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# Predicting Optimized EDM Machining Parameter through Thermo Mechanical Analysis

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**Abstract:** *Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes. EDM process is based on thermo electric energy between an electrode and the workpiece. The important process parameters in this technique are current, discharge pulse on time, discharge pulse off and gap voltage. The values of these parameters significantly affect the machining outputs material removal rate. Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which is an essential need for industries towards manufacturing of quality products at lower cost also due to difficulty of EDM, for improving cutting performance.it is very complicated to determine optimal cutting parameters, which is an important action in machining and modelling is necessary to make a precise relation between input and output parameters. In the present research, an axisymmetric thermo-physical finite element model for the simulation of single sparks machining is presented to analyse the process parameters and their effect on important responses such as material removal rate on work piece material OHNS Die steel (EN31) in electrical discharge machining (EDM) process and the model has been solved by using ANSYS 16.0 software. The model is validated conducting experiments on an EDM machine. To study the performance of machining before actual cutting operation this numerical method provides an inexpensive and time saving alternative solution. A transient thermal analysis assuming a Gaussian distribution heat source with temperature-dependent material properties has been used to investigate the temperature distribution on the surface. Material removal rate (MRR) was calculated for multi-discharge machining by taking into considerations the number of pulses. Comparison of the theoretical result ,experimental result and ANN process model result by considering the same process parameters has been done, and the result is highly agreed between the experimental and theoretical value.*
***Keywords**: Finite element approach, Numerical Analysis; Electrical Discharge Machining; Modeling, Optimization Process*

## I. Introduction

Electrical discharge machining is a thermal process that involves melting and vaporization of the workpiece electrode. It is widely used in the aerospace, mould making and die casting industries for manufacturing plastics moulds, forging dies and die casting dies made from hardened tool steels, together with engine components, such as compressor blades made from titanium alloys and nickel-based super alloys. The EDM process uses electrical discharges to remove material from the workpiece, with each spark producing a temperature of between 10,000-20,000°C. Consequently, the workpiece is subjected to a heat affected zone (HAZ) the top layer of which comprises recast material. The thickness, composition and condition of this layer depend on the discharge energy and the make-up of the workpiece, tool electrode and dielectric fluid, and both hard and soft surface layers can be produced despite perceived wisdom that the recast layer is always hard. Also it can be defined as process of material removal by controlled erosion through a series of electric sparks. Electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive:

The complex nature of the process involving behavior of the EDM spark makes it even tougher to analyze the process experimentally and quantifies the process responses. The frequencies of an original shape and modified shape should be within range. The process has however, some limitations such as high specific energy consumption, longer lead times and lower productivity which limit its applications. Researchers worldwide are thus, focusing on process modeling and optimization of EDM to improve the productivity and finishing capability of the process

Due to the complex and non-linear relationship between the input process parameters and output performance parameters, it is quite difficult to develop an accurate process model and use it to select the optimum process parameters for EDM process. The focus of the present work is thus, on developing an intelligent approach for process modeling and optimization of EDM process and to predict process responses such material removal rate (MRR) from the process parameters. Physics based process modeling using FEM has been used to improve prediction accuracy of the model with less dependency on the experimental data. This approach will help a process engineer to improve the process productivity, finishing capability and economical operation of die-sinking EDM process.

## II. Literature Review

According to Vinothkumar.S, “Electro Thermal Modelling of Micro EDM”, he analyzed in his investigation of Finite element modelling of RC-circuit Micro-EDM process has been carried out to predict the MRR using Finite element analysis software ANSYS (v.12). This model considers Capacitance, Resistance and Voltage to predict temperature distribution on the workpiece. The results have been verified with the experimental investigation performed with the pure copper as the tool electrode and AISI 304 stainless steel as the workpiece. [1]

According to Chinmaya P. Mohantya*, JambeswarSahub, S.S.Mahapatraa “Thermal-structural Analysis of Electrical Discharge Machining Process” In the his present work, a thermal-structural model is presented to analyze the process parameters and their effect on three important responses such as material removal rate, tool wear rate and residual stresses on work piece in electrical discharge machining (EDM) process.A Box-Behnkin design of response surface methodology is adopted to collect data for analysis. Regression analysis is conducted to develop equations relating responses with process parameters. Finally, non-dominated sorting genetic algorithm is used to obtain pareto optimal solution for multi objective optimization. [2]

According to S.N. Joshi, S.S. Pande, “Thermo-physical modeling of die-sinking EDM process” This paper reports the development of a thermo-physical model for die-sinking electric discharge machining (EDM) process using finite element method (FEM). Numerical analysis of the single spark operation of EDM process has been carried out considering the two-dimensional axi-symmetric process continuum.[3]

According to C.K.Biswas, “Thermal-Electrical Modelling of Electrical Discharge Machining Process” 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.[4]

## III. Problem Statement and Objective

In EDM process, the pulse on time, peak current and Voltage are very important machining parameters because it can control material remove rate. However, there are difficulties to determine the optimum machining parameter to increase the material remove rate. The unsuitable pulse duration and peak current will increase the cost of production. Besides that, adding the dielectric fluid flushing process will increase the material remove rate. In this study, we will determine the optimum machining parameters to increase material remove rate.To calculate Material removal Rate (MRR) of OHNS Die steel in order to get accuracy/ surface integrity of machined work piece

## IV. Theoretical Analysis

### A.Numerical modeling of the EDM process

To obtain the relationship between pulse conditions and material removal rate, many attempts have been made to calculate temperature distribution in the electrodes caused by a single pulse discharge by solving time-dependent heat transfer equations assuming various heat source models. Based on the mathematical models, the temperature profile due to the passage of an individual pulse can be created.However the scope of such analysis is limited; a more comprehensive approach is needed.

Joshi and Pande’s Model [3] considers more realistic assumptions for thermal analysis in EDM process. So it can be considered as best available, realistic and reliable thermal model for the further work of development in EDM process. Thus this model is the taken as benchmark for the present work of stress analysis.

### B.EDM spark

In EDM, the tool (anode) and the work piece (cathode) are immersed in a dielectric medium separated from each other by a small gap. A controlled spark is generated between the two electrodes by applying a voltage which breaks down the dielectric medium causing the voltage fall. The on- time of EDM spark (of the order of microseconds), electrons start flowing from cathode to anode which ionizes the dielectric medium and form a plasma channel between the cathode and anode. The intense heat generated in the plasma channel melts and even vaporizes some of the work and tool material causing material removal. The molten metal is held back at its place due to the large plasma pressure and as soon as the spark on-time is over (the spark collapse) the dielectric gushes back to fill the void. This sudden removal of pressure results in a violent ejection of the molten metal from the work surface forming small craters at locations, where material has been removed. [5]

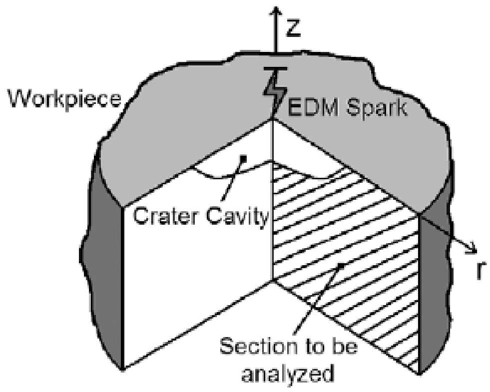



**Fig. 1** Schematic representation of the domain considered for the numerical model

**C. Process and boundary conditions**

The primary mechanism of material removal in EDM process is the thermal heating of work surface due to intense heat generated by the plasma, which raises the temperature of the electrodes (tool, work) beyond their melting point, sometimes even the boiling point. During the process, spark discharges may occur over work surface at locations where the inter electrode gap is minimum. Figs. 1 and 2 show the two-dimensional axi-symmetric process continuum and the associated boundary conditions taken for the analysis. Following assumptions have been made during the thermal Analysis.

Assumptions

1. Work piece and tool materials are homogeneous and isotropic in nature.
2. The material properties of the workpiece and tool are temperature dependent.
3. During the EDM operation, heat is transferred from plasma to electrodes by conduction and radiation, while from plasma to dielectric by convection and radiation. In the present work, the primary mode of heat transfer between plasma and electrodes is considered to be conduction.
4. EDM spark channel is considered as a cylindrical column and the spark radius is assumed to be a function of discharge current and time.
5. Gaussian distribution is taken for heat flux. The influence of the spark zone is taken to be axi-symmetric in nature.
6. Out of total spark some of total spark energy is dissipated as heat into the work piece, the rest is lost into the dielectric convection and radiation.
7. Flushing efficiency is considered as 100%. On the machined surfaces there is no deposition of recast layer.

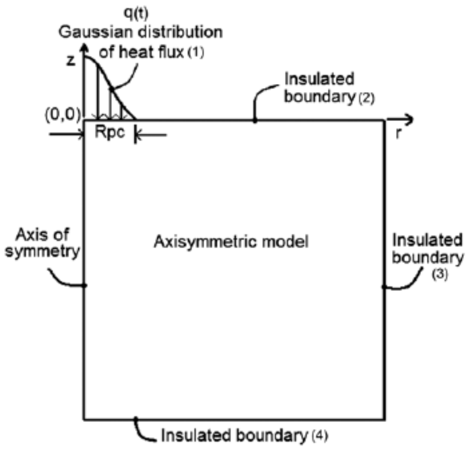



**Fig. 2** Process continuum and boundary conditions

**D. Governing equation**

For the transient, non-linear thermal analysis of EDM process, Fourier heat conduction equation is taken as the governing equation 1

$$\frac{1}{r}\frac{\partial}{\partial r}\left(K_t r\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(K_t\frac{\partial T}{\partial z}\right)=\rho C_P\frac{\partial T}{\partial t} \qquad (1)$$

Where r and z are the coordinates of cylindrical work domain; T is temperature; $K_t$is thermal conductivity; ρis density and $C_p$is specific heat capacity of work piece material. Fig. 2 shows the applied boundary conditions applied. In EDM machining process, the work piece is immersed in dielectric medium; the temperature of the domain is thus assumed to be ambient temperature ($t_a$) to start with. The top surface of the workpiece is in contact with the dielectric medium at (boundary 2).On this surface the Heat flux (q) boundary condition is applied.

**Heat input**

The factors which contribute to the accurate calculation of the MRR in single spark EDM model include the radius of plasma spark, amount of heat input and the thermo-physical properties of material. These models are simplistic in actual practice neither isthere any uniform application of heat on the work piece nor is there a point heat source. At the cathode electrode a spark radius exists. Consideration of average thermo-physical material properties and constant EDM spark radius make the available models simplistic and less accurate in predictions.

The Gaussian distribution of heat flux input has been used to approximate the heat from the plasma. Due to EDM spark is given by the heat q entering the workpiece,

$$q(r) = q_o exp\left\{-4.5\left(\frac{r}{R_{pc}}\right)^2\right\} \quad (2)$$

Using this equation, the maximum heat flux can be calculated as under.

$$q_o = \frac{4.57F_{CVI}}{\pi R_{PC}^2} \quad (3)$$

where$F_c$is fraction of total EDM spark power going to the cathode; V is discharge voltage; I is discharge current and $R_{pc}$ is spark radius at the work surface.

**Spark radius**

Spark radius is an important factor in the thermal modeling of EDM process. In practice, it is extremely difficult to experimentally measure spark radius due to very short pulse duration of the order of few microseconds. The equations proposed by these researchers are not realistic in nature as the EDM spark is controlled both by discharge energy and discharge on-time have derived a semi-empirical equation of spark radius termed as ``equivalent heat input radius" which is a function of discharge current, I (A) and discharge on-time, $t_{on}\,(\mu s)$Eq. (4)). It is more realistic when compared with the other approaches.

$$R_{pc} = (2.04e-3)I^{0.43}t_{on}^{0.44}(\mu m) \quad (4)$$

In the present work, this approach has been used to calculate the equivalent heat input at cathode using Eqs. (2) and (4). The heat flux equation derived and used for further analysis in this work is,

$$q(t) = \frac{3.4875\times10^5 F_C V I^{0.14}}{t_{on}^{0.88}} exp\left\{-4.5\left(\frac{t}{t_{on}}\right)^{0.88}\right\} \quad (5)$$

Where$F_c$ is the fraction of total power going to the cathode; V is the discharge voltage; I is the discharge current; t is the time $(\mu s)$ and $t_{on}$is time$(\mu s)$ at the end of electric discharge. Eq. (5) controls the amount of heat which is applied on the cathode which in turn, causes removal of material from cathode during operation.

The governing equation (Eq. (1)) with boundary conditions outlined earlier was solved by FEM to predict the temperature distribution at the end of each transient heat transfer analysis cycle. ANSYSTM16.0, a FEM solver was used. A two-dimensional continuum of size ten times the spark radius was considered for the analysis. Four-noded, axi-symmetric, thermal solid element (PLANE 55) was used for discretization of the continuum. The transient heat transfer problem was solved by applying the heat flux at the spark location (Eq. (5)) and using the discharge duration as the time step for the analysis. Fig. 7 shows the results for a typical problem showing the temperature contour plots. The results are for work material OHNS END31 die tool steel with machining conditions discharge current 6 A, discharge voltage 40 V and discharge duration of 30 $\mu s$ .

**Table I:** Maximum heat flux over the spark radius

| Sr No | Current ( Ip) | Pulse ON (time) | Voltage | Q in for Analysis |
|---|---|---|---|---|
| 1 | 6 | 75 | 40 | 4834.914965 |

From the calculations of maximum heat flux over the spark radius we have calculated the heat flux for case 1 as 4834.9 W/mm2.

Results for the case 1 while modelling the complete workpiece plate (OHNS) En31 of Size 100mm ×80mm×16mm. Minimum Meshing size is limited by the large geometry that we have to mesh. So minimum Mesh size used is 0.1 mm.
Plane Axisymmetric modelling approach is used from ANSYS 16. Below are the images of axisymmetric geometry and meshing with some results plots.

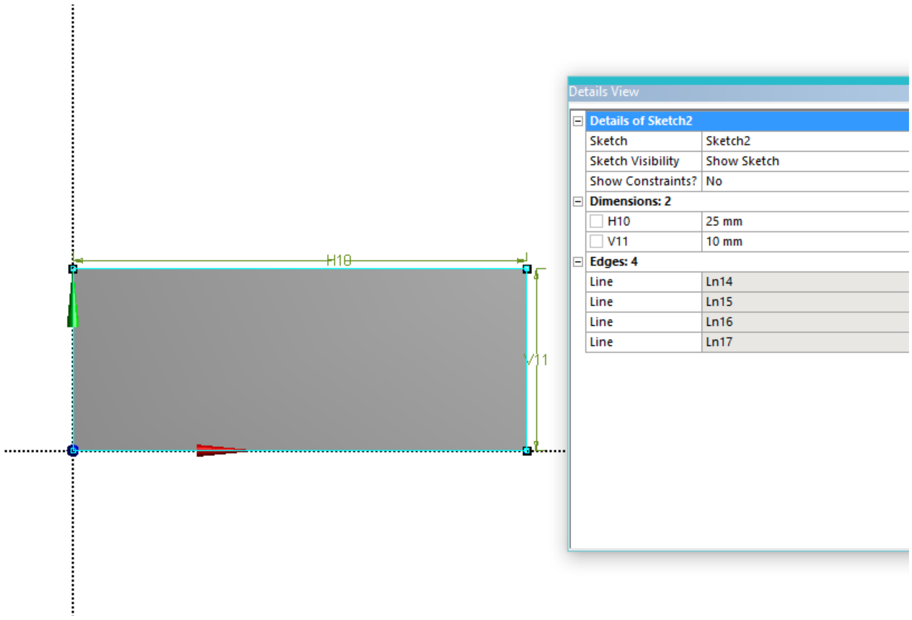



**Fig.3 -** Axisymmetric Sketch for Work Piece Complete

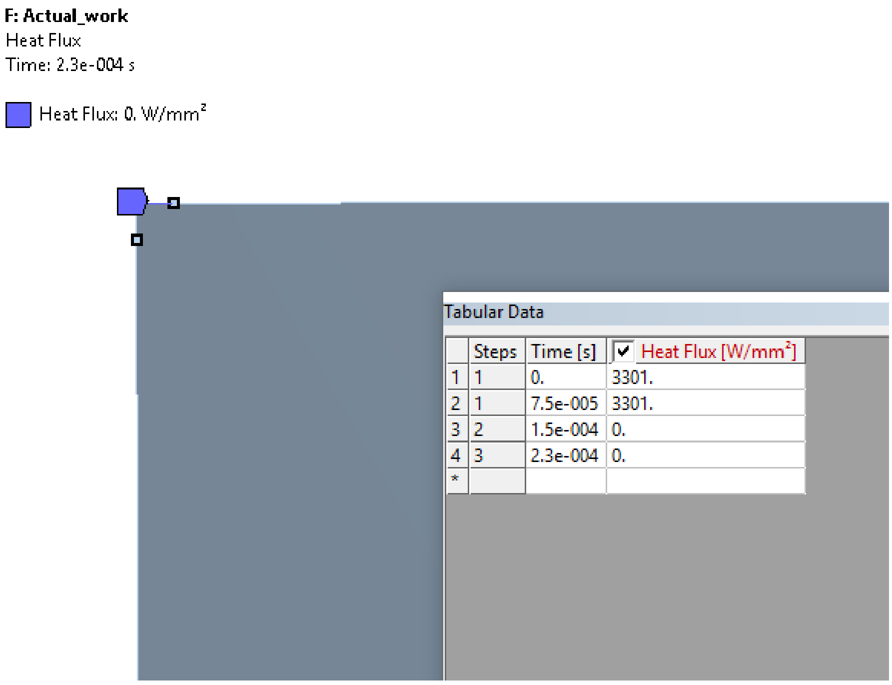



**Fig4: -** Loading Condition for Thermal Transient Analysis

**Table II:**Loading condition

| Time | Q ( W/mm$^2$) |
|---|---|
| 0 | 3301 |
| 7.50E-05 | 3301 |
| 2.3E-04 | 0 |

**Fig5:** Meshing

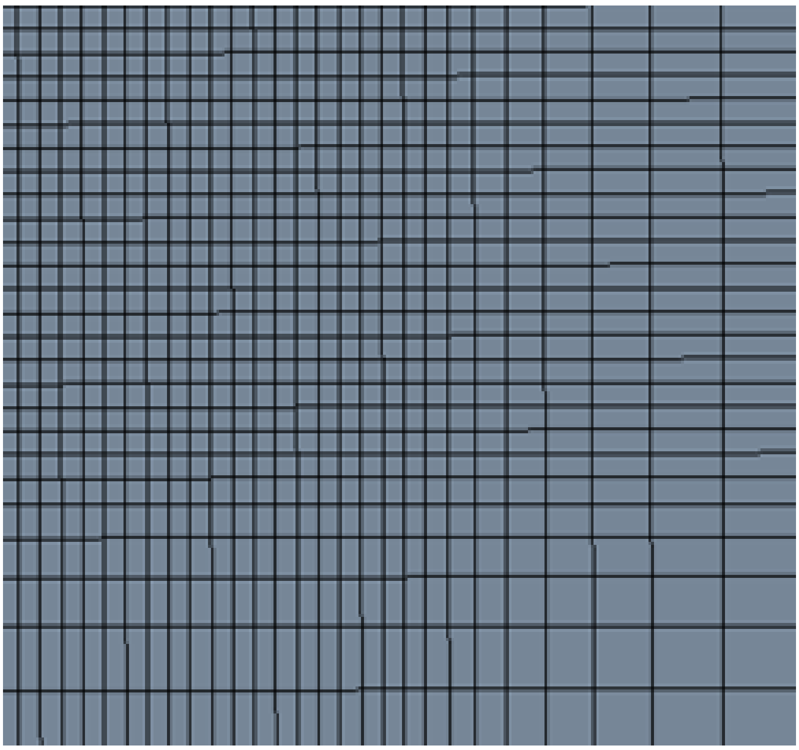
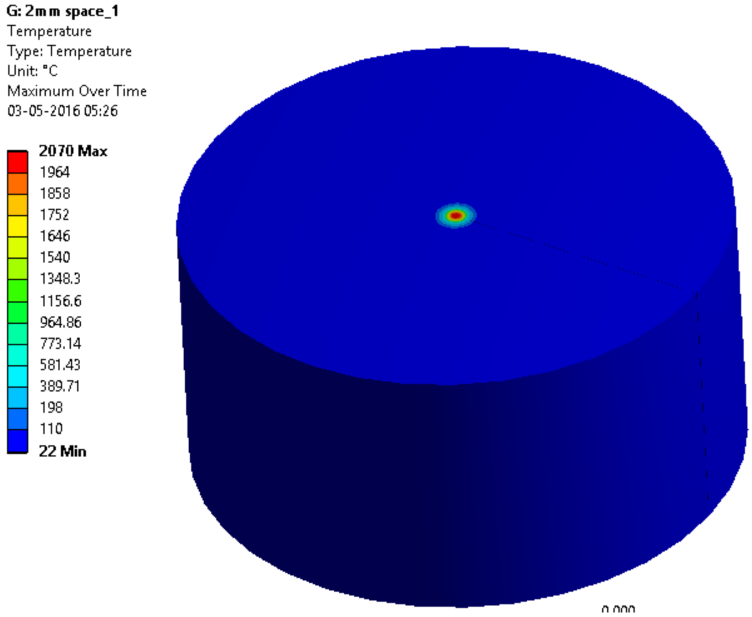


**Fig6**: Zoomed View meshing

Results plots for the same is shown below



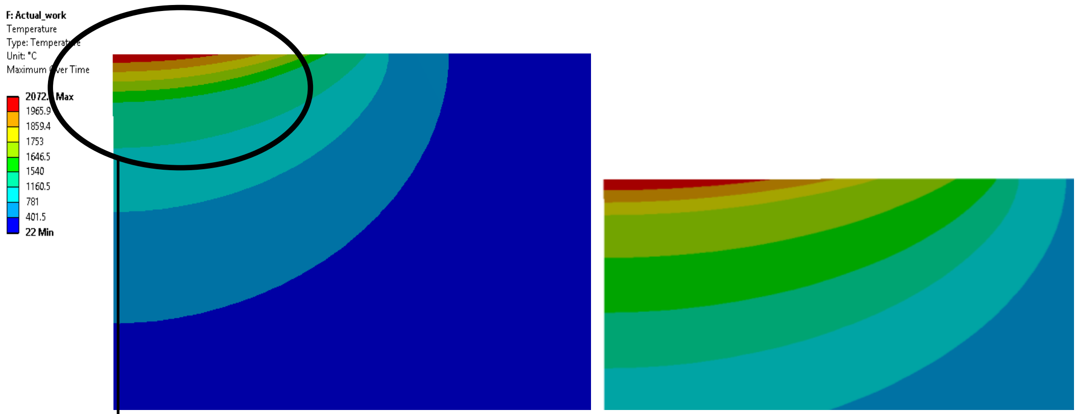




**Fig7:** Temperature Distribution Plot case 1

From Above FEA plot it is clear that we can reduce the size of the sample material taken to very small dimensions. For next analysis we will consider only 2 mm radius and 2 mm height cylinder, represented by axisymmetric model of 2 mm square geometry. From next case melting temperature for SS431 material is 1540$^{O}$C we need to calculate the volume removed in single on off cycle to get Volume removal rate

## V. Finite Element Analysis

To calculate the material removal due to single spark discharge, the cavity volume was divided into number of cylindrical discs (Fig. 8). The x-y coordinates of the node boundary are calculated from ANSYS WORKBENCH file.

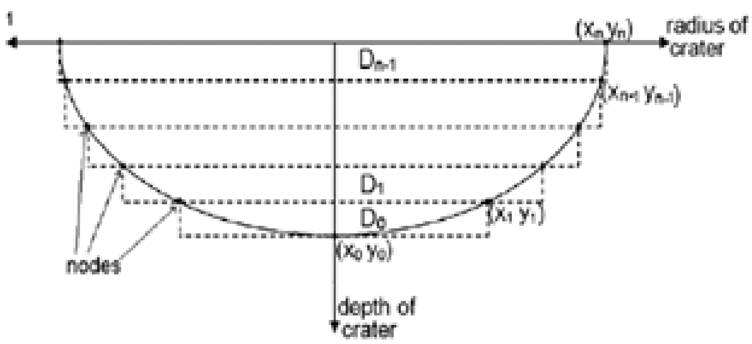



**Fig.8:**Calculation of crater volume

Total crater volume$C_{vt}$ $(mm^3)$is given by,

$$C_{vt} = \sum_{i=0}^{n-1} D_i \quad (6)$$

Where volume of a disc, $D_i$ is given by,

$$D_i = \pi \left(\frac{X_i + X_i + 1}{2}\right)^2 (y_{i+1} - y_i) \quad (7)$$

Where x and y are the coordinates of nodes and n is the number of nodes. Eqs. (6) and (7) were used to calculate the crater volume generated by a single spark discharge. MRR was computed for chosen process conditions considering that all sparks are equally effective with 100% dielectric flushing efficiency. The MRR $(mm^3/min$ is computed by,

$$MRR = \frac{60 \times C_{vt}}{t_{on} + t_{on}} \quad (8)$$

**Table III.**MMR for Case I

| Node No | X(mm) | Y(mm) | Di | $C_{vt}$ | MMR |
|---|---|---|---|---|---|
| 1 | 0.00000E+00 | 1.98800E+00 | 1.41372E-07 | 7.28177E-05 | 14.56 |
| 2 | 1.50000E-02 | 1.98880E+00 | 7.12513E-07 | | |
| 3 | 2.10000E-02 | 1.98950E+00 | 1.26669E-06 | | |
| 4 | 2.70000E-02 | 1.99020E+00 | 2.15026E-06 | | |
| 5 | 3.15000E-02 | 1.99100E+00 | 2.50493E-06 | | |
| 6 | 3.60000E-02 | 1.99170E+00 | 3.53429E-06 | | |
| 7 | 3.90000E-02 | 1.99250E+00 | 3.60710E-06 | | |
| 8 | 4.20000E-02 | 1.99320E+00 | 4.75574E-06 | | |
| 9 | 4.50000E-02 | 1.99400E+00 | 1.05207E-05 | | |
| 10 | 4.95000E-02 | 1.99550E+00 | 1.26201E-05 | | |
| 11 | 5.40000E-02 | 1.99700E+00 | 6.59198E-06 | | |
| 12 | 5.55000E-02 | 1.99770E+00 | 2.44120E-05 | | |
| 13 | 6.07500E-02 | 2.00000E+00 | | | |

Where $C_{vt}$ the material is removed per discharge pulse;$t_{on}$ is discharge duration and$t_{off}$ is the discharge off-time. T on time is 75 microseconds and T off time is 225 microseconds Actual reading recorded from machine was 13 $mm^3$/min.

**Table IV**MMR for Case I

| Exp. No | Discharge current (A) | Pulse ON time (µs) | Pulse OFF time (µs) | Voltage | MRR | MRR BY ANSYS | Error % |
|---|---|---|---|---|---|---|---|
| | 6 | 75 | 225 | 40 | 13.27 | 14.56 | 9.75% |

9.75% error is observed in case 1 for sample case all the calculations are displayed for first case. For rest of the cases temperature plots and table for the values will be provided directly.

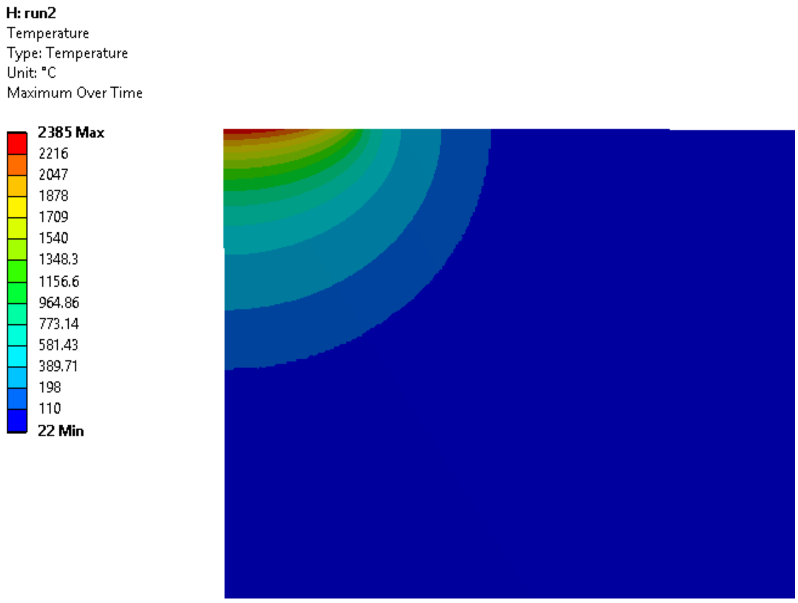



**Fig 9:** Temperature Distribution Plot case 2

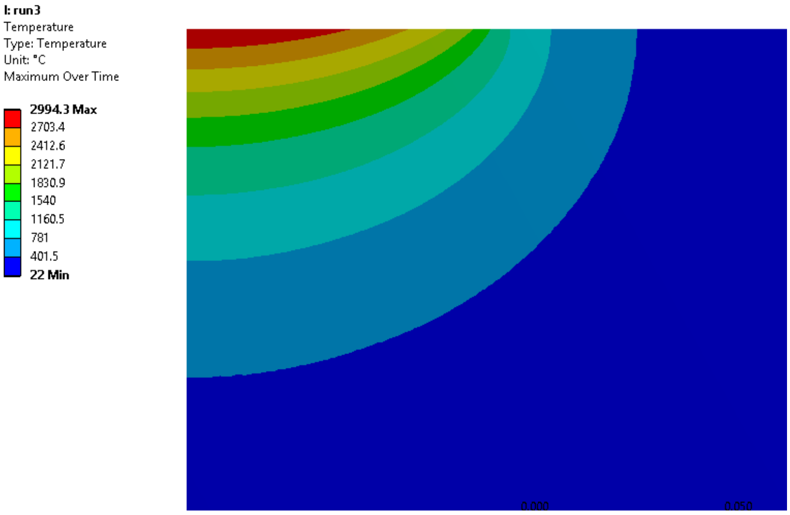



**Fig. 10**Temperature Distribution Plot case 3

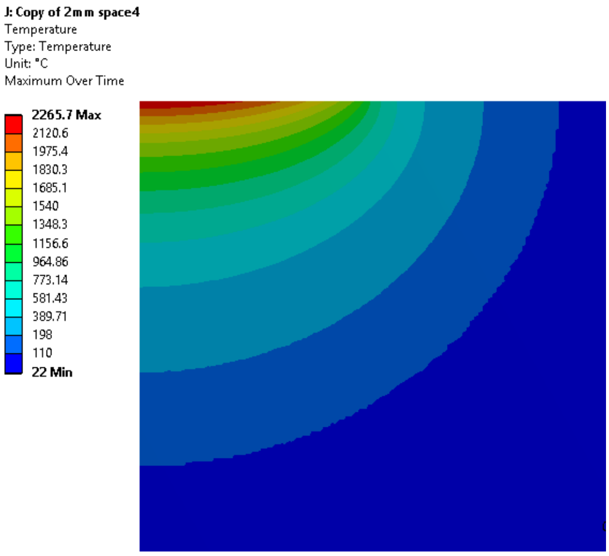



**Fig 11:** Temperature Distribution Plot case 4

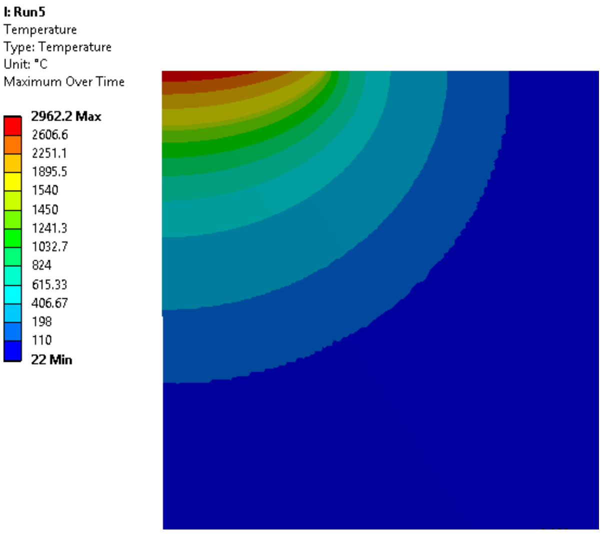



**Fig 12:** Temperature Distribution Plot case 5

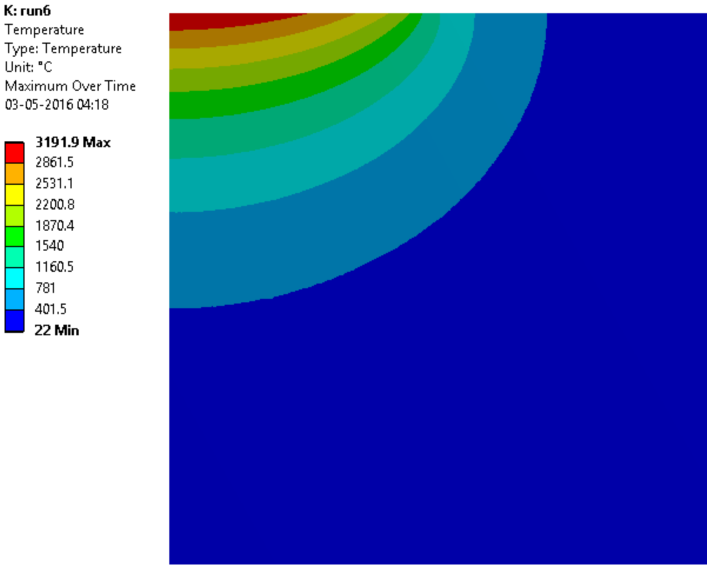



**Fig 13:** Temperature Distribution Plot case 7

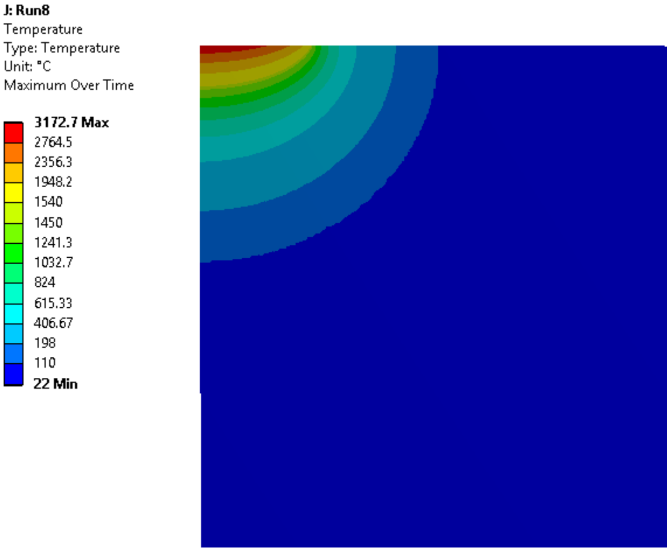



**Fig 14:** Temperature Distribution Plot case 8

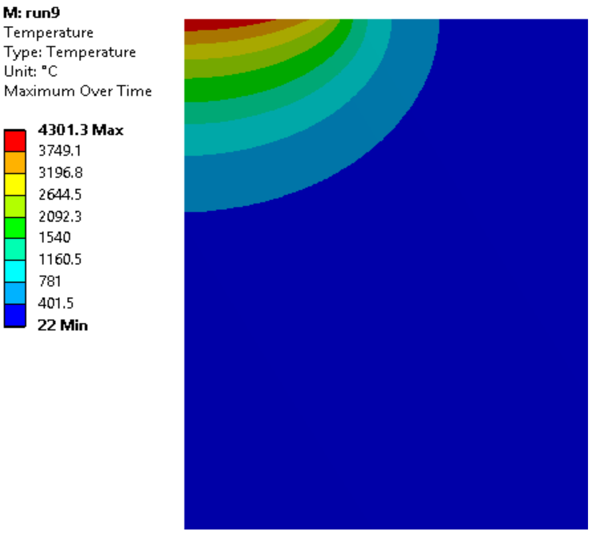



**Fig15:** Temperature Distribution Plot case 9

**Table V**MMR for all Case

| **Exp. No** | **Discharge current (A)** | **Pulse ON time (μs)** | **Pulse OFF time (μs)** | **Voltage** | **MRR (from machine manual) (mm3/mm)** | **MRR BY ANSYS** | **Error %** |
|---|---|---|---|---|---|---|---|
| 1 | 6 | 75 | 225 | 40 | 13.27 | 14.56 | 9.75 |
| 2 | 6 | 100 | 250 | 45 | 21.75 | 23.5 | 8.07 |
| 3 | 6 | 150 | 450 | 50 | 25.04 | 29.33 | 17.13 |
| 4 | 8 | 75 | 225 | 45 | 20.19 | 20.85 | 3.27 |
| 5 | 8 | 100 | 250 | 50 | 37.82 | 43.11 | 13.98 |
| 6 | 8 | 150 | 450 | 40 | 35.55 | 39.47 | 11.02 |
| 7 | 12 | 75 | 225 | 50 | 45.7 | 47.5 | 3.94 |
| 8 | 12 | 100 | 250 | 40 | 52.33 | 58.37 | 11.55 |
| 9 | 12 | 150 | 450 | 45 | 52.52 | 57.43 | 9.35 |

## VI. Experimental Analysis

### A.Machine tool

Experiments are carried out using CNC EDM (EMT 43) (Electronica) die sinking machine (shown in fig 3.2). Table 3.2 shows the specification of die sinking EDM machine.

**Table V**MMR for all Case

| **Machining Conditions** | |
|---|---|
| Machine Used | EDM (model 5535) (Electronica) |
| Electrode | Electrode Copper (99.9% Purity) |
| Electrode Polarity | Positive |
| Work piece | Oil Hardened Non Shrinking Steel (48-50 Rc) |
| Dielectric | EDM Oil |
| Flushing Condition | Pressure Flushing through 6 mm hole through work piece |

### B. Work piece material

OHNS (EN 31) PLATE tool steel Size of 100mm ×80mm ×16mmlength size has been used as a work piece material for the present experiments. The chemical composition and mechanical properties of the work-piece materials are shown in Table VI and Table VII

**Table Vi**Chemical composition of EN 31 Tool Steel

| Electrode | Chemical composition (wt. %) |
|---|---|
| C | 1.07 |
| Mn | 0.58 |
| Si | 0.32 |
| P | 0.04 |
| Si | 0.03 |
| Cr | 1.12 |
| Fe | 96.84 |

**Table Vii**Mechanical properties of EN 31 Tool Steel

| EN 31 Tool Steel | |
|---|---|
| Thermal Conductivity $(w/mk)$ | 46.6 |
| Density $(gm/cc)$ | 7.81 |
| Electrical Resistivity$(ohmcm)$ | 0.0000218 |
| Specific heat capacity (j/gm.-℃ | 0.475 |

**Fig16:** Work piece material before machining

**Fig17:** Work piece material after machining

C.Electrode material

An electrolytic pure copper with 12 mm X 30 mm is used as a tool electrode (positive polarity). Copper shows good response in metal removal rate toward high values of discharge current, due to increase in thermal conductivity and electrical conductivity of copper. The mechanical properties of the tool materials (electrode) are shown in Table VIII.

.**Table Viii**Mechanical properties of Electrode

| Copper (99% pure) | |
|---|---|
| Thermal Conductivity ($w/mk$) | 391 |
| Density ($gm/cc$) | 1083 |
| Electrical Resistivity($ohmcm$) | 1.69 |
| Specific heat capacity (j/gm-℃ | 0.385 |

**Table Ix**Different variables used in the experiment and their levels

| Response | Material Removal Rate (mm3 /min.) | | |
|---|---|---|---|
| Parameters | Tool Wear Rate (mm3 /min.) | | |
| | Surface Roughness (µm) | | |
| Control Parameters | Levels | | |
| | 1 | 2 | 3 |
| Discharge current (A) | 6 | 8 | 12 |
| Pulse ON time (µs) | 75 | 100 | 150 |
| Voltage | 40 | 45 | 50 |

**D.Experimental results**

The material removal rate found in the experiment conducted with varying $T_{on}$ and current values are shown in Table X. The difference in weights, volume of material removed and material removal rates are also presented in the table.

**Table X**Material removal rate found in the experiment conducted with varying $T_{on}$ and current values

| SN | Discharge current (A) | Pulse ON time (µs) | Voltage | Material Removal Rate (experiment) | MRR MRR BY ANSYS (mm3/mm) |
|---|---|---|---|---|---|
| 1 | 6 | 75 | 40 | 12.75 | 14.56 |
| 2 | 6 | 100 | 45 | 20.22 | 23.5 |
| 3 | 6 | 150 | 50 | 24.78 | 29.33 |
| 4 | 8 | 75 | 45 | 21.52 | 20.85 |
| 5 | 8 | 100 | 50 | 38.42 | 43.11 |
| 6 | 8 | 150 | 40 | 37.58 | 39.47 |
| 7 | 12 | 75 | 50 | 49.23 | 47.5 |
| 8 | 12 | 100 | 40 | 60.96 | 58.37 |
| 9 | 12 | 150 | 45 | 58.53 | 57.43 |

Sample Calulation:

For Ton=75, the Material removal rates at 4 different current values are:
Current = 6 Amperes
The initial weight of the sample=580.43 grams
After machining, the final weight=580.001 grams

Weight loss = 580.43-579.229 (grams) = 1.201 grams
Volume Loss = Weight loss/Density
= 1.201/0.00785
=152.99$mm^3$
Material Removal Rate = Volume of the material removed/Time = 152.99/12
=12.75 mm3/min.


**Fig. 18** Experimental setup

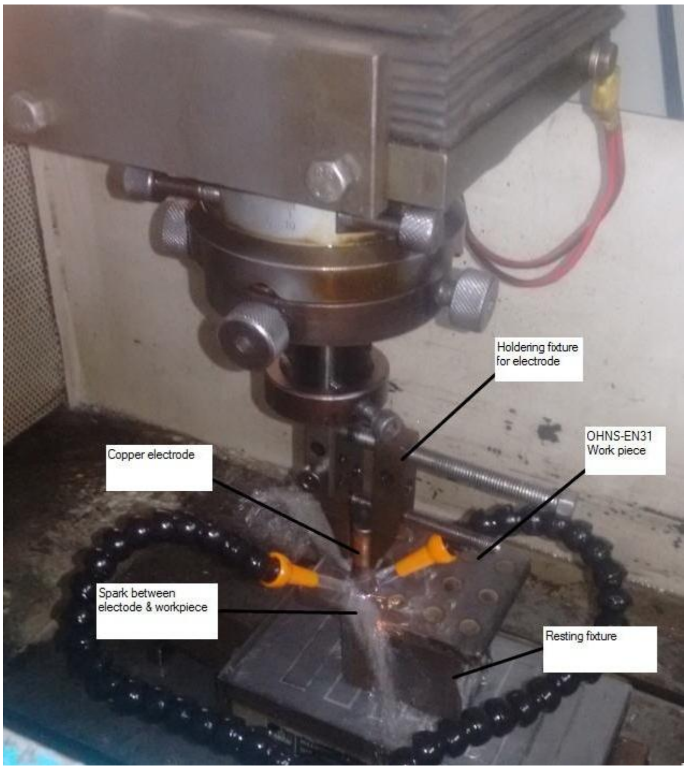



**Fig. 19** EDM machine View

## VII. Intelligent process modeling using ANN

Artificial Neural Network (ANN) is well known due to their ability to approximate non-linear and complex relationship between process parameters. It was, therefore, thought appropriate and convenient to develop a comprehensive (4 inputs – 1 output) EDM process model using ANN for quicker and accurate prediction of process performance results. A comprehensive process model of EDM was developed using ANN to accurately predict the process responses viz. MRR.

**Table X**Material removal rate found in the ANN Process modelling

| SN | Discharge current (A) | Pulse ON time (μs) | Voltage | Material Removal Rate (experiment) | MRR MRR BY ANN (mm3/mm) |
|---|---|---|---|---|---|
| 1 | 6 | 75 | 40 | 12.75 | 12.79 |
| 2 | 6 | 100 | 45 | 20.22 | 20.43 |
| 3 | 6 | 150 | 50 | 24.78 | 24.75 |
| 4 | 8 | 75 | 45 | 21.52 | 19.75 |
| 5 | 8 | 100 | 50 | 38.42 | 35.57 |
| 6 | 8 | 150 | 40 | 37.58 | 37.59 |
| 7 | 12 | 75 | 50 | 49.23 | 49.23 |
| 8 | 12 | 100 | 40 | 60.96 | 60.95 |
| 9 | 12 | 150 | 45 | 58.53 | 58.54 |

## VIII. Results and Discussion

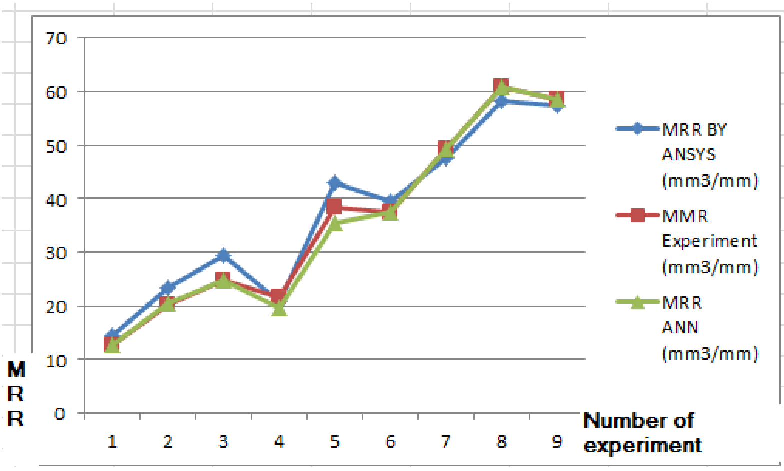



**Fig20:** Comparisons between Experimental MRR, FEM and ANN calculated MRR

Taking En-31 (OHNS) as workpiece material with single spark the results have been obtained. From Table X, it clear that the values of the responses predicted by numerical model are closer to the experimental results. Thus, it can be concluded that the numerical model would give better prediction of process responses compared to the earlier reported models. Temperature distribution in the workpiece has been shown in Fig. 7. From the simulation result it is clear evident that at the center line, on the top surface of the workpiece highest temperature generates. The high temperature rises during the spark on time can easily melt the material and formed a dome in the work piece. This is evident from the temperature distribution after material removal in FEA model as shown in Fig. 8. The volume of metal remove depends on amount of heat energy induced in the material. Therefore the MRR increase in both increase in current and voltage. Fig 20 shows the graphical representation of MRR obtained in FEM model and experimentally. Experimental result is almost equal to the predicted MRR obtained by FEM model.

## IX. Conclusion

In the present a numerical approach is presented in this work to estimate material removal rate on work piece in EDM process. The results obtained by numerical analysis and experimental methods have been compared. It can be concluded that numerical method provides reasonably accurate estimation of responses. Therefore, the method can be adopted to predict the responses before going for actual cutting operation. It may save time and cost of experimentation work. For developing such model various important process parameters are taken into account such as pulse on/off time, material properties, shape and size of heat source and heat energy given as input to the work piece. The proposed model can be used for selecting ideal process states to improve EDM process efficiency and finishing capability.

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