Finite Element Simulation of Thermal Effect in Electric Discharge Machining

Kathiravan S, Pradeep Kumar J*
Department of Production Engineering, PSG College of Technology, Coimbatore – 641 004
***Corresponding author: E-Mail: jp.psgtech@gmail.com**

ABSTRACT

Electric discharge machining (EDM) is an advanced manufacturing process that uses high energy electrical sparks to machine materials which conducts electrical materials. AISI P20 mould steel is one of the materials as difficult to machine which are machine using conventional machines material and consist of properties such as greater mechanical strength and toughness. Temperature developed while machining P20 mould steel play a dominant role in evaluation of the quality characteristics of the machining process and also the work material being machined. A model based on finite element concept model is developed to estimate the temperature generated while machining and the temperature distribution on the work piece for evaluation of material removal rate pertaining to the effects of temperature. The effects of various process parameters like discharge current, pulse on time and voltage are considered in calculation of heat flux and the influence of these parameters on temperature distribution is reported.

KEY WORDS: Electric discharge machining, finite element analysis, temperature distribution, discharge current, pulse on time, voltage.

1. INTRODUCTION

Electric discharge machining is a manufacturing process required shape is obtained by sparks and it is used in many industries such as automotive, production tooling and precision manufacturing, small hole drilling, Higher Tolerance limits can be obtained in EDM machining. During the process, voltage will be applied to both the copper electrode and the P20 work material. The working principle of EDM is presented in fig 1.The voltage in the gap will be high and it will be discharged through in the form of spark. The spark creates a plasma channel between anode and cathode that will generate enough heat resulting in melting and vaporization the P20 material. Heat transfer mostly occurs in conduction and convection. Thermal model of EDM is displayed in figure 2.The rate of removal material EDM is based on electro thermal process. The removal of material is based on high temperature in the plasma channel. The heat source will calculate the volume of material depends on heat flux. Thermal properties such as heat flux, thermal conductivity etc. influence the temperature generated during machining.

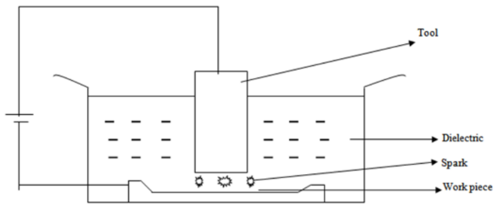

Figure.1. Working Principle of EDM

Parameters Influences on Heat Transfer in EDM: Heat transfer and heat input are the dominant parameters influences in electric discharge machining. The crucial mode of heat transfer is considered as conduction in electric discharge machining. The various parameters which contributing towards to the accurate prediction by EDM models includes the amount of heat input, radius of spark and the thermo-physical properties of the material. The important requirements for mathematical model are methods of heat transfer, heat input and boundary conditions.

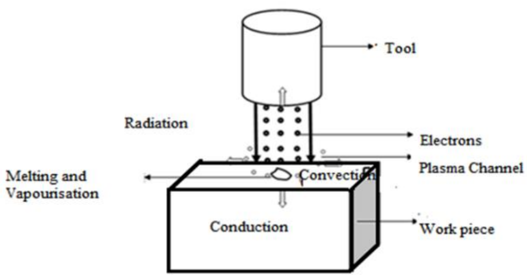

Figure.2. Heat Transfer in EDM

Literature Review: A literature review is reported in this chapter. It includes a list of authors and their contributions in the area of electrical discharge machining and temperature distribution analysis. The summary of literature review is shown in Table 1.

Table.1. Summary of Literature Review

Authors, year	Objective	Material	Process Variables	Remarks
Vinod Yadav (2012)	To estimate temperature, thermal stress	WP- HSS Tool-Copper	a)Discharge current b)Duty cycle	a)Thermal stress increase with increase in duty cycle b)Current is high , thermal stress are also get increased
Arjitsingh and amitabhghosh (2000)	Depth inside the WP, crater depth	WP-SS Dielectric - kerosene	a)Discharge time	a)Medium pulse –Crater depth increases b)short pulse-crater depth not allow metal to heat c) Discharge duration is large electric force deep inside metal become small
Yasinsarikavak, can cogun	Single discharge of EDM –MRR	WP-AISI D2 mold steel Tool - copper	a)Pulse on time b)Discharge current	a)Small amount of material removal from WP at low discharge current and pulse time values
Erden and kaftanoglu	Mathematical model of EDM by heat transfer	WP- Cu, St, Br, Al	a)Pulse time, b)Discharge power	a)100% removal – melting point of material is taken as temperature limit b) 20% removal – melting point of material is taken as temperature limit
SN Joshi and Pande	Numerical analysis of single spark – EDMGaussian distribution	WP- AISI P20 mold steel Tool -copper	a)Discharge current b)Discharge duration c)Duty cycle	a) Increase in discharge voltage result increase in MRR b) Increase in discharge current result increase in crater depth

WP- work piece, MRR- material removal rate, HSS- high speed steel, SS- stainless steel

Problem Definition: High density of thermal energy results in thermal erosion and formation of recast layer with micro cracks on the finished surface and reduces the fatigue strength. Low temperature developed in the plasma channel results in low amount of material removal in the work piece. Against these conditions present research work is undertaken to develop a thermal electrical model for sparks generated in the electric discharge machining process.

Simulation:

Thermal Modeling: A cylindrical form of P20 steel material is chosen for modal analysis, Transient analysis of uniform heat flux with axis-symmetric model is assumed. Present model analysis, bwork piece is being heated by a Gaussian type of heat source. The mode of heat transfer is considered in this work where the heat transfer based on the mode such as convection and radiation are neglected. This is because of the fact that heat transfer influence is very minimum by other modes of heat transfer.

Governing Equation: For designing the mathematical model heat input and transfer of heat is the vital parameter to be selected. The crucial mode of electric discharge machining is governed by conduction equation. The simplified mode of heat conduction is shown in equation (1.1). But the basic will be the Fourier equation.

$$\partial^2T / \partial x^2 + \partial^2T / \partial y^2 + \partial^2T / \partial z^2 = 1/\alpha * \partial T / \partial t \qquad (1.1)$$

Where T is the temperature and α is thermal diffusivity of the material (m^2/s)

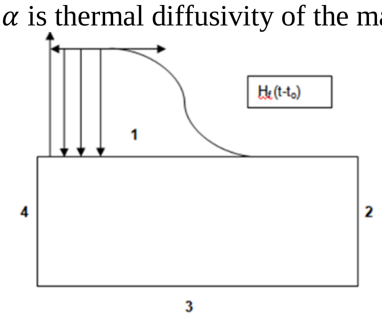

Figure.3. Boundary Conditions of EDM

A rectangular 2D model is made by ANSYS and it is meshed with finest mesh area. Heat flux is used to simulate spark energy in the region of the plasma radius (R), the region larger than R is applied conduction boundary condition on the top surface and the other three surfaces are insulated. In the Figure 2, Boundary of conditions 2 and 3 are considered to be insulated. Heating is axis-symmetric to the axis of the spark, so heat flowing from the spark to the p20 steel work material to the heat flowing out of the work piece material Therefore no heat gain or loss from the counter part of the surface domain. On the top layer, at boundary1, spark is directly contacted with the surface. Hence heat flux boundary condition is applied. Due to existence of dielectric fluid outside of the plasma channel surface, there is conduction heat transfer. Boundary conditions are until R_p.

$(K\ \delta T/\delta Z) = T_p$ (1.2)

Outside R_p:

$K\ \delta T/\delta Z = h(T-T_0)$ (1.3)

For boundaries B_2 , B_3 , B_4

$(\delta T/\delta n) = 0$ (1.4)

Here h is the coefficient of heat transfer between dielectric liquid and work piece, T_0 is the initial temperature, T is the temperature value , n is the normal surface, T_p is plasma temperature.

Heat Flux: Important parameters which contributing to the accurate calculation of the removal of material in single spark EDM model include the amount of heat input, radius of plasma spark and the thermo physical properties of material. The heat flux calculation equation is shown in Equation (1.5 -1.6)

$q(r) = q_o \exp\{-4.5\ (r / R_{pc})^2\}$ (1.5)

Where q_0 is maximum heat flux and can be calculated as

$q_0 = 4.57 F_c VI / \pi R^2_{pc}$ (1.6)

Where F_c is fraction of total EDM spark power going to the electrode (W); V is discharge voltage (V), I is discharge current (Amp) and R_{pc} is plasma channel radius at the work surface (micro-meter).

Plasma Channel Radius: The equation which express the plasma radius in terms of discharge current (I_d) and pulse on time (t_d) in equation (1.7), is used to calculate R_{pc}.

$R_{pc} = (2.04 * 10^{-3})\ (I_d^{0.43})(t_d^{0.44})$ (1.7)

3. RESULTS AND DISCUSSION

Maximum temperature reached is located in red region where the intensity of heat flux is maximum which is shown in figure 4 and figure 5. The degree of the temperature is less as the distance improves from the center line. From the figure it reveals that temperature is distributed into four regions:

- Boiling region (red region)
- Liquid region (upto light green color)
- Heat affected zone (upto light blue color)
- Solid
- metal (solid metal)

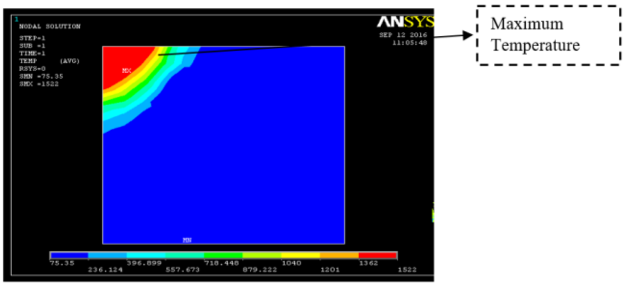

Figure.4.Temperature distribution of work material with V=30V,I_d=2A, t_d=2μS

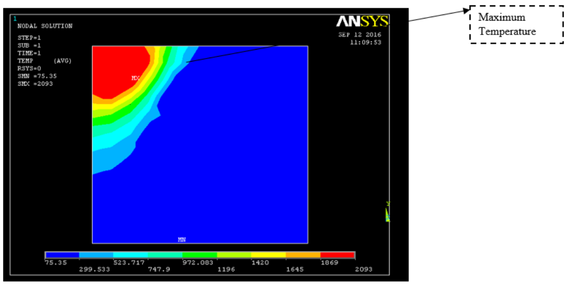

Figure.4. Temperature distribution of work material with V=40V, I_d=5A, t_d=5μS

Boiling region (red region) where the surface temperature is hotter than saturated temperature. By the concept of Fourier's law of heat conduction, the heat flux is directly proportional to the temperature.

4. CONCLUSIONS

In the present work, the conduction mode of heat transfer is used to model the EDM process. The conclusions of the work are:

- The temperature exerted on the work piece varies according to the discharge current, voltage, pulse on time. Due to high temperature developed in heat affected zone, the thermal stress exceed the yield stress of the work piece material.

- The rate of removal of material increases when discharge current increases, since discharge current is directly proportional to material removal rate.

REFERENCES

Ajit Singh and Amitabah Ghosh, A Thermo Electric model of material removal during electric discharge machining, International Journal of Machine tools and Manufacturers, 39, 1999, 669-682.

Erden A and Kaftanogulu, Heat transfer modeling of electric discharge machining, Journal of Material Processing and Technology, 142, 434-451.

Haohuang, Zheng zhang, Yanming Zhang, A novel numerical predicting method of EDM process based on specific discharge energy, International Journal of machine tools and Manufacturing Process, 2016, 22-30.

Izquierdo B, Sanchez JA, Ortega N, A numerical modeling of the EDM process considering the effect of multiple discharges, International Journal of machine tools and Manufacturing Process, 49, 2009, 220-229.

Joshi SN and PandeSS, Thermo physical model of electrical discharge machining, Journal of Manufacturing Process, 12, 2016, 45-56.

Salonits K, Stournaras A, Stavrpoulos P and Choroloyss G, Thermal modeling of the material removal rate and surface roughness for EDM process, International Journal of Advanced Manufacturing Tech, 40, 2009, 316-323.

Thomas jin, Chun der, Po heng, Numerical and experimental studies of electrical discharge machining, International Journal of machine tools and Manufacturing Process, 42, 2016, 679-684.

Vinod Yadav., and Vijay K Jain, Prakash M Dixit, Thermal stress due to electric discharge machining, International Journal of Machine tools and manufacture, 42, 2002, 877-888.