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EXPERIMENTAL INVESTIGATIONS OF ELECTRICAL DISCHARGE MACHINING OF HIGH CARBON HIGH CHROMIUM STEEL

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ABSTRACT

Electrical Discharge Machining (EDM) is one of the most successful and widely accepted processes for production of complicated shaped and tiny apertures with high accuracy. The objective of this paper is to illustrate the influence of various parameters of EDM on the machining characteristics. The effectiveness of EDM process has been evaluated in terms of the Material Removal Rate (MRR), Electrode Wear Rate (EWR), and the Surface Roughness (SR) of the work piece produced. High MRR, low EWR and high SR of the work piece are conflicting goals, which cannot be achieved simultaneously with a particular combination of control settings. Various parameters have to be controlled separately generally one at time, to study their influence on response variables. In the present study, the influence of current intensities on the MRR, EWR, and SR has been investigated for different electrode materials (Aluminum, Copper, and Graphite).

Keywords: *EDM, Surface Roughness, MRR, EWR.*

1. Introduction

The electrical discharge machining (EDM) is one of the major manufacturing processes widely used in die and mould making, to generate deep dies and three dimensional recesses cavities, in roughing and finishing operations [1]. EDM process is based on thermoelectric energy exchange between the work piece and an electrode. A current discharge occurs in a small gap between the work piece and the electrode at high pulse rate that removes the material through melting and vaporizing [1, 3]. Thousands of electrical discharges per second are generated depending upon the pulse rate and each discharge produces a tiny crater on the metal surface, thus reproduce the shape of the tool electrodes into the work piece [4]. Further, the electrode is slowly advanced towards the workpiece to obtain the required depth of cavity. The material is removed with the erosive effect of the electrical discharges between tool and workpiece [5]. A dielectric fluid flushes out the chips formed at every discharge. Hard material can easily be machined using EDM process as long as it is conductive. EDM phenomenon can be considered three stages namely, application of adequate electrical energy, dielectric breakdown, sparking, and erosion of work material [6].

Since, there is no physical contact between the tool and electrode during EDM process; as a result, there are no cutting forces involved. This eliminates the chances of mechanical stress, chatter and vibration problems, as known in traditional machining [1, 7]. However, electrode wear takes place during the EDM operation along with the erosion of workpiece. Stiff market competition and continuously growing demand for improved product Performance has lead to the development of an ever-growing variety and quality of materials. High Carbon High Chromium Steel posse's properties like high strength to weight ratio, high corrosion resistance and oxidation resistance, and chemical inertness [12]. Although these properties results in superior product performance, their precise shaping and /or machining can be difficult. Conventional machining or shaping methods are results in very high machining cost, and degradation of strength and some useful properties. Therefore, there is a need to develop processes capable of giving adequate material removal rate without destructive the material properties. EDM is finding its application in the new fields such as sports, medical and surgical instruments, optical, dental and artificial jewellery industries, including automotive research and development areas. The rate, at which the electrode wears, is considerably less than that of the wear rate of the work material [8]. The metal removal rate and surface finish are controlled by the frequency and intensity of the spark. It has been found that high frequency and low amperage settings give the best surface finish [9, 13]. Surface roughness and dimensional accuracy of spark-eroded work material depend on the value of discharge current, electrode material and polarity [10].

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2. Experimental Setup

The workpiece of High Carbon High Chromium steel and electrodes made of aluminum, copper, and graphite were selected for experimentation. The diameter of electrodes was taken as 9.96 mm (Fig. 1). The experiment was started with copper electrode. Initial masses of workpiece and copper electrode were measured using electronic balance (Mettlor-Toledogmbtt Griefensee, Switzerland, Type-BD202, SNR 04943, Least Count = 0.01g). Commercial grade kerosene oil was used as dielectric fluid. The first cut was made at 2 Amps current for a depth of 5mm. Selecting machining parameters with base value = 5, duration = 10, and ignition = 4. After the machining operation, the electrode and workpiece were weighed again to calculate the amount of metal eroded. The operation was repeated for 4 Amps, 6 Amps, 8 Amps, 10 Amps, and 12 Amps. Time taken for each cut was noted in minutes (Table 6).

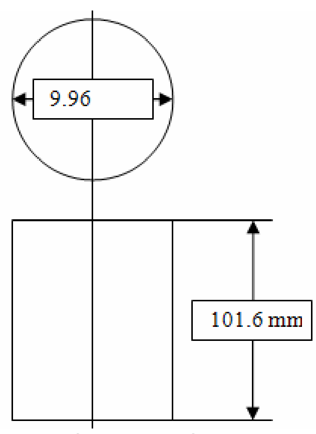

Fig. 1 Specifications of Electrode Used

The experiments were repeated with other electrode materials i.e. aluminum, and graphite with High Carbon High Chromium Steel workpiece. The composition of High Carbon High Chromium Steel is given in Table 1.

Table 1: Composition of High Carbon High Chromium (Wt %)

Silicon	Manganese	Chromium	Carbon
2.0	0.30	0.30	12

3. Die Sinking EDM Machine and Parameters

For the sake of experimentation, a die sinking EDM machine (model T-3822 manufactured by Electronica, Pune) has been used. Also, a jet flushing system in order to flush out the EDM process debris from the gap zone was used. Kerosene oil has been used as dielectric fluid. Three electrodes made of copper, aluminum, and graphite with negative polarity was selected for experimentation. The specification of the machine are indicated in Table 2.

Table 2: Technical Specifications of EDM Machine (Model T-3822 Electronica)

S.No	Items	Description
1	Height	1300mm
2	Width	730mm
3	Depth	840mm
4	Travel of quill	150mm
5	Reading accuracy	0.05 mm
6	Mounting surface	380*220 mm
7	Work piece height	125 mm
8	Travel .X. axis	200 mm
9	Travel .y. axis	125 mm
10	Net weight approx	325 kg
11	Work piece weight	80 kg
12	Tank capacity	150 liters
13	Machine current range	1-15 Amp

The various parameters of machining are current intensity (I), pulse duration (ti), duty cycle (η), open-circuit voltage (V) and dielectric flushing pressure (P). The intensity (I) depends on the power level that can be supplied by the machine transformer. The intensity values used in the EDM machine programming are the values of the peak intensity (Ip), which is applied between the electrode and the part to be work piece. Pulse time or on time (ti) is the duration of time (in µs) the current is allowed to flow per cycle. Duty cycle (η) factor is calculated by dividing pulse time by the total cycle time (i.e., pulse time plus pause time), where pause times or off time (to) be the duration of time (in µs) between two consecutive sparks [11]. Open-circuit voltage (v) is the value of the electric energy applied between the part to be machined and the electrode just before the discharge is produced. Air gap (called as spark gap) is the distance between the electrode and the work piece during the process of EDM. It is control by the Gap control. Finally, the dielectric flushing pressure (P) is the pressure of the dielectric jet removing the EDM splinter or debris from the gap zone. This pressure value is measured by a pressure gauge in the EDM machine. The current plays an important role in defining the process characteristics as well as the quality characteristics therefore, current was selected as a process variables to study its influence on the MRR, EWR & surface roughness while electric discharge machining of High Carbon High Chromium Steel.

4. Response of Study

The responses selected for this study are material removal rate (MRR), electrode wear rate (EWR) and surface roughness. These variables are defined by equation (1) and (2), respectively as follow:

If D= Diameter of tool electrode

L= Depth of cut

T= Time taken to make the cut, then

$$MRR = \frac{\Pi D^2 L}{4T} \qquad (!)$$

EWR = (Weight of material eroded from electrode per unit time/ Weight of material eroded from workpiece in the same time) *(2)*

The Surface Roughness of an EDM product can be defined as a chip-forming process where the chips are spherical debris melted by sparks [12]. So the surface roughness depends on the size of spark crater. Ra value of Surface roughness has been found using Talysurf meter whose specification is given in Table 3.

Table 3: Technical Specifications of Talysurf Meter

S.No.	Items	Description
1	Measure range	350Hm(-200Hm to 150Hm)
2	Stylus material	Diamond
3	Cut off length	0.8mm
4	Transverse speed	0.5mm/s
5	Calibration value	3.00m
6	Surface roughness parameter found	Ra

Roughness has been calculated correspond to various combination of tool and workpiece materials i.e. High Carbon High Chromium Steel and copper, High Carbon High Chromium Steel and graphite, High Carbon High Chromium Steel and aluminum.

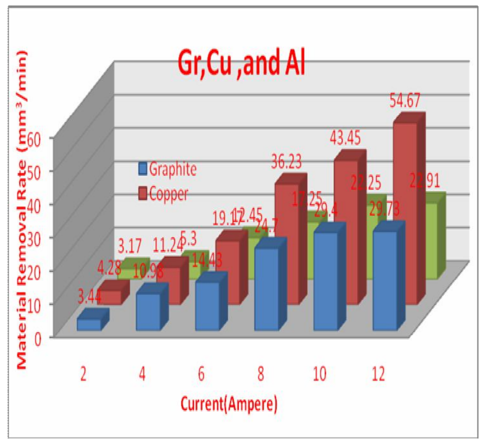

Fig. 2 Material Removal Rates for all Electrodes

5. Result and Analysis

5.1 Material removal rate (MRR)

It is seen that the trend of MRR increases with pulse current for all electrodes selected for experimentation with High Carbon High Chromium steel [13]. Tables 4,5, and 6 shows the experimental readings of the material removal rate using the electrodes (graphite, aluminum and copper) at various discharge currents. Fig. 2 illustrates the material removal rates corresponding to three electrodes indicated by different colors. Table 7 indicates the calculated values of MRR for High Carbon High Chromium Steel work material with respect to copper, graphite and aluminum electrodes for various peak intensities. For modeling of the process, Excel 2007 has been used and the following mathematical equations (Polynomial) have been derived corresponding of the observations. The equations are as follows.

a) *For Aluminum Electrode*
$MRR = -0.284I^2 + 6.403I - 4.205$

b) *For Copper Electrode*
$MRR = 0.329I^2 + 8.139I - 5.314$

c) *For Graphite Electrode*
$MRR = - 0.554I^2 + 9.509I - 6.093$

The equation can be used to calculate MRR for various electrodes corresponding to various peak currents.

Table 4: Experiment Readings using Graphite as Electrode Material

A	B	C	D	E	F	G	H	I
1	2	113.00	2446	2443	03	43.86	43.84	0.02
2	4	35.47	2443	2440	03	43.55	43.53	0.02
3	6	27.00	2440	2437	03	43.45	43.43	0.02
4	8	15.77	2437	2434	03	43.64	43.62	0.02
5	10	13.25	2434	2431	03	43.71	43.69	0.02
6	12	13.10	2431	2428	03	39.38	39.36	0.02

Table 5: Experiment Readings using Aluminum as Electrode Material

A	B	C	D	E	F	G	H	I
1	2	122.55	2467	2464	03	16.52	16.29	0.23
2	4	73.40	2464	2461	03	15.79	15.53	0.26
3	6	31.30	2461	2458	03	14.88	14.61	0.27
4	8	22.58	2456	2453	03	13.86	13.61	0.25
5	10	17.51	2453	2450	03	17.76	17.50	0.26
6	12	17.00	2428	2425	03	13.57	13.24	0.33

Table 6: Experiment Readings using Copper as Electrode Material

A	B	C	D	E	F	G	H	I
1	2	91.78	2491	2488	03	37.16	36.83	0.33
2	4	34.66	2488	2485	03	53.63	53.49	0.14
3	6	20.32	2485	2482	03	48.63	48.43	0.20
4	8	10.75	2479	2476	03	39.26	38.87	0.39
5	10	8.96	2476	2473	03	47.96	47.68	0.28
6	12	8.82	2473	2470	03	51.73	51.30	0.43

A - S.No.; B - I(amps); C - Time taken for cut (min); D - Initial weight of HCHCr before cut (g); E - Final weight of HCHCr after cut (g); F - Difference in weight of HCHCr (g); G - Initial weight of Cu tool (g); H - Final weight of Cu tool (g); I - Difference in weight Cu tool (g)

Table 7: MRR for all Electrodes

I (amps)	MRR for Al	MRR for Cu	MRR for Graphite
2	3.17	4.28	3.44
4	5.30	11.24	10.98
6	12.45	19.17	14.43
8	17.25	36.23	24.70
10	22.25	43.45	29.40
12	22.91	54.67	29.43

5.2 Electrode wear rate (EWR)

In EDM process, both the tool and work piece are eroded simultaneously during discharge. The electrode wear rate is calculated as the ratio of weight of material eroded from the tool to weight of material eroded from work piece at the same time. Table 8 indicates the calculated values of EWR for High Carbon High Chromium Steel work material with respect to copper, graphite and aluminum electrodes for various peak intensities. Figure 3 illustrate the electrode wear rate corresponding to three electrodes indicated by different colors. For modeling of the process, Excel 2007 has been used and the following mathematical equations (Polynomial) have been derived corresponding to the observations. The equations are as follow:

a) *For Aluminum Electrode*
$EWR = 0.001I^2+0.005I+0.085$

b) *For Copper Electrode*
$EWR = 0.006I^2-0.034I+0.121$

c) *For Graphite Electrode*
$EWR = 0.006I$

The equation can be used to calculate EWR for various electrodes corresponding to various peak currents.

Table 8: EWR for all Electrodes

I (amps)	EWR for Al	EWR for Cu	EWR for Graphite
2	0.076	0.11	0.006
4	0.086	0.05	0.006
6	0.09	0.06	0.006
8	0.08	0.13	0.006
10	0.086	0.09	0.006
12	0.11	0.14	0.006

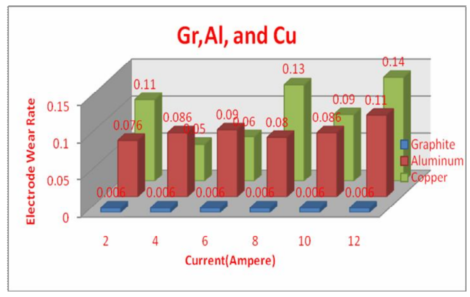

Fig. 3 Electrode Wear Rate for all Electrode

5.3 Surface roughness

From the results of the observations it was that copper electrode with High Carbon High Chromium Steel results in more surface roughness values (Ra). However for Al and graphite different trend emerged. For aluminum electrode, pattern of Ra value is zigzag while for graphite first Ra value decreases continuously and then increases. Surface texture of the machined work piece is found using Talysurf meter Mitutoyo make measurement equipment. The measurements were carried out three times on the bottom of the EDM cavity. Table 9 indicates the calculated values of surface roughness for High Carbon High Chromium Steel work material with respect to copper, graphite and aluminum electrodes for various peak intensities.

Fig. 4 illustrates the surface roughness corresponding to three electrodes indicated by different colours. For modeling of the process, Excel 2007 has been used and the following mathematical equations (Polynomial) have been derived corresponding of the observations. The equations are as follows.

a) *For aluminum Electrode*
$SR=-0.100I^2+1.667I+3.864$

b) *For Copper Electrode*
$SR= -0.085I^2+1.720I+5.536$

c) *For Graphite Electrode*
$SR=0.256I^2-1.665I+10.21$

The equation can be used to calculate Ra for various electrodes corresponding to various peak currents.

Table 9: Surface Roughness for all Electrodes

I (amps)	Ra for Aluminum	Ra for Copper	Ra for Graphite
2	5.98	7.51	8.99
4	4.63	8.42	8.15
6	11.20	8.74	6.62
8	6.72	11.59	7.06
10	10.31	13.38	10.31
12	12.22	14.97	12.52

6. Conclusion

The three tool electrodes (Copper, Aluminum, and Graphite) have been used for EDM of High Carbon High Chromium Steel work material. These experimental results are summarized below.

a) At low ampere current, the material removal rate is low which increases gradually as current increases.
b) For EDM of High Carbon High Chromium Steel, material removal rate is highest with copper electrode.
c) Electrode wear rate remains constant for graphite electrode, but it varies for aluminum and copper electrode.
d) Surface finish depends upon current rating.
e) Copper electrode with High Carbon High Chromium Steel gives better surface finish.

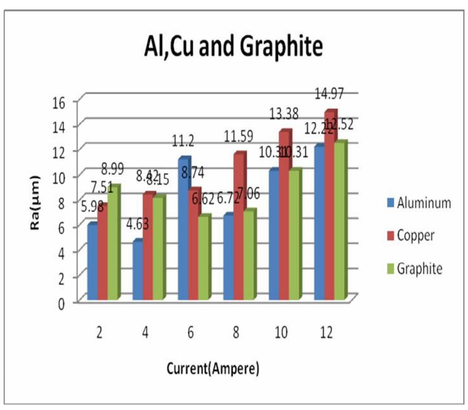

Fig. 4 Surface Roughness for all Electrodes

References

1. *Abbas Norliana Mohd, Solomon Darius G and Bahari Md. Fuad (2007), "A Review on Current Research Trends in Electrical Discharge Machining (EDM)", International Journal of Machine Tools and Manufacturing, Vol. 47(7-8), 1214-1228.*

2. *Amorim F L and Weingaertner W L (2003), "Die-Sinking EDM of AISI P20 Tool Steel under Rough Machining using Copper Electrodes", COBEF - Congresso Brasileiro De Engenharia De Fabricação. Uberlândia-MG, Vol. 1, 1 - 5.*

3. *Ekmekci Bulent (2007),"Residual Stresses and White Layer in Electrical Discharge Machining (EDM)", Applied Surface Science, Vol. 253(23), 9234-9240.*

4. *Guu Y H and Hou Max Ti-Kuang (2007), "Effect of Machining Parameters on Surface Textures in EDM of Fe-Mn-Al Alloy", Materials Science and Engineering: A, Vol. 466(1-2), 61-67.*

5. *Hascalik Ahmet and Caydas Ulas (2007), "Electrical Discharge Machining of Titanium Alloy (Ti-6Al-4V)", Applied Surface Science, Vol. 253(22), 9007-9016.*

6. *Hu C F, Zhou Y C and Bao Y W (2006), "Material Removal Rate and Surface Damage in EDM of Ti_3SiC_2 Ceramic", Ceramics International, Vol. 34(3), 537-541.*

7. *Kharana A K, Sarkar B R and Bhattacharya B (2007), "Performance of ZrB2-Cu Composites as an EDM Electrode", Journal of Material Processing Technology, Vol. 183(1), 122-126.*

8. *Kumar B V Manoj, Kumar J Ram, Basu Bikramjit and Kang S (2007), "Electro-Discharge Machining Performance of TiCN-Based Cermets", International Journal of Refractory Metals and Hard Materials, Vol. 25, 293-299.*

9. *Lauwers B, Kruth J P, Liu W, Eeraerts W, Schacht B and Bleys P (2004), "Investigation of Material Removal Mechanism in EDM of Composite Ceramic Materials", Journal of Materials Processing Technology, Vol. 149(1-3), 347–352.*

10. *Luis C J and Puertas I (2007), "Methodology for Developing Technology Tables used in EDM Processes of Conductive Ceramics", Journal of Materials Processing Technology, Vol. 189(1-3), 301-309.*

11. *Marafona J (2006), "Black Layer Characterization and Electrode Wear Ratio in Electrical Discharge Machining (EDM)", Journal of Material Processing Technology, Vol. 184(1-3), 27-31.*

12. *Singh S, Maheshwari S and Pandey P C (2004), "Some Investigations into the Electric Discharge Machining of Hardened Tool Steel using Different Electrode Materials", Journal of Materials Processing Technology, Vol. 149(1-3), 272–277.*

13. *Rakesh P K (2008), "Investigating Electrical Discharge Machining of High Carbon High Chromium with Different Tool Electrodes for Optimum Machining Condition", M.Tech Dissertation approved at Dr. B.R. Ambedkar National Institute of Engineering and Technology, Jalandhar, India.*

