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An Experimental Study of Material Removal Rate and Electrode Wear Rate of High Carbon-High Chromium Steel (AISI D3) In EDM Process Using Copper Tool Electrode

Avdesh Chandra Dixit* — ME, Deptt. & BIT, UPTU
Amit Kumar — ME, Deptt.SSET, SHIATS
Ravindra Kumar Singh — ME, Deptt. BIT, UPTU
Rahul Bajpai — ME, Deptt. BIT, UPTU

Abstract— This study investigates the influence of EDM parameters on MRR, EWR while machining of AISI D3 material. The parameters considered are pulse-on time (Ton), pulse off time (Toff) peak current (Ip) and fluid pressure. The experiments were performed on the die-sinking EDM machine fitted with a copper electrode. The experiments planned, conducted and analyzed using Taguchi method. It is found that the MRR is mainly influenced by (Ip); where as other factors have very less effect on material removal rate. Electrode wear rate is mainly influenced by peak current (Ip) and pulse on time (Ton), fluid pressure has no effect on electrode wear rate.

Keywords— EDM, MRR, EWR, HCHC Steel, Taguchi.

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional concept of machining which has been widely used to produce dies and molds. It is also used for finishing parts for aerospace and automotive industry and surgical components [1]. This technique has been developed in the late 1940s [2] where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid [3]. The electrode is moved toward the work piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric [4]. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece. The material is removed with the erosive effect of the electrical discharges from tool and work piece [5]. EDM does not make direct contact between the electrode and the work piece where it can eliminate mechanical stresses chatter and vibration problems during machining [1]. Materials of any hardness can be cut as long as the material can conduct electricity [6]. EDM techniques have developed in many areas. Trends on activities carried out by researchers depend on the interest of the researchers and the availability of the technology. In a book published in 1994, Rajurkar [7] has indicated some future trends activities in EDM: machining advanced materials, mirror surface finish using powder additives, ultrasonic-assisted EDM and control and automation.

With the above in mind, studies were conducted on EDM of AISI D3 using copper electrode to determine the MRR, EWR.

II. MATERIAL PROPERTIES

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A. Material Properties

The material used for this work is High carbon-high chromium steel (AISI D3) with density 7.7×100 kg/m3. The material is hardened to a hardness of 58 HRC. The work material properties and the photographic view of workpiece are given in table.1 and fig.1.

TABLE I
CHEMICAL COMPOSITION OF WORK PIECE (HCHC STEEL)

Element	C	S	P	Mn	Si	Cr	V	W
%	2.02	0.026	0.028	0.59	0.28	11.14	0.021	0.07

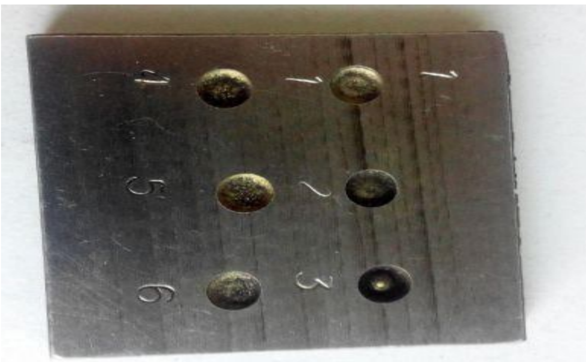

Fig. 1 HCHC steel used for experiment

B. Electrode Properties

The electrode material used for this work is 99.9 % pure copper. The physical properties of electrode and the photographic view of electrode are given in table.2 and fig.2.

TABLE 2
PHYSICAL PROPERTIES OF COPPER ELECTRODE

Specifications	**Value**
Density	8910 kg/m^3
Thermal Conductivity	392W/m-K
Melting Point	1083 ^{0}C
Electrical Resistivity	$1.69x10^{-8}\Omega$-m
Specific Heat Capacity	385 J/kg^{0}C

Fig.2 Copper tool used for experiment

C. Material Removal Rate(MRR)

Material removal rate is analysed with the help of following equation.

$$MRR = \frac{Wiw - Wfw}{T} \ gm/min \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
Wiw = initial weight of workpiece
Wfw = final weight of workpiece
T = machining time

D. Electrode Wear Rate(EWR)

Electrode wear rate is analysed with the following equation.

$$EWR = \frac{Wit - Wft}{T} \ gm/min \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
Wit = initial weight of electrode
Wft = final weight of electrode
T = machining time

E. Signal-to-Noise ratios (S/N ratio)

The main objective of the experiment is comparative study for MRR and EWR for EDM process parameters (Pulse on time, Pulse off time, Current, Fluid pressure). Table 9 shows the actual data of MRR and EWR along with its computed S/N ratio values. Whereas S/N ratios at each level of the MRR and EWR for copper and brass electrodes are calculated signal-to-noise, ration using bigger the better and smaller the better characteristic respectively
S/N ratio η is defined as

1. Bigger-the-Better

$$S/N = - 10 \log (1/n) \textstyle\sum_{i=1}^{n} 1/y^2 \ \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

2. Smaller-the-Better

$$S/N = - 10 \log (1/n) \textstyle\sum_{i=1}^{n} y^2 \ \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

III. EXPERIMENTATION

A. Equipments used in Experiment

In this experiment the whole work can be down by Electric Discharge Machine, model ELECTRONICA- ELECTRA-PULS C 3822 (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Fig.3. show the photographic view of EDM machine. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94°C) was used as dielectric fluid, with circular copper tool. EDM has maximum current capacity

20 amp. Experiments were conducted with positive polarity of electrode. The discharge current was applied in various steps in positive mode. It is capable of machining of hard material component such as high carbon high chromium, super alloys, ceramics, carbides, heat resistant steels etc. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc. AISI grades of tool steel is the most common scale used to identify various grades of tool steel. Individual alloys within a grade are given a number; for example: A2, O1, D2, P20 etc. A copper electrode of diameter 6 mm is used as electrode and the work piece of high carbon and high chromium is machined for 20 minutes to record the readings. Observations are taken in the form of mass of material removed per min (gram/min) for both work piece and copper electrode. Mass lost is measured with accuracy 0.001 milligram fig.1.show the photographic view of EDM machine. The data collected in MRR and EWR form is optimized and analyzed by Taguchi technique.

Fig.3 EDM used for experiment

B. Design of Experiment

In this experiment, the Taguchi method has been used to design the experimental parameters. This Taguchi approach can reduce the number of experiments required to obtain necessary data for optimization with the use of DOE. Therefore, DOE using and Taguchi approach has become a much more attractive tool for those who attempt the optimization of any system. A total of four parameters namely Current, pulse on time, pulse off time and fluid pressure were chosen for the controlling factor, and each parameter is designed to have three levels, namely small, medium, and large, denoted by 1, 2 and 3, as shown in the Table 3. Mean while, a L9 Orthogonal array table is used to conduct the experiments. This array table has 5 column and 9 rows as shown in Table4. Therefore only 9 experiments are needed to study the entire machining parameter space using the L9 orthogonal array. To obtain a more accurate result, each combination of experiments was repeated three times.

TABLE 3 -- MACHINING PARAMETERS AND THEIR LEVELS

Control Parameters	Level 1	Level 2
Pulse ON time (µs)	6	9
Pulse OFF time (µs)	2	5
Peak current (A)	5	8
Fluid Pressure(kg/cm^2)	1	2

TABLE 4-- TAGUCHI L9 ORTHOGONAL ARRAY DESIGN MATRIX

Exp.No.	Pulse on Time (µs)	Pulse off Time (µs)	Peak Current (Amp)	Fluid Pressure (kg/cm^2)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

TABLE 5 -- TAGUCHI L9 ORTHOGONAL ARRAY DESIGN MATRIX

Exp. No.	Pulse on Time (µ Sec)	Pulse off Time (µ Sec)	Current (A)	Fluid Pressure (Kg/cm^3)	M.R.R gm/min	E.W.R gm/min	S/N Ratio (MRR)	S/N Ratio (EWR)
1	6	2	5	1	0.036	0.0045	-28.8739	46.93575
2	6	5	8	2	0.0465	0.0005	-26.6509	66.0206
3	6	8	11	3	0.0555	0.001	-25.1141	60.0000
4	6	2	5	1	0.036	0.0045	-31.3727	66.0206
5	6	5	8	2	0.0465	0.0005	-27.7443	52.0412
6	6	8	11	3	0.0555	0.001	-40.9151	47.9588
7	6	2	5	1	0.036	0.0045	-36.7726	66.0206
8	6	5	8	2	0.0465	0.0005	-52.0412	67.9588
9	6	8	11	3	0.0555	0.001	-44.437	80.0000

TABLE 6 -- SIGNAL TO NOISE RATIO FOR MRR

LEVEL	PULSE ON	PULSE OFF	CURRENT	FLUID PRESSURE
1	0.046000	0.025833	0.015833	00.027667
2	0.025667	0.030000	0.026500	0.023333
3	0.007667	0.023500	0.037000	0.028333
DELTA	1	3	2	4
RANK	0.046000	0.025833	0.015833	00.027667

TABLE 7 -- RESPONSE MEAN FOR MRR

LEVEL	PULSE ON	PULSE OFF	CURRENT	FLUID PRESSURE
1	57.65	59.66	54.28	59.66
2	55.34	62.01	70.68	60.00
3	71.33	62.65	59.35	64.66
DELTA	15.99	7.99	16.40	5.00

TABLE 8-- SIGNAL TO NOISE RATIO FOR EWR

LEVEL	PULSE ON	PULSE OFF	CURRENT	FLUID PRESSURE
1	0.002000	0.001833	0.002967	0.002367
2	0.002333	0.001133	0.000367	0.001667
3	0.000333	0.001700	0.001333	0.000633
DELTA	0.002000	0.000700	0.002600	0.001733
RANK	0.002000	0.001833	0.002967	0.002367

TABLE 9-- RESPONSE MEAN FOR EWR

LEVEL	PULSE ON	PULSE OFF	CURRENT	FLUID PRESSURE
1	0.002000	0.001833	0.002967	0.002367
2	0.002333	0.001133	0.000367	0.001667
3	0.000333	0.001700	0.001333	0.000633
DELTA	0.002000	0.000700	0.002600	0.001733

IV. RESULT AND DISCUSSION

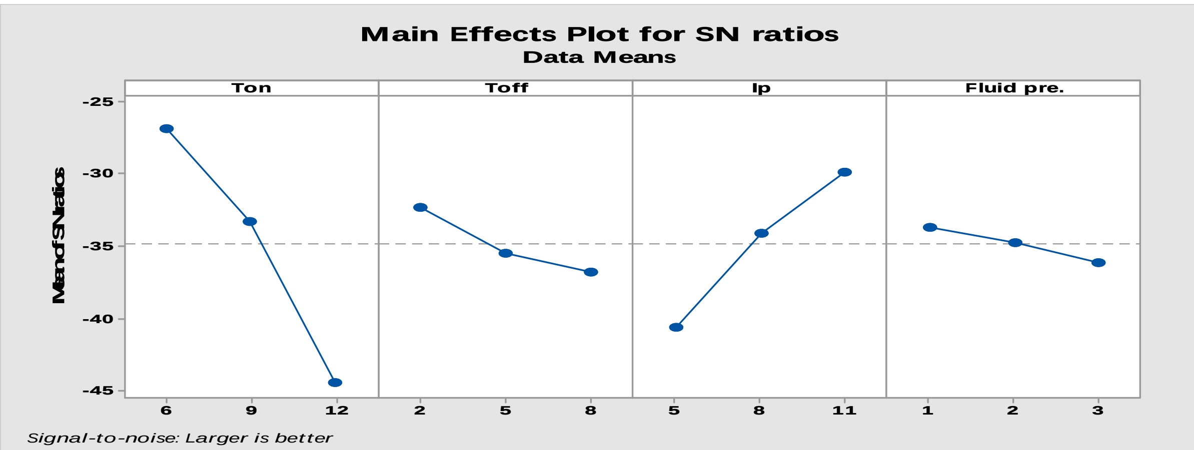

Fig. 4 Main effect plot for mean of SN Ratio of MRR

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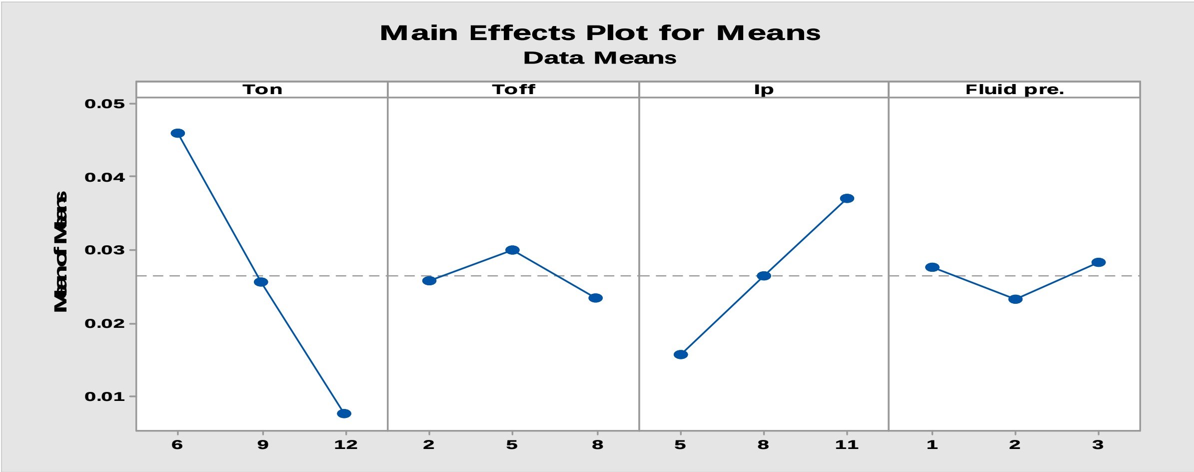

Fig. 5 Main effect plot for mean of means of MRR

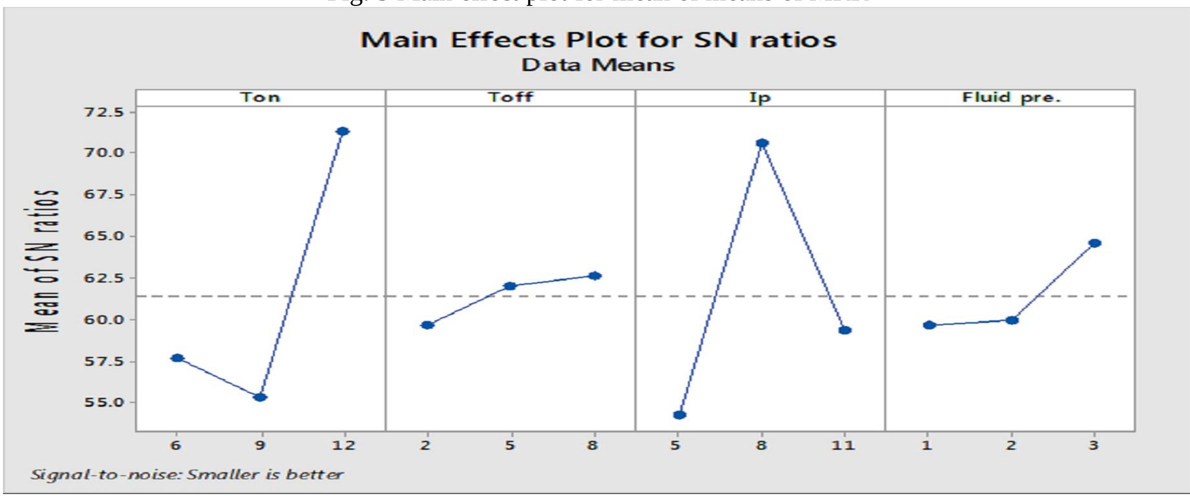

Fig. 6 Main effect plot for mean of SN Ratio of EWR

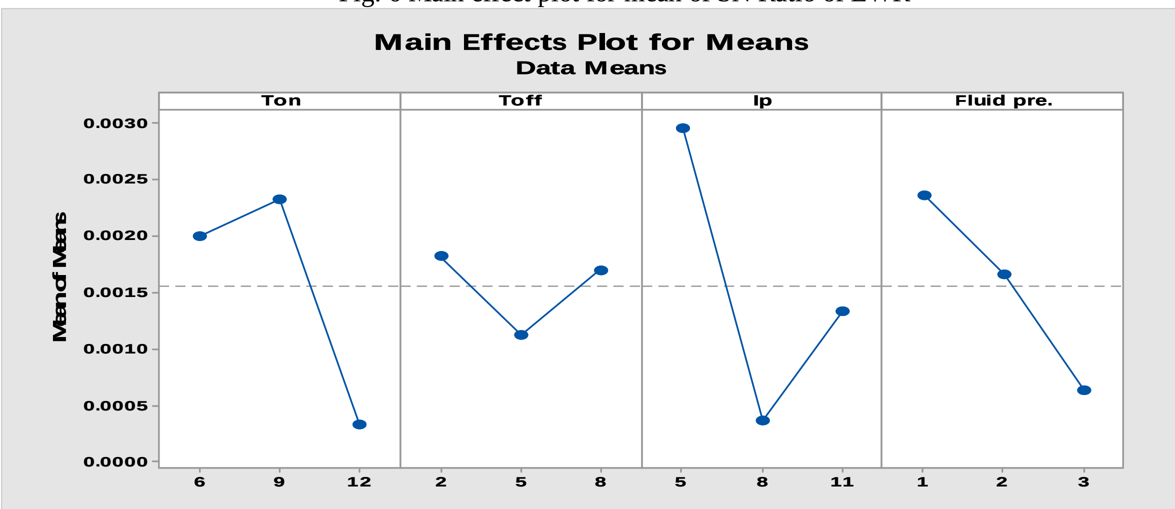

Fig. 7 Main effect plot for mean of means of EWR

V. CONCLUSIONS

The Experiment was performed with Copper by taking the entire parameter constant except of current, pulse on time, pulse off time and fluid pressure in die sinking EDM. The individual effect of current, pulse on time, pulse off time and fluid pressure is analyzed.

1-In case of MRR

The material removal rate (MRR) is mainly affected by peak current (Ip). Pulse on time (Ton) and fluid pressure have considerable effect on MRR.

Optimal setting of parameters Ton = 6, Toff = 2, Ip = 11Amp, Fluid pressure = 1kg/cm^2

2- In case of EWR

Electrode wear rate is mainly influenced by peak current (Ip) and pulse on time (Ton).and fluid pressure has no effect on electrode wear rate.

Optimal setting of parameters Ton = 9, Toff = 2, Ip = 5 Amp, Fluid pressure = 1kg/cm^2

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BIOGRAPHIES

Avdesh Chandra Dixit (Main Author)

P.G student, Mechanical Engineering Department of Bhabha Institute of Technology, Kanpur Dehat (U.P) India.

Amit Kumar

P.G Student, Production Engineering of SSET, SHIATS Nani Allahabad (U.P) India,

Ravindra Kumar Singh

P.G Student, Mechanical Engineering Department of Bhabha Institute of Technology Kanpur Dehat (U.P) India

Rahul Bajpai (Research Advisor)

Assistant Professor, Mechanical Engineering Department of Bhabha Institute of Technology Kanpur Dehat (U.P) India

