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Thermal Electrical Modelling of EDM Process

[1]Amit Bhatia, [2]Atul Aggarwal, [3]Mukesh Verma

[1]M.Tech Scholar, Sri Sukhmani Institute of Engineering & technology, Dera Bassi, Punjab India
[2]Assistant Professor, Sri Sukhmani Institute of Engineering & technology, Dera Bassi, Punjab India
[3]Associate Professor, Sri Sukhmani Institute of Engineering & technology, Dera Bassi, Punjab India

***Abstract*— The present work has been undertaken to generate a thermal-electrical model for sparks generated by electrical discharge in a liquid media and to determine the temperature distribution of tool and work piece. For a single discharge test, copper and En-19 was used as specimens. The amount of heat dissipated varies with the thermal-physical properties of the conductor. The model is developed by using ANSYS software. ANSYS uses the finite-element method to solve the underlying governing equations and the associated problem-specific boundary conditions. Material Removal Rate, Surface Roughness and the maximum temperature reached in the discharge channel is determined.**

***Keywords* — ANSYS Software, Plasma Channel, Finite Element Method**

I. INTRODUCTION

The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. Non-traditional machining has grown out of the need to machine these exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of non-traditional process. The Electrical Discharge Machining process is employed widely for making tools, dies and other precision parts. In the machining of very hard metals and alloys used in aerospace, automotive and nuclear industries. It is a promising technique to meet increasing demands for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.

II. LITERATURE REVIEW

Through literature review, it was observed that the thermal erosion theory is the most accepted mathematical model for evaluating material removal from electrodes during EDM process.

Philip Allen et al. [1] presented the process simulation and residual stress analysis for the micro-EDM machining on molybdenum. Material removal is analyzed using a thermo-numerical model, which simulates a single spark discharge process.

J. Marafona et al. [2] developed a thermal-electrical model for sparks generated by electrical discharge in a liquid media. The radii value of the conductor is a function of the current intensity and pulse duration.

K.L. Bhondwe et al. [3] proposed a thermal model for the calculation of material removal rate during ECSM. The temperature distribution within zone of influence of single spark is first obtained with the application of finite element method.

Leonid I. Sharakhovsky et al. [4] modified the step-wise model (SWM) of cold electrodes erosion of electric arc heaters for the calculation of work piece removal rate in EDM process.

B. Lauwers et al. [5] presents a detailed investigation of the material removal mechanisms of some commercially available electrical conductive ceramic materials through analysis of the debris and the surface/sub-surface quality.

III. SPECIFICATION OF THE PROBLEM

The objective of present work is to determine the temperature distribution of tool and work piece by developing a thermal-electrical model for sparks generated by electrical discharge in a liquid media. In order to determine material removal rate, surface roughness and the maximum temperature reached in the discharge channel the present work was divided into following different phases.

Phase – 1 To select element, governed the electric field in a conducting material by Maxwell's equation of conservation of charge.
Phase – 2 Described the flow of electric current by Ohm's Law.
Phase – 3 Described the heat conduction behavior by the basic energy balance relation.
Phase – 4 Described the rate of electrical energy, Pec dissipated by current flowing through a conductor.
Phase – 5 An assumption has been made that the radius of the

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electrode is 20 times larger than the discharge channel radius.

Phase – 6 Simulation has been carried out for single discharge analysis employs the commercial finite element code ANSYS Multiphasic to determine both temperature distribution and deformation of molten material by plasma pressure.

Phase – 7 Experiments are performed on the CNC lathe machine with the electrode and work piece

Phase – 8 Selection of material for electrode of 30 mm diameter and 40 mm thickness and work piece of 40 mm diameter and 10 mm thickness. The electrode material is copper and work piece material is E-19.

Phase – 9 The volume of material removed from the work piece has been calculated by temperature distribution for different current intensities.

Phase – 10 the maximum surface roughness (Rmax) of work piece (cathode) is calculated for different current intensity values.

Phase – 11 The material removal rate found in the experiment conducted with varying pulse Ton and current intensity values.

IV. SIMULATION & PROCEDURE

The single discharge analysis procedure employs the commercial finite element code ANSYS Multiphasic to determine both temperature distribution and deformation of molten material by plasma pressure. ANSYS is a generally used finite element code to solve engineering problem.

The heat flux intensity varied with discharge gap current trace and the diameter of plasma. During the discharge on-time, the melting region and the evaporating region were found. The material was assumed that certain part whose temperature goes over the evaporating point would be removed. The molten material consequently would be protruded up to crater edge. Figure 1 show the plasma channel developed during on-time.

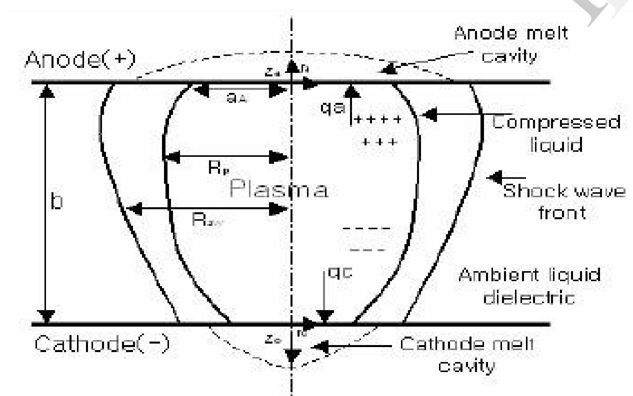

Figure 1: Plasma channel developed during on-time

Material properties for the tool, work piece and discharge channel was set as input values. The boundary conditions were given as nodal variables. Based on the governing equations, the loading conditions applied were temperature and voltage which varied between nodes.

Table 1 shows the material properties set for copper, En-19 and the EDM oil used as the dielectric fluid during the theoretical analysis.

Table 1: Material Properties for FEA

Material Property	Copper (cathode)	EDM Oil (dielectric)	En-19 (anode)
Density (g/mm^3)	8920×10^{-6}	5.7×10^{-8}	7700×10^{-6}
Conductivity (W/mmK)	400×10^{-3}	0.06	222×10^{-12}
Resistivity (Ω-mm)	1.7×10^{-11}	1	22.2×10^{-11}
Specific heat (J/gK)	385×10^{-3}	15	473×10^{-3}

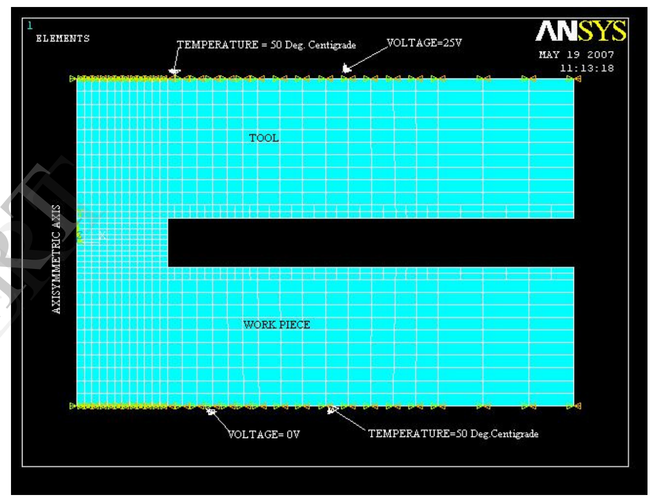

Figure 2: Elements after meshing and application of loads

The model was developed by selecting the element types and then assigning the attributes to the elements. The figure also shows the loads applied and the boundary conditions given for the model generation. The model is considered to be symmetric about Z-axis.

A. Thermal Boundary Condition:

The temperature in the upper surface of the tool and lower surface of the work piece is 50˚C.

B. Electrical Boundary Condition:

The voltage applied to the upper boundary of tool is 25V and that of the lower boundary of the work piece is 0V.

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V. EXPERIMENTAL WORK

The Electric Discharge Machine, model ELECTRONICA-ELECTRAPULS PS 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode. Fig. 3 shows the EDM machine used for the experiment.

Figure 3: EDM machine used for the experiment

Figure 4: Electrode & Work piece material used in the experiment

The electrode made up of copper was machined in cylindrical shape on a lathe machine and brazed with mild steel. Diameter of the electrode was 30mm and thickness 40mm. The work piece material is En-19 with diameter 50mm and thickness 10 mm. The initial weight of the work piece material was measured. Fig.4 shows the electrode and work piece material during the machining operation. Electric Discharge Machining is a process of repetitive sparking cycles. The figures representing the sparking cycles are shown in figure 5 and 6.

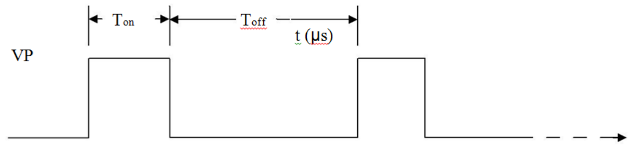

Figure 5: Graphical representation of sparking cycles

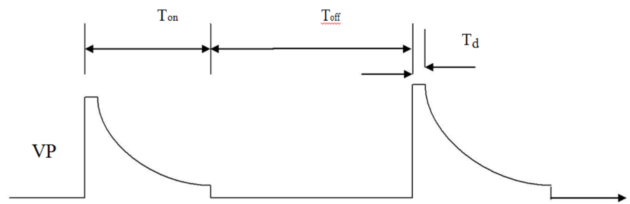

Figure 6: Series of electrical pulses at the inter electrode gap

The work material was mounted on the T-slot table and positioned at the desired place and clamped. The electrode was clamped and its alignment was checked. The machining time was set as 5 minutes.

After each machining operation, the work piece material was taken out and weighed to find out the weight loss. From the weight loss obtained, the material removal rate was calculated for different current values. Three cases were considered with varying Ton conditions and machining was done for four different current values in each case.

After the machining, the change in weight of the material, volume of material removed & material removal rate was calculated as shown:

The initial weight of the sample = 178.430 grams

After machining, the final weight = 178.270 grams

Weight loss = 178.430 – 178.270 grams = 0.160 grams

Volume Loss = Weight loss / Density

Volume Loss = 0.160 / 0.0077 = 20.779 mm3

MRR = Volume of the material removed /Time

Material Removal Rate = 20.779 / 5= 4.1558 mm3/min.

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Figure 7: Electrode and work piece after the machining operation.

VI. IMPORTANT RESULTS

i. **Volume of the material removed**: During computation of results using FEM, the width and depth of crater in the work piece for a single spark is predicted assuming that the regions which attain a temperature above the upper limit of melting temperature (10,000ºC) are completely removed. The temperature distribution of discharge channel at different current intensities is shown fin figures 8-11.

A graph showing the volume of material removed for different current intensities is presented in Figure 12. From 68 amps to 44 amps, the volume of material removed decreases uniformly whereas from 44 amps to 36 amps there is a little decrease in volume of removed material.

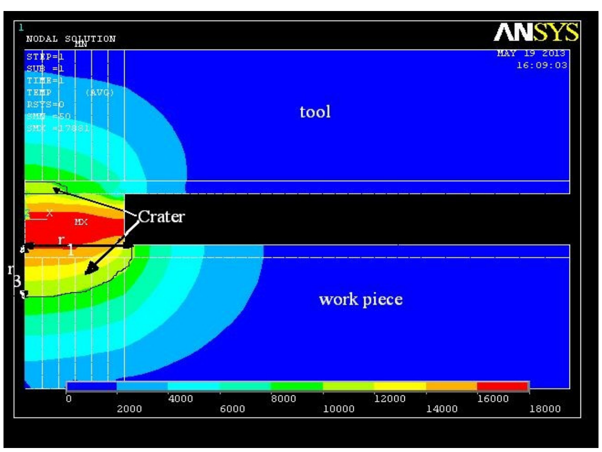

Figure 8 Temperature distribution obtained for a Current intensity value of 68 amps

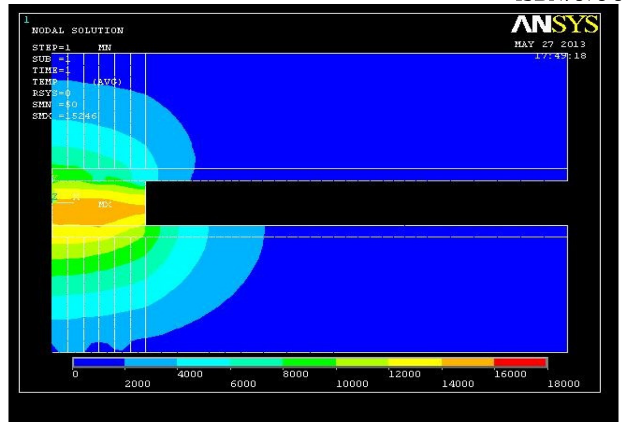

Figure 9: Temperature distribution obtained for a current intensity value of 58 amps

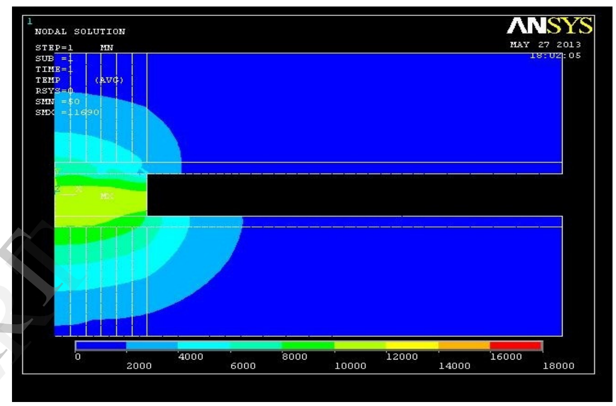

Figure 10: Temperature distribution obtained for a current intensity value of 44 amps

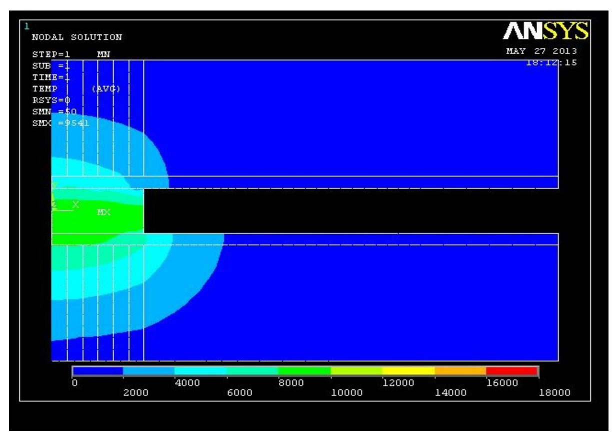

Figure 11 Temperature distribution obtained for a Current intensity value of 36 amps

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TABLE 2 Table for FEA results

Sr No.	Radii of the ellipsoid representing crater formed			Current Intensity (I) (amps)	Volume of material removed (µm3) x 109	Rmax (mm)
	r_1 (mm)	r_2 (mm)	r_3 (mm)			
1	1.2	1.2	0.615	68	1.853856	0.615
2	1.08	1.08	0.45	58	1.098748	0.45
3	0.76	0.76	0.15	44	0.181366	0.15
4	0.6	0.6	0.12	36	0.090432	0.12

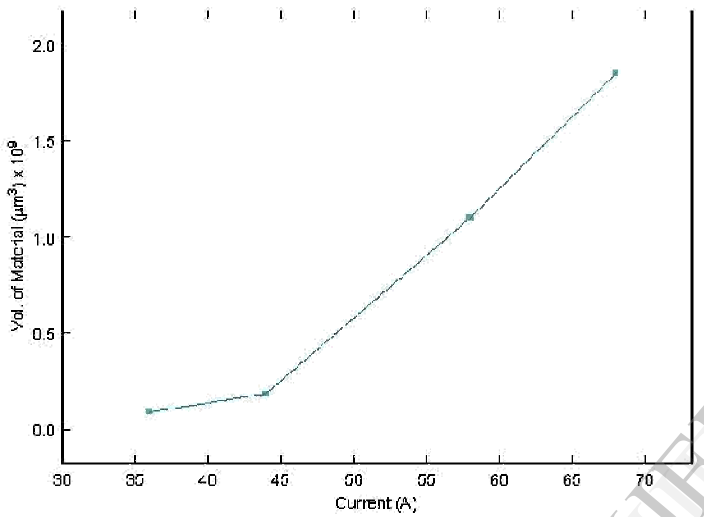

Figure 12: Volume of material removed with different current intensities for FEA

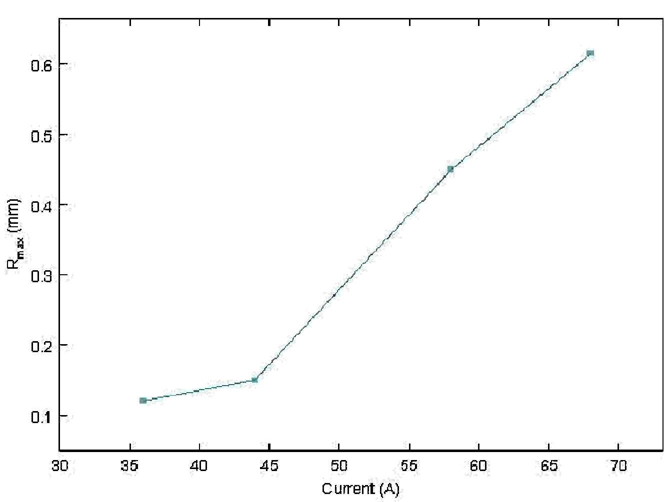

Figure 13: Rmax values with various current intensities for FEA

ii. Maximum surface Roughness: A graph showing the respective Rmax values with the corresponding current intensities is presented in Figure 13.

iii. Experiment Result: The material removal rate found in the experiment conducted with varying Ton and current values are shown in Table 3.

Table 3: Material removal rate found in the experiment conducted with varying Ton and current value

Expt. No.	**I_p (Amps)**	**Ton**	**Machining Time(min)**	**Initial Weight (grams)**	**Final Weight (grams)**	**Difference in Weight (grams)**	**Volume of material removed (mm3)**	**MRR (mm3/min)**
1	**5**	**100**	**5**	**178.43**	**178.27**	**0.16**	**20.78**	**4.16**
2	**45**	**100**	**5**	**178.27**	**174.62**	**3.65**	**474.03**	**94.81**
3	**35**	**100**	**5**	**174.62**	**171.42**	**3.2**	**415.58**	**83.12**
4	**15**	**100**	**5**	**171.42**	**169.97**	**1.45**	**188.31**	**37.66**
5	**5**	**150**	**5**	**170.01**	**169.81**	**0.2**	**25.97**	**5.19**
6	**15**	**150**	**5**	**169.81**	**168.01**	**1.8**	**233.77**	**46.75**
7	**35**	**150**	**5**	**168.01**	**164.18**	**3.83**	**497.4**	**99.48**
8	**45**	**150**	**5**	**164.18**	**159.56**	**4.62**	**600**	**120**
9	**5**	**200**	**5**	**159.56**	**159.34**	**0.22**	**28.57**	**5.71**
10	**15**	**200**	**5**	**159.34**	**157.18**	**2.2**	**285.71**	**57.14**
11	**35**	**200**	**5**	**157.18**	**153.1**	**4.63**	**601.3**	**120.26**
12	**45**	**200**	**5**	**153.1**	**148.61**	**5.62**	**729.87**	**145.97**

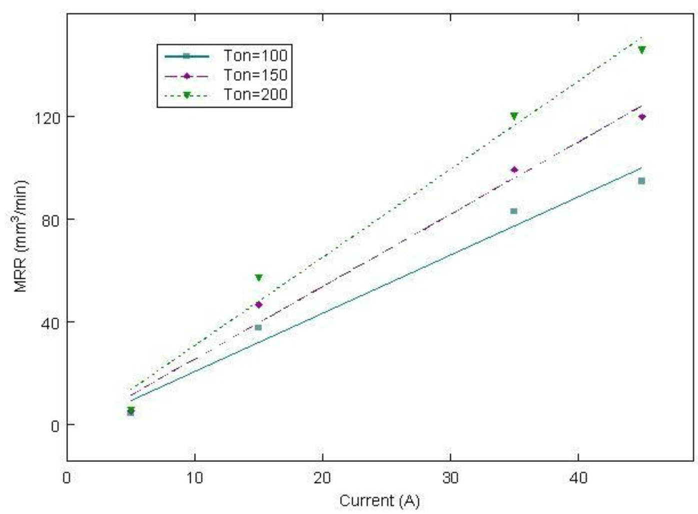

Figure 14: Material Removal rates with varying current conditions for Experiment.

The difference in weights, volume of material removed and material removal rates are also presented in the table.

A graph showing the material removal rates with varying current conditions and different Ton values is presented in Figure 14. It indicates that for Ton =100, with increase in current the material removal rate increases.

The volume of material removed is increasing as the current is increasing and hence the Material Removal Rate is also increasing for Ton = 150 and 200.

VII. CONCLUSION

In the present work, the Joule heating factor was used to model the EDM process and predict the maximum temperature reached in the discharge channel. From the temperature distribution the volume of material removed from the work piece and Rmax was estimated. Experiments were conducted with different pulse on-time (Ton) and current values and the material removal rate was calculated. The Most important conclusions of the work are:

1. With the new FEA model for the EDM process, it is possible to estimate the material removed from the work piece, the surface roughness and the maximum temperature reached in the discharge channel. The maximum temperature in the discharge channel is an indicator of the model's thermal behavior.
2. Material removal rate increases with the increase in current.
3. Maximum surface roughness (Rmax) increases with the increase in current.
4. The volume of material removed and material removal rate is calculated and its trend in variation with current is in agreement with FEA results.

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