Numerical Simulation of the Temperature Field in the process of EDM Surface Strengthening

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Abstract. A two-dimensional axisymmetric thermal model, whose heat flux is constantly changing both in magnitude and position, is created based on the temperature distribution in the process of EDM surface strengthening. Using the JMatPro software to calculate the TC4 material parameters with the temperature changing, then Using ABAQUS software to simulate temperature field of single pulse EDM. The results show that in the process of strengthening, the discharge point's temperature rises instantly, after declines rapidly, but the rise speed is faster than the decline speed significantly; radial conduction speed is significantly faster than the axial, strengthening process on the substrate performance influence is small.

Introduction

Workpieces surface damage often starts from the surface, when working in the conditions such as high speed, high pressure, overloading, corrosive medium and so on. Therefore, using EDM surface strengthening technology to improve the surface performance and extend the workpieces life has a great significance.

Scholars at home and abroad have made many achievements[1-3] on strengthening mechanism, strengthening layer's organizational structure, performance test, equipment research etc. This paper references previous research results, studies the temperature fields in the process of EDM surface strengthening. In the process of EDM, the temperature's change is very fast and the temperature is very high, so use the traditional methods are too difficult to measure, and the prices are high. This paper bases on the finite element numerical simulation methods to analyze the temperature fields change in the EDM process, provides theoretical basis for the further optimization of process parameters.

Numerical Model

This chapter in deeply analyzes the heat transfer model in the process of EDM surface strengthening, using ABAQUS software [4,5] to establish the transient heat transfer mathematical models, conducting numerical simulation of the temperature fields in single pulse EDM process. In order to calculate accurately, the mathematical model should as far as possible really describe the factors that influence the calculation results, at the same time, should be more simple in sure of the calculation accuracy, so that to simplify calculation. Therefore, make assumptions for the single pulse EDM surface strengthening process:

(1) the workpieces materials are homogeneous and isotropic, ignore the surface defects such as micro cracks and micro holes;

(2) material thermal performance is a function changes with the temperature, considering the latent influence, ignore the surface material's evaporation and weightlessness;

(3) heat transfer is mainly in the form of heat conduction, ignore the factors such as thermal radiation;

(4) in the strengthen process, ignore the structure field effect on temperature field.

According to the Fourier heat conduction theory, get the nonlinear transient heat conduction equation under the cylindrical coordinate system:

$$c\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) \tag{1}$$

The Heat Source Model

Set up the heat source model that close to the actual is the precondition of analyzing the temperature field,researches show that: in the instantaneous discharge channel,the charged particles density obey gaussian distributions. Gaussian heat sources that change with time and coordinate can't direct input in Abaqus,should use flux subroutine to write. At t time, in the places that distance the center of the discharge is r, the heat flux density can be showed as:

$$q(r, t) = q_{\max} \exp\left\{- 4.5 \times \left(\frac{r}{R(t)}\right)^2\right\} \tag{2}$$

r ——the distance from the center of discharge(mm)
$R(t)$——discharge channel radius at t moment (mm)
$q(r, t)$ ——radius r heat flux density at t moment（ $mJ / mm^2 \cdot s$ ）
$q_m(t)$——the max heat flux density at t moment（ $mJ / mm^2 \cdot s$ ）

Maximum heat flux density:

$$q_{\max} = \frac{4.55 \times \eta \times U \times I}{\pi R^2} \tag{3}$$

$U = 21.3\ I = 3.7 \quad \eta = 0.3$

This paper uses the discharge channel radius is $R(t) = 0.788 \times 10^3 \times t^{0.75}$.

Initial Conditions and Boundary Conditions

Initial Conditions. This example assumes that the initial temperature is constant 25 ℃, namely when $t = 0s$ the workpieces temperature distribution. In the process of EDM surface strengthening, the initial temperature is $T(x, y, z, 0) = 25°C$.

Boundary Conditions. There have three kinds of boundary conditions in the heat transfer model, as shown in Figure1, namely, heat flux boundary, convection boundary and constant temperature boundary.

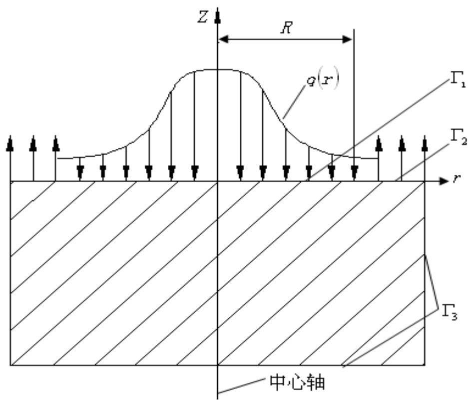


Fig.1 The boundary conditions of schematic diagram

Through flux subroutines to input the heat flux boundary $\Gamma_1 = q(r)$, convection boundary $\Gamma_2 = 0.1 mW / mm^2 \cdot °C$, constant temperature boundary $\Gamma_3 = 25°C$.

Material Parameters. Workpiece material is TC4 titanium alloy, its thermal physical parameters such as density, specific heat, coefficient of thermal conductivity change with temperature.EDM process instantaneous temperature as high as tens of thousands of degrees Celsius, material performance is extremely difficult to measure in high temperature and very expensive.So this paper use JMatPro material performance calculation software to get material parameters, namely through element percentage calculate TC4 titanium alloy material parameters. Elements percentage in TC4 titanium alloy as shown in Table 1, therefore, in this article, through JMatPro software to get material parameters that changed with temperature in the process of finite element simulation, directly import the material parameters into Abaqus software.

Table 1 TC4 Weight percentage for composition

Element	Al	Fe	V	C	O	N
Wt(%)	6.51	0.18	4.13	0.02	0.185	0.01

Heat Conduction Model and the Meshing. In this paper, use Abaqus software to simulate the temperature field in the process of EDM surface strengthening. Establish an axisymmetric geometry model in the Abaqus software, the basic size is diameter r = 200 um, height h = 200 um. When meshing, using 4 nodes' linear axisymmetric heat conduction element DCAX4, as shown in figure 2.

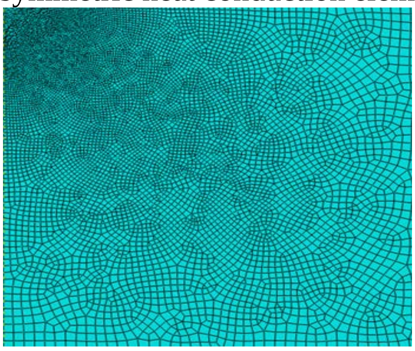
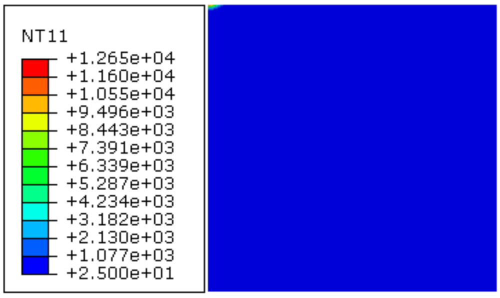


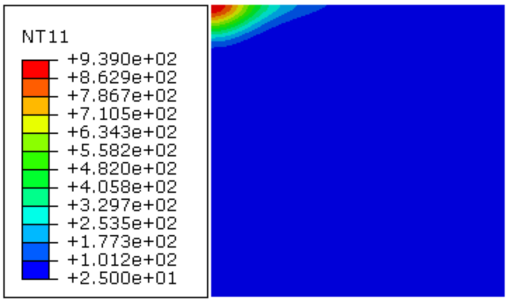
Fig. 2 geometric model

Simulation Results

Calculated by abaqus finite element software to gain the temperature field distribution of EDM process.To save space, this paper only choose the temperature field cloud pictures when workpiece temperature reached the highest, the discharge end and some time in cooling process. As shown in figure 3A, when t = 042 us,on the workpiece the maximum temperature reached 12650 ℃, because the time is so short, heat affected areas are so small, that the heat has no time to spread, leading the temperature in the discharge center too high. As shown in figure 3B, when the pulse power after discharge, the highest temperature on the workpiece is 939.0 ℃, the radial energy transmission rate significantly faster than the axial heat, in the process of strengthening has minor damage to the workpiece. As shown in figure 3C, some time in the cooling process, the highest temperature on the workpiece is 38.8 ℃, in the whole process of strengthening, heat affected areas very small, can strengthen the complex parts.



(a)



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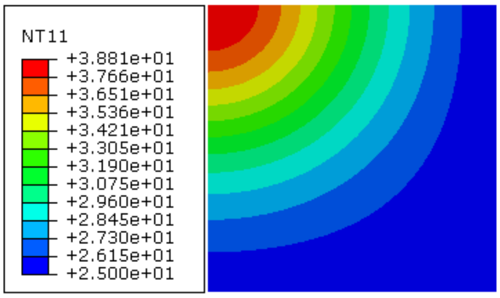


(c)

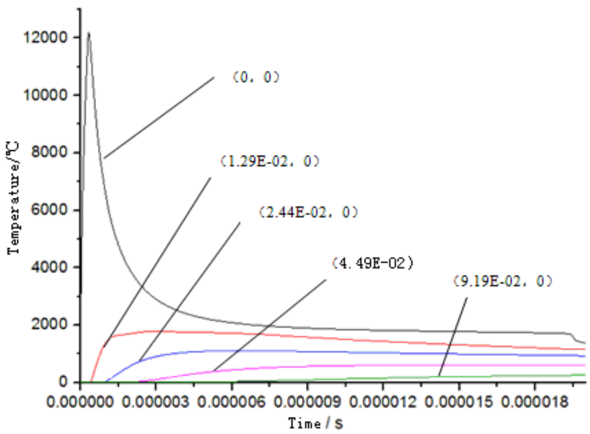
Fig. 3 Contour map of Temperature field

In the pulse discharge and cooling process,at the surface of the workpiece and the central axis, the temperature changes with time, as shown in Fig.4:

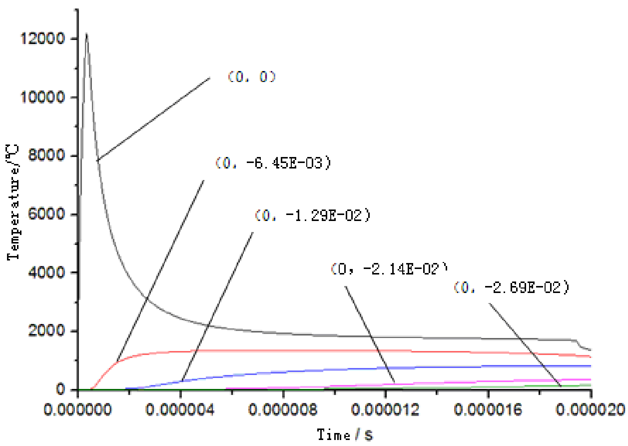
Fig 4a and Fig 4b are curves which the temperature changes with time in different node during the process of pulse discharge. During the pulse discharge process, on the workpiece, the temperature of the node near the discharge heat increases rapidly and then decreases. temperature of the nodes away from the discharge source gradually increased. The nodes close to the center of the discharge, the temperature of the node close to the discharge center changes more intense.

The Fig.4c and fig. 4d shows that in the cooling stage of EDM surface strengthen, the temperature of the nodes at the workpiece surface are gradually reduced to room temperature 25 ℃.

Compared with 4a, 4b, 4c and 4d, in the EDM surface strengthen process, the influence of the pulse discharge heat affected area to the matrix material of the workpiece is very small. The strengthening method avoids too much change of the workpiece material properties. At the same time, strengthening layer material and the substrate binding force was superior to the other methods.



(a)



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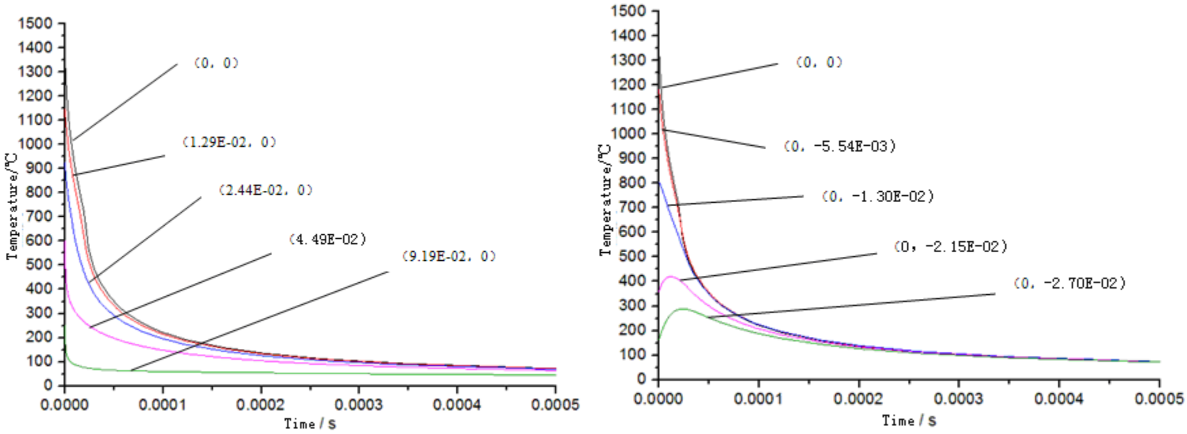

(c) (d)

Fig. 4 Temperature history during discharge and cooling

By the finite element analysis of EDM surface strengthen process, the surface temperature distribution of the workpiece under different pulse voltages can be obtained. When the discharge time is t=20E-6s, that the end of the pulse discharge, the temperature distribution of the workpiece is shown in Fig.5. Figures a-e show that, when the pulse voltages were 11.3V, 16.3V, 21.3V, 26.3V, 31.3V, the workpiece maximum temperature was located in the discharge pulse heat source center and its size respectively for 841.4 ℃, 1058℃, 1372℃, 1769℃ and 1806℃. It is se
increase of the pulse voltage, the temperature in the heat source center at the end of the EDM surface strengthening discharge is increasing, as shown in Fig.5f.

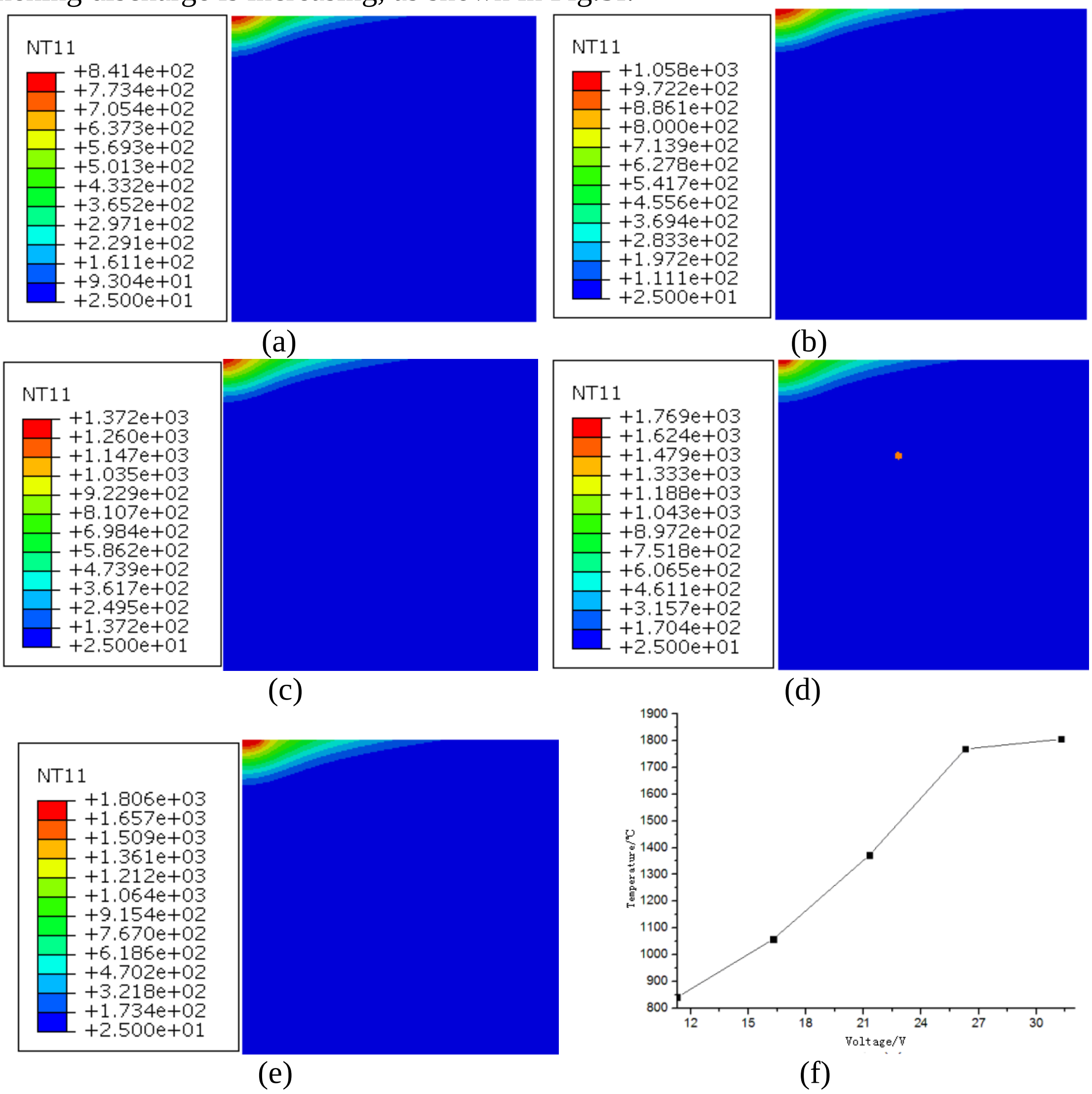

Fig. 5 temperature distribution at the end of discharge

Conclusions

(1) Temperature in discharge point instant rise, after falling rapidly, discharge strengthening process is very short;

(2) Radial conduction velocity significantly faster than the axial temperature, the effect of strengthening process on the matrix performance is minimal;

(3) Heat affected areas in the process of EDM strengthen are so small that can undertake the complex shape parts.

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