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Wear Ratio of EN8 Steel and Copper Electrode in Sinking EDM with Titanium Abrasives Suspended Dielectric Fluid

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Abstract—

The present work investigates the wear ratio of EN-8 steel with copper as a tool electrode in abrasive mixed sinking electrical discharge machining process. Five independent input process factors i.e tool electrode polarity, peak current, pulse on time, gap voltage and concentration of titanium abrasives in EDM oil (dielectric fluid) are chosen as input factors for evaluating the output parameter i.e wear ratio. Taguchi method is used to plan and analyze the results. Taguchi's recommended signal–noise ratio formulae with analysis of variance (ANOVA) are used to identify the significant input factors and their percentage contribution in the process output. Experimental results show that tool electrode polarity and peak current are the significant influential input factors for wear ratio.

Keywords— Electrical discharge machining, EN8 steel, wear ratio.

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-conventional machining process mainly used in production of die cavities with the help of electrical discharges between a tool electrode and a work-piece which cause erosive effect. This ionization produce large amount of heat which cause evaporation of metal and dielectric fluid. This evaporation makes a tiny crater at the point of discharge on the work piece. H. K. Kansal et al. [1] found that material removal rate and surface finish improved with suspending silicon powder in dielectric of EDM. Further peak current and concentration of abrasives particles in dielectric fluid were most influential parameters on material removal rate and surface finish. I. Puertas, et al. [2] studied the SR of silicon carbide on large scale application and found that intense, pulse time and duty cycle produce the influence on SR accept flushing pressure of dielectric. K. Ponappa et al. [3] identified the significant EDM parameters which affects the whole accuracy and the surface roughness. It was observed that servo speed and pulse-on time mainly affects the surface roughness and taper of drilled EDM hole. M. S. Popa et al. [4] studied and compare the values of the roughness obtained by EDM process on different materials and by taking different process parameters. N.S. Khundrakpam, et al. [5] studied the effect of kerosene dielectric with suspended zinc on EDM of EN8 steel. He observed that powder concentration, peak current and interaction of both are the significant parameters for MRR.. P. Pecas et al. [6] found the crater dimensions and surface roughness reduced positively by adding silicon powder in the dielectric fluid of EDM. The surface roughness of hastelloy steel improves by addition of aluminium powder in dielectric fluid. P.Singh, et al. [7] analyzed and perform the EDM of hastelloy steel and found all input parameters like peak current, gap voltage, pulse on time and duty cycle produce significant affect on machining performance of hastelloy steel. W. S. Zhao et al. [8] experimentally observes that, due to loss of discharge energy in the gap of powder mix EDM, it leads to reduction in melting the material so machining efficiency becomes lower and so the surface roughness becomes lesser in comparison with conventional EDM process. Y. Chen et al. [9] noted that the surface quality greatly influenced by current value and the ratio of the pulse duration and the pulse interval. It was also advised for a multi-stage erosion machining process to achieve the desired surface finish. However, a relatively large gap voltage is more suitable to achieve a super-fine surface finish. This work focused on the powder mixed EDM of EN8steel material. For this, an experimental study is conducted to investigate the surface roughness in die-sinking EDM process

II. EXPERIMENTAL PROCEDURE

A. Equipment and Work piece Material

Smart die-sinking Oscar MAX S645-CMAX Electric Discharge CNC Machine tool having 1200 litter dielectric capacity, Work table dimensions (L x W) 1000 x 600 mm and DC servo feed control system is used for sinking blind holes in work material. In this experimentation Standard EDM oil is used as dielectric fluid and the side injection of dielectric fluid with side jet flushing system was used to assure adequate flushing of the debris from the gap zone during experimentation. Cylindrical solid rod of copper with 9.5 mm diameter is used as tool electrode. The physical, mechanical and thermal properties of copper are given in table I. The EN8 steel was selected as the workpiece material. The EN8 steel work-piece was cut as a rectangular block. The surface was machined on shaper and finished on surface grinding machine. The various properties and chemical composition of EN8 steel are shown in table II. A mild steel sheet tank of capacity of 7 litres was made in which 6 litres dielectric fluid was filled. Titanium abrasives of 100 mesh size were used to mix in dielectric fluid to conduct abrasive mixed experiments. The various properties of titanium abrasives are shown in table III.

TABLE I TOOL MATERIAL (COPPER) PROPERTIES

Specification	**Value**
Density (g/cm^3)	8.96
Specific heat capacity (J/g-K)	0.385
Co-efficient of thermal exp. (/ºC)	17 x 10^{-6}
Electrical conductivity (S/m)	59.6 x 10^6
Electrical resistivity at 20 ºC (Ωm)	1.673 x 10^{-8}
Tensile strength (MPa)	90
Melting point (ºC)	1084
Boiling point (ºC)	2595
Thermal conductivity (W/m/K)	394

TABLE II PROPERTIES, COMPOSITION OF EN8 STEEL

Workpiece (steel)	EN8
Hardness (BHN)	201-255
Yield Stress (N/ mm^2 Min)	465
Max Stress (N/ mm^2 Min)	700-850
Elongation (%)	16% min
0.2% Proof Stress (N/ mm^2 Min)	450
Thermal conductivity (W/m/K)	21.9
Electrical resistivity (μΩ·m)	171 x 10^{-9}
C(%)=0.35-0.45, Mn(%)=0.60-1.00, Si(%)=0.10-0.35, S(%)=0.50, P(%)=0.050	

TABLE III ABRASIVE (TITANIUM) PROPERTIES

Specification	**Value**
Colour	Dark grey
Density	9.3
Specific heat	0.032
Electrical resistivity	5.5
Thermal conductivity	0.40
Linear coefficient of expansion	4.3 x 10^{-6}
Melting point ºC	3410

B. Experimental Design

Dr. Genichi Taguchi developed the fractional factorial method that allow a process to yield most information using relatively few experiments when there are a large number of input variables. In this experimentation, the most significant machining parameters including polarity, peak current, pulse on time, gap voltage and concentration of abrasive powder were used as input parameters. Two levels were taken for polarity and three levels were taken for other four parameters (current, pulse on time, gap voltage and powder concentration). The various experimental conditions used in AEDM process of EN8 steel are listed in table IV. The design scheme of input process parameters and their values with levels are listed in table V. The output process parameter wear ratio is directly influence the life of the electrode. Hence, the experiments are planned and performed at different levels of selected input process parameters.

TABLE IV EXPERIMENTAL SETUP AND OPERATING CONDITIONS

Condition	**Description**
Work piece	EN8 Steel
Tool electrode material	Electrolytic copper rod (Φ = 9.5mm)
Dielectric fluid	EDM oil
Grain size of abrasives	100 mesh
Polarity	+ve & -ve
Peak current	6-12
Pulse on time	120-200
Gap voltage	40-80
Abrasive concentration	0-12

TABLE V DESIGN SCHEME OF MACHINING VARIABLES

Symbol	**Control Variable**	**Level 1**	**Level 2**	**Level 3**
A	Polarity	+ve	-ve	

B	Peak current (amp)	6	9	12
C	Pulse on time (μs)	120	150	200
D	Gap voltage (volt)	40	60	80
E	Abrasive concentration (g/l)	0	6	12

C. Orthogonal Array

The Taguchi design of experiment makes use of Orthogonal Arrays (OA) to help design the experiment. By combining the orthogonal Latin squares in a unique manner Taguchi prepared a set of common orthogonal arrays. These are a set of tables of numbers, each of which can be used to lay out experiments for a number of experimental situations. Orthogonal array make it possible to carry out fractional factorial experiments in order to avoid numerous experimental work as well as to provide shortcuts for optimizing factors. The orthogonal arrays are determined by the number of factors and levels considered in the process In the present research work, one factor has two levels and other five factors have three levels. L_{18} orthogonal array is selected. This orthogonal array has 6 columns and 18 rows. The experiments are to be performed as per the orthogonal array and results are noted down.18 experiments are needed to study the entire machining parameter space using the L_{18} orthogonal array. The experimental layout using an L_{18} orthogonal array (coded levels) is shown in table VI.

TABLE VI DESIGN LAYOUT: L_{18} ORTHOGONAL ARRAY (CODED LEVEL VALUES)

Exp. No.	**Coded Variable Levels**				
	(A)	**(B)**	**(C)**	**(D)**	**(E)**
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	1	3
11	2	1	2	2	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

D. Signals to Noise Ratio

Much of Taguchi method is traditional but the orthogonal arrays are two level, three level and mixed level fractional factorial designs. The goal of the Taguchi method is to find control factor settings that generate acceptable responses natural environment and process variability. Its formula depends on whether the experimental goal is to maximize, minimize or match a target value of the quality characteristic of interest. Usually, there are three kinds of the performance characteristics in the analysis of the S/N ratio, i.e., (a) lower-the-better, (b) higher-the-better, and (c) nominal-the-better. The lower the surface roughness is always desirable in machining operations. So, the lower-the-better surface roughness is selected. The signal-to-noise ratio for the i^{th} performance characteristic in the j^{th} experiment can be expressed for lower-the-better as:

$$(S/N)_{ij} = -10*\mathrm{Log}_{10}\left\{\frac{1}{n}\sum_{k=1}^{n} y_{ijk}^{2}\right\}$$

III. RESULTS AND DISCUSSION

The 18 experiments runs were conducted and the values of WR along with the design matrix are listed in table VII. The results obtained as per table VII are used in Minitab 16.1 software to generate main effects graphic plots. Fig. 1 is the main effects plot for means for smaller the better wear ratio. Main effect plot for means depicts that the wear ratio is minimum at first level of polarity, third level of peak current, first level of pulse o n time, second level of gap voltage, and first level of concentration of titanium abrasives. Therefore the optimum condition for input machining variables is $A_1B_3C_1D_2E_1$. The main effects plot for signal to noise ratio

TABLE VII DESIGN LAYOUT: L_{18} ORTHOGONAL ARRAY (ACTUAL VALUES) AND EXPERIMENTAL RESULTS

Exp. Run	(A)	(B)	(C)	(D)	(E)	Average Value (WR)
1	+ve	6	120	40	0	0.03333
2	+ve	6	150	60	6	0.03704
3	+ve	6	200	80	12	0.03571
4	+ve	9	120	40	6	0.03448
5	+ve	9	150	60	12	0.03571
6	+ve	9	200	80	0	0.02941
7	+ve	12	120	60	0	0.03125
8	+ve	12	150	80	6	0.03030
9	+ve	12	200	40	12	0.03704
10	-ve	6	120	80	12	0.11111
11	-ve	6	150	40	0	0.17391
12	-ve	6	200	60	6	0.15385
13	-ve	9	120	60	12	0.16667
14	-ve	9	150	80	0	0.19231
15	-ve	9	200	40	6	0.20833
16	-ve	12	120	80	6	0.16000
17	-ve	12	150	40	12	0.16000
18	-ve	12	200	60	0	0.08333

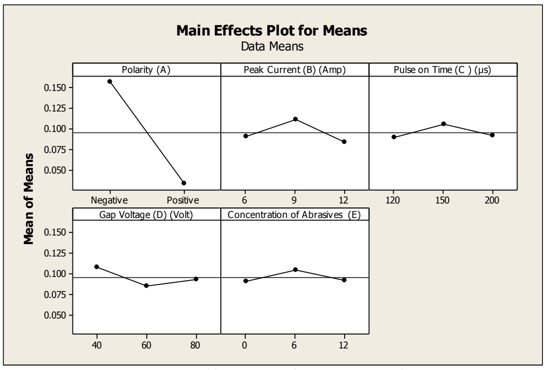

Fig. 1 Main effect plot for means for WR

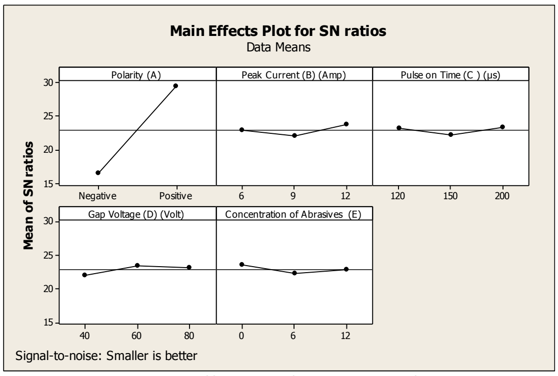

Fig. 2 Main effect plot for S/N ratio for WR

for smaller the better criterion is shown in Fig.2. This graphic plot is also used to depict the optimum level of input process factors the concerned performance measure. This plot always gives optimum level at peak position irrespective of category of performance characteristic. The same results are confirmed from this plot also.

A. Analysis of Variance

Analysis of variance (ANOVA) is a static treatment commonly applied for analysis the result of the OA experiment in product design and find how much variation of each influencing factor has contributed on output parameter i.e. surface roughness. It helps to identifies those factors which significantly affecting the experimental results. The results of ANOVA of the S/N data are given in table VIII. It observed the percentage contribution all factors towards the response characteristics of wear ratio. Table IX shows the delta values for various input machining variables to rank them with respect to their contribution towards wear ratio.

TABLE VIII ANALYSIS OF VARIANCE RESULTS FOR WR (S/N DATA)

Source	**DF***	**Seq SS**	**Adj SS**	**Adj MS**	**F#**	**P**
Polarity (A)	1	767.940	767.940	767.940	215.78	0.000
Peak Current (B)	2	478.471	478.471	239.236	67.22	0.034
Pulse on Time (C)	2	4.262	4.262	2.131	0.60	0.572
Gap Voltage (D)	2	7.418	7.418	3.709	1.04	0.396
Concentration of Abrasives (E)	2	4.516	4.516	2.258	0.63	0.555
Residual Error	8	28.471	28.471	3.559		
Total	17	821.267				

DF* = Degree of freedom

$F^{\#}$ = Tabulated value of F-ratio at 95% confidence level

TABLE IX RESPONSE TABLE FOR WR (S/N DATA)

Level	**Polarity**	**Peak Current**	**Pulse on Time**	**Gap Voltage**	**Abrasive concentration**
1	16.38	22.94	23.24	22.03	23.56
2	29.45	22.05	22.23	23.51	22.34
3		23.75	23.28	23.21	22.85
Delta	13.06	1.70	1.05	1.49	1.22
Rank	1	2	5	3	4

IV. CONCLUSIONS

Following are some conclusions which can be taken:

- WR at positive polarity is less than the WR at negative polarity.
- High peak current decreases the wear ratio in the process.
- Gap voltage increases from 40 to 60 decreases the WR.
- Pulse on time and abrasives concentration produce very little effect on WR.

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