Temperature Field Simulation of EDM Single Pulse Discharge on Electrode Adhesion Layer

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***Abstract*-A suitable mathematical model was established for single-pulse EDM machining of adhesion layer electrodes. The finite element analysis method was used to simplify the model according to the actual processing conditions. The physical model with or without adhesion layer was meshed. By comparing the temperature field distribution of the electrode surface with and without the adhesion layer, it can be knew that the temperature of the center surface of the substrate without the adhesion layer is as high as 9901°C, which is much higher than the melting point of the substrate material. From the values of the center temperature of the electrode substrate and the adhesion layer,it can be calculated that the center temperature of the substrate decreases by approximately 1.7 times, 3.0 times, 5.8 times, and 6.5 times, respectively, as the thickness of the adhesive layer increases.It's a successful simulation that the adhesion layer effectively reduces the temperature of the electrode substrate and the electrode loss.**

***Index terms*-computer Simulation Adhesion layer; EDM; Single pulse;Temperature field;**

I. INTRODUCTION

With the rapid development of science and technology and industrial production, people's demand for new materials, especially high-strength, high-melting-point, high-hardness and difficult-to-machine materials, has increased sharply, and the processing requirements for various complex parts have become higher and higher.Obviously traditional machining methods can't meet such production requirements to a certain extent, such as precision machining, deep cavity machining, and micro-groove machining. Gradually EDM, a non-contact method to remove materials, has begun to be used more and more widely. At the same time, in order to make full use of the advantages of special processing methods, scholars have proposed to compound other processing methods with EDM, such as EDM grinding , EDM milling,electro-chemical EDM, and other new composite processing methods ,enriching the scope of the EDM process system.

In the course of pursuing higher processing accuracy and surface quality,it was found that EDM also has its own problems needed to be solved.For example, the high temperature and high pressure generated during the EDM process can not only remove the surface material of the workpiece, but also make the electrode to have a certain loss, which will seriously affect the processing accuracy and shape accuracy of the workpiece.Simultaneously the process of changing the electrode will also increase the processing time and reduce the production efficiency. At the aim of improving the situation, this experiment proposes a method of adding compensation blocks in the process of EDM grinding to compensate electrodes in real time.This method employs the effect of grinding on the basis of spark discharge, which can improve the removal rate at the time of forming an adhesion layer.

However, the formation mechanism and mechanism of action of the adhesion layer are not yet clear because the EDM process is a process that generates heat.

However, the formation mechanism and effect of adhesion layer are not clear, because the EDM is a process that generates heat. Therefore, it is of great significance to study the temperature field of EDM. On the one hand, it is expensive to employ thermometer with high resolution to collect temperature field data under the present conditions and the collected results are easily affected by human factors.On the other hand, although the Finite Difference Method (FDM) is used to study the temperature field with high precision, it is not suitable for complex boundary conditions.While the Finite Element Method is just suitable for complex boundary conditions. In this paper, the finite element software ANSYS 17.0 is employed to simulate the temperature field during the single-pulse discharge process using the electrode with grinding head contained diamond particle under the conditions of possessing an adhesion layer or not.The temperature distribution of the electrode with grinding head can be obtained by means of studying the influences of the thickness variation of the adhesion layer and the presence or absence of the adhesion layer.Finally the protective effect of the adhesive layer on the electrode was verified by simulation.

II MATHEMATICAL MODEL OF SINGLE-PULSE OF EDM WITH THE ELECTRODE CONTAINING ADHESION LAYER

A. *Thermal Conductivity Model*

During the EDM process, the temperature of the tool electrode and the workpiece will change drastically with machining time.What's more, the thermal physical properties of the material also change greatly with the temperature at this process,thus the temperature field

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analysis of the EDM process changes into a problem of nonlinear heat conduction.Due to the small discharge area, the short duration of discharge, and the fast expansion of the discharge channel, the tool electrode and the workpiece can be considered as semi-infinity objects under the effect of a time-varying intensity and time-varying heat source.

The following assumptions are made so as to simplify the mathematical model,(a). The heat transfer model is a symmetric model;(b). The heat released during discharge is transferred to the workpiece by thermal conduction and the heat conduction is symmetric;(c).Only a discharge channel exists for a pulse discharge;(d). The electrode material is an isotropic homogeneous material;(e). Material removal is not considered during discharge and molten metal is finally etched together;(f). Ignoring the volumetric deformation and flow effect of molten metal;(g). Ignoring the impact of internal heat sources;(h). Ambient temperature is 20°C;(i).Loss of radiant heat during the heat transfer process transforms into convective heat loss.

The EDM process is a nonlinear transient analysis of phase change analysis and the simplified equation is as follows:

$$\rho c\frac{\partial T}{\partial t}=k\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right) \quad (1)$$

Where,T is the transient temperature;t is the time;c is the specific heat capacity of the material; ρ is the density of material;K is the thermal conductivity;r,z is cylindrical coordinate.

B. The Estimation of Heat Source Radius

Previous studies have shown that the discharge channel radius is another important parameter affecting the heat source model of EDM. Moreover, as the radius of the discharge channel is not convenient to measure directly with the instrument, the scholars have proposed their own empirical formulas to describe the expansion rule of the discharge channel radius.Among them, the discharge channel radius formula that changes with discharge current and pulse width is accepted by most scholars. Its expression is as follows [1]:

$$T_{(t)}=2.04\times10^{-3}\times I^{0.43}\times t^{0.44} \quad (2)$$

Where, R is the radius;I is the discharge current;t is the pulse width.

C. The Function of Heat Flux Distribution And Energy Distribution Between Electrodes

The heat source intensity of the EDM process is also called the heat flux density. It is caused by the violent collision of electrons and charged ions in the discharge channel to convert the kinetic energy into heat energy, instantly forming a heat source of high temperature concentrated in a very small area. Then the heat source of high temperature melts and vaporizes the materials in this area. According to the formation mechanism of the high-temperature heat source, there are two popular theories in the form of the heat source of EDM, the volume heat source and the surface heat source. However, the amount of electric erosion caused by the volume heat source only accounts for 1%~2% of the total [2]. Therefore, the high-temperature heat source generated during the EDM with single pulse can be analyzed by using a surface heat source.In the light of previous studies, there are three kinds of functions of the heat source distribution: point heat source [3], surface heat source [4] and Gaussian heat source. The point heat source model is so simple that can't meet the actual processing conditions. With regard to the surface heat source model, the heat distribution on the surface of the electrode is uniform, which is suitable for the simulation of electrical machining with a large electrical parameter range.While the heat source distribution of Gaussian is most consistent with the uneven distribution of heat sources on the electrode surface during the EDM. Therefore, the model of Gaussian heat source is frequently used in thermal field simulation of the pulsed discharge[5-6]. This paper put the model into use. The formula is as follows:

$$q=R_w\frac{U_{(t)}I_{(t)}}{\pi R^2_{(t)}} \quad (3)$$

Where q is the heat flux; U(t) is the machining voltage;I(t) is the machining current and R(t) is the coefficient of heat distribution.

In the course of modeling Electrical Discharge Machining,how to distribute energy between electrodes is also an important factor.Dibitonto [3], Patel [7] and Joshi [8] analyzed the experimental results and found that about 26% of the energy is distributed in the positive and negative electrode during the EDM.Through the study of the ratio of energy distribution in the two poles, Japanese scholar Xia Heng[9] discovered that the energy of positive electrode whose ratio is 40% is always much larger than the negative electrode whose ratio is 25% regardless of the changes of pulse width.By a combination of simulation and experiment Zhang[10] found that the workpiece obtain 44% of the total energy during EDM process.Xie [11]shared the idea that the energy obtained by the workpiece is about 30% of the total energy in the numerical simulation of machining titanium alloys with EDM.Professor Guo Zhongning of Guangdong University of Technology reached a conclusion that the energy obtained by the anode should be 33% of the total energy from a large number of experiments.In this paper, the distribution coefficient of the two poles is 33% and the energy is shown in Fig.1.

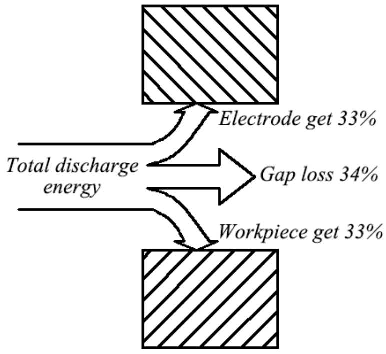


Figure 1. The diagram of energy distribution between two electrodes

III FINITE ELEMENT TEMPERATURE FIELD SIMULATION ANALYSIS

The finite element software ANSYS 17.0 was used to simulate the temperature field of a single-pulse discharge of a diamond abrasive electrode with and without an adhesion layer. The dimension was 600mm×550mm. The low-order module of PLANE55 in the ANSYS software was used for meshing. The 2D map of grid-divided is shown in Fig.2. In this paper, APDL parametric language is mainly employed to load the functions of complex heat flux and performs simulation.

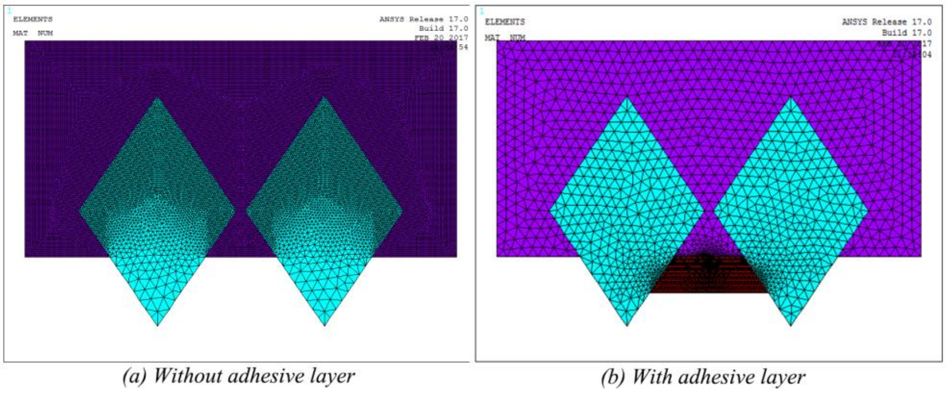
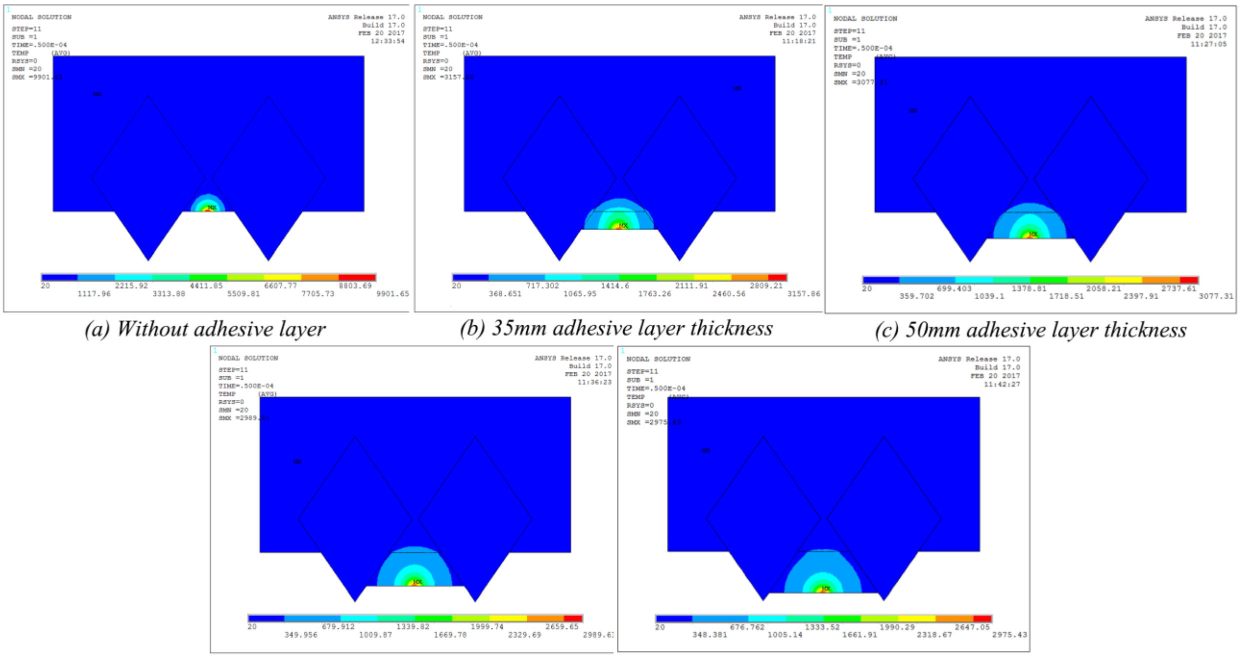


Figure 2. Mesh partition (a)Without adhesive layer (b) With adhesive layer(50mm)

A ANALYSIS AND DISCUSSION OF SIMULATION RESULTS

The simulation of temperature field in this paper,studying EDM of single pulse on the electrode surface with adhesive layer and without adhesive layer,is conducted under atmospheric conditions regardless of the influence of gas pressure.The diagram of simulation result is exhibited on Figure 3, in which the discharge voltage is 25V, the peak current is 3.5A, and the pulse width is 50ms.And in the presence of the adhesive layer, the thickness of the adhesive layer is set as 35mm, 50mm, 65mm, and 80mm, respectively, to simulate and analyze the effect of the thickness of the adhesive layer on the surface temperature of the electrode, which would verify the protection of adhesive layer on the surface of the electrode.It can be seen from Fig.3,the degree of corrosion of the electrode substrate without the adhesion layer is significantly greater than that of the electrode substrate with the adhesion layer.As the increase of the thickness of the adhesive layer, the corrosion of the electrode matrix by the temperature field of the EDM process also shows a downward trend. After adding the adhesion layer to the surface of electrode,the adhesion layer can reduce the corrosive effect of the high temperature generated by the spark discharge on the electrode substrate during EDM.That is to say, the adhesion layer can be employed to compensate for the loss of the electrode during this process, which also confirms the correctness of the experimental idea in this article



(a) Without adhesive layer *(b) 35mm adhesive layer thickness* *(c) 50mm adhesive layer thickness*

(d) 65mm adhesive layer thickness *(f) 80mm adhesive layer thickness*

Figure 3. Contour of temperature distribution

When the electrical parameters are the same, thetemperature values at the center of the electrode matrix and the center of the adhesion layer at different times are selected respectively.The selected point is fitted by using the Origin and the curve of temperature change with time is shown in Fig 4.It can see from Fig.4 that all of them share the common ground that in the initial stage of discharge, the channel is at a stage of expansion, the radius is very small, the heat flux is very high, the temperature rises very fast, and a curve similar to the exponential growth appears at the beginning .Subsequently, with the amplification of the discharge path, the radius of the heat-affected zone increases and the heat flux density gradually disperses to other regions, forming a tendency to spread from the discharge point to the surrounding area.Therefore the rising trend of the center temperature gradually slows down and appears flat finally.The difference is that the temperature at the center of the electrode substrate without the adhesion layer is much higher than the temperature at the center of the adhesion layer of electrode, which is related to the thermal conductivity coefficient and the specific heat capacity of the material.The default material of the electrode substrate material is iron whose thermal conductivity and specific heat capacity are 40×1.163W/m•°C and 0.46×103J/(kg•°C) respectively.The material of adhesion layer is aluminum whose thermal conductivity and specific heat capacity are 217.7W/m•°C and 0.88×103J/(kg•°C) respectively.In addition, the center temperature of the electrode with adhesion layer decreases with the increase of the thickness of the adhesion layer , but the decrease is not large and the maximum is 88°C.The center temperature of the electrode substrate with the adhesion layer,whose highest temperature is only 1153°C , is lower than that of the electrode substrate without adhesion layer.Furthermore due to the effect of the adhesive layer, the center temperature of the electrode substrate is reduced by 1.7 times, 3.0 times, 5.8 times, and 6.5 times respectively, with the increase of thickness of the adhesive layer , compared with the center temperature of the adhesion layer.Obviously it can be seen that the adhesive layer can effectively protect the electrode matrix and reduce the electrode loss which also verifies the correctness of this experiment.

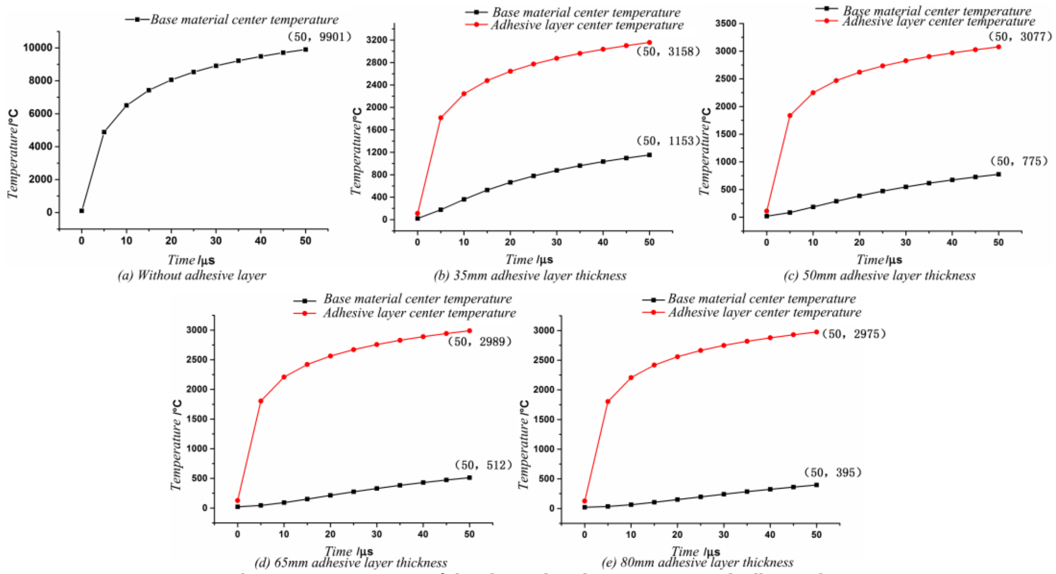


Figure 4. The temperature curve of the electrode substrate center and adhesive layer center

IV CONCLUSION

From the main mechanism of thermal analysis of single-pulse discharge, a reasonable analysis of the heat conduction process, initial conditions, boundary conditions, thermal stress, strain and phase transition during EDM was performed.Based on the Gaussian heat source distribution function an appropriate mathematical model was established.Moreover, reasonable heat source intensity and heat source radius formulas are selected to provide calculation basis for the following finite element analysis.By comparing the distribution of the temperature field of electrode surface with and without the adhesion layer, it can be knew that the temperature of the center surface of electrode substrate without adhesion layer is as high as 9901°C , which is much higher than the melting point of the substrate material.In addition, according to the center temperature of the electrode matrix and the center temperature of the adhesion layer, it is calculated that the center temperature of the substrate is reduced by 1.7 times, 3.0 times, 5.8 times, and 6.5 times, respectively, with the increase of thickness of the adhesion layer ,compared with the center temperature of the adhesion layer.Ultimately it can be concluded that the adhesion layer effectively lowers the temperature of the electrode substrate and reduces electrode loss.

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