

Surface modification by electrical discharge machining with titanium powder suspended in working fluid

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Key words: electrical discharge machining, surface modification, titanium carbide

1. Introduction

Electrical discharge machining (EDM) has been widely used as a removal process to produce parts, dies and molds for several decade. In these years, a surface modification and an accretion methods by EDM with a green compact or a semi-sintered electrode have been studied [1][2]. Fig. 1 shows examples of a green compact electrode and a result of the accretion. A thick and hard layer can be obtained. Titanium alloy powder or tungsten powder is always supplied from the green compact electrode and adheres on a workpiece after powder reacts on cracked carbon that comes from working oil by the heat caused by discharge. As results, thick TiC or WC layer can be obtained. However, production of an electrode takes much labor. An accretion process with a wire brush or bundled wire electrodes has been proposed [3]-[5]. Because a thin wire electrode wears heavily and melted electrode material adheres on a workpiece, the electrodes must be changed frequently.

On the other hand, EDM with conductive powder suspended in working oil has been studied to finish a surface [6]. In the conventional powder suspended EDM which mainly works as a removal process, powder material is dispersed into a workpiece with a several micrometers beneath its surface [7]. This phenomenon is observed also in EDM removal process with solid tungsten or silicon electrode.

In this paper, a material accretion method by EDM with powder suspended in working fluid is proposed to skip the production process of the green compact electrode. An appropriate shape of an electrode is considered after considering flow of the working fluid. Then performance of an EDM process with titanium powder suspended in working oil is discussed.

2. How to keep powder density thick

Fig. 2 illustrates flow of working fluid during EDM. A gap between an electrode and a workpiece

soaked in working fluid is several micrometers up to several tens micrometers. The electrode moves reciprocally to stabilize a machining process. When the electrode moves upward as shown in Fig. 2(a), the powder flows into the gap together with the working fluid so that a powder density becomes thick. However, discharge seldom occurs because of a long gap. When

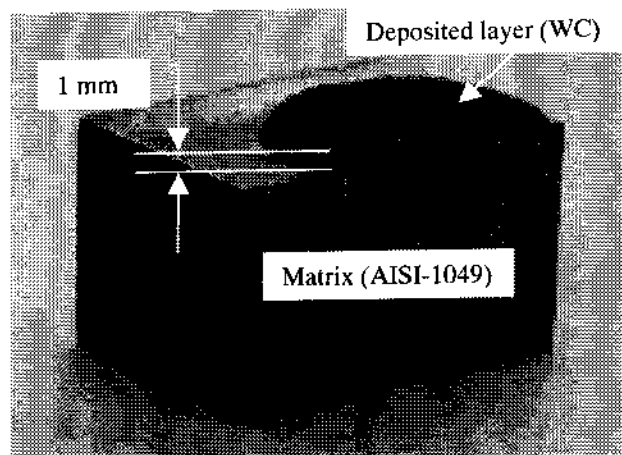
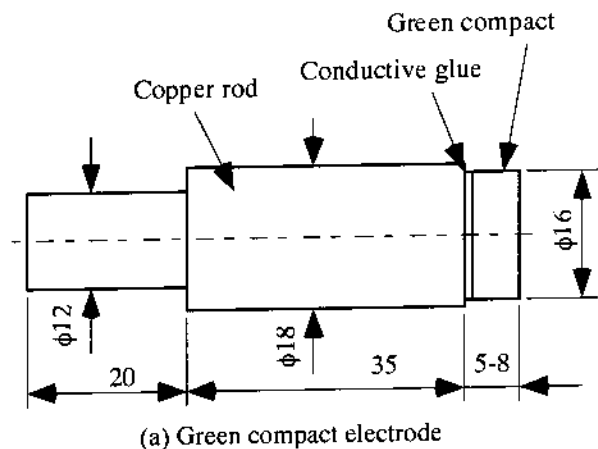


Fig. 1 Accretion with green compact electrode

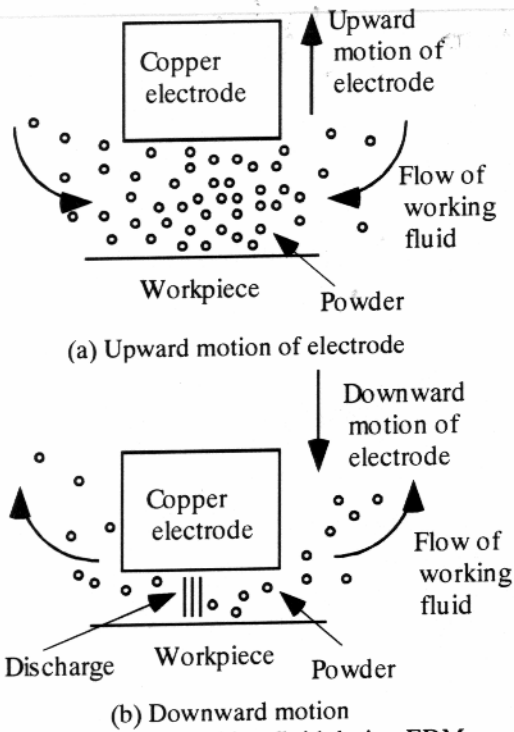


Fig. 2 Flow of working fluid during EDM

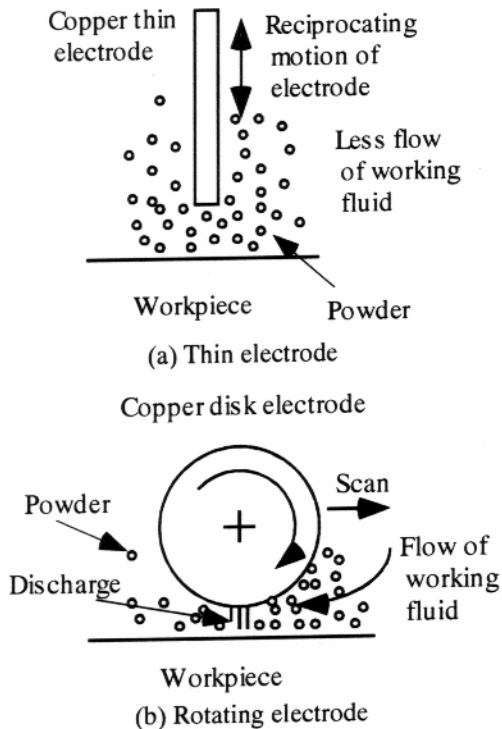


Fig. 3 Two types of electrode

the electrode moves downward as shown in Fig. 2(b), the powder is flushed with the working fluid from the gap. Though discharge often occurs, the powder density is thin. Therefore, the powder hardly adhere on

Table 1 Machining conditions

Powder	Titanium ($< 36 \mu\text{m}$)
Working fluid	Oil (EDF-K by Mitsubishi)
Electrode	Copper rod $\phi 1 \text{ mm}$
Density	50 g/l
Polarity of electrode	+,-
Peak current	1-20 A
Pulse duration	2-2046 μs
Pulse interval	2-2046 μs
Duty factor	0.04-50 %
Gap voltage	80-320 V

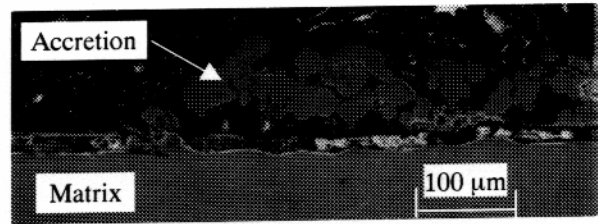


Fig. 4 Example of accretion machining by powder suspended EDM

the workpiece in the conventional powder suspended EDM. The powder should be provided into the small gap to keep the powder density thick.

There are two ways to keep the powder density thick: the use of a thin electrode and a rotating disk electrode. A thin electrode seldom thrusts the working fluid as shown in Fig. 3(a). A rotation of a disk electrode drags the powder into the gap with the working fluid because of the viscosity of the working fluid as shown in Fig. 3(b).

The use of a thin electrode and a disk electrode is investigated in Sections 3 and 4, respectively.

3. Accretion process with thin electrode

Titanium powder with a diameter of $36 \mu\text{m}$ is suspended in working oil like kerosene. A density of the Ti powder is 50 g/l. A carbon steel plate (AISI-1049) is used for a workpiece. The working fluid is circulated manually. Table 1 shows electrical conditions for accretion machining. In the case of negative as a electrode polarity, 3 A as a peak current, 2 μs as a pulse duration and 1024 μs as a pulse interval, the thickest layer is obtained. Fig. 4 shows an example of accretion. After EDM for 2 minutes with a copper electrode of 1 mm in diameter, a layer grows a thickness of $150 \mu\text{m}$. Fig. 5 shows an analysis result by EPMA. A bright area contains a certain element. Both tungsten and carbon exist from the matrix surface up to $20 \mu\text{m}$. The accretion is porous from $20 \mu\text{m}$ above the

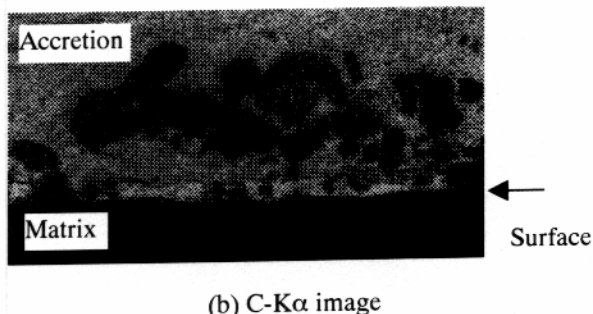
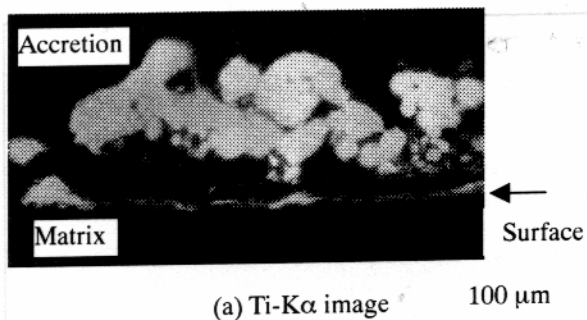


Fig. 5 Analysis result by EPMA

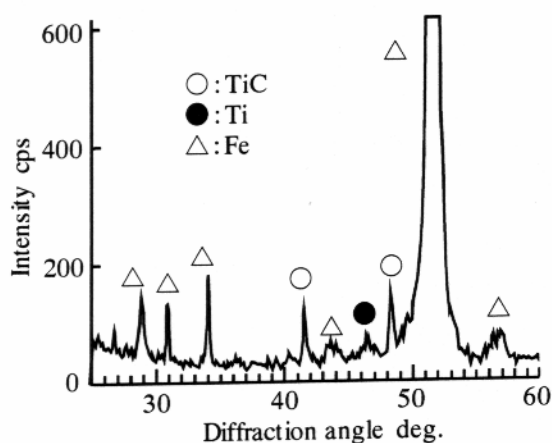


Fig. 6 Analysis result by X-ray diffraction

surface. A hardness of the accretion layer near matrix surface is 1600 Hv which is much harder than a matrix hardness of 240 Hv. Fig. 6 shows an analysis result by X-ray diffraction. Some peak angles with respect to Ti and TiC are observed on the matrix. Therefore, a material with a thickness of 20 μ m on the matrix surface is TiC. Carbon in TiC comes from cracked carbon in the working fluid. By combining a planetary motion of the electrode, a wider area of the accretion can be obtained.

ASTM-D2 powder with a diameter of 3.4 μ m is mixed with the Ti powder to improve adhesion of the TiC layer with the matrix. A ratio of the D2 powder to the Ti powder is 9:1. Although the adhesion is improved, a hardness of an accretion layer is decreased.

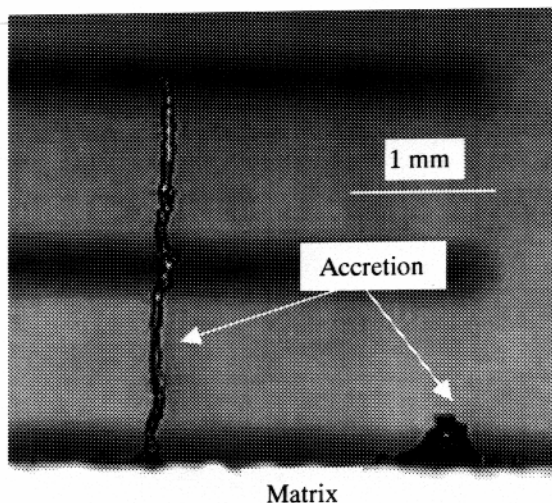


Fig. 7 Example of column-like accretion

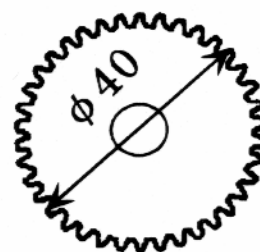


Fig. 8 Gear shaped electrode

A column with 2 mm-height and 50 μ m-diameter can be fabricated without scanning in the xy-plane as shown in Fig. 7.

4. Accretion process with rotating electrode

Fig. 8 shows a shape of a disk electrode. The electrode shapes like a gear with a tip diameter of 40 mm, a whole depth of 2 mm, 38 teeth and a width of 1 mm. A circular disk with a diameter of 40 mm and a thickness of 1 mm is also used. Each of them rotates from 0.63 to 6.3 m/s as a peripheral velocity. A thick layer is obtained with the gear shaped electrode rotating at 6.3 m/s.

Fig. 9 shows a comparison between accretion areas with the thin electrode and with the gear shaped electrode. Conditions for the rotating electrode are the same as the conditions for the thin electrode. A wider area of the accretion layer with uniform thickness can be obtained by using the rotational electrode with the gearlike shape. A rotation of the electrode promotes dragging the powder to the gap between the electrode and a workpiece.

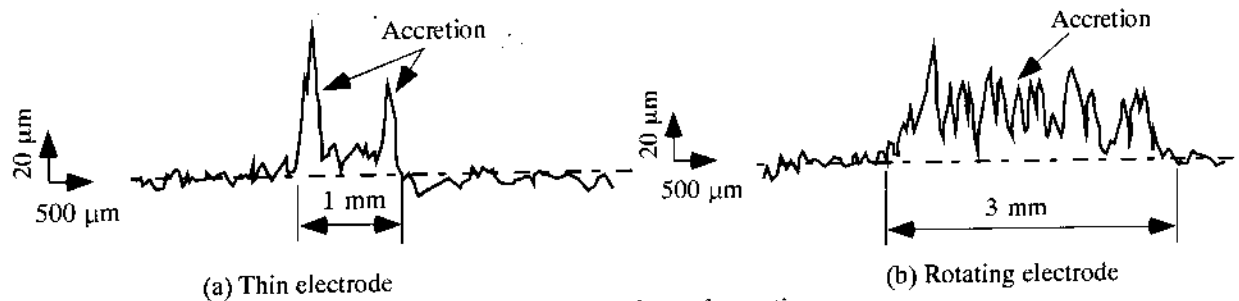


Fig. 9 Comparison of accretion

5. Use of other powders

Some other powders are also tried. Accretion of TiC layer is obtained with TiO_2 powder which is an insulator. Accretion of a hard layer can not be obtained with TiC, TiN or W powder suspended in working oil though a surface of a workpiece is modified and becomes smooth and lustrous. These are the same phenomena as the conventional powder suspended EDM [6].

Accretion of TiNi layers are also obtained with a blend of Ti and Ni powder mix suspended in pure water. A diameter of Ni powder is $30\ \mu\text{m}$. TiNi alloy works as a shape memory alloy. This will lead new technical feasibility of fabrication of miniature sensors and actuators.

6. Conclusions

In this paper, a material accretion method by EDM with powder suspended in working fluid is proposed. Conclusions can be drawn as follows:

- (1) Accretion of TiC layer can be obtained by using a thin electrode or a rotating disk electrode to keep the powder density thick.
- (2) A wide area with uniform thickness can be deposited with the gear shaped rotating electrode.
- (3) Ti-Ni layer is also fabricated.

The authors will measure properties of accretion in detail, will try to fabricate miniature structures and other functional layer for the shape feedback machining method [9].

Acknowledgement

The authors wish to thank Mr. Masaru Ohta and Mr. Motoya Furuichi of Toyota Technological Institute for their helpful cooperation. This study is financially supported by Research Foundation for OSG (Osawa Scientific Grant) Fund, the Electrotechnology of Chubu and Grant-in-Aid for Encouragement of Young Scientists (A) (11750110) of the Ministry of Education, Science, Sports and Culture, Japan.

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