Experimental Investigations On Electrical Discharge Machining of SS 316L

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Abstract – **This study presents the experimental investigations of the machining characteristics of stainless steel 316L through electric discharge machining. EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies, and sections of complex geometry and intricate shapes. The work piece material selected in this experiment is SS 316 L which is used in various industrial applications. Cylindrical copper electrode having a size of Ø13 mm is used to machine stainless steel 316L materials. The experiments are performed as per the Box Behniken design. The results indicate that MRR and TWR is strongly influenced by current(A) and Pulse on time(tw) . Further, effect of parameters on MRR and TWR are studied using response surface plots and reported here.**

Index Terms— MRR-Material Removal Rate,TWR-Tool wear rate,EDM-Electric Discharge Machining,Ra-surface roughness (avg) (µm)

I. INTRODUCTION

Electrical discharge machining is a non-traditional machining method. It is a process for eroding and removing material from electrically conductive materials by use of consecutive electric sparks. The process is carried out in a dielectric liquid with a small gap between the work piece and electrode. Each electrical discharge generates heat energy in a narrow area that locally melts, evaporates and even ionizes work piece material. 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. Some of the melted and all of the evaporated material is then quenched and flushed away by dielectric liquid and the remaining melt recast on the finished surface[1]. Important Parameters of EDM process are

Spark on-time (Ton): The duration of time (µs) the current is allowed to flow per cycle.

Spark off-time (Toff): the duration of time in between the sparks generated. During this time the molten material gets removed from the gap between the electrode and the workpiece.

Voltage (V): It is the potential difference applied between the electrode and the workpiece.

Discharge Current (Ip): It is the current flowing through the electrode and is measured in amp.

Duty cycle (ô): It is the ratio of Ton divided by total cycle time (Ton+Toff)[2].

The quality of an EDM product is usually evaluated in terms of its surface integrity, which is characterized by the surface roughness, existence of surface cracks and residual stresses. There are many process variables that affect the surface integrity such as pulse duration, peak current, open gap voltage, electrode polarity, material properties of the tool electrode, workpiece and dielectric liquid, debris concentration and even size of the electrode[1].

II.LITERATURE REVIEW

The studies carried out in these papers are mainly concerned with the EDM parameters such as voltage, current, duty cycle, pulse on time etc. and how these affect the machining characteristics such has MRR, TWR, etc. B.S. Reddy et al. [1] carried out a study on the effect EDM parameters over MRR and TWR. Mixed factorial design of experiments had been employed to achieve the desired results. The parameters in the decreasing order of importance for; MRR: servo, duty cycle, current and voltage. TWR: current, duty cycle and servo. M.M. Rahman et al. [2] investigated the effect on pulse duration and peak current on the performance characteristics of the EDM. The result obtain were: the current and pulse on time greatly affected the MRR and TWR, the MRR increases linearly with increasing current, the SR increases linearly with current for different pulse on time, TWR increased with increasing peak current while decreased when the pulse on time was increased. I. Puertas et al. [3] carried out results which showed that pulse time factor and intensity were the most important in case of SR while the duty cycle factor was not significant at all. The intensity factor was again influential in case of TWR. The important factors in case of MRR were the intensity followed by pulse time and the duty cycle. S.H. Tomadi et al. [4] investigated the machining of tungsten carbide with copper tungsten as electrode. The full factorial design of experiments was used for analyzing the parameters. In case of SR, the important factors were pulse off time and voltage while current and pulse on time were not significant. For MRR the most influential was pulse on time followed by voltage, current and pulse off time. Finally in case of TWR the important factor was pulse off time followed by peak current.

III. EXPERIMENTAL DETAILS

The experiments were conducted using an Electronica C-425 die-sinking machine. The material removal process are carried out by EDM process. The job material was typical Stainless Steel 316L with following composition: 0.03% C, 16-18.5% Cr, 10-14% Ni, 2-3% Mo, 2% Mn, 1% Si, 0.045% P, 0.03% S rest Fe. The size of each work sample is 70mm×40mm×4mm . To study the influences of various EDM process parameters on material removal rate and tool wear rate, a tool diameter of 13mm was selected for sparking a blind hole on Stainless Steel for a period of 10 min. Copper was considered as electrode material for the present experimental studies since it worked better in combination with Stainless steel workpiece as compared to other tool materials. Variable pulsed DC supply was used for experimentation. The effects of peak current and pulse-on duration were verified through the pilot experimentations and pulse current , pulse-on time and voltage were varied from 5 to 15A , 40 to 120,and 30 to 50v respectively. During experiments kept the duty factor 65% constant. With help of Box Behniken design which has 3 columns and 15 rows (table 3) which is a three level process parameter.The calculation of the material removal rate and tool wear rate were carried out and reading are tabled.

IV.WORKIPECE MATERIAL

The workpiece selected for this experiment is TYPE 316L is a grade of austenitic chromium nickel stainless steel um. Grade 316L, the low carbon version of 316 and is immune from sensitization (grain boundary carbide precipitation). 316L stainless steel is a Chromium-Nickel stainless steel with added molybdenum to increase corrosion resistance and mechanical properties. [3].

Properties of SS 316 L

Table.1

Mechanical Properties	**Typical**	**Minimum**
Tensile Strength	600MPa	485MPa
Proof Strength, (off set 0.2%)	310MPa	170MPa
Elongation (Percent in 50mm)	60	40
Hardness(Brinell)	217	
Hardness (Rockwell)	95	
Endurance (fatigue Limit)	240MPa	

V.TOOL MATERIAL

The tools selected for this experiment is a C11000 Electrolytic Copper, which is a ductile metal with high thermal and electric conductivity. Pure copper is soft and mallable, freshly exposed copper surface has reddish-orange colour. It is used as conductor of heat and electricity and constituent of various metal alloys.

The properties of copper materials

Density	8.89g/cc
Tensile strength	220MPa
Tensile strength	69 MPa
Poisons ratio	0.333
Melting point	1065-1083^{o}c

Table.2

VI. EXPERIMENTAL PROCEDURE

Initially workpiece and copper tool materials are weighted each time before the machining process are carried out. The electrodes and workpiece after machining process are cleaned to remove the carbon deposition, and are weighted measuring using electronic weighing machine, which has a resolution of 0.0001 grams. Each experiment was repeated for three times and the averaged of MRR in term of (grams/min) and TWR in terms of (grams/min). The Materials Removal Rate and Tools Wear Rate are defined by a formula

$$MRR = \frac{\mathbf{wi - wf}}{\mathbf{t}}$$

$$TWR = \frac{ti - tf}{t}$$

Reading are tabulated

EXP NO	Ip (A)	Tw	V	MRR (mg/min)	TWR(mg/min)
1	5	40	40	8.69	0.1296
2	15	40	40	122.2	55.446
3	5	120	40	27.6	0.24
4	15	120	40	235.2	8.55
5	5	80	30	23.04	0.168
6	15	80	30	195.12	24.45
7	5	80	50	6.78	0.27
8	15	80	50	43.74	8.058
9	10	40	30	125.34	24.678
10	10	120	30	139.44	0.828
11	10	40	50	38.16	12.768
12	10	120	50	98.7	2.136
13	10	80	40	124.2	4.95
14	10	80	40	121.2	4.428
15	10	80	40	123.54	3.126

Table.3

VII.EXPERIMENTAL ANALYSIS

Response Surface Regression: MRR (mg/min) versus Ip (A), Tw, V

Estimated Regression Coefficients for MRR (mg/min)

Term	Coef	SE Coef	T	P
Constant	-525.495	224.353	2.342	0.066
IP(A)	53.988	12.85	4.201	0.008
Tw	-2.216	1.606	-1.323	0.243
V	22.269	9.215	2.416	0.06
IP(A)*IP(A)	-1.156	**0.435**	**-2.658**	**0.045**
Tw*Tw	0.003	0.007	0.399	0.706
V*V	-0.269	0.109	-2.475	0.056
IP(A) *Tw	0.118	0.052	2.252	0.074
IP(A)*V	-0.676	0.209	-3.234	0.023
Tw*V	0.029	0.026	1.111	0.317

Table.4

S = 20.8908 PRESS = 34845.6
R-Sq = 96.72% R-Sq(pred) = 47.59%
R-Sq(adj) = 90.81%

Analysis of Variance for MRR (mg/min)

Source	DF	Seq SS	Ad Ms	F	P
Regression	9	64307.8	7145.3	16.4	0.003
Linear	3	51384.7	3688.4	8.45	0.021
Square	3	5606.4	1868.8	4.28	0.076
Interation	3	7316.8	2438.9	5.59	0.047
Residual error	5	2182.1	436.42		
Lack of fit	3	2177.2	725.72	292	0.003
Pure error	2	5	2.49		
Total	14	66490			

Table.4

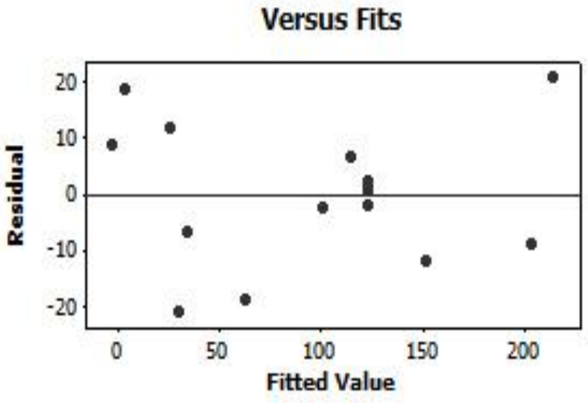

Fig. 1

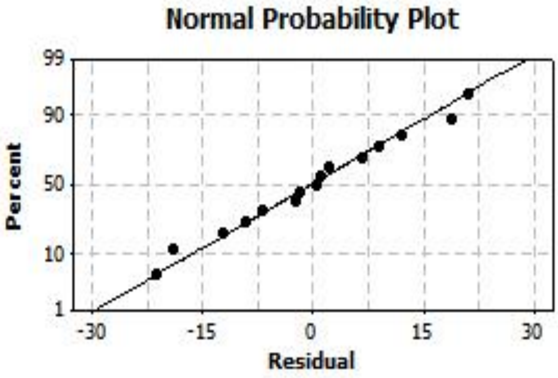

Fig. 2

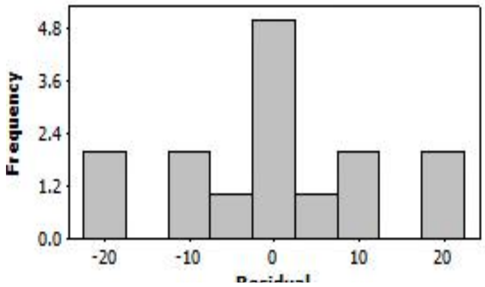

Fig. 3

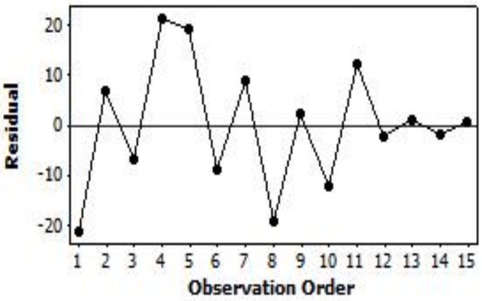

Fig. 4

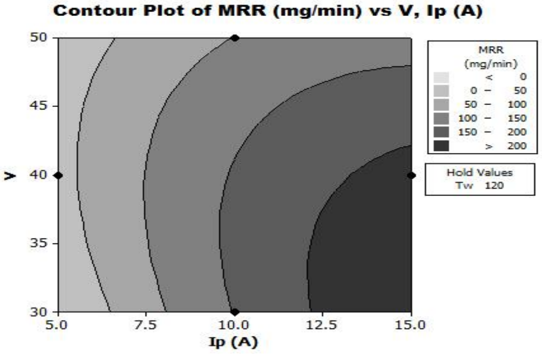

Fig. 6

Fig.6 & 8 shows that when current increases with least voltage, MRR increases significant. We can see that at 15A and voltage at 30v material removal rate is high. From this it is clear that MRR mainly depends on current and voltage

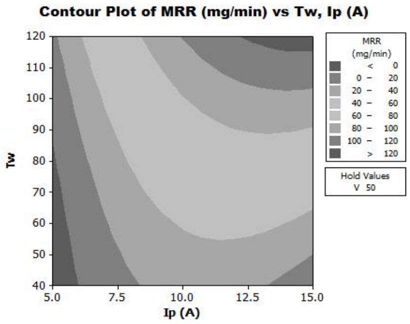

Fig. 7

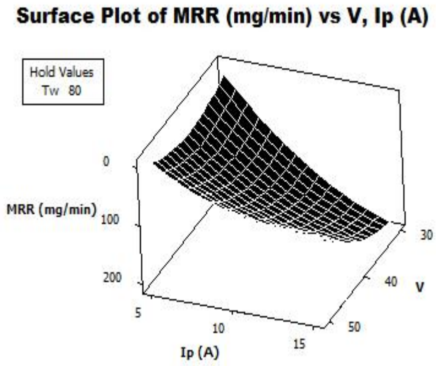

Fig. 8

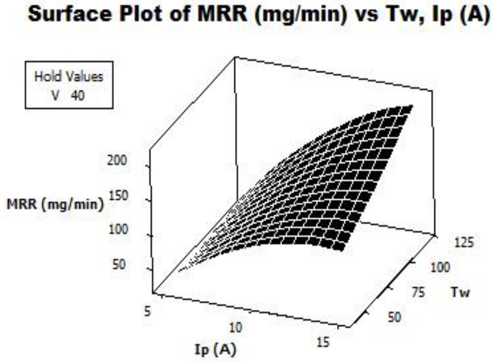

Fig.9

Fig.7 &9 shows that When current increases with pulse on time, MRR increases significant. We can see that at 12A and pulse on time at 125 µs maximum material removal rate take place. From this it is clear that MRR mainly dependents on current , pulse on time and less significant on voltage.

From table4 it can be concluded that all the factors except for the interaction between V*V , Ip (A)*V, Ip*Ip,Tw,Ip,V are significant as the value of $p<0.05$. The non significant response are Tw,Tw*Tw,IP(A) *IP(A),Tw*V because this value is less t**han p<0.05**Subsequently in the following columns degree of freedom (DF), Sum of squares (Seq SS), adjusted mean of square (Adj MS), F distribution and Probability are calculated respectively.The standard deviation of errors in the modeling, S=20.8098 . R2=96.72% which indicates that the model is capable of predicting the response with a high accuracy.

Response Surface Regression: TWR(mg/min) versus Ip (A), Tw, V

Estimated Regression Coefficients for TWR(mg/min)

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	-7.221	58.6661	-0.123	0.907
IP(A)	6.368	3.3601	1.895	0.117
Tw	-0.6863	0.42	-1.634	0.163
V	0.5958	2.409	0.247	**0.815**
IP(A)*IP(A)	0.201	**0.113**	**1.769**	0.137
Tw*Tw	0.0043	0.001	2.425	0.06
V*V	-0.0096	0.028	-0.338	0.749
IP(A) *Tw	-0.0587	0.0137	-4.302	0.008
IP(A)*V	-0.0824	0.0546	-1.51	0.192
Tw*V	0.0082	0.0068	1.21	0.28

Table.5

S = 5.46273 PRESS = 2363.05

R-Sq = 95.24% R-Sq(pred) = 24.67%

R-Sq(adj) = 86.68%

Analysis of Variance for TWR(mg/min)

Source	**DF**	**Seq SS**	**Ad Ms**	**F**	**P**
Regression	9	2987.7	331.97	11.1	0.008
Linear	3	2060.68	72.589	2.44	0.18
Square	3	262.94	87.645	2.94	0.138
Interation	3	664.09	221.36	7.42	0.027
Residual error	5	149.21	29.841		
Lack of fit	3	147.44	147.44	49.1	0.018
Pure error	2	1.76	0.882		
Total	14	66490			

Table.6

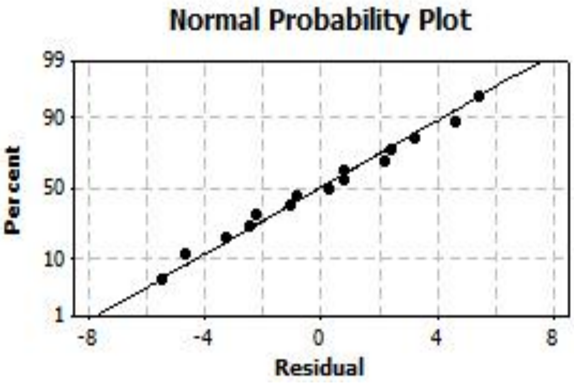

Fig. 10

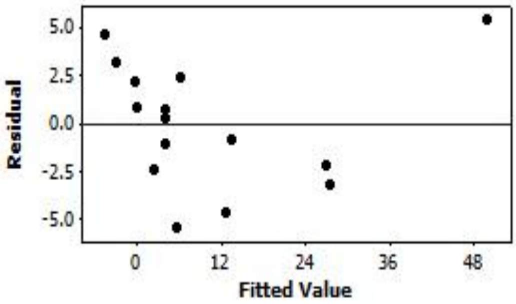

Fig. 11

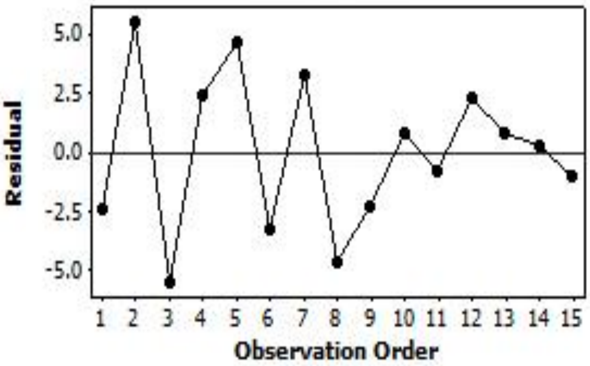

Fig. 12

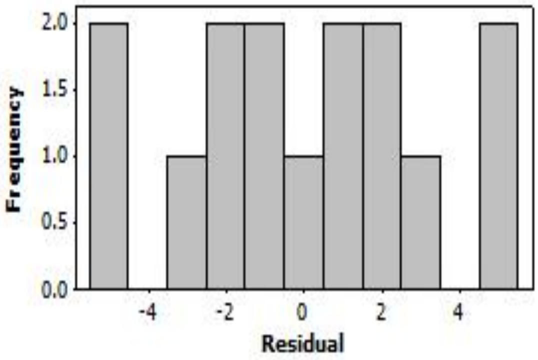

Fig. 13

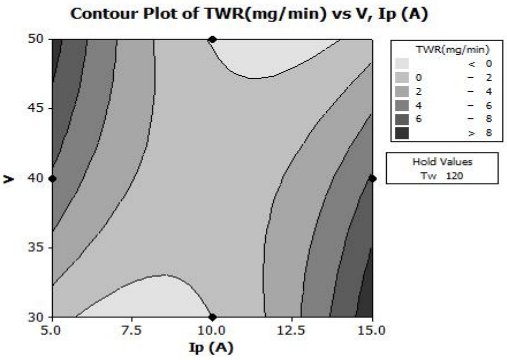

Fig. 14

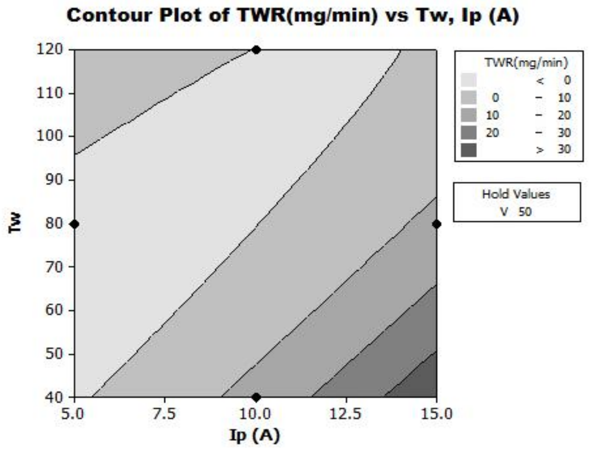

Fig. 15

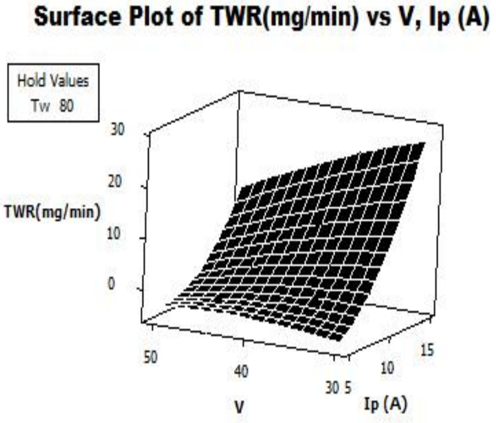

Fig. 16

In fig14 & 16 shows that tool wear rate is optimized with low voltage and low current. Tools wear increases with increase in current and decrease in voltage. Hence tools wear mainly dependent on input current.

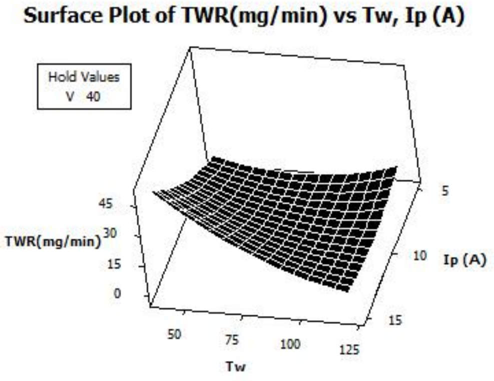

Fig. 17

In fig15 & 17 shows that optimized tool wear is obtained with less pulse on time and current.Tool wear increases with high current,the most significant factor for tool wear is current.

The standard deviation of errors in the modeling, S=5.46273. R2=95.24% which indicates that the model is capable of predicting the response with a high accuracy. From this table it can be concluded that all the factors except for the interaction between Ip (A)*Tw,Ip & Tw are significant as the value of $p<0.05$. The non significant response are IP(A)*V, V*V, IP(A)*IP(A), V, Tw, IP(A) because this value is less t**han $p<0.05$**

VIII.CONCLUSION

In this study the experiments were conducted by considering three variable parameters namely current, pulse on time and gap voltage. The objective was to study the effects of variable parameters on Material Removal Rate, and Tool wear. The following conclusions were drawn:

1. For MRR the most significant factor was found to be Pulse on time (tw) followed by peak current(A) and the least significant was gap voltage. The MRR increased linearly with the increase in current(A).
2. For tool wear the most significant factor was current(A) followed by Pulse on time(tw) and also along with the increase in voltage.

IX.APPENDIX

In this chapter we will discuss about the machines and equipment used while conducting the Experiments.

1. Experiments were conducted using this machine model ELECTRONICA C425 (die25-sinking type) with servo-head (constant gap).
2. The values of surface roughness were measured using this **Handheld Portable Surface Roughness Tester SJ-301**, MITUTOYA-SJ307 made in Japan.

X. REFERENCES

[1]. Rao P.S., Kumar J.S, Reddy K., Reddy B., Parametric Study of Electric Discharge Machining of AISI 304 Stainless Steel, International Journal of Engineering Science and Technology, Vol. 2(8), 2010, 3535-3550.

[2]. Rahman M.M., Khan M.A.R., Kadirgama K., Noor M.M. and Bakar R.A., Experimental Investigation into Electrical Discharge Machining of Stainless Steel 304,Journal of Applied Sciences, 11: 549-554.

[3]. Puertas I., Luis C.J., Alvarez L., Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co, Journal of Materials Processing Technology, 153-154 (2004), 1026-1032.

[4]. Tomadi S.H., Hassan M.A., Hamedon Z., Analysis of the influence of EDM parameters on surface quality, material removal rate and electrode wear of tungsten carbide, Proceedings of the International MultiConference of Engineers and Computer Scientists, Vol II (2009).

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