fatigue performance and higher specific strength, specific stiffness, and wear resistance. It can be used to make turbine engine blades, skin and truss of airplanes, the inertial navigation platform and support components of satellites, electronic packaging and so on [1-7]. But it has a poor mechanical machining property because of the hard and brittle SiC particles. However, EDM can meet these machining demands regarding the specific application.

Compared with conventional EDM (EDM), in the process of powder-mixed EDM (PMEDM), the discharge gap is enlarged because of the existence of conductive Al powder. The discharge energy is smaller. So the surface quality is better. PMEDM is mainly used in finishing. One kind of moderate volume fraction (40%) of SiCp/Al is used to research how the surface properties are affected in EDM and PMEDM. The surface properties include roughness, hardness, affected layer, physical properties and so on. Two kinds of machined surfaces with the diameter of 50 mm have been prepared to do research. Before this research, a lot of experiments had been done to find the relatively appropriate powder concentration and machine tool settings for this research as shown in Table 1.

| Working fluid | Al powder concentration: 35 g/L | Kerosene |
| Machine tool | Electric spark shaping mill CNC950 |
| Material | SiCp/Al composite |
| Electrode | Copper electrode; diameter: 50 mm; area: 1962.5 mm²; surface roughness: Ra 0.256 μm |
| Polarity | Normal (workpiece) |
| Electrical parameters | Current: 0.5 A; pulse duration: 12 μs; pulse interval time: 40 μs; gap voltage: 50 V |
| Machining time | 40 minutes |

2. Analyses of the surface textures

Each surface was measured 10 times by TR200 rough-meter. The results are shown in Fig. 1. It can be figured out that the surface roughness using EDM is...
While the surface roughness using PMEDM is Ra=0.571 μm which is 31.5% less than that when using EDM. Besides, the variation range of the roughness is smaller.

![Graph showing surface roughness comparison between PMEDM and EDM](image)

**Fig. 1. Roughness of the two kinds of surfaces**

In whatever kind of EDM, the material erosion relies on the effect of heat concentration. The instant high temperature can remove some material. On the effect of heat, some surrounding material appears metallographic changes which form discharge pits with convex edges. While a small part of this material solidifies again after being melted on the effect of refrigeration of the working fluid. Fig. 2 can be used to express the formation structurally. The machined surface is melted into melting zone on the effect of heat concentration. After most of the melted material being thrown out, a small number of the melted material solidifies into solidified layer again. Inside the solidified layer, it is the heat affected zone and the base material [8].

![Diagram showing surface deterioration layer](image)

**Fig. 2. The surface deteriorative layer**

The melting and solidification layer is on the upper layer and its surface is the machined surface. The melting point of Al matrix material and SiC particles are respectively 660 °C and 2730 °C. On the effect of the instant high temperature, the Al matrix material is melted, gasified and eroded more easily. While the SiC particles can’t be melted easily. SiC particles are melted, or decomposed and fall off. There exists a small part of recast material, which forms bulges or thicker melting and solidification layer [9]. There is not much difference between the melting point and the decomposition point of SiC, so there are SiC particles decomposing in high temperature which produces free C. Therefore, there is some carbon deposition attached on the surface.

Fig. 3 was the micro surface textures taken by super depth of field electron microscope. The machining conditions are shown in Table 1. The amplification is 500. Large numbers of deep holes and cracks on the surface machined by using EDM can be seen in Fig. 3(a). And the cracks distribute along the discharge textures. While the surface machined by using PMEDM (Fig. 3(b)) is better and smoother. This is because the phenomena of discharge concentration and short circuit are more serious in EDM. Besides, the distribution and shapes of the discharge pits are more irregular. Moreover, when machining in large area, the inter-electrode capacitance effect will occur. This phenomenon may make the discharge energy larger. And larger discharge pits and even micro cracks will emerge on the machined surface. The surface quality can hardly be ensured.

![Micro surface textures (a) after EDM ; (b) after PMEDM](image)

**Fig. 3. Micro surface textures (a) after EDM ; (b) after PMEDM**

The reasons why the cracks emerge are because that the stress is produced on the surface on the effects of the instant high temperature and rapid refrigeration; and that the residual stress is produced as a result of the thermal expansion and shrinkage rate differences between the affected layer and the base material. The stress produces thermal stress cracks which distribute along the discharge outline and the residual stress may produces tensile cracks extending into the base material gradually. The experiment indicates that cracks generally emerge inside the melted layer. But when the discharge pulse energy is large enough, such as in rough machining, cracks may extend into the heat affected layer and the base material. Generally speaking,
larger the discharge pulse energy is, the deeper and wider the micro cracks are. The discharge pulse energy of PMEDM is smaller, cracks can’t be formed easily. Therefore, compared with EDM, PMEDM can decrease the cracks more efficiently.

Fig. 4 shows these two kinds of micro surface textures by Quanta 200F ESEM. The machining conditions are shown in Table 1. And the amplification is 1000. By comparing these two kinds of micro surface textures, the surface machined by using EDM (Fig. 4(a)) has much more and deeper discharge pits attached by large numbers of particles that are not thrown out. The surface carbon deposition is more serious. And the machined surface seems not uniform enough. While the surface machined by using PMEDM (Fig. 4(b)) is smoother and the metallic luster is better. The discharge etch-pits are larger but smoother and shallower. The machined surface is better.

**3. Analyses of the surface elements**

Quanta 200F ESEM was used to do the energy spectrum analyses and measure the surface elements mass fractions of these two kinds of surfaces. And Fig. 5 and Fig. 6 show the results of the energy spectrum analyses and the surface elements mass fractions of EDM and PMEDM respectively.

By comparing Fig. 5 and Fig. 6, there is not much difference of the C content of these two kinds of the machined surfaces. The C content in Fig. 6 is a little higher than that in Fig. 5. The Al content in Fig. 6 is higher than that in Fig. 5. This is mainly because that there is large numbers of Al powder in the working fluid and some remains on the workpiece surface. The Si content in Fig. 6 is higher than that in Fig. 5. The reasons are as follows. In finishing, compared with EDM, there is large numbers of conductive Al powder in PMEDM which makes the insulation strength of the working fluid decreased, the discharge channel enlarged, and the working fluid broken down more easily. On the condition of the same current and pulse width, the effective discharge times increase [9-11]. Therefore, the decomposition of SiC particles increases and the contents of Si and C attached on the surface increase accordingly.

**4. Analyses of the surface hardness**

The hardness comparison experiment mainly uses MC010-HVS-1000 digital micro hardness tester and the load is 9 N. ASP-23 alloy steel is a kind of common tool steel with high wear resistance and toughness and was also chosen to research how PMEDM influences the surface hardness. The machined surfaces of SiCp/Al material and ASP-23 alloy steel by using these two kinds of EDM were tested respectively 5 times. The statistic results are shown in Fig. 7. The surface micro hardness by using PMEDM is much higher than that of EDM. For ASP-23 alloy steel, the micro hardness increases by 60%. And for SiCp/Al material, the micro hardness increases by almost 40%. By inquiring material, the hardness of the unprocessed SiCp/Al material is generally lower than 200 HV. Therefore, the surface affected layer by using EDM becomes harder, and the
surface affected layer by using PMEDM becomes much harder.

![Micro hardness comparison](image)

Fig. 7. Micro hardness comparison

5. Tests of the surface corrosion resistance

These two kinds of surfaces were chosen to do corrosion resistance test. The erosion processes are shown in Fig. 8 (snapshot in test). The machining conditions are shown in Table 1. The left one of the two surfaces in every figure of Fig. 8 is the surface machined by using EDM and the right one is that of PMEDM. The corrosive used is home-made aqua regia. After the two surfaces being cleaned by acetone, several drops of aqua regia were dripped on the surfaces as shown in Fig. 8.

![Comparison of erosion status](image)

Fig. 8. Comparison of the erosion status (a) at the beginning; (b) 5 minutes later; (c) 10 minutes later; (d) 15 minutes later; (e) 20 minutes later; (f) surface after test

The moment the aqua regia drops were dripped, large numbers of micro bubbles emerged on both surfaces (Fig. 8(a)). But there were more bubbles by using EDM and the chemical reaction was much fiercer. The number of the bubbles by using PMEDM increased gradually. Within 5 minutes, there were large numbers of bubbles on both surfaces, and the aqua regia drops kept on reacting with the surface material (Fig. 8(b)). After 10 minutes, the erosion reaction drew to a close, and the number of the bubbles decreased gradually (Fig. 8(c)). After 15 minutes, there were a small number of bubbles on the surfaces (Fig. 8(d)). 20 minutes later, there were only some bubbles on the edge (Fig. 8(e)). After 30 minutes, the reaction remains were rubbed out. The eroded surfaces are shown in Fig. 8(f). There was large numbers of black slag on the surface machined by using EDM. While there was almost no black slag on the surface machined by using PMEDM. Only the whiter and very shallow eroded trace can be seen.

Fig. 9 shows the micro surface textures of the eroded surfaces. The machining conditions are shown in Table 1.

![Micro surface textures after erosion](image)

Fig. 9. Micro surface textures after erosion (a) EDM; (b) PMEDM

By comparing the surfaces of EDM (Fig. 9(a)) and PMEDM (Fig. 9(b)), the erosion type of the SiCp/Al material is pitting. It starts from the areas where the micro surface texture is non-uniform and where the oxidation film is damaged. Then the metal matrix begins to be dissolved and the pits grow. Because the micro cracks and serious cracks exist on the surface machined by using EDM and the pits are deeper, the chapped and obvious gullies emerge easily on the whole surface. This makes more areas of the surface contact with the aqua regia easily. And the reaction is more serious which makes the metal matrix dissolved. Therefore, the erosion mainly occurs in the places where there are cracks and gullies. While the pits distribution on the surface machined by using PMEDM is more uniform and the number of the cracks is much less. The aqua regia remains in these pits for a while. And then, they begin to react and the pits start to be eroded, so the bubbles emerge a little later. This indicates that PMEDM can improve the surface corrosion resistance. It’s because, as stated in Section 2 and 3, the Al powder mainly enlarges...
the discharge gap and decreases the discharge energy. The pits are shallower and smoother, and the surface cracks are micro and less. So the surface is more compact, and the corrosion resistance is better.

6. Tests of the surface wear resistance

One of the main applications is being used as the material of the vehicle friction brake and the wear resistance is paid more attention in application, so it is necessary to do wear resistance test to research how these two kinds of machining methods affect the wear resistance. The original surface machined by using grinding and surfaces machined by using these two kinds of EDM were chosen to do the test. The type of the friction used in the test is rolling friction under unlubricated conditions, and the test is conducted on HIT friction and wear tester. The grind-ball is Si₃N₄ ceramic material. The diameter is 6 mm. And the hardness is about 7 Mohs.

The main process of the test is that the grind-ball is pressed on the machined surface, and the grind-ball doesn’t rotate while the test sample does the reciprocating motion. The test is conducted in room temperature and atmospheric pressure. 500 g weight is loaded on the grind-ball. In the whole test, the time was set as 60 minutes every time; the test machine was controlled by pulse to ensure its reciprocating ratio was 1 time/sec. Therefore, the time and friction distance of every test could be ensured to be same. The same grind-ball was adopted and the contact position of the grind-ball was adjusted after every friction test to ensure that the contact point of the grind-ball was new in every friction test. The surfaces were cleaned and weighed after test. The surface wear resistance is valued by comparing the surface trace and wear mass. The wear mass is shown in Fig. 10. The wear mass of the original surface is almost 7 times that of EDM and 13 times that of PMEDM. And EDM is about 2 times of PMEDM. This means that EDM can improve the surface wear resistance greatly. Moreover, PMEDM can improve the surface wear resistance more efficiently [12-14].

Surface textures after the test are shown in Fig. 11, and surfaces in Fig. 11(a) from left to right are respectively the original surface, the surface machined by using EDM and the surface machined by using PMEDM. The machining conditions are shown in Table 1. By comparing these three kinds of surfaces, it can be seen that the wear scar of the original surface is the deepest. And the wear scar of the surface by EDM is shallower. While the wear scar of the surface by PMEDM is obviously the shallowest. After the test, alcohol was used to clean the grind-ball to carry on comparison. There is almost no wear of the grind-ball after the original surface being tested while there is obvious wear of the grind-ball after the surfaces machined by using these two kinds of EDM being tested.

The micro textures of these three kinds of surfaces after the test are observed by Quanta 200F ESEM and are respectively shown in Fig. 11(b) (the original surface), Fig. 11(c) (the surface machined by using EDM) and Fig. 11(d) (the surface machined by using PMEDM). Changes of the surfaces and depth of the wear traces can be see obviously in Fig. 11(b). The deformations of particles and matrix due to extrusion can be seen clearly. While for the surface in Fig. 11(c), because of the effect of wear, most of the pits have been ground off, so the surface is smoother. There is little wear on the surface in Fig. 11(d), so the pits can still be seen clearly.

![Fig. 11. Traces after wear resistance test (a) traces; (b) original surface; (c) machined by EDM; (d) machined by PMEDM](image-url)
7. Conclusions

Through analyses and research, compared with conventional EDM, many surface properties machined by using powder-mixed EDM are improved.

1. The roughness decreases by about 31.5%.
2. Si and C contents increase within some degree. The hardness increases by about 40%.
3. The corrosion resistance is also better. And the wear resistance increases by almost 100%.
4. It has promising applications in metal matrix composites machining field.

Acknowledgements

This work was supported by the NSFC of China (51275116), the postdoctoral science-research developmental foundation of Heilongjiang Province (LBH-Q11090), and the aero science foundation of China (2012Z22010).

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