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An Experimental Investigation of Machinability of Stainless Steel 316 Using Stainless Steel Electrodes

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ABSTRACT: The selection of optimum process parameters is time consuming and costly process. This study mainly focuses on the selection of optimum process parameters for the combination of work material stainless steel 316L and Solid & Hollow tool electrode of Stainless Steel material having 3 mm diameter. The Material has been experimentally investigated for its machinability using Z-axis numerically controlled (ZNC) electro discharge machining (EDM) process. The effects of the four process parameters, namely, current, gap voltage, pulse-on time, and pulse-off time are investigated on material removal rate (MRR), tool wear rate (TWR), and Overcut (OC) by varying one parameter at a time approach. Totally a set of 28 experiments with two trials has to be done by using each tool material and for every machining the readings are to be tabulated and corresponding graphs are to be drawn.

KEYWORDS: SS 316, Solid & Hollow tubes of Stainless Steel electrode, One Parameter varying approach, MRR, TWR and Overcut.

I. INTRODUCTION

The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of nontraditional process. EDM has been replacing drilling, milling, grinding and other traditional machining operations and is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece.

II. THE LITERATURE REVIEW

Various attempts have been made to analyze or improve the machining performance of EDM along with optimization of machining process parameters for various materials.

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Balbir Singh et al. (2013) investigated the influence of process parameters of ZNC EDM such Current, gap voltage, pulse on time and pulse off time. Experimental work was conducted on Al6061 /10% SiC composite with electrolytic copper tool in the presence of kerosene as dielectric fluid. Previously the composite has been fabricated by stir casting process. Also the composite material was characterized through optical microscopy, X-ray diffraction analysis and SEM with EDX Analysis. Optical microscopy and SEM analysis showed the clusters of SiC reinforcement throughout the composite and TG,DTA and DTG tests interpreted the result as it was thermally stable up to 650°C. The data compiled during experimentation has been used to yield response in respect to material removal rate, tool wear rate and Surface roughness. Optimum results were obtained at large current and short pulse duration and pulse interval from 90 to 200 μ s.

B.Mohan et al. (2002) analyses the effect of EDM variables namely Polarity, Current, Electrode material, volume percentage of SiC (20% & 25%), pulse duration and rotation of electrode on Al-SiC composite. The experiment was done to evaluate the feasibility of machining Aluminum metal matrix composite with 20% and 25% of SiC reinforcement. The MRR was more with less volume percentage of SiC, large current, positive polarity, increase in the rotational speed of the electrode. Also the MRR was more with the Stainless Steel electrode when compared with copper electrode. The tool wear rate was reduced when less volume percentage of SiC with large current. The Surface roughness was decreased with decrease in pulse current and increased with increase in volume percentage of SiC.

N.Natarajan et al. (2013) experimented and analysis of micro holes machining in EDM on Stainless steel-304 with Stainless Steel electrode of diameter 300 μ m. from this study they suggested, the optimal parametric combination for higher MRR has achieved at that the pulse on time of 200 μ s, current of 4 A, voltage of 40 V and for the lesser TWR and OC have achieved at pulse on time of 100 μ s, current of 2 A, and voltage of 30 V.

SurajChoudhary et.al [13] study in this research investigates the parameter optimization of EDM on a copper, Stainless Steel and graphite were selected as a tool electrodes. The experimental generate output responses such as material removal rate (MRR) and surface roughness. The best parameters such as current and pulse on-time were studied for best machining characteristics. A plan of experiments, based on L_9 orthogonal array based on Taguchi design method, was selected for sparking of material. From the analysis of variance (ANOVA) shows the percentage contribution of the control factor in the machining of stainless steel 316 in EDM. The optimization result showed that the pulse on-time has the most significant influence on MRR and surface roughness within the specific test range for copper, Stainless Steel and graphite electrodes.

Rajmohan T et.al [4] in this investigation, the effect of electrical discharge machining (EDM) parameters such as pulse on-time (T_{on}), pulse off-time (T_{off}), voltage (V) and current (I) on material removal rate (MRR) in 304 stainless steel was studied. The experiments are carried out as per design of experiments approach using L_9 orthogonal array. The results were analyzed using analysis of variance and response graphs. From this study, it is found that different combinations of EDM process parameters are required to achieve higher MRR for 304 stainless steel. Signal to noise ratio (S/N) and analysis of variance (ANOVA) is used to analyzed the effect of the parameters on MRR and also to identify the optimum cutting parameters. The current and pulse off-time are the most significant machining parameter for MRR in EDM of 304 SS.

III. EXPERIMENTAL PROCEDURE

3.1. MATERIAL SELECTION.

Stainless steel 316 Low carbon alloy is selected. Grade 316 has excellent corrosion resistance in a wide range of media. Its main advantage over grade 304 is its increased ability to resist pitting and crevice corrosion in warm chloride environments. It resists ordinary rusting in virtually all architectural applications, and is often chosen for more aggressive environments such as sea-front buildings and fittings on wharves and piers. Like grade 304, 316 has good oxidation resistance in intermittent service to 870°C and in continuous service to 925°C. Like other austenitic stainless steels, grade 316 has excellent forming characteristics. It can be deep drawn without intermediate heat softening enabling it to be used in the manufacture of drawn stainless parts, such as sinks and saucepans.

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Table 1: Chemical Composition of Stainless steel 316 Alloy

Alloy	Carbon	Manganese	Silicone	Chromium	Nickel	Molybdenum	Phosphorus	Sulphur	Steel
% Level	0.08	2.00	1.00	0.88	10/14	0.714	0.045	0.03	Balance

3.2 EDM MACHINE DETAILS



Fig.1 ZNC Sparkonix EDM Machine



Fig.2 The machined workpiece

Experiments have been performed on ZNC electrical discharge machine (model S-50) made by Sparkonix, India which is shown in Figure 2. Various machining characteristics such as MRR, TWR, and OC are investigated at different settings of current, voltage, pulse-on time, and pulse-off time. The experiments have been performed using Solid & Hollow tool electrode of Stainless Steel & Stainless steel having 3 mm diameter and 50mm height with negative polarity. During experimentation, electrode area was kept constant throughout all experiments. Honex 401 EDM oil was used as the dielectric fluid with side flushing, keeping constant pressure at 0.5Kgf/cm² during the entire machining process. The experiments have been performed at different levels of peak current, pulse-on time, voltage, and pulse-off time as mentioned in Table 2 by varying one parameter approach. The machining was carried out for a fixed time interval of 15 mins repeating each experiment two times. The machined workpiece is shown in Figure 3. The MRR and TWR were evaluated for each cutting condition by measuring average weight before and after each experiment using precision measuring balance with 0.001mg accuracy. The Overcut (OC) was measured taking the average of three readings using optical Microscope.

S.No	Machining parameters	Levels						
1	Current, I (Amp)	6	9	12	15	21	30	45
2	Pulse-on time, T_{on} (μs)	15	30	60	90	120	150	200
3	Pulse-off time, T_{off} (μs)	2	4	8	15	45	90	200
4	Gap voltage (Volt)	30	40	50	60	70	100	120

Table 2: Machining process parameters and their levels.

3.3 CALCULATION OF PARAMETERS

In this Experiment we are used Stainless Steel electrode material and input parameters such as Pulse on Time, Pulse off time, Voltage and Current. We found the output parameters such as Overcut, Material Removal Rate and Tool wear rate. In the first set of experiment (1-7 observation) pulse on time, pulse off time and Voltage are maintaining constant and varying Current. In the second set of experiment (8-14 observation) current, pulse off time and Voltage are maintaining constant and varying Pulse on time. In the Third set of experiment (15-21 observation) current, pulse on time and Voltage are maintaining constant and varying Pulse off time. and then the Fourth set of experiment (22-28 observation) current, pulse on time and Pulse off time are maintaining constant and varying Voltage. The corresponding output values are tabulated as shown in below. Those are calculated by using the following formulas,

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3.3.1 MATERIAL REMOVAL RATE

The material removal rate of the work piece is the weight of the material removed per minute.

$$MRR = \frac{W_{bm} - W_{am}}{\rho * t}$$

MRR- material removal rate,

W_{bm}-Weight of workpiece before machining,

W_{am}- Weight of workpiece after machining

ρ -Density of workpiece

t = Machining time (In this experiment the machining time is sec)

3.3.2 TOOL WEAR RATE

TWR is expressed as the ratio of the difference of weight of the tool before and after Machining to the machining time.

$$TWR = \frac{W_{bm} - W_{am}}{t}$$

Where,

TWR-Tool wear rate,

W_{bm}-Weight of workpiece before machining,

W_{am}- Weight of workpiece after machining

t = Machining time (In this experiment the machining time is sec)

3.3.3 OVERCUT

OC is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown in these equations.

$$OC = \frac{D_H - D_T}{2}$$

Where, D_H = diameter of hole produced in the workpiece

D_T = Diameter of tool

5.2.3 READINGS OF MRR, TWR AND OC FOR BOTH SOLID & HOLLOW SS ELECTRODES:

S.No	Current	PulseON Time	PulseOFF Time	Gap voltage	MRR (gm/min)		TWR (gm/min)		OC (mm)	
					Solid	Hollow	Solid	Hollow	Solid	Hollow
1	6	200	200	120	0.0002	0.0001	0.0002	0.0011	0.155	0.1
2	9	200	200	120	0.0004	0.0002	0.0005	0.0066	0.1	0.105
3	12	200	200	120	0.0021	0.0002	0.0011	0.0002	0.225	0.2
4	15	200	200	120	0.0005	0.0003	0.0016	0.0006	0.2	0.25
5	21	200	200	120	0.0014	0.0006	0.0022	0.0013	0.25	0.25
6	30	200	200	120	0.001	0.0012	0.0034	0.0024	0.26	0.275
7	45	200	200	120	0.0005	0.0007	0.0032	0.0060	0.255	0.325
8	45	15	200	120	0.0004	0.0005	0.0004	0.0012	0.1	0.15
9	45	30	200	120	0.0004	0.0008	0.005	0.0043	0.2	0.21
10	45	60	200	120	0.0004	0.0008	0.0075	0.0035	0.205	0.325

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11	45	90	200	120	0.0003	0.0008	0.0048	0.0031	0.22	0.305
12	45	120	200	120	0.0002	0.0003	0.0034	0.0026	0.3	0.34
13	45	150	200	120	0.0005	0.001	0.0044	0.0027	0.29	0.35
14	45	200	200	120	0.0008	0.0003	0.0025	0.003	0.315	0.3
15	45	200	2	120	0.0010	0.0002	0.0028	0.0036	0.45	0.36
16	45	200	4	120	0.0004	0.0006	0.0033	0.0020	0.4	0.35
17	45	200	8	120	0.0003	0.0001	0.0013	0.0017	0.325	0.5
18	45	200	15	120	0.0005	0.0016	0.0018	0.0024	0.45	0.35
19	45	200	45	120	0.0018	0.0011	0.0026	0.0025	0.6	0.65
20	45	200	90	120	0.0008	0.0008	0.0023	0.0024	0.4	0.45
21	45	200	200	120	0.0008	0.0012	0.0033	0.0030	0.45	0.3
22	45	200	200	30	0.0014	0.0012	0.004	0.0036	0.6	0.6
23	45	200	200	40	0.001	0.0006	0.0041	0.0036	0.5	0.5
24	45	200	200	50	0.0011	0.0012	0.0036	0.0042	0.45	0.4
25	45	200	200	60	0.001	0.0008	0.0033	0.0035	0.55	0.65
26	45	200	200	70	0.0012	0.0002	0.0042	0.0020	0.3	0.455
27	45	200	200	100	0.0004	0.0014	0.0032	0.0024	0.42	0.425
28	45	200	200	120	0.0011	0.0006	0.0033	0.0035	0.455	0.39

IV. RESULTS

4.1 MATERIAL REMOVAL RATE:

4.1.1 CURRENT Vs MRR

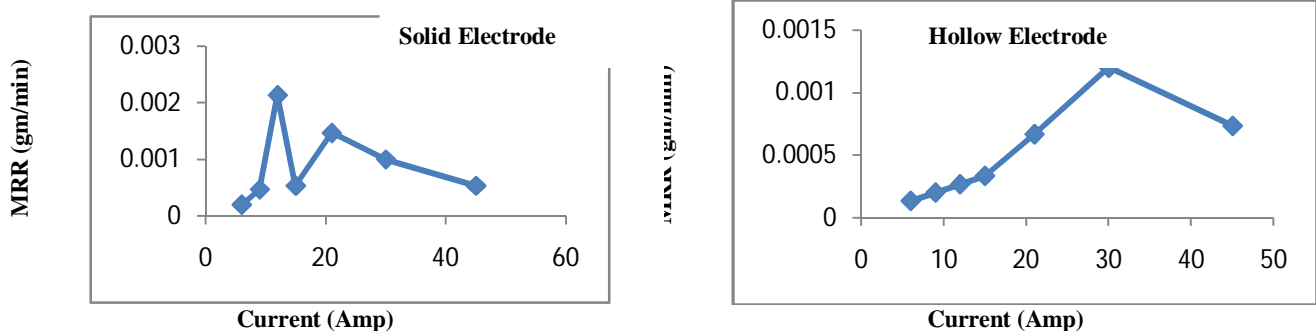


Figure 4 (a) & (b): Influence of current on MRR at constant voltage 120V, pulse-on time 200 μ s, and pulse-off time 200 μ s.

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4.1.2 PULSE ON TIME Vs MRR

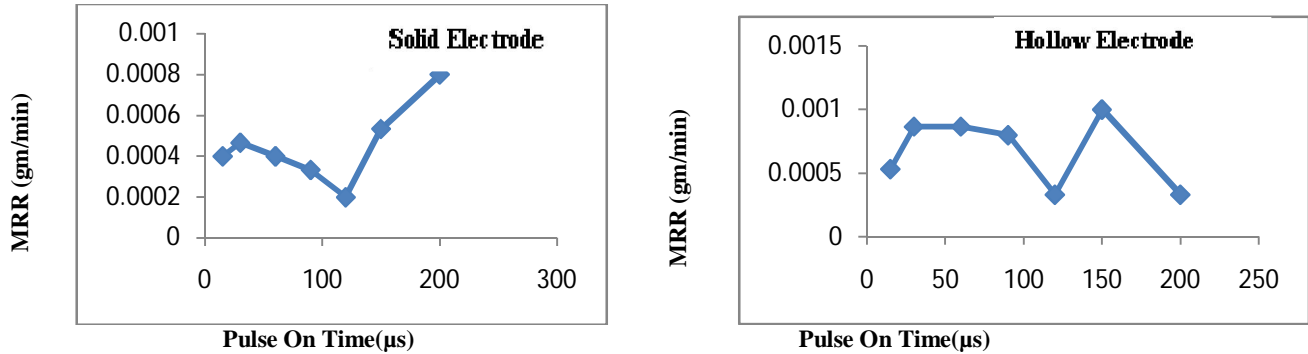


Figure 5 (a) & (b): Influence of Pulse on time on MRR at constant voltage 120V, Current 45 amps, and pulse-off time 200 μs.

4.1.3 PULSE OFF TIME Vs MRR

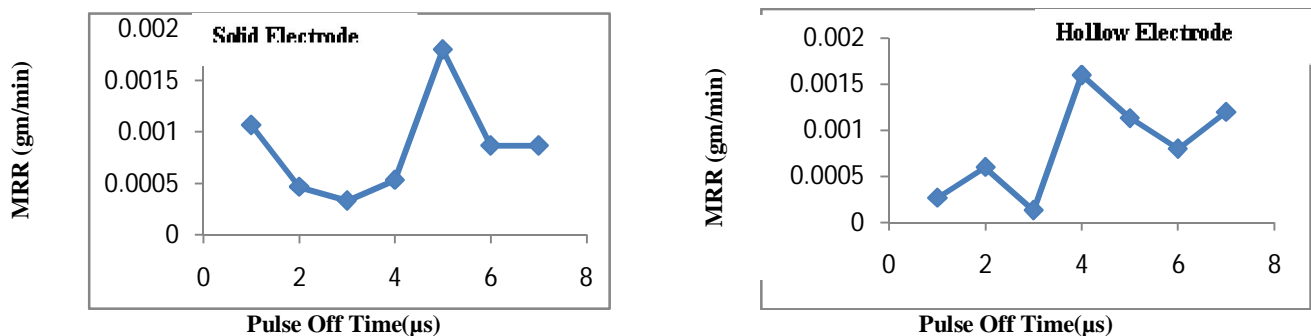


Figure 6 (a) & (b): Influence of pulse off time on MRR at constant voltage 120V, Current 45 amps, and pulse-on time 200 μs.

4.1.4 GAP VOLTAGE Vs MRR

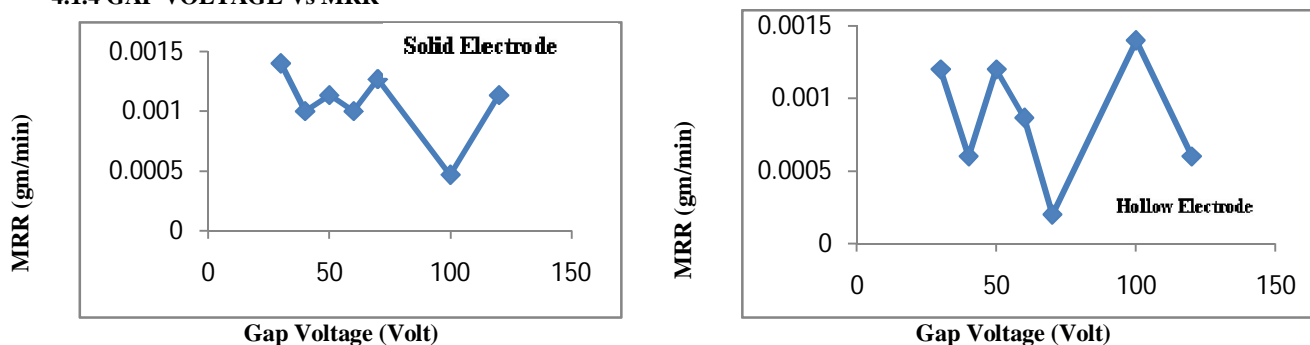


Figure 7 (a) & (b): Influence of Gap voltage on MRR at Current 45 amps, pulse on time 200 μs and pulse-off time 200 μs.

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4.2 TOOL WEAR RATE:

4.2.1 CURRENT Vs TWR

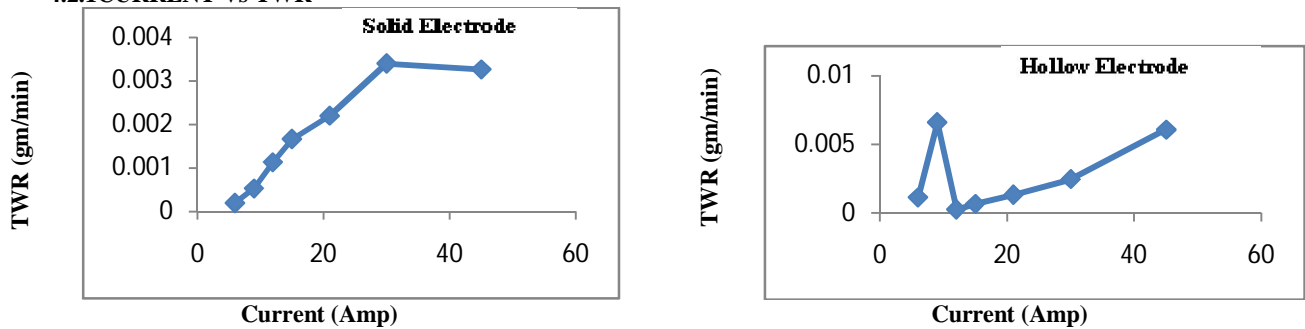


Figure 8 (a) & (b): Influence of current on TWR at constant voltage 120V, pulse-on time 200 μ s, and pulse-off time 200 μ s.

4.2.2 PULSE ON TIME Vs TWR

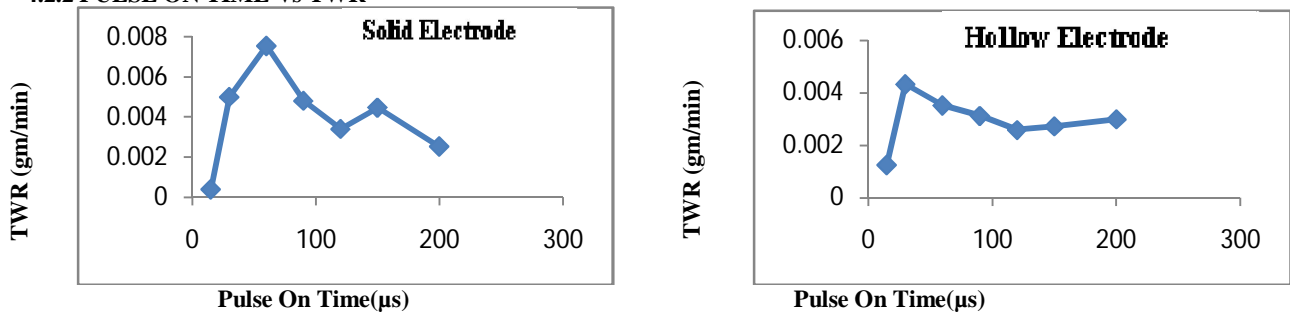


Figure 9 (a) & (b): Influence of Pulse on time on TWR at constant voltage 120V, Current 45 amps, and pulse-off time 200 μ s.

4.2.3 PULSE OFF TIME Vs TWR

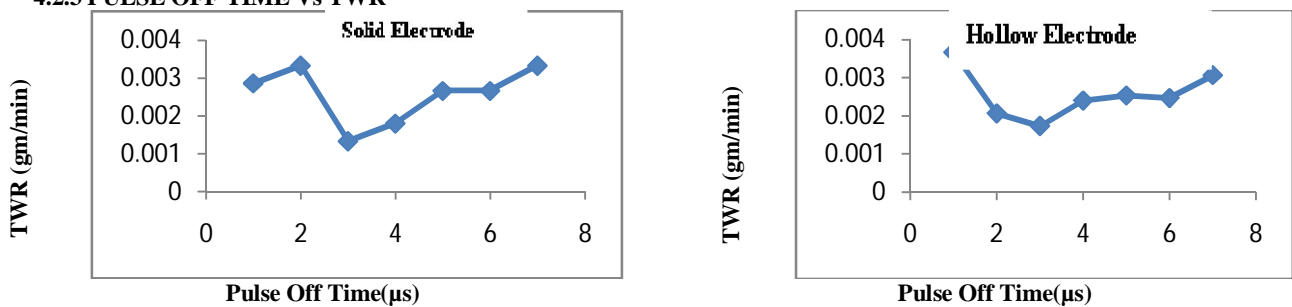


Figure 10 (a) & (b): Influence of pulse off time on TWR at constant voltage 120V, Current 45 amps, and pulse-on time 200 μ s.

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4.2.4 GAP VOLTAGE Vs TWR

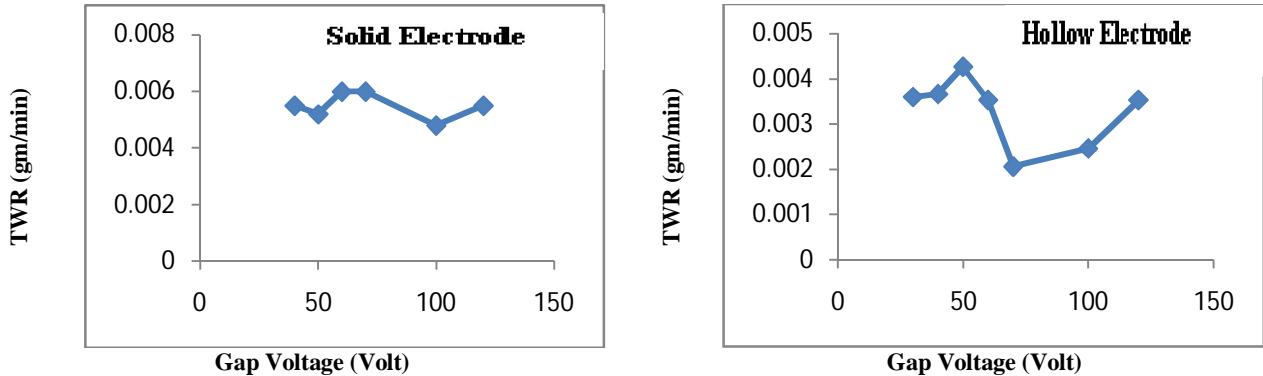


Figure 11 (a) & (b): Influence of Gap voltage on TWR at Current 45 amps, pulse on time 200 μ s and pulse-off time 200 μ s.

4.3 OVERCUT:

4.3.1 CURRENT Vs OVER CUT

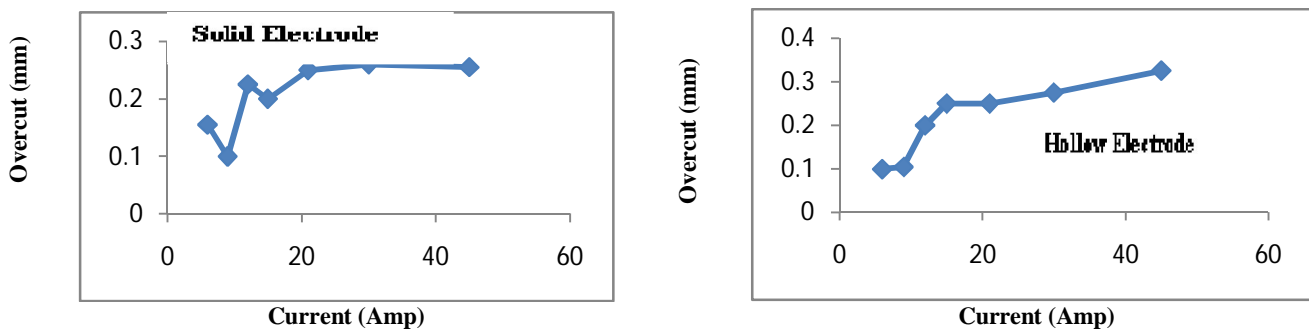


Figure 12 (a) & (b): Influence of current on OC at constant voltage 120V, pulse-on time 200 μ s, and pulse-off time 200 μ s.

4.3.2 PULSE ON TIME Vs OVER CUT

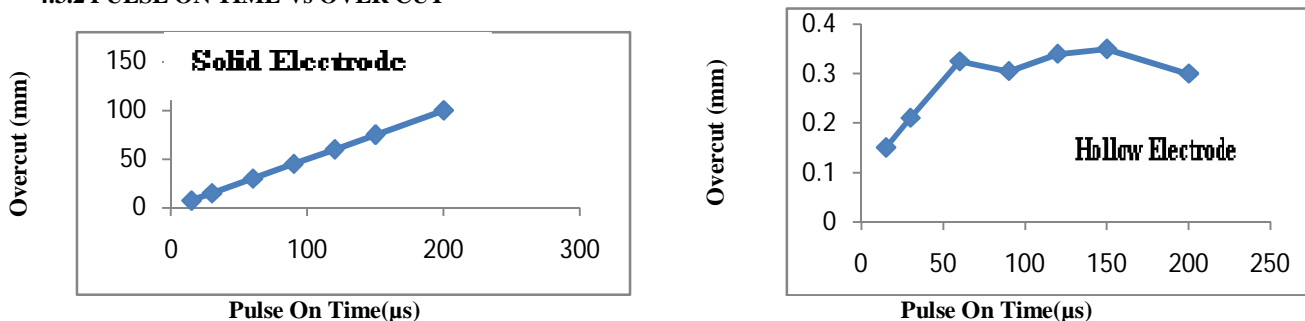


Figure 13 (a) & (b): Influence of Pulse on time on OC at constant voltage 120V, Current 45 amps, and pulse-off time 200 μ s.

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4.3.3 PULSE OFF TIME Vs OVER CUT

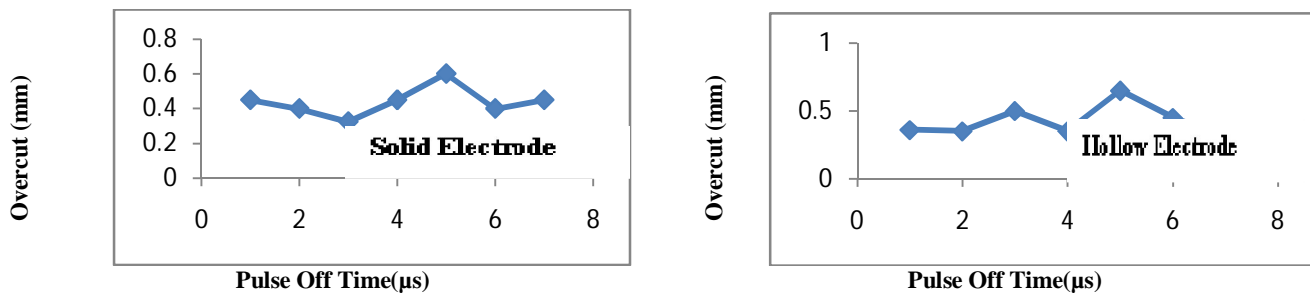


Figure 14 (a) & (b): Influence of pulse off time on OC at constant voltage 120V, Current 45 amps, and pulse-on time 200 μ s.

4.4.4 GAP VOLTAGE Vs OVER CUT

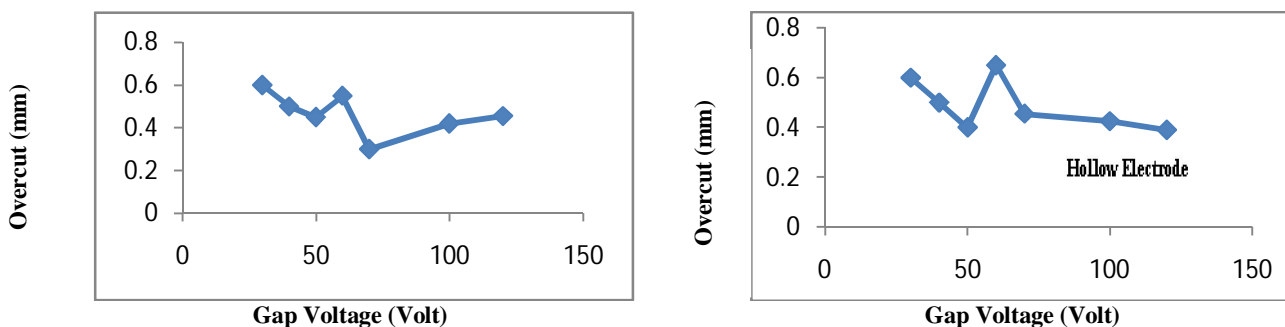


Figure 15 (a) & (b): Influence of Gap voltage on OC at Current 45 amps, pulse on time 200 μ s and pulse-off time 200 μ s.

IV. CONCLUSION

1. From the graph we conclude that The machining characteristic MRR achieved best results at the Average setting of current of 30 amps, Maximum setting of pulse on time 200 μ s for solid stainless steel electrode & maximum setting of current of 45 amps, pulse on time and for the Hollow type electrode.
2. With an increase of pulse-on time, all the three dependent characteristics, namely, MRR, TWR, and OC, increase.
3. While varying the pulse-off time, the MRR increase with increase in pulse-off time and the tool wear rate is also maximum.
4. The lowest tool wear rate may be obtained at lower setting of current and pulse on time for the both the Hollow and solid type electrodes.
5. The Maximum overcut produced at the maximum setting of Current and pulse on time.
6. The gap voltage range between 50-70 V is optimum value to produced best result for MRR, TWR and OC.
7. Solid Stainless Steel electrode produces better MRR, Maximum TWR When compared to Hollow type electrode. Also Solid electrode produces maximum overcut then the hollow type electrode.

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