Simulation & Thermal FEA of Micro EDM

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Abstract
The Micro-structures are very difficult to produce by conventional machining methods and hence non-conventional machining methods are required for this purpose Present thesis work involves the use of Micro-machine tool to produce Micro-aperture on molybdenum work piece by using Micro-electric discharge machining. Molybdenum is one of the most attractive high energy and power aperture materials due to its mechanical and physical properties, mainly its high melting temperature and relatively high thermal conductivity. A finite element-based thermo-numerical model is developed for the Micro-EDM for the determination of temperature distribution in the zone of influence of single spark. The model is able to predict the shape and size of the crater that is formed by single spark as a result of the material removal.

Keyword — *ANSYS, Thermal Conductivity, Temperature, Distribution*

Nomenclature

Cv	Crater volume (µm3)
I	Current (A)
r, z	Cylindrical coordinate of work piece
FES	Finite element simulation
P	Fraction of heat input to the work piece
Q(r)	Heat flux (W/m2)
T_0	Initial temperature (K)
MRR	Material removal rate (mm3/min)
Micro-EDM	Micro Electrical discharge machining
µs	Micro second
µm	Micro meter
r	Radial coordinate
Cp	Specific heat (J/kgK)
Ton	Spark-on time (µs)
Toff	Spark-off time (µs)
R	Spark radius (µm)
K	Thermal conductivity (W/mK)
T	Temperature variable (K)
U	Voltage (V)

I. INTRODUCTION

Electro discharge machining (EDM) has grown over the last few decades from novelty to a main stream manufacturing process. It is successfully and widely applied for the machining of various electrically conducting materials [1]. Micro-electric discharge machining the modification of EDM process has the capacity to produce complex three-dimensional shapes on any electrically conductive material regardless of its hardness, strength, and toughness. It is an ideal process for obtaining burr-free micron-size apertures with high aspect ratios in most metals. Similar to conventional EDM, material is removed in micro-EDM by a series of rapidly recurring electric spark discharges between the cutting tool (the tool electrode) and the work piece. A typical micro-EDM tool electrode ranges in size between 5 and 300 micrometre diameter [4]. During the process, the work piece is immersed in a dielectric fluid and a voltage is applied between a tool electrode and work piece. When the tool electrode is brought close to the work piece, sparks will arc across the inter electrode gap (~µm), melting and vaporizing microscopic bits of the work piece. The molten work piece particles harden and are washed away by the continuously flushing dielectric fluid. The area and the movement of the tool determine the shape of the cavity created in the work piece.

Current micro-EDM technology used for manufacturing micro-features can be categorized into four different types:

• Micro-wire EDM, where a wire of diameter down to 0.02mm is used to cut through a conductive work piece.
• Die-sinking micro-EDM, where an electrode with micro features is employed to produce its mirror image in the work piece
•Micro-EDM drilling, where micro-electrodes (of diameters down to 5–10 µm) are used to 'drill' micro-holes in the work piece.
•Micro-EDM milling, where micro-electrodes (of diameters down to 5–10 µm) are employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling [2].

In this paper a two dimensional axe-symmetric Finite Element Simulation of single spark Micro-EDM process has been done based on more realistic assumptions such as Gaussian distribution of heat flux for the calculation of MRR [4].

II. MODELING OF MICRO-EDM PROCESS USING ANSYS

Micro-EDM is a complicated process that requires a powerful tool to simulate the process. In present analysis the simulation has been done on ANSYS 13.0 multi-physics. Analysis of any complex geometry can be easily done using ANSYS. It has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis in the field such as structural mechanics, thermal systems, fluid mechanics, and electromagnetic.

A. Thermal Models of Micro-EDM

The principle of working for EDM and Micro-EDM are same, the material is removed due to melting and vaporization caused by repetitive sparks between tool and work piece. A two-dimensional thermo-numerical model developed to simulate a single spark discharge process of the Micro-EDM machining on molybdenum.

The following assumptions are made to simplify the simulation:

- Constant heat flux over a radius *R*.
- Work piece material is isotropic.
- Heat source radius remains constant
- Thermal material properties are independent of temperature.

All of the energy discharged from the tool is transferred to the work piece.

B. Governing Equation

The governing equation of the heat conduction in axisymmetric model is given by

$$\frac{\partial}{\partial r}\left(k\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)=\rho Cp\frac{\partial T}{\partial t}$$

Where ρ is density, C_p is specific heat, K thermal conductivity of the work piece, T is the temperature, t is the time and r & z are coordinates of the work piece.

C. Heat distribution

Many authors have assumed a uniform disc source. However, Allen et al [4], Rajeev Kumar et al. [5] and S.N. Joshi et al [6] have shown Gaussian heat distribution is more realistic and accurate than disc heat source for Finite Element Simulation. So In present study Gaussian heat distribution is considered.

D. Boundary Conditions

A small cylindrical portion of the work piece around the spark is used as a domain. The heat energy transferred to the work piece as heat input serves as the thermal boundary condition on the top surface is shown in the figure 1 that shows a schematic diagram of thermal model with the applied boundary conditions.

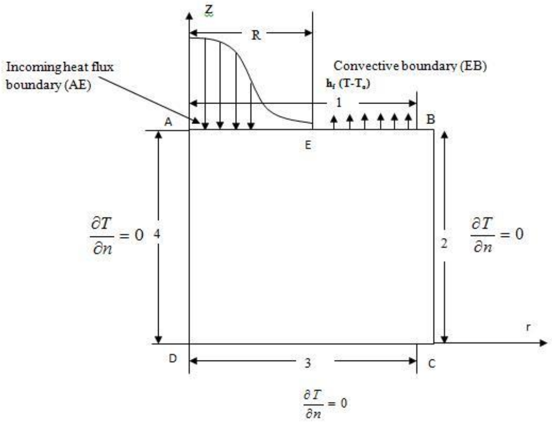

Figure1. Axisymmetric Model for the Micro-EDM Process Simulation

On the top surface the heat transferred to the work piece is represented by a Gaussian heat flux distribution during the spark on-time. Heat loss to the coolant and ambient air is modeled using convective boundary conditions on surfaces 1 and 3. No heat transfer occurs across surfaces 2 or 4 as they are either symmetry line or boundary in the far distance.

In mathematical terms, the applied boundary conditions are given as follows:

1. $Q(r)$ if $r \leq R$ on boundary 1
2. $h_f\,(T-T0)$ if $r > R$ on boundary 1
3. ∂T/∂n = 0 on boundaries, 2, 3 and 4

Where $Q(r)$ is the heat flux entering the work piece during the on-time and it has a zero magnitude during the off-time, *R* the spark radius, h_f the heat transfer coefficient for the dielectric fluid, and T_o is the room temperature.

E. Heat Flux

A Gaussian heat flux distribution is assumed as follows in this study Where *P* is the percentage of heat input distributed to the work piece, *U* the discharge voltage (different from the applied voltage), and *I* is the current.

$$Q(r)=\frac{4.45PUI}{\pi R^{2}}\exp\left\{-4.50\left(\frac{r}{R}\right)^{2}\right\}$$

The *P* value has been previously determined by Yadav et al. [7] to be 0.08 for their theoretical work of EDM and the same value was used in this study. According to the above equation, the heat flux is at its maximum Q_o at the axis of spark and becomes $Q(r)$ as the radius increases to *R*.

III. THERMAL FINITE ELEMENT MODELING OF MICRO-EDM

In order to assess the accuracy and efficiency of the present finite element formulation, the numerical procedure and developed FEM based model using, a heat transfer problem with various boundary conditions (specified boundary, insulated boundary, convective boundary and incoming heat flux boundary) is simulated. The temperature distribution using present FEM based model is compared with analytical solution in the literature Allen et al. [4]. The results using present FEM based model are matching well with the values given in the literature. The molybdenum work piece domain of size 60 µm x 10 µm is discretized into two-dimensional, 4 nodes quadrilateral element (thermal solid plane 55). The mesh size is in excess of elements. We employed a non-uniformly distributed finite element mesh with more elements mapped towards the heat-affected regions as shown in figure 2.

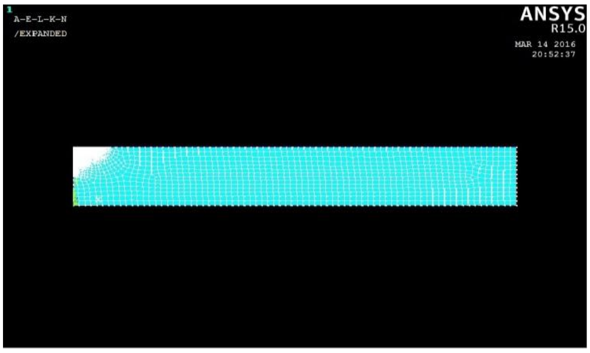

Figure 2. Non-Uniformly Distributed Finite Element Mesh of Molybdenum Work Piece

The following procedures have been followed to develop FE
Simulation model-
Step 1: Start ANSYS 13.0.
Step 2: Units: S.I.
Step 3: Analysis method: Thermal, h method
Step 4: Problem domain: In this step, the geometry of the problem is created using ANSYS.
Step 5: Type of element: Two-dimensional, 4 Node Quadrilateral Element (thermal solid plane 55).
Step 6: Define material properties.
Step 7: Apply loads as per the given boundary conditions.
Step 8: Solve the current load step to get the results.
Step 9: Plot the required results from the obtained results.
Step 10: Finish

IV. RESULTS AND DISCUSSION

A. Determination of Temperature

The temperature distribution of the tool and work piece is to be determined with the help of ANSYS Software. The material properties of Molybdenum work piece (Table 1) Tungsten tool electrode (Table 3) and the process parameters (Table 2) are to be used in this software.

With the initial temperature set as the room (298 K) temperature, a transient analysis was conducted dividing the heating period (spark on-time 2µs) into 10 sub steps and the cooling period (spark off-time 200µs) into 20 sub steps. Temperature distribution during single spark has been obtained using ANSYS 13.0 and also obtained the nodal co-ordinates corresponding to the nodal temperature. The nodal co-ordinates along with temperature used in the SURFUR Software. This software plots the isotherm line corresponding to radius and depth of work piece. Then the crater radius and depth of crater is obtained with the help of this software.

So, crater volume is calculated with the crater radius and depth and finally MRR is obtained.

Table1. Material Properties of Molybdenum for the FEM Thermal Simulation

Serial no.	Properties	Symbols	Units	Values
1	Density,	P	Kg/m^3	10220
2	Melting temperature	T_m	K	2896
3	Evaporation temperature	T_e	K	4912
4	Thermal conductivity	K	w/mk	138
5	Specific heat,	C	j/kg K	276
6	Latent heat of fusion	M	j/kg	2.9E5

Table 2. Process Parameters for the FEM Thermal Simulation

Table 3 Relevant Material Properties of Tungsten and Steel

S. No.	Material	Density	Melting Temperature	Evaporation Temperature	Thermal Conductivity	Specific heat	Latent heat of fusion
1	Tungsten	19250	3695	5828	182	130	0.192E6

B. Determination of Temperature Distribution

The temperature distribution of the tool and work piece is to be determined with the help of ANSYS Software. In which the transient thermal analysis is applied on the work piece. The Gaussian heat distribution flux is applied that are varies with the radius. This has maximum value where the radius should be zero. It decreases with increase in radius.

C. Determination of Temperature Distribution in Molybdenum Work Piece

This figure 3. shows temperature distribution over surface applying Gaussian heat flux distribution maximum temperature attains by body is 4492.31 K temperature when body is kept at room temperature (298K). In this the process parameter are discharge voltage, and discharge current and heat input. In this spark radius has the constant value. Pulse on time is selected for this Process is 2μs and pulse off time is 200μs.

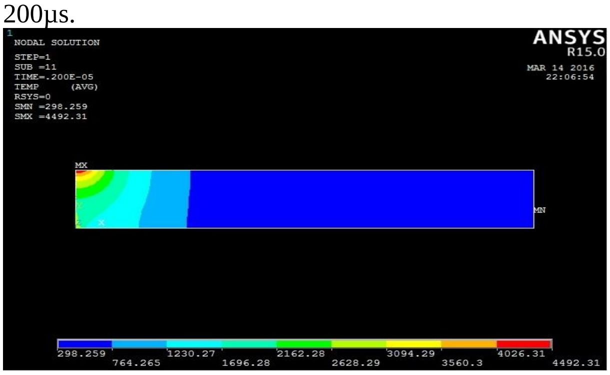

Figure 3. Temperature distribution in molybdenum with in the U=20V, I=1.5A and P=0.08

The figure 4. shows the axisymmetric view of the work piece, through which it is clearly shows that a spheroidal shape is formed. From the figure 5. it is clearly shown that the temperature decreases with increase in radius of crater and in depth also decreases. This figure 5. is generated with the help of SURFUR

Serial no.	Properties	Symbols	Units	Values
1	Voltage	U	V	20
2	Heat input	P		0.08
3	Discharge current	I	A	1.5
4	Spark radius	R	μm	5
5	Convective heat transfer coefficient for dielectric fluid,	hf	w/m^2K	680
6	Convective heat transfer coefficient for ambient air	h_a	w/m^2K	0.5
7	Pulse on time	ton	μs	2

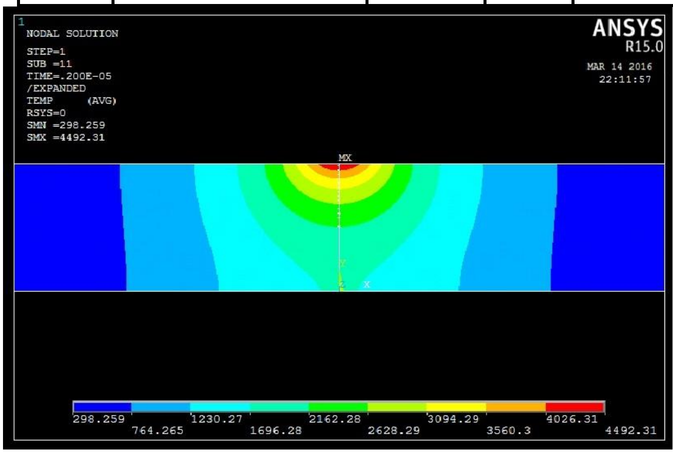

Figure 4 Axisymmetric View of Temperature Distribution in Domain of Molybdenum Work Piece

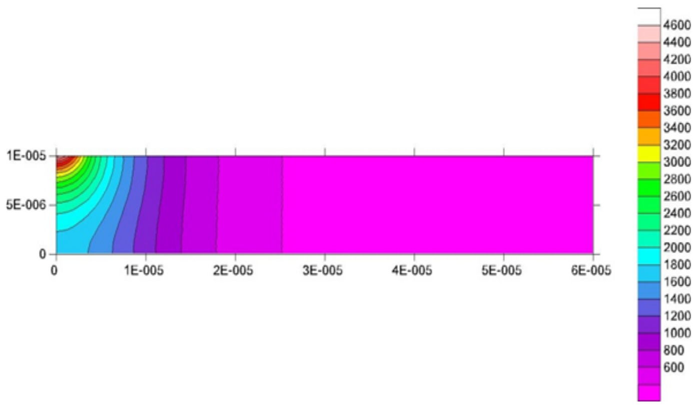

Figure 5. Distribution of Temperature with Respect to Depth and Radial Distance in Molybdenum Work piece

And the figure 5. also shows the 2-D representation of temperature with respect to crater depth and crater radius. Melting temperature T_m of molybdenum is 2896 K whereas temperature obtain through simulation is approximately 4492 K through which melting crater will form, will eject out from the surface in electrolyte solution.

D. Temperature Distribution on Tungsten (Tool)

The temperature distribution in Tungsten tool electrode has been found apply the same method used in previous. Tungsten is also analyzed with the same process parameter used in above case. So the maximum temperature obtained is 3876.31 K as shown in figure 6. that is lower than the temperature obtained in Molybdenum and Steel because of it has high thermal conductivity and low specific heat. High thermal conductivity means higher the heat transfer rate within the work piece, so the temperature decreases. Due to this reason Tungsten material is used as tool electrode.

The figure 7 is also obtained same as with the help of SURFUR Software that developed a plot for temperature verses crater radius and crater depth. In which single spark heat flux is applied on the tool then within the domain temperature generated is higher than melting temperature of tool Through this software depth and radius of crater is also obtained. Melting temperature T_m of Tungsten is 3695 K whereas temperature obtain through simulation is approximately 3876.31 K through which melting crater will form, will eject out from the surface in electrolyte solution.

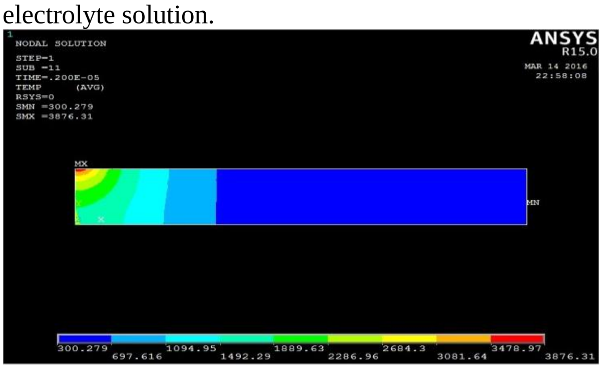

Figure 6 Temperature Distribution in Tungsten with In theWork U=20V, I=1.5A And P=0.08

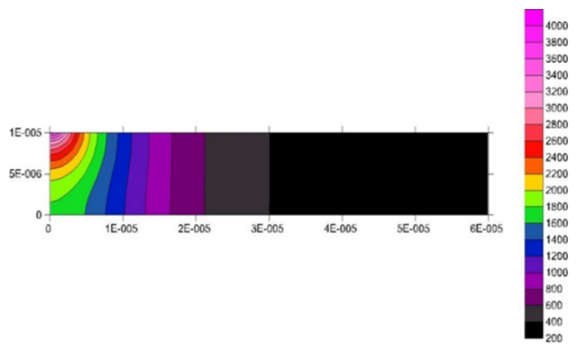

Figure 7 Distribution of Temperature with Respect to Depth and Radial Distance in Tungsten Tool Electrode

E .Validation of Temperature in Work Piece

From figure 9 it can be seen that the temperature distribution of present work for molybdenum work piece is well in agreement with the Allen et al [4] from where the problem has been taken. The maximum crater temperature in the paper was reported to be 4550 K (in figure 24) where as in the present work it is found as 4492K in Molybdenum work piece. This is approximately closer to the result of literature that we have selected.

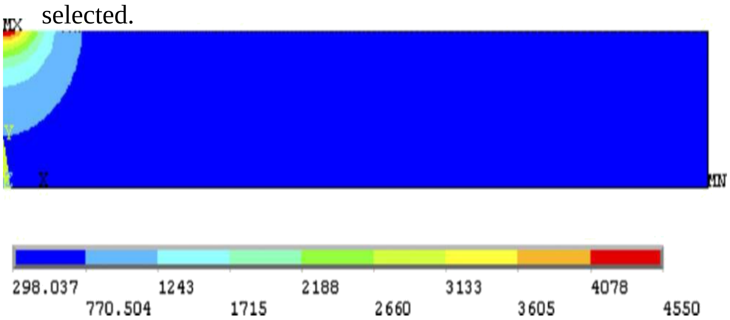

Figure 8 Temperature (K) Distributions after A Heat Flux (Power = 30W, Pulse Duration = 2μs)

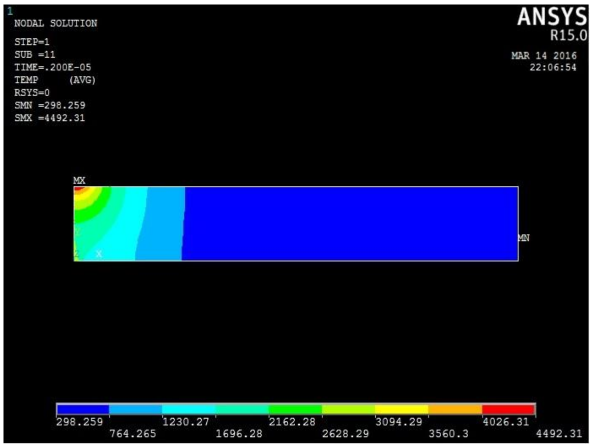

Figure 9 Temperature (K) Distribution after A Heat Flux (Power = 30W, Pulse Duration = 2μs)

V. CONCLUSIONS

It can be seen from this paper that the temperature distribution for molybdenum work piece is well in agreement with the Allen et al [4] from where the problem has been taken. The maximum crater temperature in the paper was reported to be 4550 K (in figure 24) where as in the present work it is found as 4492K in Molybdenum work piece. This is approximately closer to the result of literature that we have selected.

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