OPTIMIZATION AND EXPERIMENTAL INVESTIGATION ON EN19 USING HEXAGONAL SHAPED ELECTRODE IN ECM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

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In

Mechanical Engineering

By

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108ME039

Under the Guidance of

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CERTIFICATE

This is to certify that thesis entitled, "**OPTIMIZATION AND EXPERIMENTAL INVESTIGATION ON EN19 USING HEXAGONAL SHAPED ELECTRODE IN ECM**" submitted by Mr. **ROHIT KUMAR GOUTAM** in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Mechanical Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ABSTRACT:-

Electrochemical machining (ECM) has inaugurated itself as one of the major other possible way to conventional methods for machining hard materials and complicated outlines not having the residual stresses and tool wear. Electrochemical machining has vast application in automotive, Aircrafts, petroleum, aerospace, textile, medical and electronic industries. Studies on Material Removal Rate (MRR) are of extremely important in ECM, since it is one of the factors to be Determined in the process decisions. So the aim of present work is to investigate the metal removal rate, overcut diameter and surface roughness of EN19 alloy steel of diameter 13cm as work piece by using hexagonal shaped Brass electrode and brine solution as electrolyte by using Taguchi approach. Then optimizing to find best setting of process variables for higher MRR, lower surface roughness and overcut. Three parameters were chosen as process variables are: voltage, tool Feed rate and Electrolyte concentration.

Result shows that

1 Among 3 factors feed rate is effecting MRR most then comes voltage and at last electrolyte concentration.
2 For surface roughness, feed rate effects it most then concentration and at last voltage.
3 Tool feed rate effects most to overcut at second rank is voltage and at third rank is concentration which affects most to overcut.
4 In optimizing the quality loss function, it is found that experiment run no 5 is most optimal i.e. voltage=10V, tool feed rate= 0.4 mm/min and electrolyte concentration =22.03g/l for maximizing MRR and minimizing both overcut and surface roughness.

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CHAPTER 1

INTRODUCTION

Electrochemical machining is a nontraditional machining process which is used to machine hard materials which cannot be machined easily without causing any harm to tool. This can be used for mass production and can machine external and internal of any geometry. But use of it is limited only to electrically conductive materials.

Unlike conventional processes ECM removes metal atom by atom.it can be regarded as a solution to a variety of metal removal problems such as cavity sinking, contouring machining and machining helices(rifle barrels) [1].

1.1 FUNDAMENTAL PRINCIPLE:-

As ECM is controlled removal of metal by anode dissolution in an electrolyte. Removal of metal of work piece occurs which is anode and tool is cathode. This removal of metal happens on the principle of Faraday law of electrolysis.

Let us consider iron alloy as work piece and copper as tool and brine solution as electrolyte. Electrolyte is mixture of NaCl and water. This breaks as

$NaCl= Na^{+}+Cl^{-}$ and $H_2o = H^{+}+OH^{-}$

when potential is applied between work piece and tool negatively charged ions move towards anode and positively charged ions move towards cathode.at cathode hydrogen ions takes electron from cathode (tool) and becomes hydrogen gas.

$2H^{+}+2e^{-} = H_2$

At anode iron ions comes out of work piece and loses two electrons and combines with chloride ions to form iron chloride which acts as precipitate.

$Fe = Fe^{++} + 2e^{-}$ and $Fe^{2+} + Cl^{-}=FeCl_2$

Similarly hydroxyl ions combine with sodium ions and form sodium hydroxide.

$Na^+ + (OH)^- = NaOH$

In this way material is machined and removed material is found as precipitate in electrolyte. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool or cathode.

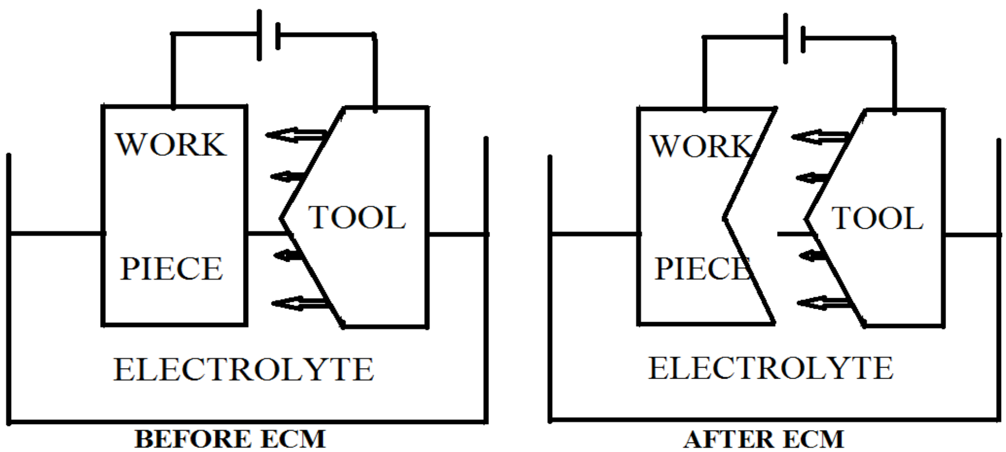


Fig. no 1.1.1schematic principle of ECM

1.2 ADVANTAGES OF ECM:-

1. No mechanical stress impact on to the processed work piece.

2. No thermal impact of the work piece.

3. The removal rate is not determined by hardness or toughness of material.

4. No tool wear.

5. Great versatility for producing complex shapes.

1.3 DISADVANTAGES OF ECM:-

1. High specific energy consumption.

2. Not suited for non-conducting pieces.

3. High initial and working cost.

1.4 APPLICATION

This material can be used for making:

- axial shafts
- propeller shaft joint
- crankshafts
- high tensile bolts and studs
- connecting rods
- riffle barrel
- gears
- high tensile bolts and studs

CHAPTER 2

LITERATURE SURVEY

In this chapter, some research papers related to electrochemical machining are reported. They deal with material removal rate, surface roughness, overcut, tool shape, concentration of electrolyte, micro electrochemical machining, tool design and other responses.

T. Haisch et al. [2] they investigated anodic metal dissolution of alloyed carbon steel in NaCl and $NaNO_3$ as electrolyte. They applied high current densities up to $70A/cm^2$ and turbulent electrolyte flow velocities in flow channel experiment. They found carbide particles on surface in NaCl solution, which they detected using in ex situ scanning electron microscopy and energy dispersive x ray experiment. They used auger electron microscopy with sputter depth profiling to find film composition which resulted from $NaNO_3$ process. They proved that increase of carbide particles not yet separated from surrounding steel. They proposed qualitative metal dissolution model on experimental basis for NaCl and $NaNO_3$ as electrolyte.

B. Bhattacharyya et al. [3] in this paper tried to develop EMM experimental setup for carrying out research for succeeding in control over EMM process parameters to meet micromachining requirement. sets of experiments were carried out to investigate effect of process parameters such as voltage, electrolyte concentration, and pulse on time and frequency of power supply on MRR. According to their investigation, most effective zone of pulse on time and electrolyte concentration is considered as 10-15ms and 15-20g/l respectively. this gives satisfactory amount of MRR and lesser overcut .from SEM micrographs of machine jobs he observed that lower value of electrolyte concentration with high voltage and normal pulse on time produces more accurate shape with less overcut and normal MRR.

D. ChakraDhar et al. [4] they investigated the effect and parametric optimization of process parameters for ECM of EN 31 using grey relation analysis. They considered process parameters voltage tool feed rate and electrolyte concentration. They optimized considering MPCI of MRR, overcut, surface roughness, cylindricity error. They observed tool feed rate is most significant which affect ECM robustness.

C. SenthiKumar et al. [5] they investigated the influence of most important electrochemical process parameters such as applied voltage, electrolyte concentration, tool feed rate, electrolyte flow rate on MRR, surface roughness to fulfill effective utilization of electrochemical machining of LM 25 Al/10%SiC composites produced through stir casting. Contour plot generated by them to study the effect of process parameters as well their interactions. The process parameters were optimized by RSM.

Marcio bacci da silva et al. [6] they studied the intervening variable In ECM of SAE-XAV-F valve steel. A prototype developed by federal university of Uberlandia was used by them for their study. They studied MRR, surface roughness and overcut. Four parameters were changed in experiment which are feed rate, electrolyte flow rate, electrolyte, voltage .they conducted forty experiments. They used two electrolytes NaCl and $NaNO_3$.their result shows that feed rate effects most to MRR. With electrolyte NaNO3 they got best result for surface roughness and overcut.

D. Zhu et al. [7] they presented a method for studying machining accuracy in ECM using dual pole tool with a metallic bush outside the insulated coating of cathode tool. The bush was connected with anode so the electric field at side gap area was weakened. Simulation and modeling presented by them shows dual pole tool decreases current density at side gap area of the machined hole and hence reduces stray material removal. They experimentally observed that machining accuracy and process stability significantly improved by his method.

H. Hochang et al. [8] in this paper, they analyzed a process to erode a hole of hundreds of micrometers on metal surface. They presented a computational model to show machined profile as time passes. Their analysis was based on finite width tool and fundamental law of electrolysis .they also discussed influence of experimental variables as time of electrolysis, voltage, molar concentration of electrolyte and electrode gap upon MRR and machined hole. Result showed that MRR increases with increasing voltage, molar conc. Of electrolyte, time of electrolysis and decreased initial gap. Time of electrolysis is most significant factor for hole of diameter.

AIM OF PRESENT WORK:

Aim of the present work is to find the responses, their interaction with input variables, and to find combination of input variables to find optimum value of the response variables using hexagonal shaped electrode on EN19 special steel as work piece in brine solution using Taguchi approach. The input variables selected are voltage; tool feed rate and electrolyte concentration. To find optimum value of factors we use quality loss function for higher the better (MRR) small the better (surface roughness and overcut).

CHAPTER 3

EXPERIMENTATION

In this chapter, experimentation is discussed which consists about work piece specification, Machine specification, tool design, concentration measurement, formation of the L-9 orthogonal array based on Taguchi design and response calculations Orthogonal array decreases the total number of experiments to be conducted. Total nine experimental runs have been conducted and MRR, overcut diameter and surface roughness are calculated. Multi response optimization of quality loss function is used to find best parameter setting as single response optimization cannot be used in Taguchi design.

3.1 SPECIFICATION OF WORKPIECE MATERIAL:

The material that was selected for experiment was EN19 alloy steel .the description of the Material EN19 alloy steel is given in table no. 4.1 and chemical composition in table 4.2and mechanical and thermal properties are given in table no. 4.3 .the dimension of work piece is 50 mm diameter and 10 mm thickness. The work piece material is circular in shape. 2 pieces ofEN19 alloy steel were taken to conduct 9 experiment runs .3 experiments were conducted on each side of the work piece.

Table no. 3.1.1: *chemical composition*

Element	C	Si	Mn	Cr	Mo	S	P
Weight%	0.36-0.44	0.1-0.35	0.70-1	0.9-1.20	0.25-0.35	0.035	0.040Max

Table no. 3.1.2: *mechanical and thermal properties of EN19*

Parameters	values
density	7.700g/cm^3

3.2 SPECIFICATION OF MACHINE:

All experiments were conducted on Electrochemical Machining set up from Metatech Industry, Pune which have input Supply of 415 V ± 10%, 3 phases AC, 50 HZ and Output supply is 0-300A DC at any voltage from 0-25V. The cable insulation resistance is not less than 10 Mega ohms with 500V DC. This machine consists of three major sub systems which are being discussed in this Chapter.

1. Machining setup
2. Control Panel
3. Electrolyte Circulation

3.2.1 Machining setup

This electro-mechanical gathering is a strong build structure, associated with accurately Machined components, servo motorized vertical up/down movement of tool, an electrolyte providing arrangement, machining chamber with transparent window, job holding Arrangement, job table lifting mechanism and strong build stand. All the exposed components are properly insulated so to be free from corrosion. ECM setup is shown in figure 3.2.1.1

Fig no. 3.2.1.1 *ECM Setup*

3.2.2 CONTROL PANEL

On control panel we regulate the current (I), voltage (V), feed rate (F) and time (T) for duration of every experiment. The power supply is a perfect combination of high electrical current, power electronics and accurately programmable microcontroller based technologies. Since the machine works at very low voltage so there are no chances of any electrical shocks during operation.in Control Panel .there is a siren to indicate the end of experiment after allotted time to an Experiment. Control panel is shown in figure 3.2.2.1

Fig. no. 3.2.2.1 *control panel*

3.2.3 ELECTROLYTE CIRCULATION

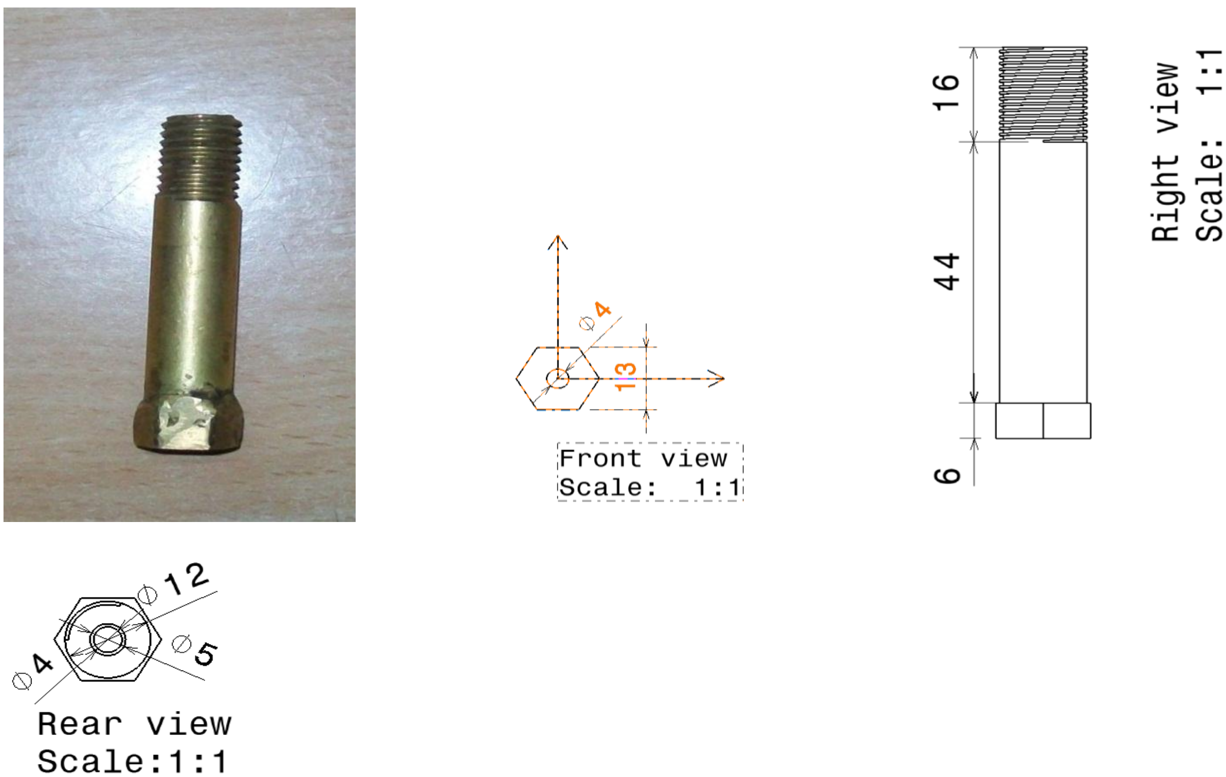
The electrolyte is pumped from tank filled with brine solution. First it is fed to filter then it is fed to the job. Used electrolyte will return back to the tank. The hydroxide sludge arising will Settle at the bottom of the tank & can be easily drained out. Electrolyte supply shall be controlled by flow control valve. Extra electrolyte flow is passed back to the tank.. All fittings are of corrosion resistant material or of Stainless steel, as necessary.

Fig no. 3.2.3.1 *Electrolyte tank*

3.3. TOOL DESIGN

A tool is required for desired way of removing material from the work piece. Different tool shapes are required for different use giving different shapes to the work piece for same conditions.so a tool was made as follows:

Tool for electrochemical machining was made of brass .A solid cylindrical rod of brass of 15mm Diameter was taken and a piece of 65mm was cut .two faces were smoothen by facing the two Faces in lathe and maintained length 60 mm. diameter was reduced to 12mm diameter by turning In lathe and M12 external thread was made on one end of rod using thread die as tool holder has M12 internal thread. A through hole was made of diameter 5mm at the Centre using 5mm drill Bit from a hexagonal shaped rod a piece of 6mm thick piece was cut. A 4mm hole was made at Centre using 4mm drill bit .both these parts were brazed to make tool.



All dimensions are in mm

Fig. no. 3.3.1 *Tool*

3.4 TAGUCHI DESIGN:

As we know Dr. Genichi Taguchi is considered as the foremost presenter of robust parameter Design called as Taguchi design which is a engineering method for increasing value of output or process design that concentrates on minimizing variation and/or sensitivity to noise. When used in precise way, Taguchi designs give a persuasive and effective method for designing products that can operate influentially and optimally over different conditions. There are several approaches to Experimental designs proposed by Taguchi that are sometimes called "Taguchi Methods." two, three, four, five, and mixed-level designs are used by these methods Proposed by Taguchi. Experimental design by Taguchi is referred as "off-line quality control" because it is a method of being confident of getting good performance in the design stage of products or processes.

3.5 DESIGN OF EXPERIMENT IN MINITAB

Taguchi method uses orthogonal array for arranging suitable combination of input signals in a Table to give useful value of output responses. Orthogonal arrays are generalized Graeco Latin squares. In a static response experiment MINITAB software provides both static and dynamic response experiment; the quality characteristic of interest has a fixed level. The quality Characteristic operates over a certain range of values in dynamic response experiment and aim of This experiment is to make better the relation between input signal and output response. This design experiment is used to find best combination of input signals or variables setting that can achieve robustness against noise factors. MINITAB software calculates response tables and generates main effects and interaction plot for:--

- Signal to noise ratios versus input variables or control factors.
- Mean versus input variables or control factors.
- Standard deviation versus input variables or control factors.
- Natural logarithm of standard deviation versus control factors.

Table no.3.5.1: *types of design*

2-level design	2 to 31 factors
3 level design	2 to 13 factors
4 level design	2 to 5 factors
5 level design	2 to 6 factors
mixed level design	2 to 26 factors

For my experiment I have selected 3 level design .voltage, tool feed rate, and concentration are taken as control factors. Level of each factor is taken as 3 .so I had choice of L9 and L27 Orthogonal array. I chose L9 OA' for my experiment.

Table no.3.5.2: *parameters and their level*

Parameters	symbols	unit	Level 1	Level 2	Level3
voltage	V	V	7	10	13
Tool feed rate	F	mm/min	0.2	0.4	0.6
concentration	C	g/l	22.03	30.06	35

3.6. MEASUREMENT OF BRINE SOLUTION CONCENTRATION

As brine solution is a solution of sodium chloride and water.so certain quantity of sodium Chloride is mixed in some liter of water. To measure concentration of a brine solution we can Measure conductivity of same solution and then can convert conductivity into concentration. Conductivity of a solution can be measured by instrument called “deluxe conductivity meter Model no.601 E”.

MEASUREMENT OF CONDUCTIVITY OF BRINE SOLUTION

Functional testing:-

- Connected the instrument to the AC supply and allowed it to warm up for few minutes.
- Put the function switch CHECK position.
- We need to see display reading if it reads 1.000 then it is all right if not then adjust it to 1.000 with the help of CAL control provided at back panel.
- So the instrument was ready to use.

Operation:-

Connecting the conductivity cell:-

- Wash the conductivity cell thoroughly with distilled water (before use, the cell kept in Distilled water for at least twenty four hours).
- Fit the electrode leads to input sockets provided at rear of the instrument.

Measurement procedure:-

- Rinsed the conductivity cell with brine solution as conductivity of brine solution was going to measure.
- Dipped the conductivity cell in brine solution.
- Set function switch to check position.
- Display must read 1.000 as it was not showing 1.000 so I adjusted it with CAL control provided at back panel.
- Put the function switch to cell const. position and set the cell constant control to cell constant value of the conducting cell which is 1.
- Moved the function switch to conductivity Position and ranged the switch to appropriate range.
- Connected the conductivity cell at rear of instrument.
- Set the temperature control to temperature of the solution which is set to 25˚c.
- Brought the range switch at position where maximum resolution is obtained.

- Read the display .this showed exact conductance of the brine solution at 25˚c. Unit of conductivity was mili Siemen/cm.

  Same procedure was repeated for more two times for calculating conductivity of brine solution

.

Fig. no. 3.6.1 *deluxe conductivity meter*

CONVERSION OF CONDUCTIVITY TO CONCENTRATION:-

- Raise the conductivity value by 1.0878
- Multiply by 0.4665. This will give concentration in g/l.

3.7 PROCEDURE OF THE EXPERIMENT

- Before starting, the experiment measured initial weight of the work piece so we can Measure MRR.
- Set the work piece in chamber in horizontal position and fixed in tool in tool holder in Vertical Position.
- The distance between work piece and tool tip is taken approximately 1.5mm.
- After setting control parameters and duration of experiment to 5 minutes machining started.
- After 5 minutes experiment was over. Stopped the machine, taken out work piece, cleaned properly and measured the final weight.

➢ Measured the surface roughness using Talysurf and overcut using DC large tool maker's microscope.

Expt. Run no. 1, 5, 9

Expt run no. 2, 6, 7

Expt run no. 3,4,8

Fig no.3.7.1 work piece

Table no 3.7.1: *observation*

Run	Voltage (v)	TFR (mm/min)	Conc. (g/l)	Initial weight (g)	Final weight (g)	Change in weight (g)	MRR (mm^3/min)	Avg. surface roughness (μm)	Overcut diameter (mm)
1	7	0.2	22.03	177.382	177.266	0.116	3.013	6.80	0.4230
2	7	0.4	30.06	156.898	156.650	0.248	6.442	7.07	0.5055
3	7	0.6	35	157.780	157.399	0.381	9.896	4.13	0.5625
4	10	0.2	35	157.399	157.218	0.181	4.702	5.13	0.5345
5	10	0.4	22.03	177.266	176.966	0.30	7.792	8.93	0.5398
6	10	0.6	30.06	156.418	156.008	0.410	10.649	4.93	0.6150
7	13	0.2	30.06	156.650	156.418	0.232	6.026	3.2	0.5325
8	13	0.4	35	157.218	156.812	0.406	10.545	7.73	0.6195
9	13	0.6	22.03	176.96	176.479	0.487	12.649	5.80	0.6760

3.8 SAMPLE CALCULATION

MRR can be calculated as:-

$$MRR= \frac{Change\ in\ weight}{densityx\ time}$$

Overcut- diameter can be measured as:-

$$Overcut = \frac{Do - Di}{2}$$

Di is internal diameter at the top of work piece.

Do is external tool diameter.

3.9 CONCLUSION

Experiments were conducted using designed hexagonal shaped brass electrode and machining setup in Taguchi method .control factors voltage, tool feed rate and concentration were varied to get 9 experiments.at the end MRR, diameter -overcut and surface roughness measurements were done.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter the analysis and discussion on responses which are MRR, surface roughness and diameter-overcut are discussed.

4.1 RESULT AND DISCUSSION ON MRR

The machinability of a material in ECM depends on many factors as voltage ,tool feed rate ,concentration, tool diameter, tool design, electrolyte flow rate and many more.in my case of study voltage, tool feed rate and concentration are input factors and others are kept constant.

In this two tables and six graphs are discussed.

The effect of these parameters on MRR (mean) is shown in fig no. 4.1.1.

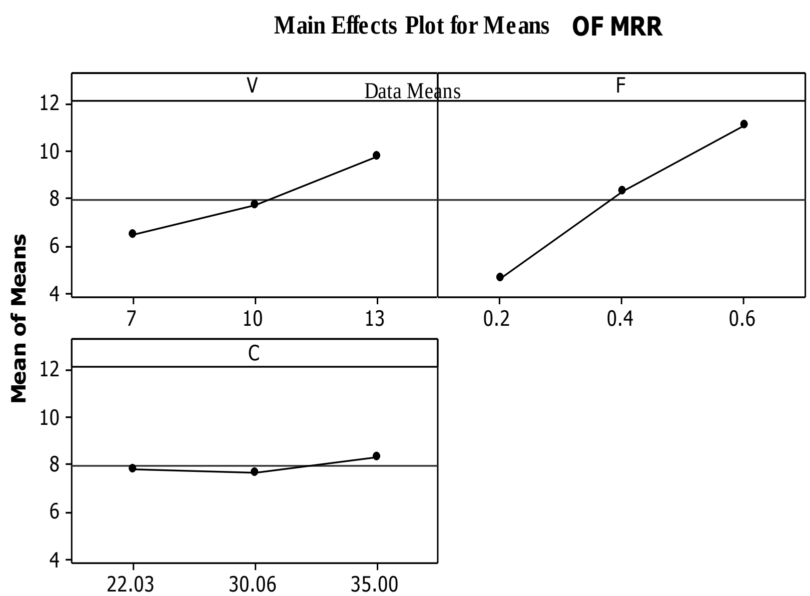


Fig. no. 4.1.1 *Main effect plot for means of MRR*

There is large increase in MRR when feed rate increases from 0.2mm/min to 0.4mm/min than increase in MRR when voltage increases from 7V to 10V.MRR is also more when tool feed rate changes from 0.4mm/min to 0.6mm/min than voltage when it changes from 10V to 13V.In case of electrolyte concentration MRR decreases slightly first till concentration is 30.06 and then increases slightly till concentration reaches 35.

In table no. 4.1.1 column 1 represents source of variation are voltage, tool feed rate and concentration. Column2 represents degree of freedom (DF) of each control factor which is two. Column 3 represent sum of squares (seq. SS).column 4 represents adjusted sum of square. Column5 represents adjusted mean of square.column6 represents F distribution and column 7 represent probability.

Significant factors are voltage and tool feed rate as their p value is less than 0.05 whereas insignificant factor is concentration of brine solution.

Sum of square (seq. SS) is used to find amount of variation that can be explained by each factor. Degree of freedom (DF) indicates the number of independent pieces of information involving the response data needed to calculate the sum of squares. Degree of freedom of each component is (n-1) where n is the number of observation.

In an ANOVA the term mean square refer to an estimate of population variance based on the variability among a given set of measures. The calculation for mean square for model term is

$$MS_{Term} = \frac{adj\ SSTerm}{DFTerm}$$

F-value

F-value is the measurement of the distances between individual distributions.as F value goes up the p value goes down .F is a test to determine whether the interaction and main effects are significant.

$$F = \frac{MSTerm}{MS(Error)}$$

P value

P value is the probability of obtaining a test statistic that is at least as extreme as actual calculated value, if null hypothesis is true. A commonly used cut-off value for p value is 0.05.for example if calculated p value of a test statistic is less than 0.05 we reject the null hypothesis.

Table no.4.1.1: *analysis of variance for means of MRR*

source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
V	2	16.5229	16.5229	8.2615	353.49	0.003
F	2	63.4521	63.4521	31.7260	1357.47	0.001
C	2	0.7857	0.7857	0.3928	16.81	0.056
Residual error	2	0.0467	0.0467	0.0234		
Total	8					
S =0.1529			R-Sq. =99.9%		R-Sq.(adj.) =99.8%	

R-Sq. depicts the amount of variation seen in MRR and is explained by input factors. R-Sq. =99.9% says that model is able to predict response with high accuracy. Standard deviation of error is S=0.1529. R-Sq.(adj.) is modified R-sq. that has been adjusted for a no. of terms in model. If unwanted terms are present in the model R-Sq. may be high but R-Sq. (adj.) may be small. If P value is less than or equal to 0.05 then effect is considered significant otherwise not.

In table 4.1.2, the main effect of voltage, tool feed rate and electrolyte concentration on MRR are 3.290V,6.484mm/min and 0.675g/l.in order of importance tool feed rate is more significant and then voltage and at last brine solution concentration.

Table no.4.1.2: *response table for means of square*

level	V	F	C
1	6.450	4.580	7.818
2	7.714	8.260	7.706
3	9.740	11.065	8.381
delta	3.290	6.484	0.675
rank	2	1	3

The calculation of MRR is done by taking the difference between model values of MRR with observed value of MRR.

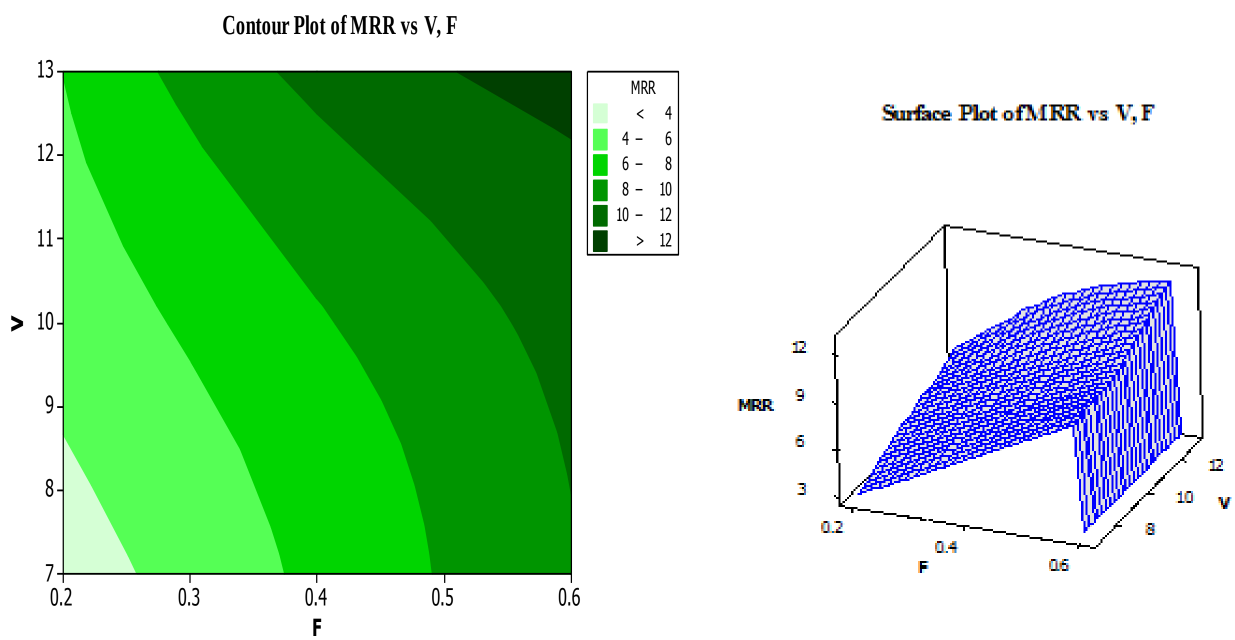
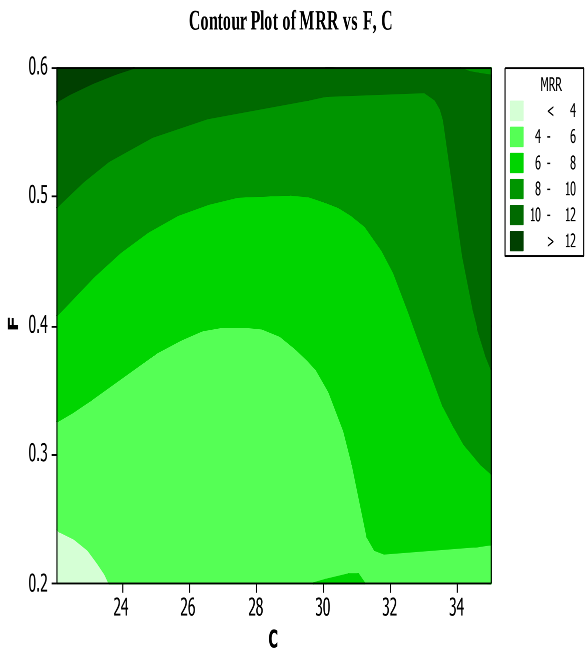


Fig no. 4.1.2 *Contour plot and surface plot for MRR vs. V, F*

In fig. no. 4.1.2 Contour plot of MRR versus V, F shows that with increase in voltage and tool feed rate simultaneously MRR also increases. MRR is maximum when voltage and tool feed rate are at maximum level.at constant voltage range of tool feed rate is increasing to give same MRR in that range. In surface plot I see that at feed rate 0.6mm/min MRR is increasing rapidly with increase in voltage. MRR is increasing linearly with tool feed rate at constant voltage.



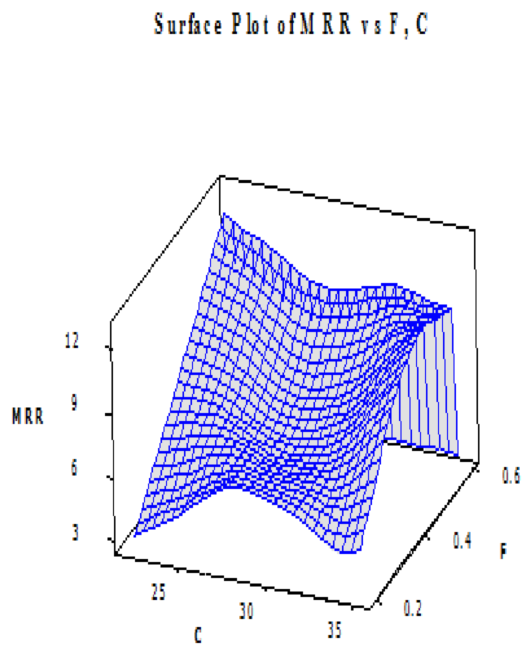


Fig no. 4.1.3 *contour plot and surface plot of MRR vs. F, C*

In contour plot of MRR vs. F, C MRR is increasing with increase in concentration and feed rate.at constant feed rate MRR is nearly same for wide range of concentration. 4-6mm^3/min MRR covers more area than for other range of MRR.in surface plot at constant concentration MRR is approx. in linear relation with tool feed rate

4.2 RESULTS AND DISCUSSION ON SURFACE ROUGHNESS

The effect of control factors voltage, tool feed rate and concentration on surface roughness are shown in figure number 4.2.1

Surface roughness of EN19 increases slightly with increase in voltage value from 7V to 10V and then decreases with increase in value of voltage value from 10V to13V.

Surface roughness of EN19 increases with increase in feed rate from 0.2mm/min to 0.4mm/min and then decreases with increase in value of feed rate from 0.4-0.6mm/min.

In case of concentration surface roughness decreases with increase in value of concentration from 22.03-30.06g/l and then increases with increase in concentration from 30.06-35g/l.so most effective factor looks to be tool feed rate and then concentration.

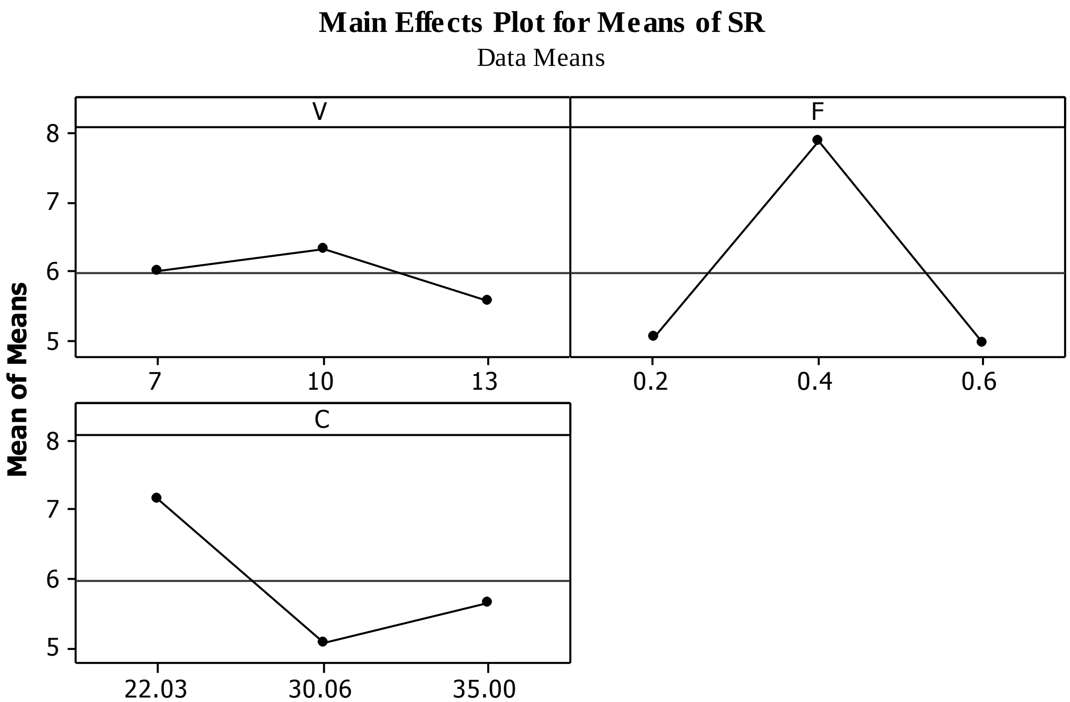


Fig no. 4.2.1 *main effect plot for means of SR*

Table no..4.2.1: *analysis of variance for means of surface roughness*

source	DF	Seq.-ss.	Adj. SS	Adj. MS	F	P
V	2	0.8556	0.8556	0.4278	0.50	0.667
F	2	16.9678	16.9678	8.4839	9.92	0.092
C	2	7.0983	7.0983	3.5491	4.15	0.194
Residual error	2	1.7110	1.7110	0.8555		
total	8	26.6327				
S = 0.9249		R-Sq. = 93.6%		R-Sq.(adj.) =74.3%		

No factor is found to be significant as p value of all factors is greater than 0.05, to be significant value should be less than or equal to 0.05

Standard deviation of error is 0.9249.amount of variation is 93.6% and adjusted amount of variation is 74.3%.

Table no. 4.2.2: response table for means of surface roughness

Level	V	F	C
1	6.000	5.043	7.177
2	6.330	7.910	5.067
3	5.577	4.953	5.663
delta	0.753	2.957	2.110
rank	3	1	2

In table no. 4.2.2 the main effect of input variables voltage, feed rate and concentration on Surface roughness are 0.753V,2.957mm/min and 2.110g/l.

Tool feed rate is more significant and voltage is least significant. Concentration is ranked 2 in order of significance.

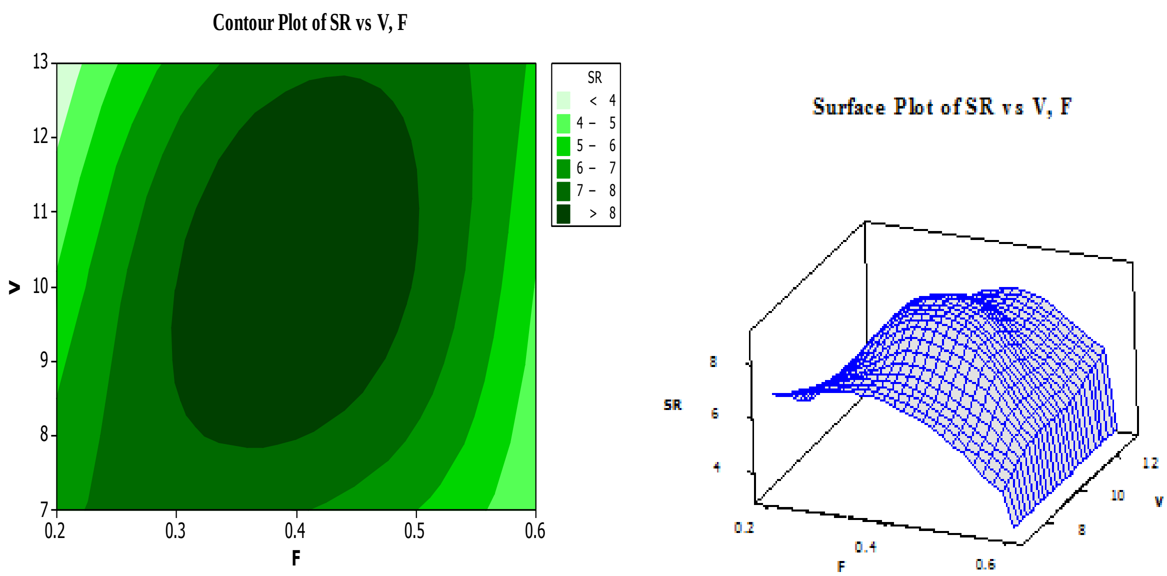


Fig. no.. 4.2.2 *Contour plot and surface plot of SR vs. V, F*

In fig no. 4.2.2 contour plot shows that surface roughness >8 at Centre which looks like elliptical region and decreases in radial direction. Minimum surface roughness <4 is obtained when voltage is high and feed rate is low.

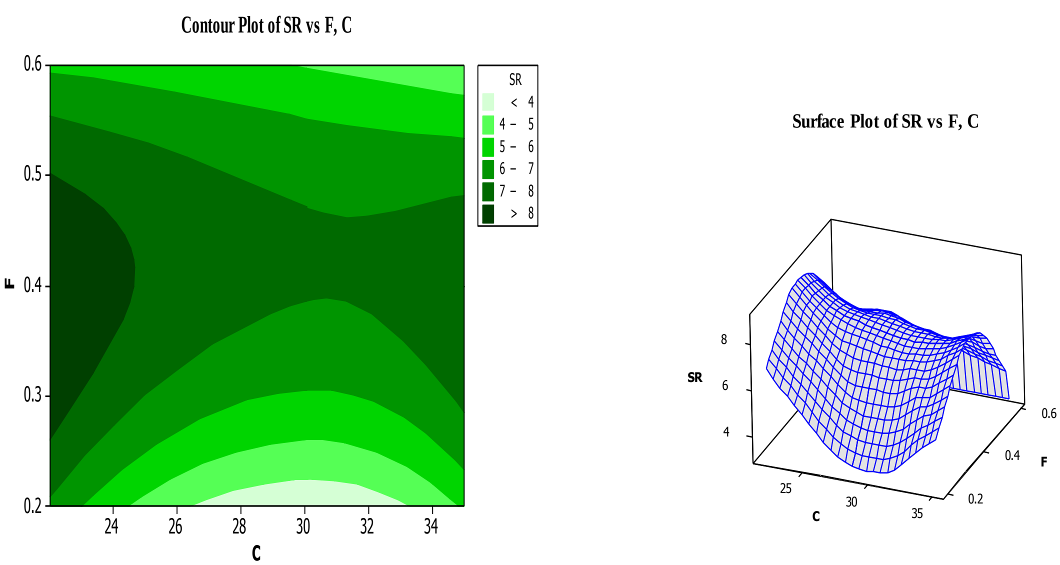


Fig no. 4.2.3 *contour plot and surface plot of SR vs. F, C*

Surface roughness value is minimum feed rate is low and concentration value is average. Surface roughness value is maximum when concentration is low and feed rate is average. The region of high surface is like parabolic area at corner of figure.

4.3 RESULT AND DISCUSSION ON DIAMETER OVERCUT

The influence of input factors on overcut-diameter is shown in diagram no. 4.3.1

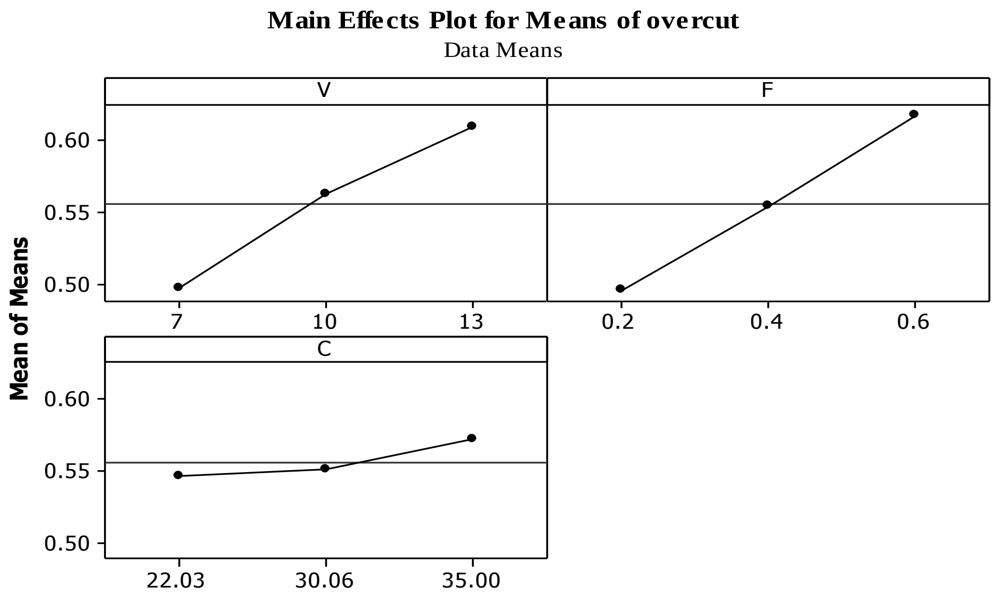


Fig. no. 4.3.1 *main effect plot means of overcut*

Overcut diameter increases linearly with tool feed rate .overcut diameter also increases with increase in voltage but in piece wise linear fashion.it also increases with increase in concentration but in piece wise linear fashion.

Table number 4.3.1: *Analysis of variance for means of overcut*

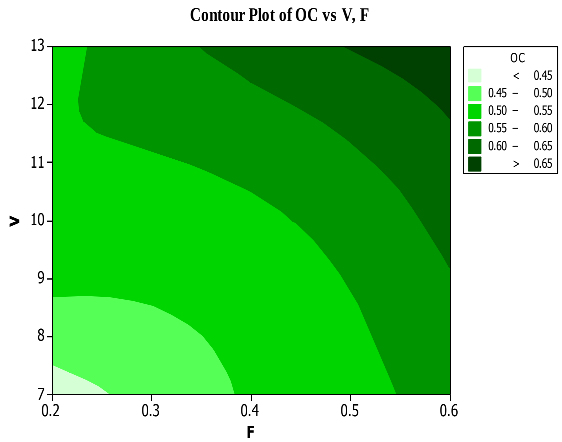
source	DF	Seq.-SS	Adj. SS	Adj. MS	F	P
V	2	0.019126	0.019126	0.009563	16.35	0.058
F	2	0.022033	0.022033	0.011016	18.83	0.050
C	2	0.001141	0.001141	0.000571	0.98	0.506
Residual error	2	0.001170	0.001170	0.000585		
total	8					
S = 0.02419		R-Sq. = 97.3%		R-Sq.(adj.) = 89.2%		

From above table 4.3.1 only significant factors is tool feed rate as p value is equal to 0.05. Standard deviation of error is 0.02419, amount of variation is 97.3% and adjusted amount of variation is 89.2%.

Table no. 4.3.2: *response table for means of overcut*

level	V	F	C
1	0.4970	0.4967	0.5463
2	0.5631	0.5549	0.5510
3	0.6093	0.6178	0.5722
delta	0.1123	0.1212	0.0259
rank	2	1	3

Major effect of voltage, tool feed rate and concentration are 0.1123V,0.1212mm/min and 0.0259g/l respectively. So tool feed rate affects most to overcut-diameter and overcut –diameter is least affected by concentration of brine solution.



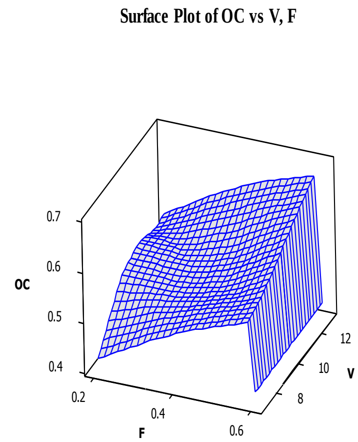
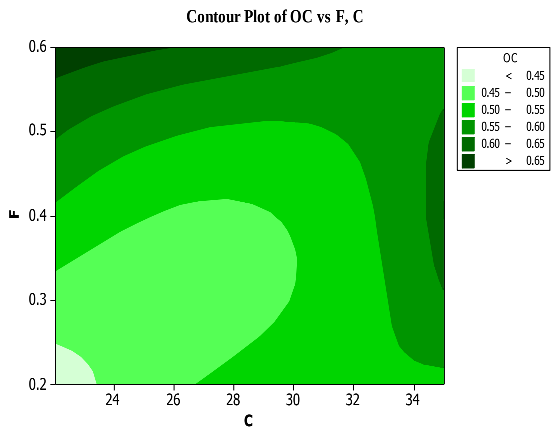


Fig. no. 4.3.2 *contour plot and surface plot of OC vs. V, F*

In figure different regions of overcut are shown. Overcut increases with increase in feed rate and voltage, overcut is maximum in region where voltage and feed rate is max simultaneously.



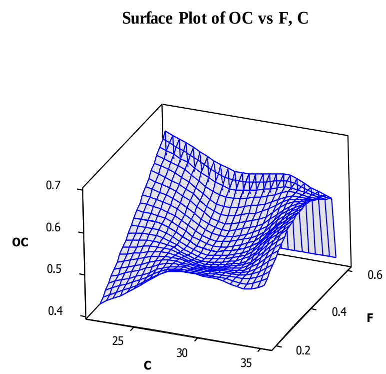


Fig. no. 4.3.3 *contour plot and surface plot of overcut vs. F, C*

Overcut is max When tool feed rate is max and concentration is minimum.in surface plot when concentration is min. then feed rate and overcut varies linearly.

CHAPTER 5

OPTIMIZATION

OPTIMIZATION USING QUALITY LOSS FUNCTION:-

To calculate the difference between wished value and experimental value quality loss function is used.

Responses can come under three categories

1. Large is better
2. Normal is better
3. Small is better

In multi performance characteristic each characteristics may be in different category.so in optimization they have to be deal in different way.

MRR comes in larger the better category and surface roughness and overcut in small is better category.

Loss function for MRR=Lij=1/(Y_{ij})^2	*Loss function for surface roughness and overcut = Lij=(Yij)^2*

Yij is performance value for i_{th} quality characteristic at j_{th} trial

Table no..5.1 : *Table for loss function*

SL.NO	MRR	Surface roughness	overcut	Lij (MRR)	Lij (SR)	Lij (OC)
1	3.013	6.80	0.4230	0.1102	46.24	0.1789
2	6.442	7.07	0.5055	0.0241	49.9849	0.2555
3	9.896	4.13	0.5625	0.0102	17.0569	0.3164
4	4.702	5.13	0.5345	0.0452	26.3169	0.2857
5	7.792	8.93	0.5398	0.0165	79.7449	0.2914
6	10.649	4.93	0.6150	0.0082	24.3049	0.3782
7	6.026	3.20	0.5325	0.0275	10.24	0.2836
8	10.545	7.73	0.6195	0.00899	59.7529	0.3838
9	12.649	5.80	0.6760	0.00625	33.64	0.4570
maximum				0.1102	79.7449	0.4570

As all responses are in different units so we need to normalize

Normalized quality loss function = $N_{ij} = \frac{Lij}{L*}$

Where L*ij is max loss function of that characteristic

Lij is quality loss function

Table no.5.2: MPCI of MRR, SR, OC

Experiment no.	N_{ij} MRR	N_{ij} SR	N_{ij} OC	T_{ij} (MPCI)	Rank
5	0.4197	1.0000	0.6376	0.6701	1
1	1.0000	0.5798	0.3915	0.6610	2
8	0.0816	0.7493	0.8398	0.5473	3
9	0.0567	0.4218	1.0000	0.4965	4
4	0.4102	0.3300	0.6250	0.4613	5
2	0.2187	0.6268	0.5591	0.4603	6
6	0.0744	0.3048	0.8276	0.4071	7
7	0.2495	0.1284	0.6206	0.3431	8
3	0.0926	0.2139	0.6923	0.3389	9

$$T_{ij} = \sum_{i=1}^{p} W_i N_{ij}$$

T_{ij} is total loss function or multi performance characteristic index

W_1=0.35, W_2=0.3, W_3=0.3 (Assumed)

W_i –scalar weighing factor for ith performance

P -number of performance factor

Table no. 5.3: *MPCI mean table*

Level	V	F	C
1	0.4867	0.4885	0.6092
2	0.5128	0.5595	0.4035
3	0.4623	0.4142	0.4492

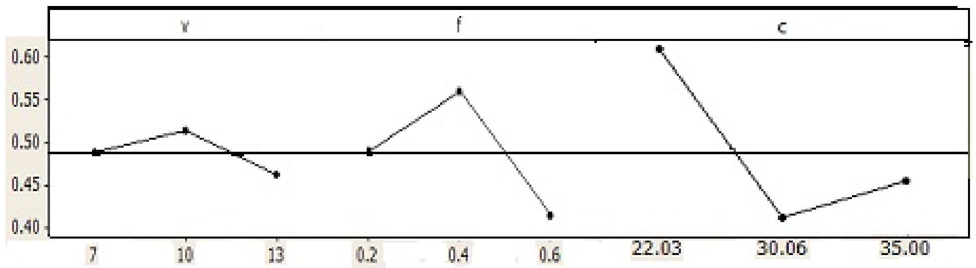


Fig. no.5.1 *Main effect plot for means of MPCI*

Max value of MPCI is at level 2 for voltage, at level 2 for tool feed rate and at level 1 for brine solution concentration. So, optimum combination of responses should be 10V, 0.4mm/min and 22.03g/l.

CHAPTER 6

CONCLUSION

In this study of ECM process on EN19 alloy steel by hexagonal shaped electrode I considered 9 experiments by Taguchi design. .in this three factors were considered that are voltage, tool feed rate and electrolyte conctration. These 9 experiments were conducted to obtain high MRR, low overcut and low surface roughness. optimization by quality loss function was used to obtain suitable combination of factors to get large MRR, small overcut and small surface roughness. I arrived at following conclusion:-

1. Among 3 factors feed rate is effecting MRR most then comes voltage and at last electrolyte concentration.
2. For surface roughness, feed rate effects it most then concentration and at last voltage.
3. Tool feed rate effects most to overcut at second rank is voltage and at third rank is concentration which affects most to overcut.
4. In optimizing the quality loss function, it is found that experiment run no 5 is most optimal i.e. voltage=10V, tool feed rate= 0.4 mm/min and electrolyte concentration =22.03g/l for maximizing MRR and minimizing both overcut and surface roughness.

CHAPTER 7

APPENDIX

7.1. Technical specification of deluxe conductivity meter 601E model

Range	200µS/cm to 1000mS/cm in 5 ranges
Accuracy	±1% F.S. ±1 digit
Resolution	1.0µS/cm
Measuring Frequency	1000 HZ
Temperature Compensation	Manual 0-50℃
Cell Constant	0.4 TO 1.5 adjustable
Display	3 ½ digital bright red LED display
Power Supply	230V ±10%, 50HZ AC
Dimensions	76×275×175 mm(approx)
Weight	2 kg (approx)

7.2. Technical specification of dc large tool maker's microscope

Least count along x axis	1 micron
Least count along y axis	1 micron
circular table movement	0-360˚
Objective magnification	× 1,× 1.5,× 3,× 5
Precision scale of ganio meter	Eye piece reads to 1 minute

7.3. Technical specification of weight balance

model	DJ 300S
name	Sansui vibra
voltage	9V DC
Least count	0.001g
Max weight	300g
system	Tuning fork vibration system

7.4 Technical specification of ECM machine setup

Job holder.	100mm opening x 50mm depth x 100 width.
Tool feed motor	Servo type
Cross head stroke	150mm

7.5 Technical specification of ECM control panel

Electrical output rating	0-300amps at any voltage between 0-20V
Operation mode	Automatic/manual
timer	0-99.9 minutes
Tool feed rate	0.2-2 mm/min
Electrical supply	415V$\pm$10%, 3 phase AC ,50HZ
Z axis control	Forward, reverse by microcontroller

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