MODELLING OF ELECTRO DISCHARGE MACHINING IN AISI 304 MATERIAL

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Abstract – An axi – symmetric three dimensional thermo-physical model for the electrical discharge machining of AISI 304 was developed using finite element method and experiment on die sinking EDM have been conducted using L9 orthogonal array design using various process control parameter like voltage(V), Spark on time(Ton), Discharge current(Ip) which are varied in three different level. Material removal rate (MRR) for AISI 304 has been measured for each experimental run. Also the parametric analysis using ANSYS has been carried out by considering same process parameter to predict the MRR and result are verified with experimental investigation. The optimum values have been determined with the help of given main effect plotter and ANOVA Annexure to find out optimum value and most significant parameter which affect the MRR. Commercial grade oil has been taken as dielectric fluid. MINITAB software has been used for mathematical modeling of MRR.

Keywords- EDM i.e. electrical discharge machining; thermo-physical modesl; FEM i.e. finite element method, discharge current, discharge voltage, spark on time, MRR.

1. INTRODUCTION

What is EDM process? Electrical discharge machining (EDM) process is the most popular among the non-conventional machining processes. EDM is the erosion process that the discharge sparks in gap generates enough heat to melt and even vaporize some of the material on the surface of work piece, so any difficult-to-cut material can be cut in EDM as long as the material which can conduct electricity. also the complex nature of the process involves simultaneous interaction of mechanical, thermal, chemical, thermal and electrical phenomena, which makes process model very difficult. Therefore, many observer /researchers have concentrated their attention on the machining in EDM process by experiments; however, few theoretical analysis of the erosion mechanism of EDM process was involved.

The aim of this study was to introduce the finite element methods in determining the material removal rate for AISI 304 material by taking a voltage, spark on time and discharge current as a input parameter. For this purpose the experimental investigation is carried out for AISI 304 material and find out the material removal rate for same input parameter for each experimental run (L9 array). Also the parametric analysis using ANSYS has been carried out by considering same process parameter to predict the MRR and result are verified with experimental investigation. The most influential factors for the material removal rate were found. According to experimental result and FEA results discharge current was found be the major factor affecting the material removal rate, whereas voltage was found to be the second rank and spark on time was on third ranking factor.

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2. EDM PROCESS THERMAL MODEL

The EDM process can be described as the thermal process, as shown in Fig. 1. Material is heated up with help of the action of electrical sparks of high energy. The spark generated melts and vaporizes a little area on the electrode surface. Ending of the pulse on-time, a little amount of melt material is ejected from the top of material surface, and producing craters on and above the work piece surface. The EDM process involves simultaneous interaction of mechanical, chemical, thermal phenomenon as well as the electromagnetism, which therefore makes process model as difficult as much so the following assumptions are made to ease / simplify the model. 1) The model is developed for a single spark; 2) Heat transfer is done mainly through conduction and convection. Radiation heat losses are neglected; 3) The material over the melting point is completely removed after the end of spark discharge; 4) EDM spark channel is considered as uniform cylindrical columns process 5) the isotropic & homogeneous in nature materials work pieces, and the material thermal properties are temperature dependent (temperatures well below 800 °C) and are kept constant when temperatures are over this value.

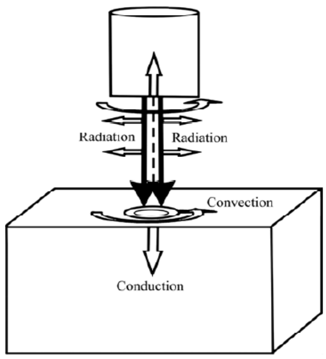


Fig. 1 Thermal model of EDM process

2.1 Governing equation and boundary conditions

For the temperature distribution referring the governing partial differential equation and considering the boundary conditions in a cylindrical coordinate system is

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

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

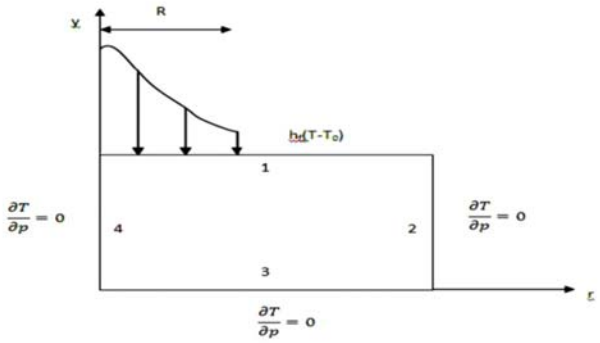


Figure 2 An Axi-symmetric model for the EDM process

On the upper surface the heat is transferred to the work piece shown by Gaussian hat flux distribution. On boundary 1 the heat flux is applied up to spark generated radius R, beyond the R convection heat transfer takes place because of dielectric fluids. As 2 & 3 are far from the spark location and also very short spark on time no heat transfer conditions are assumed for them. For the boundary 4, as it is axis of symmetry the heat flux is considered as zero.

In the mathematical terms, the applicable boundary conditions are mentioned as follows:

$K\frac{\partial T}{\partial z} = Q(r)$, When R<r for boundary 1

$K\frac{\partial T}{\partial z} = h_f(T-T_0)$, When R≥r for boundary 1

$\frac{\partial T}{\partial p} = 0$ For boundary 2, 3 & 4.

Here 'hf' is dielectric fluid heat transfer coefficient, Q(r) is heat flux due to the spark, T0 is the initial temperature and T is the temperature.

2.1 Plasma channel radius:

The plasma channel radius, the size of heat flux on the work piece surface, is an important factor in the model of the EDM process. Many authors have observed the shape and evolution of the plasma channel radius. In practice, it is extremely difficult to experimentally measure spark radius due to very short pulse period of the orders of few microseconds time. There are some Researchers who considered the plasma channel radius is time dependent, and other researchers considered the plasma channel radius is time and current dependent. IKAI and HASHIGUCHI [10] derived a semi-empirical equation of spark radius defined as "equivalent heat input radius" as assumed a function of the duration of the spark, *t*(μs), and the current, *I*(A). It is more realistic compared with the ot her approaches.

R(*t*)=0.002 04 *I*0.43 *t*0.44

2.2 Material Properties:

The material selected for present work is AISI 304 tool steel material (density 8 g/cm3) work piece using a copper tool (density 8.9 g/cm3) The work piece is in the form of a thin strip of dimensions 75 mm x 75 mm x 1 mm. Tool electrode is in the form of a tube such that high velocity dielectric flows through it.

Chemical composition of AISI 304							
C	Mn	Si	Cr	Fe	P	S	Ni
0.08	2	1	18-20	66-74	0.045	0.03	8-10.5

Mechanical Properties of AISI 304			
Density (g/cm^3)	Modulus of elasticity(GPa)	Ultimate tensile strength (MPa)	Elongation %
8	197	241	70

Table 1. Material properties for AISI 304

2.3 Heat flux:

A Gaussian heat flux distribution is assumed in present analysis based on the expanding heat source model (Patel et al, 1989), the heat flux has a Gaussian distribution in the plasma channel,

$$Q(r) = \frac{4.45PVI}{\pi R^2}\exp\{-4.5(\frac{r}{R})^2\}$$

Where P is energy portion to the work piece, V is the discharge voltage, I is current and R is spark radius.

Value of P mainly depends upon the material properties of the electrode.

2.4 Modelling procedure using ANSYS;

EDM is a complicated process that needs a sound tool to simulate the process. In present analysis the simulation has been done on ANSYS 12.0 multi-physics.

Step 1: Start ANSYS 12.0.

Step 2: Units: S.I.

Step 3: Analysis method: Thermal, h method

ISSN NO:0376-8163

Step 4: Problem domain: the geometry of the problem is created using ANSYS.
Step 5: Choice 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 result.
Step 9: Plot the required results from the obtained results.
Step 10: Finish.

2.5 Solution of thermal model:

The model of the EDM process was carried out using ANSYS software. Axi-symmetric three-dimensional quarter model was created with a dimension of 60 µm × 60 µm × 60 µm. A finite element mesh of non-uniformly distributed with elements mapped for the heat-affected regions was meshed and with a total number of up to 32 000 elements (Fig. 3).

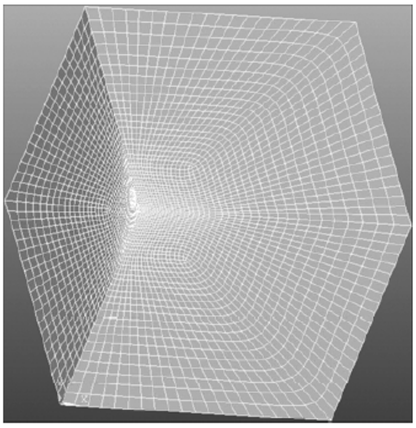


Fig 3 Three-dimensional meshed model

With boundary conditions, the governing equation mentioned above is solved by (FEM) finite element method to predict the temperature distribution at the spark location with the heat flux and the discharge duration as the total time steps.

2.6 ANSYS Model Validation:

Firstly we have developed a model of EDM process for AISI 304 tool steel with parameter V=60, Ton=12.8, I=8. Later the value has been compared with Shankar et al. as element size is 10µs so we are getting a distance of 40 µs at node 6. the temperature at node 6 is coming 2942 K, which is approximately same as given by Shankar et al. so we can say that we are proceeding right way. Further in the analysis the EDM problem is extended.

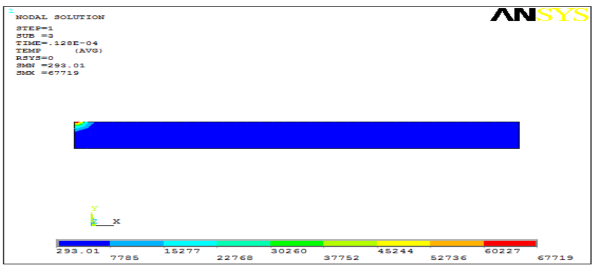


Fig 4. Temprature distrubution with V=60, Ton=12.8, I=8

After getting the temperature distribution for different process parameter, the element rises above the melting point using "kill" element.

2.7 Mechanism of MRR:

To find out the MRR the element model has been divided into cylindrical disc and volume of disc is given by:

$$Vi = \pi(Xi - Xo)^2(Yi - Yi - 1)$$

Cv = 0.022 µm3
MRR for single discharge is given by:

$$\frac{60 \times Cv}{(Ton + Toff) \times 10^3}$$

MRR = 1.192 × 10^{-5}
For multi-discharge

NOP= 160992.90
(MRR)multi-discharge =NOP × (MRR)single-discharge =1.96 mm3/min

run	Voltage	Spark on time	current	MRR
1	60	12.8	8	1.96
2	60	50	12	3.04
3	60	100	16	8.72
4	90	12.8	12	3.65
5	90	50	16	5.56
6	90	100	8	3.13
7	120	12.8	16	2.58
8	120	50	8	1.90
9	120	100	12	2.86

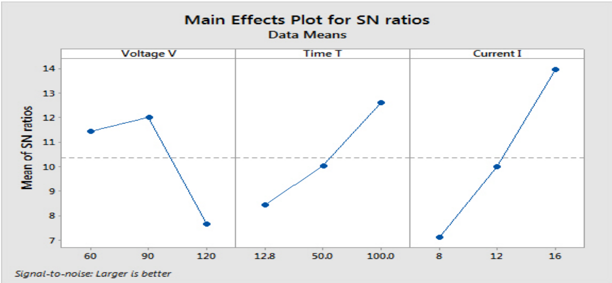
Table 2. FEA result of MRR for AISI 304

2.8 Optimal settings evaluation :

From the experimental result, the effect of process parameters on MRR are plotted by using MINITAB software as shown below.

Table 3. S/N ratio for AISI 304 material.

Expt .No.	Voltage (V)	Spark on time (µs)	Discharge Current (A)	MRR (y_i) mm³/min	S/N ratio $\eta = -10 \ln_{10} \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$
1	60	12.8	8	1.96	5.843731
2	60	50	12	3.04	9.652809
3	60	100	16	8.72	18.81149
4	90	12.8	12	3.65	11.23797
5	90	50	16	5.56	14.90759
6	90	100	8	3.13	9.91668
7	120	12.8	16	2.58	8.230216
8	120	50	8	1.90	5.564898
9	120	100	12	2.86	9.13803



Graph 1 Individual (Main) effect plot for S/N ratio (larger-the-better) AISI 304.Material

Process parameter	units	Optimal values
Voltage (V)	V	90
Spark on time (Ton)	µs	100
Discharge Current (C)	A	16

Table 4. Optimal values of process parameter

The calculated mathematical regression equation of MRR for AISI304 Material is

MRR= -1.54 - 0.0282 V + 0.0316 T + 0.479 C

Term	Coefficient	SE Coefficient	T	P
Constant	-1.54	3.72	-0.41	0.696
V	-0.0282	0.0216	-1.30	0.249
Ton	0.0316	0.0163	1.94	0.110
C	0.479	0.182	2.63	0.046

Source	DF	SS	MS	F	P
Regression	3	31.5714	10.5238	4.49	0.070
Voltage	1	3.9836	3.9836	1.7.	0.249
Ton	1	8.8347	8.8347	3.77	0.110
Current	1	16.2712	16.2712	6.94	0.046
Error	5	11.7266	2.9317		
Total	8	43.2980			

Table 5. ANOVA for AISI 304 of FEA

3 EXPERIMENTS

3.1 Introduction:

The experimental work which is consisting of L9 orthogonal array based on taguchi design. The orthogonal array reduces the total number of experiments. In this experimental work total numbers of runs are 9. Experimental setup, selection of work piece and tool, experimental procedure and taking all the value and calculation of MRR are explained below.

Fig 5. The Experimental Setup

Experiments were conducted by using the machining set up. The control parameters like Voltage (V), discharge current (Ip) and pulse duration (Ton) were varied to conduct 9 different experiments and the weights of the work piece before and after machining by using digital weighing machine were we take it for calculation of MRR.

3.2 Mechanism of MRR:

The material MRR is expressed as the ratio of the difference of weight of the work piece before and after machining to the time of the machining and density of the material.

$$MMR = \frac{Wjb - Wja}{t \times \rho}$$

Using the above formula for the MRR, we have calculated the material removal rate for each experiment of AISI 304 material.

run	Voltage	Spark on time	current	MRR
1	60	12.8	8	1.92
2	60	50	12	2.85
3	60	100	16	9.15
4	90	12.8	12	3.24
5	90	50	16	5.82
6	90	100	8	2.92
7	120	12.8	16	2.25
8	120	50	8	1.81
9	120	100	12	2.62

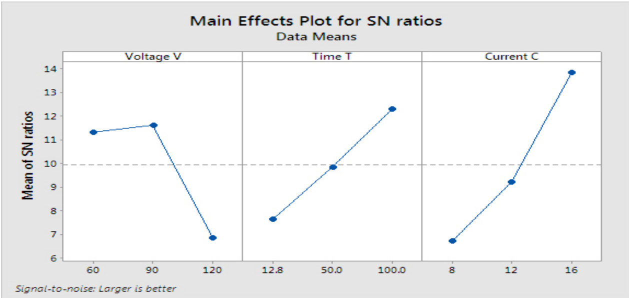
Table 6. Experimental results.

3.3 Optimal Settings evaluation:

From the experimental result, the effects of process parameters on MRR are plotted by using MINITAB software as shown below.

run	Voltage	Spark on time	current	MRR	S/N ratio
1	60	12.8	8	1.92	5.666025
2	60	50	12	2.85	9.096897
3	60	100	16	9.15	19.22842
4	90	12.8	12	3.24	10.2109
5	90	50	16	5.82	15.29846
6	90	100	8	2.92	9.307657
7	120	12.8	16	2.25	7.04365
8	120	50	8	1.81	5.153571
9	120	100	12	2.62	8.366026

Table 7. S/N ratio for experimental results.



Graph 2 Individual (Main) effect plot for S/N ratio (larger-the-better) AISI 304.Material

Process parameter	units	Optimal values
Voltage (V)	V	90
Spark on time (Ton)	µs	100
Discharge Current (C)	A	16

Table 8. Optimal values of process parameter

The calculated mathematical regression equation of MRR for AISI304 Material is

MRR = 0.44 - 0.0402 V + 0.0278 T + 0.440 C

Term	Coefficient	SE Coefficient	T	P
Constant	0.44	2.52	0.18	0.867
V	-0.0402	0.0187	-2.15	0.084
Ton	0.0273	0.0128	2.17	0.082
C	0.440	0.140	3.14	0.026

Source	DF	SS	MS	F	P
Regression	3	36.262	12.087	6.41	0.036
Voltage	1	8.736	8.736	4.63	0.084
Ton	1	8.905	8.905	4.72	0.082
Current	1	18.621	18.621	9.87	0.026
Error	5	9.429	1.886		
Total	8	45.691			

Table 9. ANOVA for AISI 304 of experiment.

4 CONCLUSIONS

In present work the finite element analysis using ANSYS and experiment were conducted and study the effect of parameters i.e. voltage, spark on time, discharge current on MRR for AISI 304. L9 orthogonal array based on taguchi was used for design of experiments. MINITAB software used for DOE and analysis of finite element analysis results as well as experimental results. The FEA and experimental results of MRR are compared and following observation are noted.

- Material removal rate increases with the increase in current.
- From the S/N plot it can be observed that the optimal parameter settings are same for FEA and experimental analysis. i.e. V=90V, Ton=100µs, I=16A.
- It can also observe that for FEA and experiment the discharge current is most prominent factor affecting the response.
- From ANOVA, the per cent contribution of discharge current was found to be the major factor affecting the material removal rate, whereas voltage was found to be the second ranking factor. The per cent contribution of spark on time was found to be third ranking factor respectively.
- 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. However in the discharge channel maximum temperature is an indicator of the model's thermal behavior.
- The 2D axisymmetric finite element analysis can be solved easily and computation takes few seconds only.

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