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Finite Element Analysis of Tool Wear Rate in Electrical Discharge Machining and Comparison with Experimental Results

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Abstract

Electrical discharge machining (EDM) is one of the precise non-traditional machining processes in which desired shape is obtained in workpiece using electrical sparks. In EDM, material removal from workpiece and tool takes place by means of successive sparks occurring between them. The tool wear is a critical problem in EDM as the change in tool shape directly affects the final shape of the workpiece. In this paper, finite element analysis of tool wear in electrical discharge machining is carried out for copper tool. The input data required for simulation are taken from experimental details available in existing literature. For energy distribution factor, an empirical formula is used. The simulation results are compared and validated with experimental results which showed good agreement.

Keywords: *EDM, TWR, experiment, finite element analysis*

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INTRODUCTION

The electrical discharge machining (EDM) process uses principle of spark erosion for material removal from workpiece and tool. At present, EDM is an extensively used process in industry for machining of materials which requires high precision. To run machine tools at their maximum level, there is a need to optimize process parameters affecting performance of process. Many researchers have tried different techniques for optimization of EDM process but the experimental optimization is not cost effective and consumes more time.

Hence, finite element analysis can be used as a tool for process optimization and certain methodology should be established for that. The thermo-physical model was developed by Joshi and Pande for parametric studies of EDM process using finite element analysis [1].

Liu *et al*. used finite element method to simulate tool wear during small hole drilling in titanium alloy by EDM [2]. Mohanty *et al*. carried out thermal-structural analysis of EDM process to analyze effect of process parameters on performance measures [3]. For prediction of recast layer, a numerical model was developed by Tan and Yeo based on multiple discharge approach in micro EDM [4].

Kansal *et al*. developed a finite element model to predict material removal rate in powder mixed electric discharge machining process [5]. In this work, experimental data are taken from available literature and used as input for finite element analysis (FEA) of tool wear in electrical discharge machining process.

EXPERIMENTAL DATA

Table 1 shows experimental parameters and TWR from experiments as well as Patel's model in which steel workpiece and copper tool were used [6]. These experimental parameters are used as input for modeling of EDM process.

THERMAL ANALYSIS OF EDM PROCESS

Thermal analysis of EDM process is carried out to predict tool wear rate (TWR) using experimental data available in literature.

Table 1: *TWR from Experiments and Patel's Model [6].*

Exp. No.	V (V)	I (A)	Ton (μs)	Toff (μs)	Experiment TWR (mm^3/min)	Patel's Model [6] TWR (mm^3/min)
E1	25	68	560	10	4.47	4.78
E2	25	58	420	7.5	4.84	6.70
E3	25	44	240	5.6	3.69	6.01
E4	25	36	180	4.2	6.78	8.54
E5	25	25	100	4.2	3.37	5.38
E6	25	20	56	3.2	3.59	5.69
E7	25	12.8	42	3.2	0.76	1.84
E8	25	10	32	2.4	0.62	1.07
E9	25	8.5	24	2.4	0.30	0.94
E10	25	5.3	18	2.4	0.07	0.16
E11	25	3.67	13	2.4	0.03	0.11
E12	25	2.85	7.5	1.3	0.02	0.07
E13	25	2.34	5.6	1	0.01	0.06

Assumptions

As EDM process is highly complex and uncertain in nature; the following assumptions are made to solve the proposed model mathematically:

- The model is developed for a single spark.
- The material of the tool is homogeneous and averaged values of its thermal physic properties are used.
- Thermal analysis is considered to be of transient type.
- The heat source is assumed to have Gaussian distribution of heat flux on the surface of the tool.
- The mode of heat transfer to the tool is by conduction.
- Heat loss due to radiation is neglected.
- The material flushing efficiency is assumed to be 100%.

Energy Distribution Factor

An energy distribution factor (F_c) is required for calculation of heat input to the model. From the existing literature data [7], a power regression model is developed and it is represented by:

$$F_c=0.0582\times I^{4.3243}\,T_{on}^{-2.7167} \qquad (1)$$

Heat Distribution

Plasma channel incident on the tool surface causes the temperature to rise in the tool. The mode of heat transfer in solid is conduction. The distribution of plasma channel can be assumed as point source, uniform disk source or Gaussian heat distribution. For EDM, Gaussian distribution of heat flux is more realistic and accurate than point and disc heat source [8]; so, it is assumed in present analysis. The heat flux for single spark can be written as follows:

$$Q(r) = \frac{4.45 F_c V I}{\pi {R_s}^2} \exp\left\{-4.5\left(\frac{r}{R_s}\right)^2\right\} \qquad (2)$$

Where, *Q(r)* is the heat flux at the radius of *r*, F_c is the percentage heat input to the tool, V is the voltage between anode and cathode during discharge occurs, I is the peak current, R_s is the spark radius and *r* is the distance from the center of arc plasma.

Spark Radius

Spark radius is an important parameter in the thermal modeling of EDM process. In practice, it is very difficult to measure spark radius due to very short pulse duration. So, in this analysis, a semi-empirical relation of spark radius derived by Ikai and Hashigushi is used [9].

$$R_s=2.04 x I^{0.43} x t_{on}^{0.44} \qquad (3)$$

Determination of TWR

The prediction of TWR depends upon the crater morphology. The morphology of crater is assumed to be hemispherical cap shape where R_c is the radius of hemispherical cap and h is depth of cap. The volume of hemispherical capis calculated by Eq. (4):

$$V_c = \frac{1}{6}\pi h(3{R_c}^2 + h^2) \qquad (4)$$

Tool wear rate (TWR) can be calculated in mm^3/min using Eq. (5).

$$\mathrm{TWR} = \frac{V_c \times 60 \times 10^{-3}}{T_{on} + T_{off}} \qquad (5)$$

Simulation Condition

The single discharge analysis procedure employs the commercial finite element code ANSYS Multi physics to determine temperature distributions as well as radius and depth of crater.

Modeling

A 3D model of tool is created with radius of 2000 µm and depth of 800 µm as shown in Figure 1. Meshing of the model is done using thermal solid eight node brick elements (Solid 70). Figure 2 shows the meshing of the spark region and other remaining regions of the model. The number of elements is 164124.

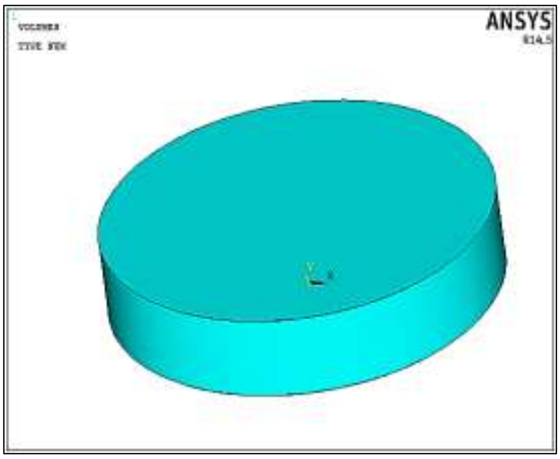

Fig. 1: *3D Model of Tool.*

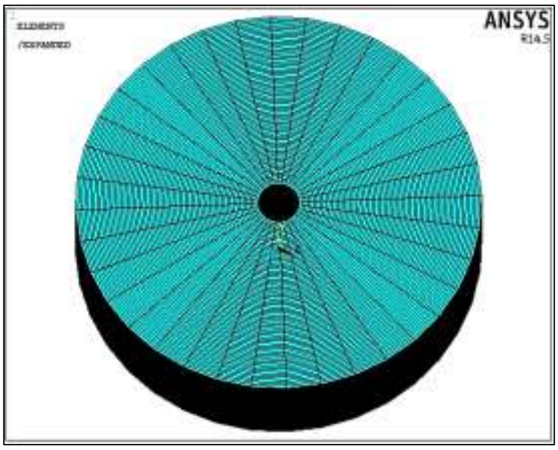

Fig. 2: *Meshing of Tool.*

Material Properties and Boundary Conditions

Copper is taken as tool material and its properties are: density –8640 kg/m^3, thermal conductivity –367 W/mK, specific heat –438 J/kgK and melting point –1356 K. In this model, heat flux for a single spark is applied on the surface B_1 up to spark radius R_s using Gaussian distribution and heat convection is applied on B_1 surface beyond spark radius. As the boundaries B_2 and B_3 are very far from the spark radius and also the spark has been made to strike for a very little moment, no heat transfer conditions have been assumed for them. Figure 3 shows the schematic diagram of thermal model with the applied boundary conditions. The initial bulk temperature is set at 298 K.

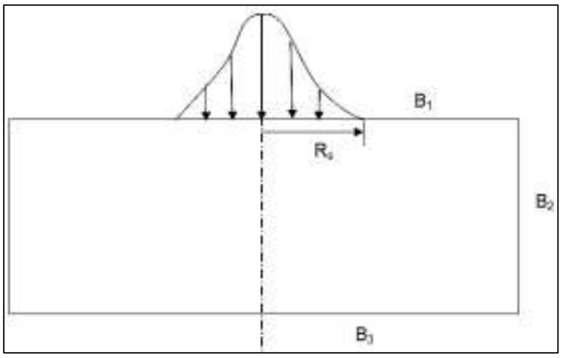

Fig. 3: *A Model with Boundary Conditions.*

RESULT

Figures 4 and 5 show temperature distribution and wear in tool after single discharge respectively. Figure 6 shows comparative graph for tool wear in experiment, Patel's model and FE model (Table 2).

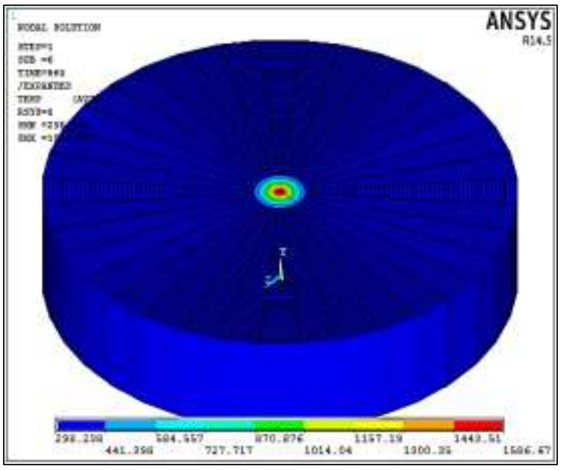

Fig. 4: *Temperature Distribution in Tool.*

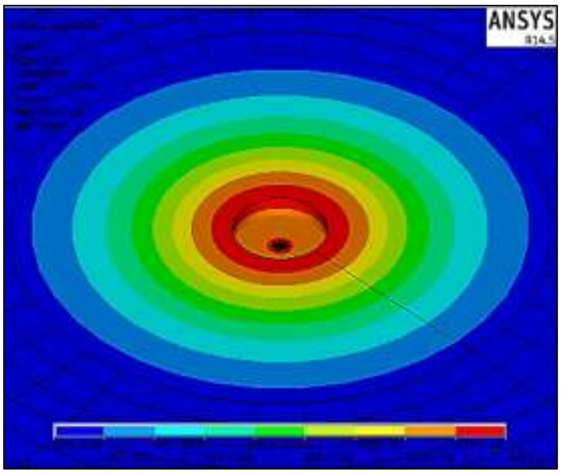

Fig. 5: *Tool Wear after Single Spark.*
(I=68 A, V=25 V, Ton=560 μs, Toff=10 μs)

Table 2: *TWR from FE Model.*

Exp. No.	**V (V)**	**I (A)**	**Ton (μs)**	**Toff (μs)**	**FE Model TWR (mm^3/min)**
E1	25	68	560	10	5.38
E2	25	58	420	7.5	5.67
E3	25	44	240	5.6	4.02
E4	25	36	180	4.2	6.52
E5	25	25	100	4.2	4.76
E6	25	20	56	3.2	4.13
E7	25	12.8	42	3.2	1.86
E8	25	10	32	2.4	1.24
E9	25	8.5	24	2.4	1.01
E10	25	5.3	18	2.4	0.21
E11	25	3.67	13	2.4	0.15
E12	25	2.85	7.5	1.3	0.06
E13	25	2.34	5.6	1	0.04

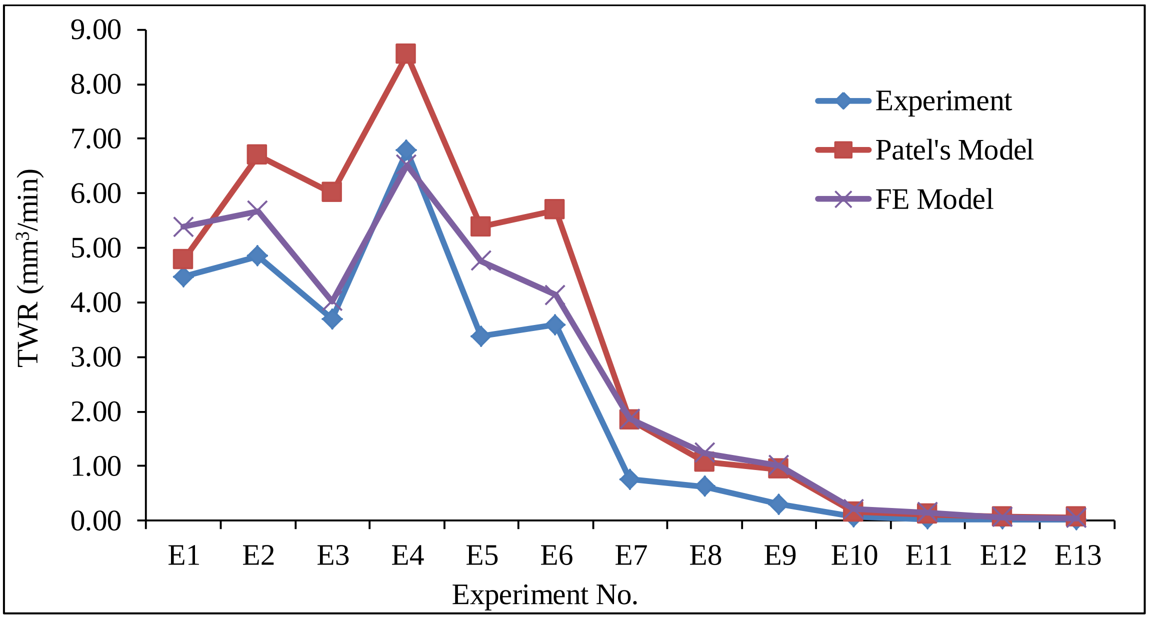

Fig. 6: *Comparison of the Experiment, Patel's Model and FE Model for TWR.*

CONCLUSION

In this study, thermal analysis of EDM process is carried out to predict tool wear rate (TWR) and validated using same literature results. A comparative analysis is done for TWR from experiment, Patel's model and FE model. The FE model is in good agreement with the experimental values reported in the literature compared to Patel's model and capable to provide better prediction of tool wear rate in EDM [6].

NOMENCLATURE

V = Discharge voltage (V)

I = Discharge current (A)

T_{on} = Pulse on time (μs)

T_{off} = Pulse off time (μs)

F_c= Fraction of energy transferred to tool (%)

R_c= Crater radius (μm)

h = Depth of crater (μm)

V_c = Crater volume (μm^3)

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