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# Mechanism and Experimental Research on Small-Hole EDM with Cu-Cr Composite Electrode

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**Abstract:** During the EDM small hole processing, the material removal rate decreases rapidly with the increasing of processing depth, to analyze the mechanism of process, the fluid field around the processing gap simulation is studied based on Fluent. A solution based on Cu-Cr Composite electrode is put forward, and the influence of voltage of cathode and nonuniform of electric corrosion on the material removal rate and processing precision were analyzed. Some Cu-Cr Composite electrodes were produced; contrast experiments of brass electrodes and Cu-Cr Composite electrodes on material removal rate and processing quality were carried out. The experimental results show that the material removal rate of composite electrodes increase about 2 times and the processing precision is also improved. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** EDM, Small hole drilling, Combination electrode, Mechanism, Experimental research.

## 1. Introduction

Electrical discharge machining (EDM) is a well-established option in the manufacture of civilian and military products with the constant development and progress when it was first used for construction in the 1940s. Today it plays an irreplaceable position and role in modern manufacture industry [1, 2]. Though EDM has distinctive advantages in the manufacture of exotic materials, it still exists some shortcomings, for example, during the EDM small hole process, the debris is difficult to be eliminated, the process is unstable, low-speed and even can not be carried out normally, in addition, the accuracy deviates seriously particularly for the high demand of size and position tolerance, so it is difficult to achieve the ideal processing results with the increase of processing depth. Fig. 1 shows EDM blind hole of 2 mm diameter, the cylindricity has obviously deformed for appearing large taper. Taper are the fatal flaw and the key obstacle for finishing machining in EDM small hole processing. For many years of exploring research although, there is still no very effective solution [2, 3].

The machining precision mainly depends on the maintain of the electrode shape in EDM, so the electrode is a very important element and its material property will directly influence the processing performance. Electrode should meet the demand of high melting point, low thermal expansion coefficient, well electrical conduction and mechanical properties [4, 5], in addition, it requires processing stability, high productivity during machining, easy processing, rich sources and low price. The wide spread use of electrode materials at present in research and manufacture are graphite, tungsten copper or metal, copper, tungsten alloy, copper, iron copper matrix composites, polymer composites, diamond and so on [6, 7]. Copper is commonly used as electrode material during EDM

small hole processing in the form of copper pipe. Copper has a low melting point, while used as electrode it loses seriously especially during the EDM small deep holes processing existing the problems of debris removing difficultly, electrode losing seriously, processing rate decreasing, dull edges and taper appearing and so on. This paper put forward that Cu-Cr composite electrode can solve the above problems in some ways.

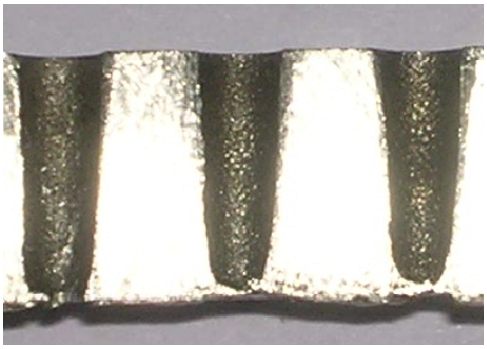


**Fig. 1.** EDM blind hole.

## 2. The Problems Existing in the Copper Electrode and the Reason Analysis During the EDM Small Hole Processing

During the EDM small hole processing, the main factor influencing the processing speed and accuracy is the process of debris removal. The initial electric corrosion is ejected occurring mainly in the bottom of the hole as shown in Fig. 2, in A region, the debris can be continuously ejected through the gaps in the bottom and side clearances under the action of high pressure water, but the high pressure water fall flat at the bottom edge of the hole, thus depositing the debris which is difficult to be ejected under the action of gravity and so on, at the same time, the erosion quantities of electrode surface enlarge leading to taper at the end edge of electrode and hole processed ultimately and becoming more serious with the increase of hole depth due to the skin effect (the surface erosion rate is greater than the inside) [8, 9]. The anaphasis erosion and ejection are shown as Fig. 3, as the electrode feeding, A and B region in Fig. 3 become electric discharge area, while B region will continual expanding. The debris in B section increase because the impact force is weak due to far away from high pressure water, yet there are two different erosion debris in B section, one comes from the hole bottom (erosion debris produced in A region), which is close to the high pressure water and will be ejected smoothly unless suffering great resistance; the other one is produced by the discharge happened in this area. Fig. 4 shows the stress nephogram in the bottom and sides clearances based on the fluent software simulation, in the simulation the hole diameter is set 3 mm, the pump pressure 3.2 MPa, as shown in Fig. 4, the bottom gap pressure is 0.59~0.87 MPa while the side clearance pressure is 0.11~0.35 MPa, the former is 3~5 times than the latter. The simulation results show that water pressure in B region is lower than A region in Fig. 3, so the debris in B section do not get enough pressure to get biggish acceleration and may stranded there under the action of gravity and electric erosion thermal explosive arc thus blocking the channel of debris ejected and causing secondary discharge or abnormal arc discharge, ultimately deteriorating the processing conditions and decreasing the processing speed and quality.

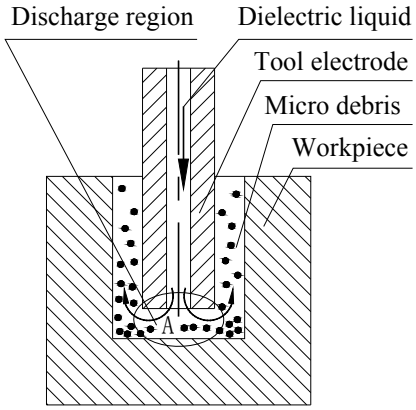



**Fig. 2.** Initial debris removal.

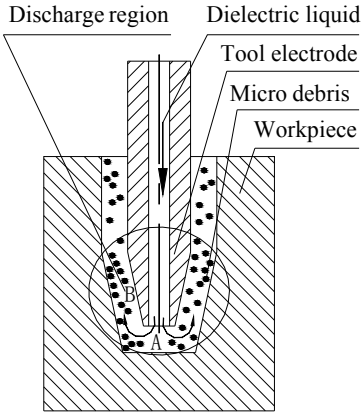



**Fig. 3.** Anaphasis debris removal.

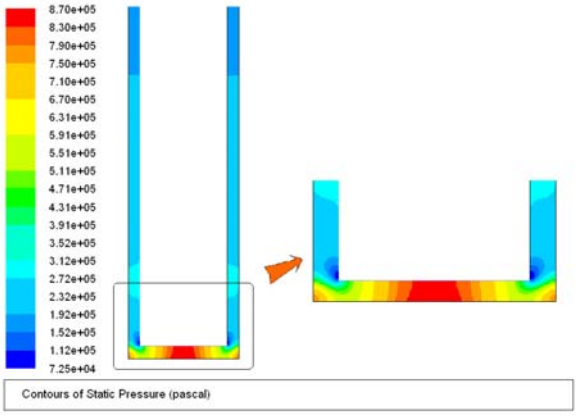



**Fig. 4.** Gap flow field simulation of cloud pressure.

## 3. The Electric Erosion of Cu-Cr Composite Electrode and Analysis of Debris Removal

EDM theory research shows that when the interelectrode dielectric is disruptive discharged, electrode voltage is divided into three parts including cathode voltage dropping, anode voltage dropping and the voltage dropping of plasma channel.

$$U = U_a + U_b + U_c, \quad (1)$$

where $U$ is the electrode voltage (V); $U_a$ is the anode voltage dropping (V); $U_b$ is the cathode voltage dropping (V); $U_c$ is the voltage dropping of plasma channel (V).

The speed of anode depth dissolution is proportional to the voltage dropping of plasma channel [10].

$$v = \frac{\eta \omega U_c}{\rho \cdot L}, \quad (2)$$

where $\eta$ is the current efficiency; $\omega$ is the electrochemical equivalent volume; $\rho$ is the dielectric fluid resistance; $L$ is the polar distance.

The electron detachment rely mainly on the electric field intensity of cathode surface (field-emission is the majority) requiring much cathode voltage dropping for materials with low melting point can not exist at high temperature, while for materials with high melting point, they can exist at high temperature making the free electrons inside the cathode electrode get enough energy to overcome the attraction of inside positive ions and then free from the electrode surface, that is thermionic emission. In this case, the electron emission mainly depends on the cathode temperature rather than the high electric field intensity in cathodic. So the cathode voltage dropping is generally low when using materials with high melting point as cathode [10].

Composite electrode is made by depositing a layer of chromium metal outside the original tubular copper which is single material, the depositing thickness is determined by the processing technology and experimental conditions. Due to the high melting point of chromium on outer electrode, the cathode voltage dropping $U_b$ is low when adopting composite electrode as EDM cathode, according to the formula (1) and formula (2), when the interelectrode voltage U is equal (interelectrode discharging voltage mainly depends on the dielectric fluid properties but has nothing to do with the electrode material), the dissolution speed V of anode adopting Cu-Cr composite electrode EDM hole is greater than the single copper electrode indicating the processing speed is greater.

Studies have also shown that the electrode removal rate of EDM is inverse with the melting point of electrode material [11], that is to say, electric erosion quantity is large while melting point is low, the opposite is high. For Cu-Cr composite electrode, the central material melt faster than the surface in the electrode because the chromium has a high melting point than copper, thus remedying the weakness of being taper because of the accumulation of debris in the edge and the affection of skin affect, its mechanism is shown as Fig. 5. The erosion quality along the radial inside direction of composite electrode is greater than single material remedying the edge erosion, this method can make the processing end of electrode approximately keep cylindrical, improve the processing speed and ensure the quality of hole by changing processing technique to get different thickness of chromium and materials deposited.

## 4. EDM Small Hole Processing Experiment with Cu-Cr Composite Electrode

### 4.1. The Material Removal Rate of Workpiece

The experiment is done on D703F high-speed EDM small hole machine, the anode of pulsating direct current supply connects workpiece, the cathode connects tool electrode. The dielectric liquid is tap-water with 4 *Mp* pressure, the workpiece materials is 45#steel, tool electrode rotating speed is 120 *r/min*, processing parameters is set as voltage is 20 *V*, current intensity is 10 *A*, pulse duration is 20 *us*, pulse interval is 20 *us*. The measuring method of material removal is recording processing time with digital stopwatch, measuring the depth of EDM small hole per regular time and then calculating the processing speed and material removal rate.

Contrast experiments of tubular copper with 1.5 *mm* in outer diameter, 0.3 *mm* in inner diameter and Cu-Cr composite electrode with 1.54 *mm* in outer diameter, 0.3 *mm* in inner diameter in EDM small hole processing are done respectively. The relationship between material removal rate and processing time is shown in Table 1, the material removal rate with the processing time is shown in Fig. 6 according to Table 1.

As shown in Fig. 6, the material removal rate between the two different electrodes is becoming larger with the increase of processing time, when the processing time reach to 5 min, the processing material removal rate of Cu-Cr composite electrode is 2 times than the single copper electrode, we can also get the message from Fig. 6 that EDM material removal rate of workpiece adopting Cu-Cr composite electrode is hardly changed in initial 5 *min*, while the single copper reduced significantly in initial 1.4 *min*.

**Table 1.** The change of material removal rate with time changing.

| The processing time (*min*) | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Material removal rate adopting cu electrode (*mm/min*) | 3.6 | 3.7 | 3.53 | 3.25 | 3.0 | 2.77 | 2.71 | 2.45 | 2.22 | 2.1 |
| Material removal rate adopting Cu-Cr composite electrode(*mm/min*) | 4.8 | 4.5 | 4.27 | 4.25 | 4.12 | 4.07 | 3.89 | 3.83 | 3.87 | 3.78 |

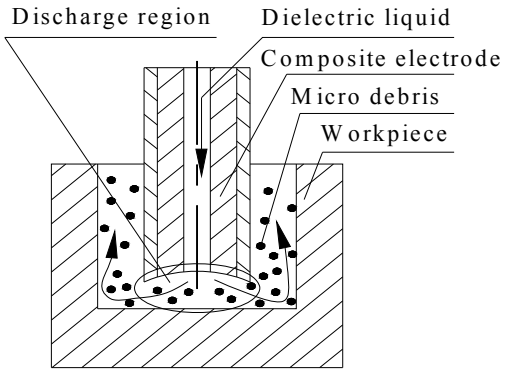



**Fig. 5.** Electric erosion and debris removal adopting composite electrode.

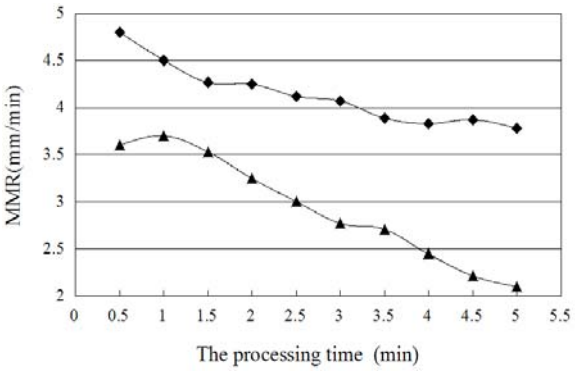



**Fig. 6.** Material removal rate.
◆— Cu-Cr composite electrode; ▲ — Cu electrode.

### 4.2. The Removal Situation of Tool Electrode

Under the condition of 4.1, the electrode end is shown as Fig. 7 after 5 minutes processing. As shown in Fig. 7, the Cu-Cr composite electrode end keep well cylindricity, while the copper electrode have obvious taper and removal gaps, we can conclude that composite electrode can effectively improve the taper problem in EDM small hole processing according to the fact that the machining precision mainly depends on the maintain of the electrode shape.



(a) Cu electrode



(b) Cu-Cr composite electrode

**Fig. 7.** Dissipative contrast of tool electrode end after five minutes processing.

## 5. Conclusions

1) With the increase of depth-diameter ratio, the rapidly decreasing reason of material removal rate of workpiece in EDM small hole processing is the accumulation of settlement of electric erosion debris which is difficult to be ejected at the bottom edge of the hole under the action of gravity and skin effect thus increasing the erosion quantity at the electrode outside end, leading to the tool electrode and the hole processed becoming conform and increasing the discharge probability between the side clearances.

2) It can improve the material removal rate effectively when adopting Cu-Cr composite electrode in EDM small hole processing. The difference of material removal rate between two different electrodes is becoming larger with the increase of processing depth, when the processing current is 10 *A*, pulse duration 20 *us*, workpiece 45#steel, the material removal rate of workpiece adopting Cu-Cr composite electrode is 2 times than the one adopting single copper electrode.

3) The central material melt faster than the surface because the chromium has a high melting point than copper while adopting composite electrode, thus remedying the weakness of being taper due to the accumulation of debris at the edge of the hole processed and improving the processing precision. Under certain conditions, the taper is smaller and the orifice diameter is closer to the ideal hole.

## 6. Acknowledgements

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