Modeling Of Electro Discharge Machining In Aisi 304 Material

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ABSTRACT

An axisymmetric 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 main effect plot and ANOVA table 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.

Keyword: - *Electrical discharge machining, thermo-physical model, finite element method, discharge current, discharge voltage, spark on time, MRR.*

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1. INTRODUCTION

The electrical discharge machining (EDM) process is the most popular among the non-conventional machining processes. The erosion process of EDM is that the discharge sparks in gap generate enough heat to melt and even vaporize some of the material on the surface of workpiece, so any difficult-to-cut material can be cut in EDM as long as the material can conduct electricity. However, the complex nature of the process involves simultaneous interaction of thermal, mechanical, chemical and electrical phenomena, which makes process model very difficult. Thus, many researchers have focused 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.

2. THERMAL MODEL OF EDM PROCESS

The EDM process can be described as the thermal process, as shown in Fig. 1. Material is heated up by the action of high energy electrical sparks. The spark melts and vaporizes a small area on the electrode surface. At the end of the pulse on-time, a small amount of molten material is ejected from the surface, producing craters on the workpiece surface. The EDM process involves simultaneous interaction of thermal, mechanical, chemical and an electromagnetism phenomenon, which makes process model very difficult so the following assumptions are made to simplify the model.

1) The model is developed for a single spark; 2) Heat transfer is mainly by conduction and convection. Radiation heat losses are neglected; 3) The material over the melting point is removed completely after the end of spark discharge; 4) EDM spark channel is considered a uniform cylindrical column; 5) Work piece materials are homogeneous and isotropic in nature, and thermal properties of the material are temperature dependent for temperatures below 800 °C, they are kept constant when temperatures are over this value.

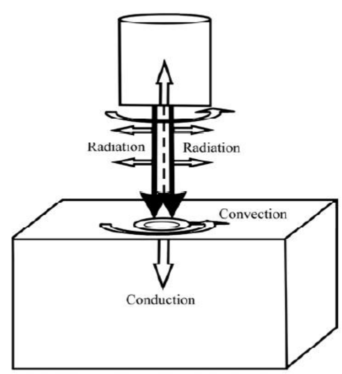


Fig. 1 Thermal model of EDM process

2.1. GOVERNING EQUATION AND BOUNDARY CONDITIONS

The governing partial differential equation considering boundary conditions for the temperature distribution 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 workpiece, T is the temperature, t is the time and r & z are coordinates of the workpiece

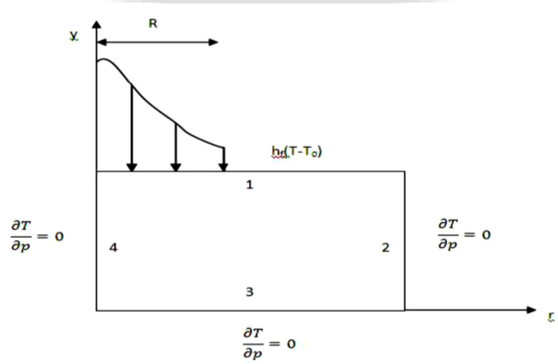


Figure 2 An axisymmetric model for the EDM process

On the top surface the heat is transferred to the workpiece shown by Gaussian hat flux distribution. Heat flux is applied on boundary 1 up to spark radius R, beyond R convection takes place due to dielectric fluids. As 2 & 3 are far from the spark location and also very short spark on time no heat transfer conditions have been assumed for them. For boundary 4, as it is axis of symmetry the heat flux is taken as zero. In mathematical terms, the applied boundary conditions are given as follows:

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

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

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

Where hf is heat transfer coefficient of dielectric fluid, Q(r) is heat flux due to the spark, T0 is the initial temperature and T is the temperature.

2.2. PLASMA CHANNEL RADIUS

The plasma channel radius, the size of heat flux on the workpiece surface, is an important factor in the model of the EDM process. The shape and evolution of the plasma channel radius have been studied by many authors. In practice, it is extremely difficult to experimentally measure spark radius due to a very short pulse duration of the order of few microseconds. Some researchers considered the plasma channel radius is time dependent, others considered the plasma channel radius is time and current dependent. IKAI and HASHIGUCHI [10] derived a semi-empirical equation of spark radius termed as “equivalent heat input radius” which is assumed as 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

2.3. 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

2.4. 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.

2.5. MODELLING PROCEDURE USING ANSYS

EDM is a complicated process that requires a powerful 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
Step 4: Problem domain: In this step, 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.

2.6. SOLUTION OF THERMAL MODEL

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

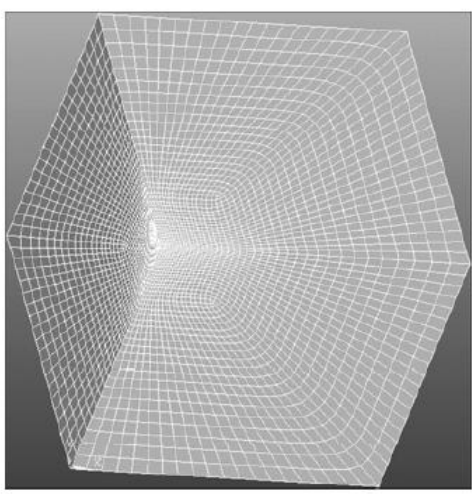


Fig 3 Three-dimensional meshed model

The governing equation with boundary conditions mentioned above is solved by finite element method to predict the temperature distribution with the heat flux at the spark location and the discharge duration as the total time step.

2.7. 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.

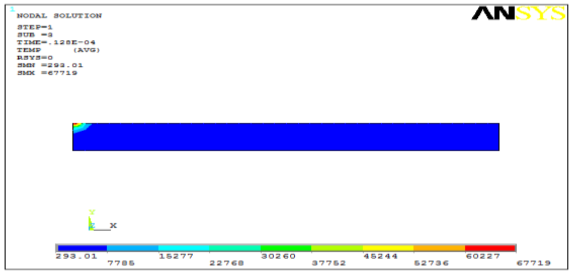


Fig 4. Temprature distrubution with V=60, Ton=12.8, I=8

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

2.8. 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$\times$(MRR)singledischarge =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

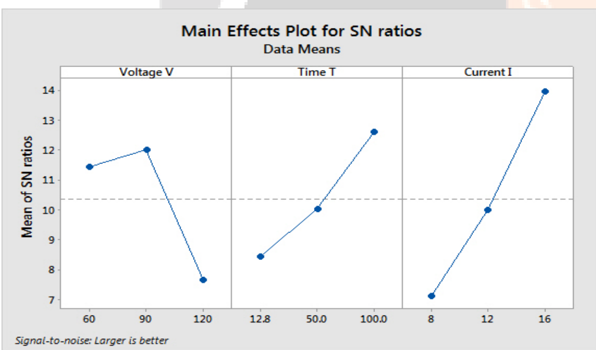
Table 2. FEA result of MRR for AISI 304

2.9. EVALUATION OF OPTIMAL SETTINGS

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

Expt. No.	Voltage (V)	Spark on time (µs)	Discharge Current (A)	MRR (y_i) mm^3/min	S/N ratio
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

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



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)	Ms	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

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 machining and after machining by using digital weighing machine were taken 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 machining time and density of the material.

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

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

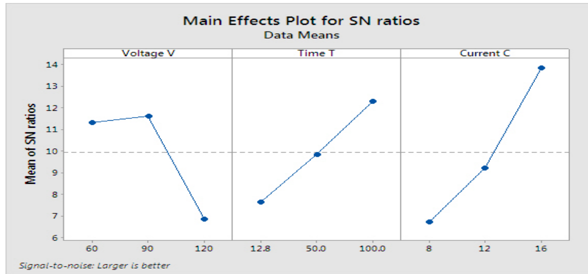
Table 6. Experimental results.

3.3 EVALUATION OF OPTIMAL SETTINGS

Form the experimental result, the effect 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)	Ms	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 5. 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.

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