International Engineering Research Journal Page No 906-911

Modeling, Simulation and Experimental validation of electrical discharge machining of EN24 Alloy Steel

Rohit Inamdar, S. Sudheendra

***Abstract*— Non-traditional machining has grown out of the need to machine exotic engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity. Electric Discharge machinery has been accepted worldwide as a standard process in manufacturing and is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys.**

The present work has been undertaken to generate a thermo electrical model for sparks generated by electrical discharge in a liquid media and to determine the Material Removal Rate, Surface Roughness and the maximum temperature reached in the discharge channel. For a single discharge test, copper and En-24 was used as specimens. The amount of heat dissipated varies with the thermo-physical properties of the conductor. The model is developed by using ANSYS software. Material removal rate increases with increase in current but at the same time surface finish decreases.

***Index Terms*—** material removal rate, surface roughness, super alloys, electric discharge machine

I. Introduction

EDM is a non-traditional manufacturing and a stand-out amongst the most prominent material removal methods on the basis of material evacuation from a metallic (generally solidified and hardened surfaces) part by electric discharges between the tool and the work piece in the vicinity of a dielectric liquid. The dielectric liquid makes it conceivable to flush the dissolved particles (for the most part as emptied surfaces) from the crevices and it is extremely vital to keep up this flushing efficiently for the procedure to be done proficiently.

EDM machining is done by the help of electric sparks which are created between tool and workpiece, when immersed in a dielectric liquid and subjected to a voltage. Subsequently, the voltage applied must be sufficient to make an electric field to overwhelm the dielectric rigidity of the liquid utilized within the procedure. As an outcome of this electric field, electrons and positive ions accelerate, transforming a discharge channel that is conductive. When the spark jumps, collision caused between both the particles and creates a channel of plasma. The sudden drop of electric resistance of the past channel permits the current density to reach a very high value producing increment in ionization and also the creation of a powerful magnetic field which melts or vaporizes some of the metal.

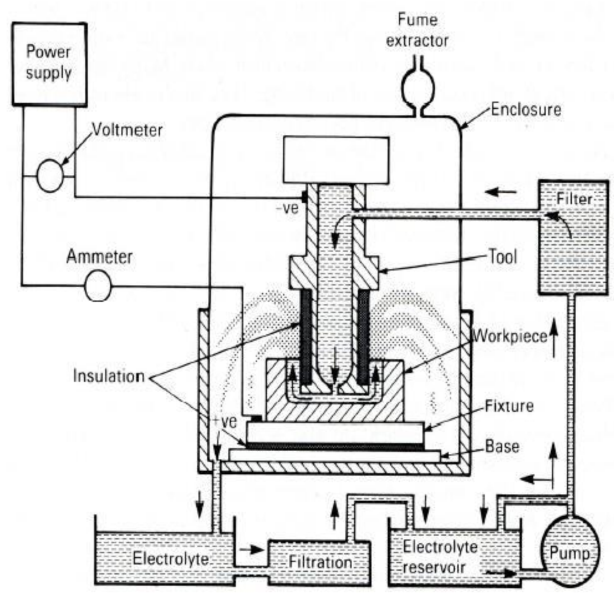

Fig 1: Basic elements of an EDM

II. LITERATURE REVIEW

Bitonto et al. (1989) [3] presented a simple cathode erosion model for EDM process. This point heat-source model accepts power rather than temperature as the boundary condition at the plasma/cathode interface. A constant fraction of the total power supplied to the gap is transferred to the cathode over a wide range of currents.

Madhu et al. (1991) [4] proposed a model for predicting the material removal rate and depth of damaged layer during

Rohit Inamdar, PG Student, Mechanical Design Department, FIT, Savitribai Phule Pune University, Pune, India, inmrohi@gmail.com
S. Sudheendra, HOD, Mechanical Department, FIT, Savitribai Phule Pune University, Pune, India, sudhimys@gmail.com

EDM. The transient heat conduction equation for the work piece which accounts for the heat absorption due to melting has been solved by Finite Element Method. Simulations have been performed for a single spark in the form of pulses. The width of crater and the depth of penetration depend on spark-radius and the power intensity. It was found that MRR increases with power per spark and decreases with an increase in computational machining cycle time.

Rebelo et al. (1999) [5] presented an experimental study on the effect of EDM parameters on material removal rate (MRR) and surface quality, when machining high strength copper-beryllium alloys. Processing parameters for rough, finishing and micro-finishing or polishing regimes were analysed. The surface integrity of electro discharge machined is quantified by measuring the roughness values, crater diameter and white layer thickness. ``Thermal erosion models", as justification for the optimal setting of different EDM parameters and achievement of distinct surface integrity using materials with different thermal properties.

Haron et al. (2001) [6] determined the possible correlation between the EDM parameter (current) and the machinability factors (material removal rate and electrode wear rate). The material removal rate of the work piece material and the wear rate of electrode material were obtained based on the calculation of the percentage of mass loss per machining time. It was found that the material removal rate and electrode wear rate were dependent on the diameter of the electrode and had a close relation with the supply of current. Low current was found suitable for small diameter electrode while high current for large diameter of electrode.

Valentincic et al. (2004) [7] proposed that rough machining parameters have to be selected according to the size of the eroding surface to achieve a high removal rate and low electrode wear. The size of the eroding surface varies according to the depth of machining and it has to be determined online. The work presented shows that the electric current signal depends on the size of the eroding surface. To detect the size of the eroding surface based on the electric current signal in the gap, it is necessary to build a different model for each machining regime.

Salah et al. (2006) [8] presented numerical results concerning the temperature distribution due to electric discharge machining process. From these thermal results, the material removal rate and the total roughness were deduced and compared with experimental observations. The temperature variation of conductivity was taken into account and shown that it is of crucial importance and gives the better correlations with experimental data.

Marafona et al. (2006) [9] 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. The thermal–physical values used in the model are the average of both the ambient and melting value. Copper and iron are the materials used for anode and cathode, respectively. The Finite Element Analysis (FEA) results were compared with the experimental values of the table of AGIE SIT used by other researchers. The Joule heating effect is considered not only in the EDM electrodes but also in the discharge channel, which is considered by the authors as the driving phenomenon of the EDM process.

Four successive steps by which an electrical discharge between the tool electrode and the work piece proceeds [2]:

1. The ignition phase
2. Formation of the plasma channel
3. Melting and evaporation of a small amount of work piece material
4. Ejection of the liquid molten material

Abbreviations

Symbol	***Description***
ρ	Density
Cp	Specific heat
Kr	Thermal conductivity of the work piece
T	Time
r and *z*	Coordinates of the work piece
Rc	Spark radius
I	Gap current
Ton	Pulse on time
T off	Pulse off time
P	Percentage heat input to the work-piece
V	Gap voltage

III. MATERIAL USED FOR EXPERIMENT

A. Workpiece Material - EN24

It is a high quality, high tensile strength, alloy steel. Usually supplied readily machinable in ‘T’ condition, it combines high tensile strength, shock resistance, good ductility and resistance to wear. EN24 is available from stock in round bar, flat bar and plate.

Table 1: Chemical Properties of EN24

C	Si	Mn	Ni	Cr	Mo
0.40%	0.30%	0.60%	1.50%	1.20%	0.25%

B. Electrode Material - Copper (Cu)

Copper is second only to silver in terms of bulk electrical conductivity. Copper has better strength than silver, but offers inferior oxidation resistance. Often, copper is used as a base metal in electrical contact and electrode applications. Copper is also used to manufacture EDM electrodes. Copper has better EDM wear resistance than brass, but is more difficult to machine than either brass or graphite. Copper is also more expensive than graphite. Copper is useful in the EDM machining of tungsten carbide, or in applications requiring a fine roughness.

Table 2: Material Properties for FEA

Material Property	Copper (cathode)	En-24 (anode)
Density (g/mm^3)	8920 x 10^{-6}	7700 x 10^{-6}
Conductivity (W/mmK)	400 x 10^{-3}	25 x 10^{-3}
Resistivity (Ω-mm)	1.7 x 10^{-11}	55 x 10^{-11}
Specific Heat (J/gK)	385 x 10^{-3}	460 x10^{-3}

IV. DESIGN OF STUDY

The thermal model which will be considered for the analysis is Gaussian distribution model because it is the only heat distribution where in maximum amount of heat transfer is going take place from cathode to anode. According to this equation heating of work piece due to a single spark is assumed to be axis symmetric. The differential governing equation of thermal diffusion differential equation in an axis symmetric model is governed by the following [11]

$$\rho C_p \left[\frac{\partial T}{\partial t}\right] = \left[\frac{1}{r}\frac{\partial}{\partial r}\left(K_r\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(K_r\frac{\partial T}{\partial z}\right)\right]$$

Where, ρ – Density (kg/mm^3)
Cp -Specific heat (J/kg K).
K_r - Thermal conductivity work piece (W/mK).
T – Temperature (K)
t – Time (min)
r and z - Coordinates of the work piece.

A. Spark radius

Spark radius is a most vital parameter in the thermal modeling of EDM process. Since the spark occurs for a very short time it is very difficult to measure its radius. Many researcher were proposed their theories to calculate the spark radius but the most significant and relative theory is as below [11]

$$R_c = 2.04 \times I^{0.43} \times T_{on}^{0.44}$$

Where, R_c - Spark radius (µm)
I - Gap current (A)
T_{on} - Pulse on time (µs).

B. Heat flux in single spark

According to Gaussian distribution model the heat flux generated during the single spark is given as [11]

$$Q_{(r)} = \frac{(4.45 \times P \times V \times I \times K)}{(\pi \times R_C^2)} \times e\left\{-4.45 \times \frac{r^2}{R_c^2}\right\}$$

Where, $Q_{(r)}$ = Input heat flux (W/mm^2).
V = Gap voltage (V).
I = Gap Current (A).
P = Percentage heat input to the work-piece. (Based on Gaussian theory it is taken as 45%).
R_c = Spark radius (mm).
r = Point of application of heat input (Since we always apply at the centre, r is taken to be as zero).
K = Powder concentration (%).

C. Material Removal Rate

Using the heat flux, and process parameters, the temperature distribution profiles can be obtained. Simulated temperature profiles on giving the flux as input, the region above the melting temperature of the work piece material was identified assuming100% flushing efficiency. This region was isolated from the model to define the crater volume. To calculate MRR first we need to calculate volume of material removed. Formula for calculating the volume is as shown below.

MRR = Volume of material removed from the work piece / Machining time (i)

V. SIMULATION CONDITION AND PROCEDURE

In EDM, a series of discrete electric sparks occur in the gap between tool and work electrodes for a cycle of few microseconds. This process can be modeled as a thermal transient model with some assumptions required for the simulation, governing equation, and boundary conditions as explained below.

A. Assumptions made for the simulation

1. The modeling and its analysis represent results for a single spark.
2. Thermal properties of the work-piece material are temperature dependent.
3. The expansion of the body due to the thermal heating is negligible, thus the element shape in the mesh remains unaffected.
4. The effect of latent heat of fusion and vaporization on simulation study has been neglected.
5. Density and specific heat of the work-piece material are independent of temperature.
6. Thermal analysis is transient and heat source has Gaussian distribution of heat flux incident on the work-piece surface.
7. Fraction of heat that goes into the work-piece remains constant during the pulse.
8. Flushing efficiency is almost 100% with continuous stirring.
9. Transfer of heat to the electrode is by conduction. Convection is applied on the top surface of the work-piece which is in contact with powder mixed dielectric.
10. Work-piece material composition is homogeneous and isotropic and is free from any internal residual stresses before machining.
11. The effect of impulse force is not considered during modeling.

B. Experimental details

MRR is also obtained by finding the difference in mass of work piece before and after machining. To simplify calculation, 0.2 mm depth of cut is used for alters and MRR can be found by

MRR = Volume of material removed from workpiece / Machining time.
= (eroded diameter x depth) / Machining time.

VI. EXPERIMENTAL WORK

A. EDM machine Specifications.

Technical specification of machine:-
Manufacturer - Electronica sales & services, Pune
Model - Electra 6040 H
Sr.no. - 6040 H-09-85

1. Work tank dimension - 820 mm x 480 mm x 300 mm
2. Table size - 600 mm x 400 mm.
3. X-axis travel (mm) = 300
4. Y-axis travel (mm) = 250
5. Z-axis travel (mm) = 150
6. Maximum job height (mm) = 300
7. Maximum current (Amp) = 35
8. Gross weight = 1200 kg
9. Dielectric fluid:- DEF 92 EDM fluid
10. Inbuilt micrometer least count (mm) = 0.005

Fig 2: Electronica made EDM machine.

Workpiece dimensions-
Diameter = 100 mm
Thickness = 16 mm

Electrode dimensions-
Diameter = 20 mm
Length = 25 mm

B. Machining

- Hold the work piece in worktable.
- Adjust the current value to 5 Amp and set first duty cycle (T_{on} =12 sec and T_{off} =9 sec). Then actual machining process started measure time required for getting 0.2 mm depth.
- Repeat same procedure for next duty cycles.
- Repeat above procedure for 7 Amp current.

C. *Observation Table*

1. For 5 Amp

Table 3: Observation Table for 5 Amp current

Sr.No.	T_{on} in Sec.	T_{off} in Sec.	Time require for machining 0.2 mm depth in min
1	12	9	17.86
2	23	9	9.28
3	33	9	8.6
4	43	9	10.8

Fig 3: Work piece machined with 5 Amp current.

2. For 7 Amp

Table 4: Observation Table for 7 Amp current

Sr.No.	T_{on} in Sec.	T_{off} in Sec.	Time require for machining 0.2 mm depth in min
1	12	9	12.83
2	23	9	4.26
3	33	9	3.78
4	43	9	4.23

Fig 4: Work piece machined with 7 Amp current.

D. Sample Calculations

For 5 Amp

T_{on} =12,T_{off} =9, Time = 17.86 min.

MRR = (Eroded area ×depth)/machining time (mm^3/min)
= (π/4×20^2×0.2)/17.86
= 62.3818/17.86
= 3.5180 mm^3/min

Duty cycle = (T_{on}/ (T_{on} + T_{off}))×100.
= (12/ (12+9)) ×100.
= 57.14 %

Table 5: Material Removal Rate for 5 Amp current

Sr. no.	Time required for 0.2 mm depth in min	MRR mm^3/min	Duty cycle
1.	17.86	3.5180	57.14
2.	9.28	6.7706	71.87
3.	8.6	7.3060	78.57
4.	10.8	5.8177	82.69

For 7 Amp

T_{on} =12,T_{off} =9, Time = 12.83 min

MRR = (Eroded area ×depth)/machining time (mm^3/min)
= (π/4×20^2×0.2)/12.83
= 62.3818/12.83
= 4.8972 mm^3/min

Duty cycle = (T_{on}/ (T_{on} + T_{off}))×100
= (12/(12+9))×100
= 57.14 %

Table 6: Material Removal Rate for 7 Amp current

Sr. no.	Time required for 0.2 mm depth in min	MRR mm^3/min	Duty cycle
1.	12.83	4.8972	57.14
2.	4.26	14.7492	71.87
3.	3.78	16.6221	78.57
4.	4.23	14.8421	82.69

E. Surface roughness measurement

Instrument used for measurement of surface roughness is Surface Roughness Tester Manufactured by Mitutoyo, model number SJ 201.

Fig 6: Surface Roughness tester

. Table 7: Surface Roughness values in Microns for 5 Amp & 7 Amp.

Sr.no.	5 Amp	7 Amp
1.	4.16	4.645
2.	6.055	8.07
3.	6.97	9.6
4.	5.8233	8.725

VII. Conclusion

On the basis of experimental results, the following conclusions are drawn.

1) The metal removal rate can be increased by increasing the current in the circuit for same machining area.
2) But there is some optimum value of the mean current at which the metal removal rate will be maximum this depends on machining area duty cycle and current. For example: 7 Amp current and 78.57 duty cycle the metal removal rate is maximum that is 16.6221mm^3/min.
3) It has been observed that the quality of surface roughness becomes poorer as the value of current increases that is for higher value of current surface obtained will be rough
4) In the case of the Ra parameter, the most influential factors were current, pulse ON time, while the voltage and pulse OFF time was not significant at the considered confidence level.
5) In order to obtain a good surface finish in the case of EN24, low value of peak current should be used. The material removal rate depends mostly on current followed by pulse ON time.
6) In order to obtain a high MRR in the case of EN24, high peak current should be used.

Note: The simulation of the effect of current and voltage on Material removal rate and surface finish is in progress.

REFERENCES

[1] Abbas Mohd Norliana, Solomon.G.Darius and Bahari Fuad Md., “A review on current research trends in electrical discharge machining (EDM), International Journal of Machine Tools & Manufacture, Volume 47, (2007):p.1214-1228.

[2] Benedict.F.Gray, “Nontraditional Manufacturing Processes” Marcel Dekker,(1987):p.209

[3] DiBitonto.D.D., Eubank P.T., Patel M.R. and Barrufet.M.A, “Theoretical models of the electrical discharge machining process-I: a simple cathode erosion model” Journal of Applied Physics, Volume 66, (1989):p.4095–4103.

[4] Madhu.P, Jain.V.K.and Sundararajan.T, “Analysis of EDM process: A Finite Element Approach”, Computers in Engineering ASME, (1991), Volume 2:p.121-127.

[5] Rebelo J.C., Dias A. Morao, Mesquita Ruy, Paulo Vassalo and Mario Santos, “An experimental study on electro-discharge machining and polishing of high strength copper-beryllium alloys” Journal of Materials Processing Technology, Volume 108, (2000):p.389-397.

[6] Che Haron .C.H, Md. Deros .B, Ginting.A. and Fauziah.M, “Investigation on the influence of machining parameters when machining tool steel using EDM” Journal of Materials Processing Technology, Volume 116, (2001):p.84-87.

[7] Valentincic Josko and Junkar Mihael, “On-line selection of rough machining parameters” Journal of Materials Processing Technology, Volume 149, (2004):p.256-262.

[8] Salah Nizar Ben, Ghanem Farhat and Atig Kaıs Ben, “Numerical study of thermal aspects of electric discharge machining process” International Journal

[9] Marafona J. and Chousal J.A.G., “A finite element model of EDM based on the Joule effect” International Journal of Machine Tools & Manufacture, Volume 46, (2006):p.595-602.

[10] Allen Philip, Chen Xiaolin, “Process simulation of micro electro-discharge machining on molybdenum” Journal of Materials Processing Technology, Volume 186, (2007):p.346-355.

[11] Sasmeeta Tripathy, “Thermal electrical modeling of electrical discharge machining process” thesis of master project.

[12] ASM metals Handbook, Volume-1, (1978):p.124

[13] Manual of Electronica for EDM.