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Study of Influence of Process Parameters in Electrochemical Machining of AISI-304 Stainless Steel

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Abstract: *Electrochemical machining is a non-traditional machining process that is used to machine hardened materials such as super alloys, Ti-alloys, stainless steel, etc. The basic working principle is based on the Faraday law of electrolysis due to which the material is removed. The process of electrolysis occurs from atom to atom. It is intended to incorporate the reciprocal and higher-order effects of various machining parameters on the development of an important mathematical model, including material removal rate (MRR), surface roughness (SR) and over craft (OC) through critical machining criteria. The present work has been done to find the material removal rate, surface roughness, and overcut by electrical dissolution of anodically polarized work pieces (AISI 304 stainless steel) with copper electrodes of hexagonal cross section. Experiments were performed to analyze the effect of machining parameters such as feed rate, voltage and electrolyte concentration. Analysis of variance (ANOVA) is employed to indicate the level of significance of the machining parameters. It has been observed that concentration is the most important factor for the reaction of material removal rate and roughness voltage is the most important factor in the case of surface. For overcut response, voltage is the most important factor.*

***Key Word**: Electrochemical machining, feed rate, voltage, electrolyte concentration, material removal rate and surface roughness, overcut.*

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I. Introduction

Electrochemical machining is a non-traditional machining system used to machine harder materials which are difficult to machine using conventional machining like alloy steel, Ti alloys, formidable alloys and stainless steel and so forth. Electrochemical machining is known as another electrolysis process. Within the year 1983, Faraday established the laws of electrolysis. It is the idea of this process that is not very well known in industries, but moreover the power of different substances for some different functions outside certain industries.

In electrochemical machining, work pieces are also referred to as a cathode and tool known as anode Electrolyte which is special type of fluid continuously flows between the anode and cathode through the electrode C program language. Whenever power supply is made to increase, elimination of the fabric is achieved and ions are washed using electrolyte northward flow. Metal hydroxide ions are shaped by the use of ions that are dissipated via centrifugal separation from conductive electrolyte ions. The electrochemical method is particularly useful for high electrolytic alloys. Electrochemical machining is an essential system for semi-conductor machines and skinny steel films because a simple requirement of a semi-conductor enterprise is the machining of components of critical size and high energy alloys. This technique is also used to operate and shape the unique components of openings in the aerospace and digital industries. Electrochemical micro machining offers many benefits; it is promising as a future micro-machining method. Author has created suitable Micro Tool Vibration Framework created, which includes Micro Tool Vibrating Unit, Micro Tool Vibrating Unit, etc. The developed framework was used to meet small-scale machining prerequisites to control the accuracy of MRR and machining. Micro holes were made on a thin copper workpiece by EMM using a stainless steel micro tool. The test has been completed to estimate the process parameters for electrolyte concentration, amplitude, and micro-tool vibration frequency to create micro holes with high accuracy and MRR calculations[1].Various electrolytes can be used like sodium nitrate ($NaNO3$) and sodium chloride (NaCl) [2]. In electrochemical machining of an iron work piece the role of NaCl in the process plays vital role [3]. Authors investigated Significant benefits of the ECM process like high MRR, damage-free and smooth mechanized surfaces, regularly imbalanced by poor control dimensions. Based on fundamental ECM dynamics, presents a model of controlling the ECM that is responsible for the dynamic nature of the ECM process. The state space approach is used to convert ECM control systems based on digital space into control models. Simulations were performed to examine the model and controller configuration [4]. MRR of aluminum work pieces calculated by the ECM using NaCl electrolyte at different current densities is also compared with theoretical values. It is also concluded that the resistance introduced by the electrolyte arrangement decreases rapidly with the expansion of current density, and at the same time the over-voltage of the framework increases first and subsequently increases the saturation value with expanding current density [5].Authors reported that the electrochemical spark machining method has been effectively used to cut quartz using a controlled feed and a wedge tool [6]. An attempt to construct a thermal model for calculating MRR in the ECSM process was made. Authors found that nodal temperature plays an essential role in finding MRR. The accuracy of test results based on the FEM thermal model is explored in the range. The increase in MRR with an increase in electrolyte concentration is found[7].The estimation of important process parameters of ECM methods such as feed rate, flow velocity of electrolyte and voltage plays an important role in improving measures of process performance. These include dimensional accuracy, MRR, machining costs and equipment life. A particle optimization algorithm is demonstrated to detect the optimal combination of process factors of ECM process [8].Authors discussed prior techniques for instrument design in ECM. In presented work authors actually created and tested another way to deal with the issue that controls these disturbances using FEM [9].The hypothetical and test examinations of the relationship between imported characteristic size measurements on the work surface were investigated by microscopic characteristics of the tool electrode under given machining conditions. The work included electrochemical insulating groove features, grooves, and slots in which mini-holes were examined. Restricted cases of micro-ECM are considered to mimic and micro-shape using the non-profile tool cathode[10].ECM method is now progressively used in other commercial enterprises, where hard-to-cut materials and coppers with significant shapes are required. The most recent developments are investigated, and primary issues have been raised in ECM reform and related exploration. Improvements in device design, micro-shaping, finishing, pulse current, numerically controlled and hybrid processes has been found[11].Authors investigated the steady electrolyte flux and tries to identify elements like insulation prerequisites that can identify with other parts of the ECM. These assumptions will be used when making ECM electrodes. Authors has worked on by taking a new cathode to remove the casting gate[12]. Authors has highlighted about accurate forecasting of instrument size for ECM. It poses a way to use FEM to design equipment in ECM. This process is capable of drawing 3-D freestyle surface equipment from scanned information of known work pieces [13]. ECM used to make hundreds of micrometer holes on a metal surface. The effect of variables such as electrolysis, voltage and electrode gap on hole formation was studied. The results shows increase in MRR with increasing molar concentration of electrolyte and electrical voltage [14].Authors investigated about current patterns and the methods used for the subtle fabrication of parts. An Attempt was made to create a reasonable, fast micro-manufacturing and cost-effective method [15]. Authors examined that the over voltage plays a more important role than the feed rate and IEG in material removal rate. The MRR drops when the voltage increases and the current efficiency decreases, which is directly related to the electrical conductivity of the electrolytic solution[16].Electrochemical machining (ECM) was is performed using a relatively short duration and pulsed power of small IEG (10 - 50 μm) to improve the surface to 0.03 μms Ra. Authors found that small IEGs make this process significantly more important than ordinary ECMs[16].

II. Objective of Present Investigation

The aim of the present work is to optimize material removal rate (MRR), surface roughness (Ra) and overcut (OC) for stainless steel (AISI304) with an electrode. Experiments have been conducted using the reaction surface methodology. The working material is AISI 304 SS and the machining parameters selected for the study are feed rate, voltage and electrolyte concentration. In the rate of my work flow of electrolyte, the current is kept constant across the work electrode and electrolyte conductivity.

III. Experimentation

In the present work piece of material stainless steel (AISI 304) having area 100 x 60 mm x 5 mm is used .The chemical composition and mechanical properties are given in Table no 1 and Table no.2 respectively .ECM provided by Metatech-Industry, Pune - supply 415 v +/- 10%, 3 phase AC, 50 Hz has been used with copper as tool . Moreover it includes design of electrode, preparation of electrolyte solution. Electrode made up of copper rods with a length of 40 mm with a hexagonal cross section used**.** The electrolyte is prepared by addition of common salt with water while maintaining the conductivity of water**.** To properly maintain the material removal rate it is necessary to maintain conductivity thought the experiment . Three different concentrations of 100 grams of salt, 125 grams of salt and 150 grams of salt per 1000 mL of water has been used. Total runs of 20 experimental have been used. RSM technique has been used for optimizing Material removal rate , surface roughness and overcut**.**

Table no 1 : Chemical composition of AISI 304 spot stainless steel.

Rank		C	Si	P	S	Mn	Cr	Ni	N
304	Least	-	-	-	-	-	18.0	8.0	-
	Extreme	0.08	0.75	0.045	0.030	2.0	20.0	10.5	0.10

Table No.2: Mechanical properties of AISI 304 rank stainless steel

Grade	Tensile Strength (MPa) Minimum	Yield Strength 0.2% proof (MPa) Min	Elongation % (in 50 mm) min.	Hardness	
				Rockwell(B) Max.	Brinell(HB) Max
304	515	205	40	92	201

After investigating the available for the experiment, three factors voltage (V), feed rate (F) and electrolyte concentrations (C) were taken into account for this experiment. Machining factors and their levels are given in Table no.3

Table no.3: Machining factors and their level

Machining factor	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

Initial weight and final weight of the work piece is measured using an accurate electronic balance (at least 0.001 g) to calculate MRR. After determining all parameters of the control panel (such as feed rate, voltage, current and time) and the work piece in the chamber, machining was started using copper electrodes. The machining time of the work piece at a fixed rate and voltage is being noted. Surface roughness values are measured through a portable type of profilometer, TalSurf (model: certified 3+, Taylor Hobson). After measurement it is calculated as an absolute value by the arithmetic mean of the two data. The overcut is calculated after observing the mechanized surface under the instrument manufacturer microscope.

IV. Results and discussions

Following values of material removal rate (MRR) , surface roughness (Ra) and overcut has been observed after measurement which are given in Table no.4.

Table No. 4: Investigational Layout (RSM Design Stainless steel AISI 304)

Std Order	Concentration (in gm/litre)	Voltage (volts)	Feed (mm/min)	MRR (mm^3/min)	Ra (µm)	Overcut (µm)
1	100	10	0.4	12.2500	2.22	0.9684
2	150	10	0.4	6.9000	2.20	0.4754
3	100	17	0.4	9.2250	2.52	0.0795
4	150	17	0.4	6.2000	2.72	0.0894
5	100	10	0.8	9.1875	2.18	0.0099
6	150	10	0.8	7.5000	1.34	0.0298
7	100	17	0.8	7.8700	3.64	0.3865
8	150	17	0.8	6.0800	3.22	0.5886
9	100	13.5	0.6	8.6500	1.70	0.5396
10	150	13.5	0.6	6.8500	0.94	0.5311

11	125	10	0.6	7.2700	1.42	0.5796
12	125	17	0.6	5.5800	2.46	0.5058
13	125	13.5	0.4	14.8700	2.64	0.2369
14	125	13.5	0.8	13.5600	3.24	0.2486
15	125	13.5	0.6	7.4500	2.44	0.4890
16	125	13.5	0.6	8.1300	2.24	0.4953
17	125	13.5	0.6	5.8980	2.18	0.5206
18	125	13.5	0.6	7.2400	2.86	0.4965
19	125	13.5	0.6	7.9200	2.32	0.5205
20	125	13.5	0.6	8.5400	2.84	0.5249

Effect on Material removal rate: The machinability of the ECM depends on electrolyte concentrations, feed rate, and voltage. The effect of various machining parameters on MRR (instrument) is shown mean effect plot for MRR. The MRR gradually decreases with the increase in electrolyte concentration. The MRR increases and then decreases with an increase in voltage in the range of 10 to 13.5. But the MRR increases the feed rate from 0.4 to 0.6 and decreases thereafter.

Table 5 : Analysis of Variance for Means of MRR

Basis	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	101.351	101.351	11.2612	6.50	0.004
Linear	3	28.039	28.039	9.3463	5.40	0.018
Square	3	69.574	69.574	23.1914	13.40	0.001
Interaction	3	3.738	3.738	1.2458	0.72	0.563
Lack-of-Fit	5	13.027	13.027	2.6054	3.04	0.124
Pure Error	5	4.286	4.286	0.8572		

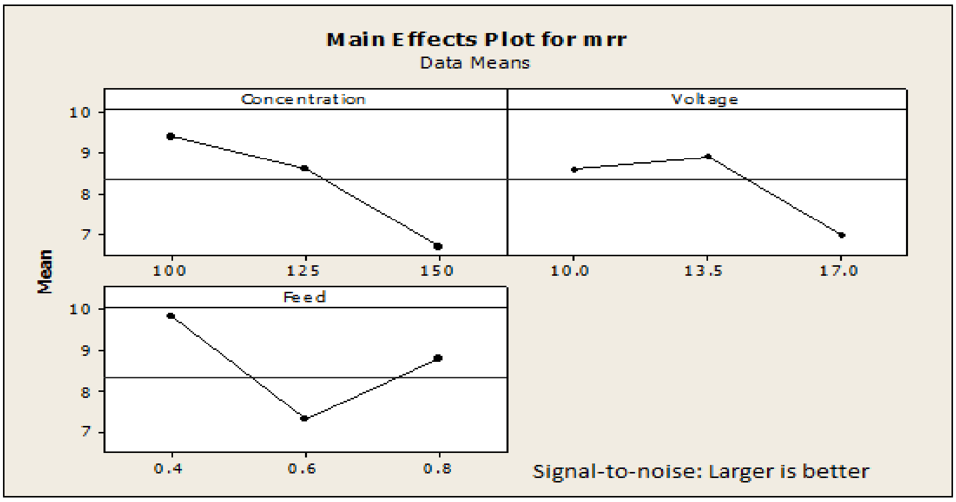


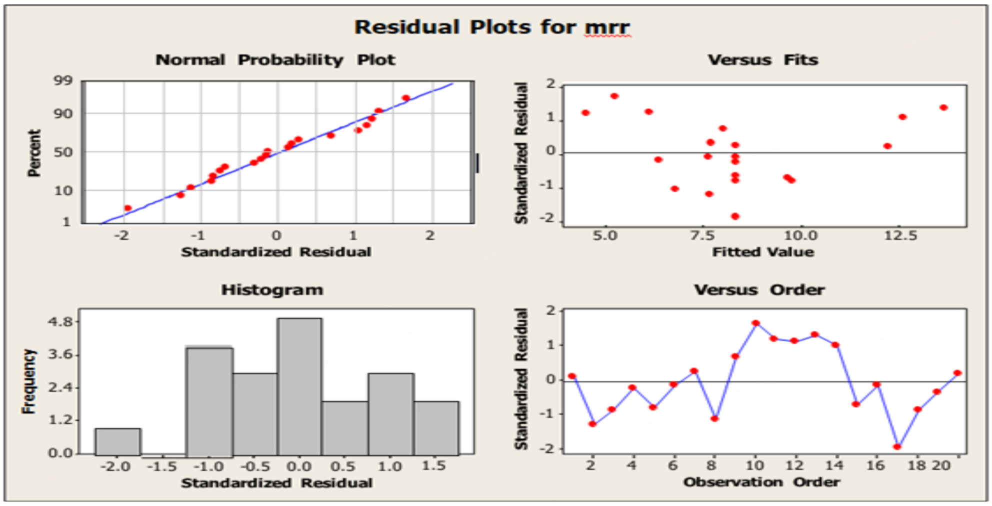
Table no. 6: Valued Lapse Coefficients for MRR

Period	Coef	SE Coef	T	P	Remarks
Constant	8.2830	0.4523	18.312	0.000	Significant
Concentration	-1.3652	0.4161	-3.281	0.008	Significant
Voltage	-0.8152	0.4161	-1.959	0.079	Non Significant

Feed	-0.5247	0.4161	-1.261	0.236	Non Significant
Concentration* Concentration	-1.6630	0.7935	-2.096	0.063	Non Significant
Voltage*Voltage	-2.9880	0.7935	-3.766	0.004	Significant
Feed*Feed	4.8020	0.7935	6.052	0.000	Significant
Concentration*Voltage	0.2778	0.4652	0.597	0.564	Non Significant
Concentration*Feed	0.6122	0.4652	1.316	0.218	Non Significant
Voltage*Feed	0.1234	0.4652	0.265	0.796	Non Significant
S=1.31579		R-Sq=85.41%		R-Sq(adj)=72.28%	

Table no.6 shows the estimated regression coefficients of MRR. R2 = 85.41% indicates that the model is capable of predicting response with good accuracy. Value of R2 (adj) = 72.28%. The standard deviation of errors in modeling, S = 1.31579, concentration (P = 0.008) is significant. The squares V * V and F * F are important, while the squares C * C and interactions C * V and C * F are insignificant.

In residual plot of MRR shows that the normal probability plot shows that the data are approximately normally distributed and the variables are influencing the response. A standardized residual range ranges from −2 and 2. Residual versus fitted values indicate that the variance is constant and a nonlinear relationship exists as well as no outliers are present in the data. The histogram proves that the data are approximately normally distributed This may be due to the fact that the number of digits is very small. The residual versus order of the data indicates that the data have an almost systematic effect.



From RSM, empirical relationship between response and factors in coded forms are given as, MRR = . 8.2830 - 1.3652 × concentration -2.9880× (voltage) ^{2} + 4.8020× (feed) ^{2}

Effect on Surface Roughness (SR): The effect of different machining parameters on SR (instrument) is shown in mean effect plots for RA. SR increases slightly with increase in concentration from 100 to 125 and then decreases. SR increases with increase in voltage. But in SR feed increases from 0.4 to 0.6 and then increases.

Table 7 : Analysis of Variance for Means of SR

Basis	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	7.06540	7.06540	0.78504	5.95	0.005
Linear	3	3.21680	3.21680	1.07227	8.13	0.005
Square	3	2.74440	2.74440	0.91480	6.94	0.008
Interaction	3	1.10420	1.10420	0.36807	2.79	0.095
Lack-of-Fit	5	0.86988	0.86988	0.17398	1.94	0.243
Pure Error	5	0.44880	0.44880	0.08976		

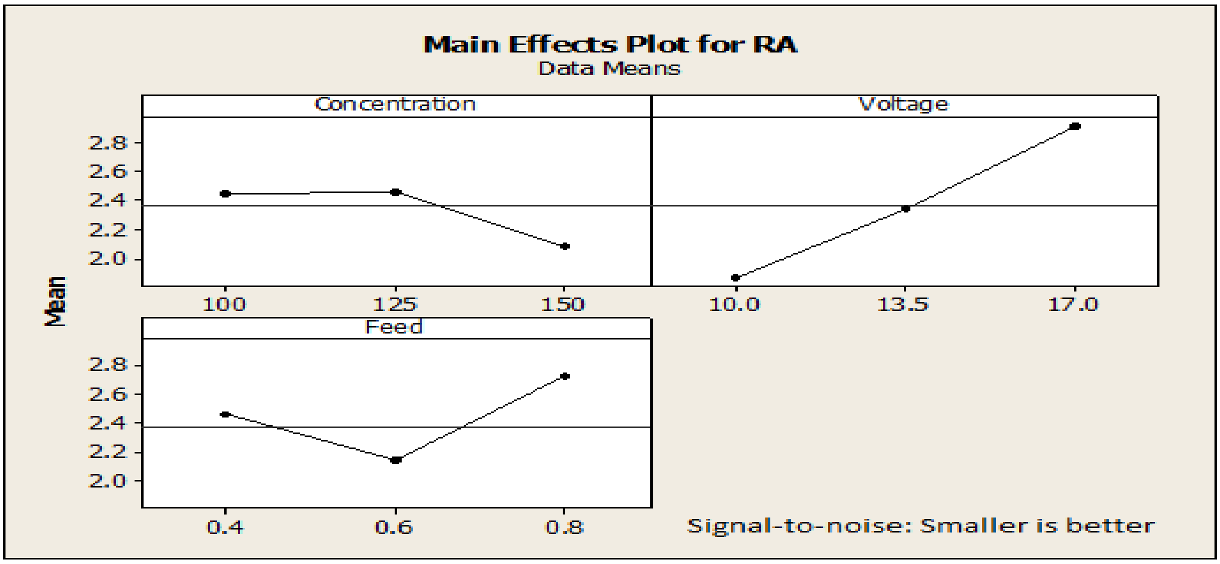
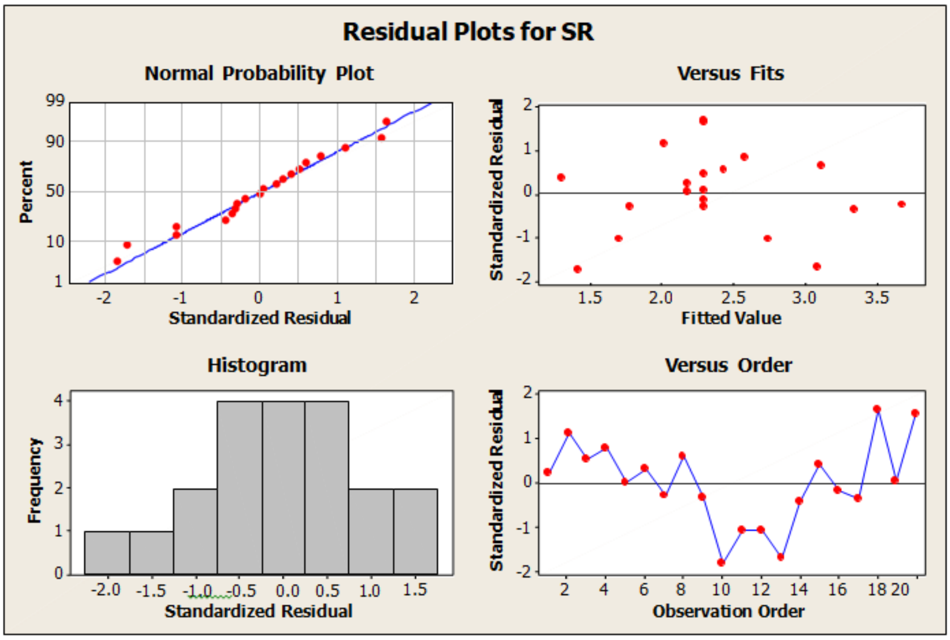


Table no.8: Estimated Regression Coefficients for SR

The estimated regression coefficient for SR is shown in Table no. 8. R2 = 84.27% indicates that the model is capable of predicting response with good accuracy. Adjusted R2 is a modified R2 adjusted for the number of words in the model and has a value of R2 (adj) = 70.12%. The standard deviation of errors in modeling, S = 0.363136, the parameter voltage (P = 0.001) is significant while the concentration (P = 0.140) and feed (P = 0.277) are insignificant. Squares f * f,C*C and interactions V*F are significant while square V*V and interactions C*V, C*F are insignificant .In residual plot of SR is s.Normal probability plot shows that the data are not normally distributed and the variables are influencing the response. A standardized residue ranges from -2 and 2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed it may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data.

Term	Coef	SE Coef	T	P	Remarks
Constant	2.29600	0.1248	18.392	0.000	Significant
Concentration	-0.18400	0.1148	-1.602	0.140	Non Significant
Voltage	0.52000	0.1148	4.528	0.001	Significant
Feed	0.13200	0.1148	1.149	0.277	Non Significant
Concentration* Concentration	-0.70000	0.2190	-3.197	0.010	Significant
Voltage*Voltage	-0.08000	0.2190	-0.365	0.722	Non Significant
Feed*Feed	0.92000	0.2190	4.201	0.002	Significant
Concentration*Voltage	0.08000	0.1284	0.623	0.547	Non Significant
Concentration*Feed	-0.18000	0.1284	-1.402	0.191	Non Significant
Voltage*Feed	0.31500	0.1284	2.453	0.034	Significant
S=0.363136		R-Sq=84.27%		R-Sq(adj)=70.12%	



From RSM, empirical relationship between response and factors in coded forms are given as, $SR = 2.29600 + 0.52000\times Voltage - -0.70000\times(Concetration)^2 + 0.92000\times(Feed)^2 + 0.31500\times Voltage\times Feed$.

Effect on Overcut (OC): The effect of various machining parameters on the overcuts (means) is shown in 3main effect plot for overcut .It shows that overcuts increase and then decrease with an increase in electrolyte concentration in the range of 100 to 125. The overcut increases and then decreases with an increase in voltage in the range of 10 to 13.5. Overcuts increase and then decrease with an increase in feed rate from 0.4% to 0.6.

Table no.8. Analysis of Variance for Means of Overcut

Basis	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1.17002	1.17002	0.130003	54.43	0.000
Linear	3	0.00622	0.00622	0.002073	0.87	0.489
Square	3	0.30117	0.30117	0.100389	42.03	0.000
Interaction	3	0.86264	0.86264	0.287547	120.39	0.000
Lack-of-Fit	5	0.01788	0.01788	0.003575	2.98	0.128
Pure Error	5	0.00601	0.00601	0.001202		

The potential reflection coefficient for OC is shown in Table no.9. R2 = 98.00% indicates that the model is capable of predicting response with good accuracy. The adjusted R2 is the modified R2 adjusted for the number of words in the model and has a value of R2 (adj) = 96.20%. Standard deviation of errors in modeling, S = 0.0488717. Concentration (p = 0.047) and voltage (p = 0.008) are significant while feed (0.808) is non-significant. Classes F * F and interactions V * F are important, while classes V * V, C * C and interactions V * C, C * F are important

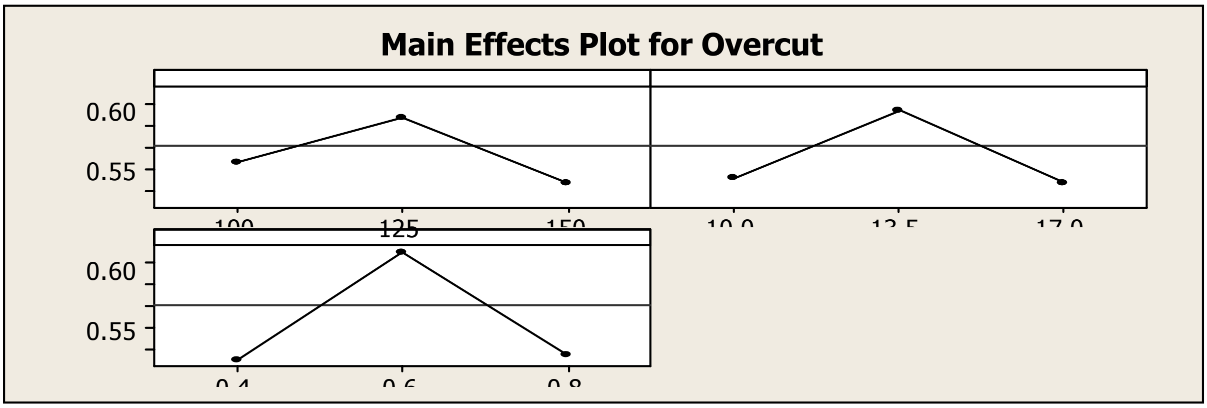
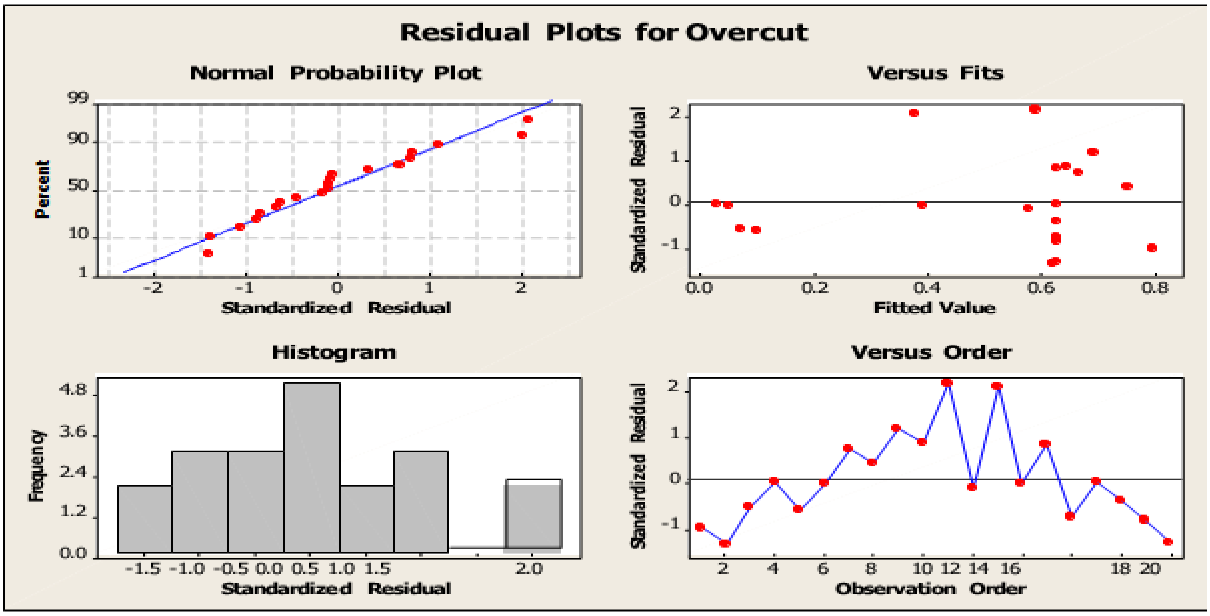


Table no.9 : Probable Relapse Coefficients for Overcut

Period	Coef	SE Coef	T	P	Remarks
Constant	3.93132	0.74087	5.306	0.000	Significant
Concentration	-0.02784	0.01228	-2.267	0.047	Significant
Voltage	-0.23460	0.07119	-3.296	0.008	Significant
Feed	0.25937	1.04177	0.249	0.808	Non Significant
Conc.*Conc.	0.00007	0.00005	1.512	0.162	Non Significant
Voltage*Voltage	-0.00347	0.00241	-1.444	0.179	Non Significant
Feed*Feed	-6.08761	0.73677	-8.263	0.000	Significant
Concentration*Voltage	0.00039	0.00020	1.953	0.079	Non Significant

The residual plot for Overcut is shown in below figure. This layout is suitable for defining whether the model meets the assumptions of the analysis. The data are approximately distributed according to a general probability plot and the variables are influencing the response. A standardized residual range ranges from −2 and 2. Residual versus fitted values indicate that the variance is constant and a nonrelation relationship exists as well as no outliers are present in the data. The histogram proves that the data are approximately normally distributed. This may be due to the fact that the number of digits is very small. The residual versus order of the data indicates that the data have an almost systematic effect.



From RSM, empirical relationship between response and factors in coded forms are given as, OC = 3.93132 - 0.0278399×Concentration - 0.234603×Voltage - 6.08761×$(\text{Feed})^2$ + 0.464339×Voltage×Feed

Combining all we get the optimal condition for maximum MRR, minimum SR and min OC is electrolyte absorption 100gm/lit, voltage 17 volts and feed 0.6 mm/min.

V. Conclusion

In this investigative experiment on electrochemical machining, the effect of machining reaction material removal rate (MRR), surface roughness (SR) and overcut (OC) of stainless steel AISI304 samples using copper electrodes has been studied. The experiment was performed under different machining parameters of voltage (V), feed (F) and electrolyte concentration (C). Experiments were performed using RSM designs that were performed by Minitab software and the results were analyzed and these responses were validated experimentally. The conclusions based on the RSM design are given below:

(1) The parameters affecting the rate of removal of material are voltage and concentration. MRR gradually decreases with increase in electrolyte concentration. The MRR increases and then decreases with an increase in voltage in the range of 10 to 13.5. But MRR decreases and then increases with an increase in feed rate in the range of 0.4 to 0.6. The optimum condition for maximum MRR is electrolyte concentration 100 g / liter, voltage 13.5 volts and feed rate 0.6 mm / rate.

(2) The parameters affecting the surface finish are voltage then interaction feed and voltage. SR increases with increase in voltage. SR increases slightly with increase in concentration from 100 to 125 and then decreases. But increases in feed from 0.4 to 0.6 causes increase in SR. The optimum condition for minimum surface roughness is electrolyte concentrations 125 g / liter, voltage 10 volts and feed 0.6 mm / min.

(3) The parameters affecting overcut are feed, voltage and electrolyte concentration. The OC increases and then decreases as there is increase in electrolyte concentrations from 100 to 125 range. Overcut increases with increase in voltage across the range from 10 to 13.5 and then decreases. The overcut increases and then decreases with an increase in the feed rate from 0.4% to 0.6. The optimal condition for minimum overcut is electrolyte concentrations 150 g / liter, voltage 17 volts and feed rate 0.4 mm / min.

(4) The optimum state electrolyte concentration for maximum MRR, minimum SR and minimum OC is 100 g / liter, voltage 17 volts and feed 0.6 mm / min. The overall response to maximum MRR, minimum SR and OC was most affected by feed rate, then voltage and then electrolyte concentration.

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