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Effect on Material Removal Rate and Surface Finish in ECM Process When Machining Stainless Steel-316 with Cu Electrode

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Abstract: ***Electrochemical Machining process is one of the popular non-traditional machining processes which is used to machine materials such as super alloys, Ti-alloys, stainless steel etc. Its working principle is based upon Faraday law of electrolysis. The aim of the present work is to optimize the ECM process parameters with the combination of SS 316 (job material) and Copper electrode (tool material). To explore the effect of ECM process parameters such as electrolyte concentration, voltage and current, feed rate on MRR and surface finish (Ra) of the job, total 27 experiments were conducted as per experimental scheme. The results of these experiments revealed that increase in electrolyte concentration decrease the mrr and surface roughness initially increases then decreases. Further, increase in current increases mrr initially and then decreases, surface roughness also increases. It is also noticed that increase in Feed rate mrr decreases and then increases, also surface roughness decreases then increases. Through RSM analysis it is found that the optimum conditions for maximum MRR, and minimum Surface roughness (Ra) is electrolyte concentration 150gm/lit, Voltage 13.5 V & feed 0.8 mm/min. The findings are discussed in the light of previous researches and subsequently conclusions are drawn.***

Keywords: **Electrochemical machining (ECM), Material removal rate (MRR), Surface roughness (Ra), Electrolyte concentration**

I. INTRODUCTION

Electro-chemical Machining (ECM) is a nontraditional machining process which is used for machining materials which are difficult to machine by traditional machining processes such as alloy steel, Ti alloys, super alloys and stainless steel etc. Literature review revealed that many studies were conducted in the past by various researchers to evaluate the effect of ECM process parameters such as electrolyte concentration, current and voltage, surface finish, material removal rate (MRR), tool and workpiece gap current and voltage etc. for its optimization with different materials.

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ECM is a non-contact type machining process, and it gives exact replica of the tool, a cavity in the job material. In this machining process [1] and [2] a very high current is passed among the job (anode) and the tool (cathode) through a electrolyte and a cavity (as the shape of the tool) is obtained in the workpiece. EDM has been found to be a better for smaller batch sizes whereas ECM is more suitable for large scale production [3].

One of the researchers, Neto J., et. al. [4] results showed that feed rate is the important factor which affects the material removal rate. In ECM process, $NaNO_3$ showed the good results on surface roughness and overcut. Also it had been observed that material removal rate increases with increase in tool feed rate because of the decrease in machining time. Further, Sodium Chloride had better machining results on MRR than Sodium Nitrate as NaCl solution is a non-passivated electrolyte and has constant current efficiency. In another research, Milan Kumar Dasa, et.al. [5] ANOVA results revealed that the electrolyte concentration has the maximum influence on metal removal rate and surface roughness characteristics. Further, P. Rodriguez et. al. [6] observed that when current intensity is increases, it directly affects the material removal rate and as material removal rate is increases surface finish on the other hand decreases in the ECM process. Therefore there should be a balance in between material removal rate and the surface finish.

Also Kai Egashira et.al. [7] suggested that a semi-cylindrical tool electrode, long pulse width, high pulse frequency, high low-level voltage, and high electrolyte concentration were preferable for high-speed drilling without widening the lateral gap between the tool electrode and hole. Ming-Chang Jeng et al. [8] showed that the material removal rate & current efficiency increases with carbon content. Also the quenched microstructure and the tempered microstructure have a greater removal rate and current efficiency than those of annealed microstructures, work-piece machined at a working pressure of 3-4 kg/cm^2 has the greatest removal rate and current efficiency, and the roughness of the machined surface of the annealed microstructure is greater than those of the quenched and tempered steels.

Another study of Joao Cirilo da Silva et.al. [9] concluded that resistance offered by electrolyte arrangement decreases stridently with increasing current densities, and at the same time the over-voltage of framework first increases and then achieves a saturation value with increasing current densities.

In any job the primary requirement is surface finish of the job, a study was conducted by the
Keeping this in mind the present experimental work is focused on "Optimization of ECM process parameters for maximum material removal rate (MRR), and minimum surface roughness (Ra) for the stainless steel (SS-316) as a job material and a Copper (Cu) electrode as a tool material.

II. EXPERIMENTAL SET UP

For experimental work these constituents are required;

- Work Piece (SS 316)
- ECM Machine
- Electrolyte
- Electrode
- Weighing Machine
- Surface Roughness Tester

The detail information all of the above mentioned components are given below.

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2.1 Specifications of SS 316:

Table 1: Composition Specification (%) for SS 316

Grade		C	Si	P	S	Mn	Cr	Ni	N	Mo
SS 316	Min.	-	-	-	-	-	16	10	-	2.0
	Max.	0.08	0.75	0.045	0.030	2.0	18.0	14	0.10	3.0

Table 2: Mechanical Properties of SS 316

Grade	Tensile Strength (MPa) Minimum	Yield Strength 0.2% proof (MPa) Min	Elongation % (in 50 mm) min.	Hardness Rockwell B (HR B) max	Hardness Brinell (HB) max
SS 316	515	205	40	95	217

Four Stainless Steel (SS 316) workpieces are having dimensions of 60 mm x 60 mm x 5 mm, weighing 0.153 Kg each are used for machining. In SS 316 workpieces, 16 cavities are made as shown in Figure 7.

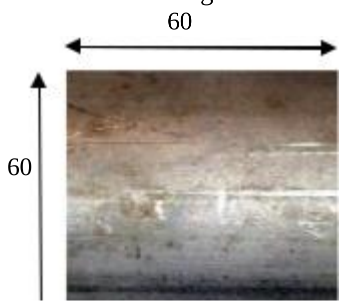

Figure 1: Work Piece

2.2 ECM MACHINE

ECM machine specifications are as follows;
Tool area – 259.8 mm^2 Cross head stroke - 150 mm, Job holder - 100 mm opening x 50 mm depth x 100 mm width. Tool feed motor - DC Servo type. AC Three phase power supply of - 415 V +/- 10%V, 50 Hz
The machining on SS 316 workpieces are to be carried out on ECM set up as shown in Figure 2. It mainly consists of electro-mechanical assembly, servo automated system for the tool vertical upward and downward motion, an electrolyte supply system, machining chamber with crystal clear window and, vice for holding the job.

Figure 2: ECM set up Metatech Industries, Pune

Figure 3: ECM Control Panel

2.3 ELECTROCHEMICAL MACHINE CONTROL PANEL

The Control panel (Figure 3) is used for adjustment of voltage (V), current (C), feed rate (F) and time (T) during machining of the SS jobs. The specifications of control panel are as follows;

- Electrical Output Rating: 0-300 Amperes. DC from 0-20 V.
- Efficiency: Better than 80% at partial & full load condition.
- Operation Modes - Manual/Automatic.
- Tool Feed - 0.2 to 2 mm / min.
- Supply - 415 V +/- 10%, 3ϕ AC, 50 Hz.

2.4 ELECTROLYTE CIRCULATION SYSTEM

The pumping of electrolyte (Figure 4) is done from a tank through a pump. The used electrolyte returns to the tank. The hydroxide sludge produced will settle down at the base of the tank and further drained out. Also electrolyte supply is controlled by flow control valve. For experiments we have taken 100 gm, 125 gm and 150 gm of salt sample in 1000 ml of water at room temperature.

Figure 4: Electrolyte chamber

Figure 5: Circular cross section of the copper tool

2.6 ELECTRODE OR TOOL

For machining of SS 316 jobs, copper tool (Figure 5) is used having a length of 50 mm with diameter 21mm.

Figure 6: Digital weight balance (Model: DJ 300S)

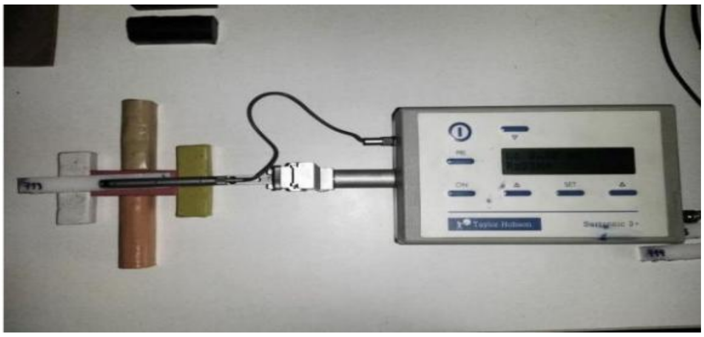

Figure 7: Surface Roughness Tester

2.7 WEIGHING MACHINE

The material removal rate of each job has been found out by electronic weighing machine (figure 6). Initial weight and after machining of the SS jobs were measured by weighing machine by taking care of jobs i.e. all jobs must be free from water, chips etc. This weighing machine weight up to 300g with an accuracy of 0.001 g.

2.8 SURFACE ROUGHNESS TESTER

A moveable type surface roughness tester (Make: Taylor Hobson, Model: Surtronic,) as shown in figure 7, has been used for measurement of surface roughness (Ra) of the machined SS 316 jobs. The readings are taken at three points on the surface and take average value of it.

2.9 PROCEDURE FOR THE EXPERIMENT

Following steps are involved in machining of workpiece and completion of experiment:

a. Weigh the initial weight ($W_{bm)}$ of work piece.
b. Place the job in ECM Machine
c. Fix the Cu electrode in ECM tool holder
d. Now Copper Tool is brought near to the SS 316 job and maintains a particular gap with the help of press buttons which are provided in the control panel.
e. Fill the electrolyte solution in Tanks and run the pump
f. Start the ECM machine through push button and set the process parameters like tool feed rate, voltage and electrolyte concentration.

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g. The procedure is happening in the existence of an electrolyte flow, filling the gap between anode (job) and cathode (tool). Electrolyte flow is adjusted by flow control valve.

h. After completion of ECM on a job (after 10 minutes) a beep sound is produced. And stop the Machine.

i. After electrochemical machining on the SS 316 job note down the weight (W_{am}) of the workpiece.

j. Calculate MRR for the experiment.

k. Calculate the SR with help of surface roughness tester

l. Repeat all above steps **from a. to k.** for taking experimental values Output (i.e. MRR & SR) & varying Inputs (i.e. Electrolytic concentration, Voltage and Feed Rate) on the remaining 15 experiments

2.10 INPUT VARIABLES

Table 3: Electrochemical Machining variables and their levels

Machining Parameter	Unit		Level	
		Level 1	Level 2	Level 3
Voltage (V)	Volt	10	13.5	17
Feed rate (F)	mm/min	0.4	0.6	0.8
Concentration (C)	gm/lit	100	125	150

2.11 RESPONSE SURFACE METHODOLOGY (RSM)

Response Surface Methodology (RSM) is used Central Composite Design (CCD) with three variables yield a total of 27 runs in seven blocks, where the cardinal points used are; 8 cube points, 6 axial points and 6 center points [Minitab16, 2011]. Electrolyte concentration, voltage and feed rate were the three experimental factors capable of influencing the process responses, namely, MRR, SR. Hence, these factors were considered for exploration.

To find out the effect of input variables on the output response, the Equation for output (y) is as follows;

$Y = f(x_1, x_2) + e$

The input variables x_1 and x_2 are independent variables and, y is the dependent variable. Also the experimental error term, denoted as e, which represents any measurement error on the output variable. Let the output is a linear function of independent variables, then the approximating function is a first-order model. A first-order model with two independent variables is; $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$

Further, if there is a curvature in the response surface, then a higher degree polynomial with two variables is called a second-order model; $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_{22}^2 + \beta_{12} x_1 x_2 + \varepsilon$

$X\, n^2$ - square terms of parameters

$x_1\ x_2$ - interaction terms of parameters $\beta_0\ \beta_1\ \beta_2$ - unknown regression coefficients and ε – Error

III. RESULTS AND ANALYSIS

Figure 8, depicts the 27 number runs on SS 316 jobs after electrochemical machining.

Figure 7: Work piece (SS 316) after machining

After experimental work results are obtained, which are shown in Table 4

Table 4: Experimental outcomes for 27 runs

Std Order	Concentration (gm/liter)	Voltage (volts)	Feed (mm/min)	MRR (mm^3/min)	Ra (μm)
1	100	10	0.4	12.25	2.22
2	100	10	0.6	7.66	2.16
3	100	10	0.8	9.19	2.18
4	100	13.5	0.4	15.32*	2.37
5	100	13.5	0.6	8.65	1.70
6	100	13.5	0.8	8.99	2.04
7	100	17	0.4	9.23	2.52
8	100	17	0.6	7.19	2.24
9	100	17	0.8	7.87	3.64
10	125	10	0.4	9.58	2.21
11	125	10	0.6	7.27	1.42
12	125	10	0.8	8.42	1.82
13	125	13.5	0.4	14.87	2.64
14	125	13.5	0.6	7.45	2.44
15	125	13.5	0.8	13.56	3.24
16	125	17	0.4	9.58	2.86
17	125	17	0.6	5.58	2.46
18	125	17	0.8	7.58	2.66
19	150	10	0.4	6.90	2.20
20	150	10	0.6	6.60	1.20
21	150	10	0.8	7.50	1.34
22	150	13.5	0.4	14.42	2.91
23	150	13.5	0.6	6.85	0.94#
24	150	13.5	0.8	10.64@	1.93@
25	150	17	0.4	6.20	2.72
26	150	17	0.6	5.96	2.22
27	150	17	0.8	6.08	3.22

IV. EXPERIMENTAL ANALYSIS

4.1 Effect on Material Removal Rate

The machinability of ECM process depends on the electrolyte concentration, feed rate and voltage. The influence of various machining parameters on material removal rate (means) are revealed in figure 9 (a) (b) (c). The important and major finding is material removal rate is gradually decreases (Figure 9a) with increase in electrolyte concentration. This might be due to there is no increase in electrolyte flow as a consequence the material which is already removed cannot be dislocated taken away from the machining area. So eventually mrr is decreased with increase in the electrolyte concentration.

This finding is not in line with the past researches such as studies [10, 11] concluded that the increase in electrolyte concentration and its flow rate, increases mrr. This is occur because of when we increase in electrolyte flow rate, the reaction products (small chips) in between Inter-electrode gap (IEG) removes at faster rate with electrolyte concentration and also fresh electrolyte flow in between IEG, which increases the conductivity of the electrolyte.

Therefore in the future more work has to be done specifically in combination with SS316 and Cu as tool material.

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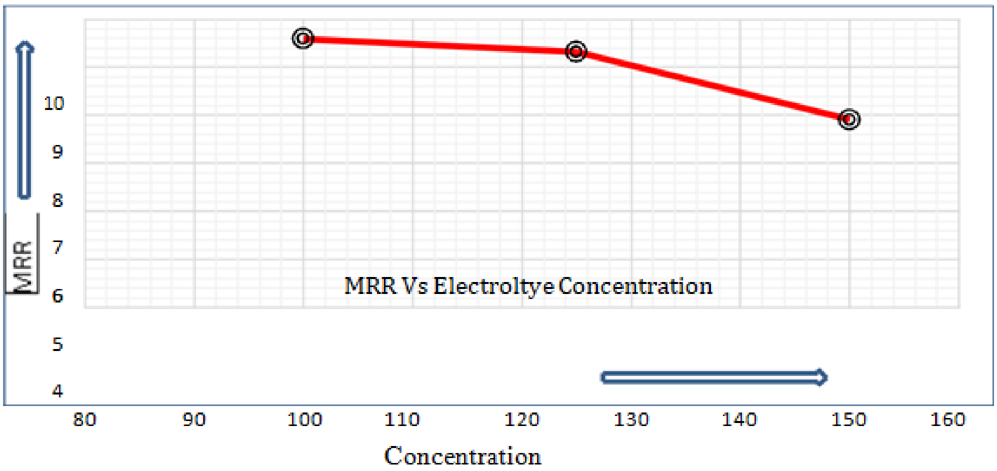

Figure 9 (a): Effect of Electrolytic Concentration on MRR (data means)

Further, Figure 8(b) showed that the material removal rate increases noticeably with increase in voltage in the range of 10 to 13.5 V and, then further decreases from 13.5 to 17 V. A similar study of **Mukherjee et. al . [12]** observed that resistance of the electrolyte solution decreased rapidly with increase in current. Further, initially, the over-voltage of the system increases and attains a saturation value with increasing current densities.

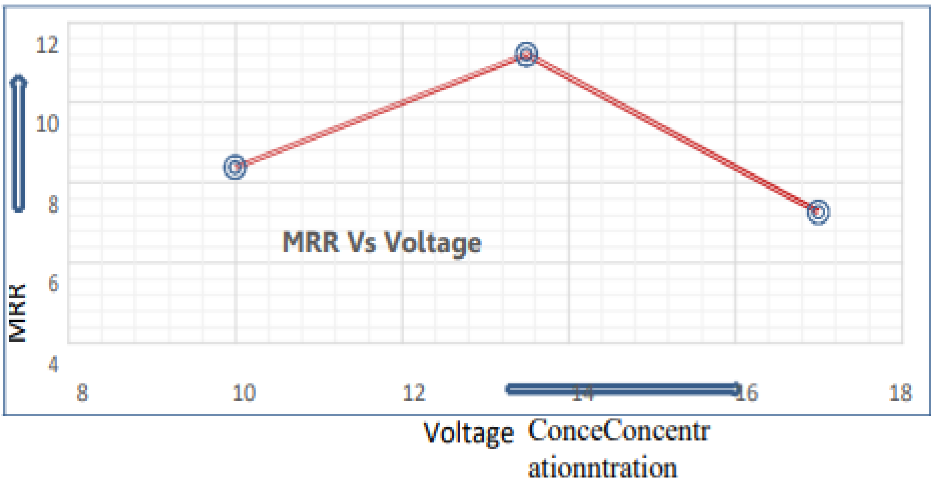

Figure 9 (b): Effect of Voltage on MRR (data means)

Also Figure 9 (c) revealed that the MRR decreases linearly with increases in feed rate in the range of 0.4 to 0.6, and then further increases considerably in the range of 0.6 to 0.8

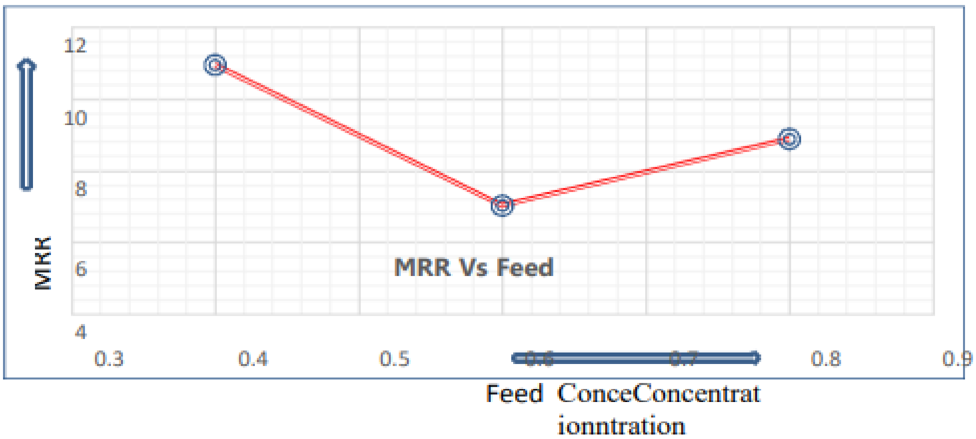

Figure 9 (c): Effect of Feed on MRR (data means)

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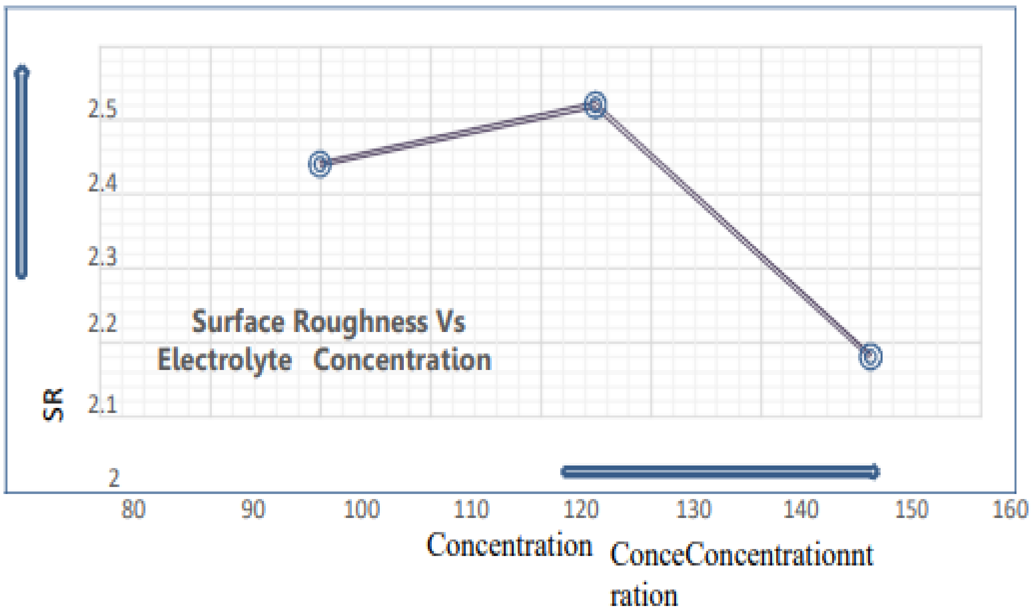
4.2 EFFECT ON SURFACE ROUGHNESS (Ra)

The influences of Surface Roughness (data means) Vs electrolyte concentration, surface roughness Vs voltage and surface roughness Vs feed are depicted in figure 10 (a) (b) (c). The figure 10 (a) showed that the Surface Roughness, has slightly increased with increase in electrolyte concentration (NaCl) in the range of 100 to 125 gm and then decreased significantly in range of 125 to 150gm. This might be due to the higher electrolyte concentration; generations of machined products are more, which changes the property of electrolyte and leads to the higher surface roughness.



[14].

Figure 10(a): Effect of Electrolytic Concentration on SR (data means)

Further, Figure 9 (e) revealed that the surface roughness (Ra) increases gradually with increase in voltage. Also figure 10(c) depicted that the surface roughness (Ra) decreases with increase in feed rate in the range 0.4 to 0.6 and then increases in the range of 0.6 to 0.8.

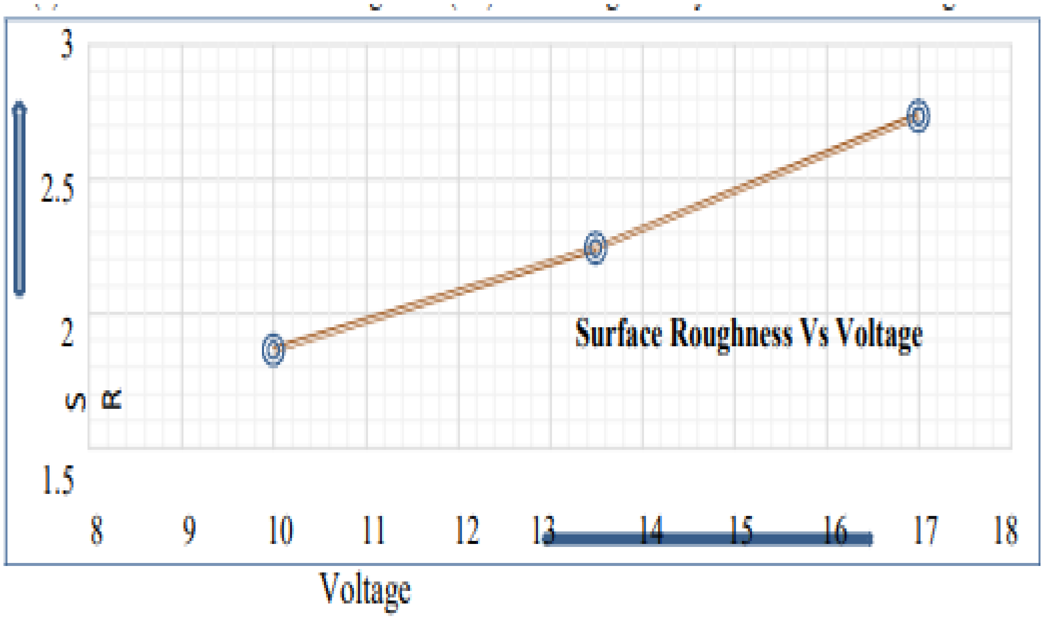


Figure 10 (c): Effect of Feed rate on Surface Roughness (data means)

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4.3 DETERMINATION OF OPTIMUM SOLUTION

By combining all the objectives, we obtained a multi-objective optimization relation, Min.(Z1) = W1 Z_{sr} /SRmin- W2Zmrr / MRRmin

The optimum conditions for maximum MRR, and minimum Surface Roughness (Ra) is:

Electrolyte concentration 150gm/lit, Voltage 13.5 V & feed 0.8 mm/min

V. CONCLUSIONS

The following conclusions have been drawn on the basis of results and discussions;

1) The optimum condition for **maximum material removal rate** is electrolyte concentration 100 gm/liter, voltage 13.5 volts and, feed rate 0.4 mm/rate.

2) The optimum condition for **minimum surface roughness** is electrolyte concentration 150 gm/liter, voltage 13.5 volts and feed is 0.6 mm/min.

The Feed rate, voltage, electrolyte concentration and its flow rate effects maximum material removal rate, and minimum surface roughness parameters.

3)

The Feed rate, voltage, electrolyte concentration and its flow rate effects maximum material removal rate, and minimum surface roughness parameters.

The following conclusions have been drawn on the basis of results and discussions;

4) The optimum condition for maximum material removal rate is electrolyte concentration 100 gm/liter, voltage 13.5 volts and, feed rate 0.4 mm/rate.

5) The optimum condition for minimum surface roughness is electrolyte concentration 150 gm/liter, voltage 13.5 volts and feed 0.6 mm/min.

The Feed rate, voltage, electrolyte concentration and its flow rate effects maximum material removal rate, and minimum surface roughness parameters.

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