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Optimization of Process Parameters During Electrochemical Machining

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Abstract: ***Electrochemical machining is one of the most efficient machining processes due to its ability to produce completely stress-free machined components without any need of further finishing process. However, the right understanding of the effects of key factors during machining of various materials is very important to carry out the machining. It is one of the most efficient way of cutting present in modern era. This present paper deals with the electrochemical machining of Nimonic 80A. Design of the experiments are done by using response surface methodology to study the material removal rate and surface roughness. Process parameters such as voltage, tool feed rate, inter-electrode gap and electrolyte concentration has been optimized by using the ANOVA. The regression models are developed to be used as predictive tools. The confirmation test was conducted to validate the results achieved by GRA approach. This research work helps the industrialist for selecting parameters to attain desired outputs.***
Keywords: Grey relation analysis; Micro electrochemical

Keywords: Electrochemical Machining, ECM, Faraday's Law, Electrolyte, Anodic Dissolution, Nimonic 80A.

I. INTRODUCTION

Electrochemical machining is classified as advanced manufacturing or Non-conventional machining process. In short Electrochemical machining is very popularly known as ECM, it is characterized as reverse Electroplating/Electrodeposition because in this material removal occurs due to atomic dissolution which results in stress- free machined surface and hence provides an excellent surface finish. No thermal damage occurs as the temperature during machining stays within 20 – 50°C. As in modern era, alloys have become harder, especially such superalloys developed in the machine-tool for aerospace industries and other such applications. The cutting rate of such superalloys by conventional machining processes is very poor and hence it is uneconomical.

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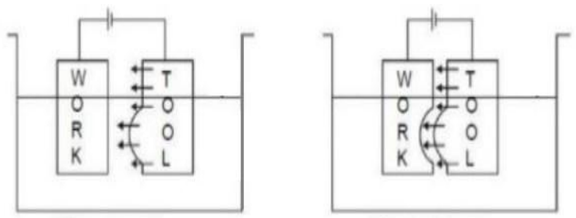
Later it will be discussed in detail that how in comparison to conventional machining techniques electrochemical machining is found to be one of the most promising methods in the cutting of hard materials and has its main application in cutting superhard, exotic alloys and composites [1]. These are the basic characteristics of electrochemical machining. The electrochemical machining has many homologous techniques as they are very similar to ECM such as electrochemical honing, electropolishing, electrochemical grinding, electrochemical discharge machining, electrolyte etching and electrode scaling. Several published articles are available for making a comparison on the basis of the principles and applicability of some or all of the mentioned techniques. In this process workpiece and tool are immersed in an electrolyte, the most common electrolytic solutions are NaCl or $NaNO_3$ to provide with a better understanding a simple schematic diagram in fig. 1 has shown the workpiece and tool immersed in the electrolyte. The tool is connected to the negative terminal and workpiece is connected to the positive terminal, hence tool will be the cathode and the workpiece will be the anode. As the workpiece is anode this process is also known as controlled anodic dissolution process. The basic principle of ECM is administered by The Faraday's Law which states "Amount of material dissolution or deposition during electrolysis is proportional to the amount of charge and Electrochemical Equivalence (ratio of atomic weight and valency)". This statement helps us to understand that the material removal process is completely independent of the hardness of the material.



(A)INITIAL STATE (B) STEADY STATE
FIG. 1. SCHEMATIC DIAGRAM OF WORKPIECE AND TOOL IN ECM.

Not much data is available related to electrochemical machining of Nimonic 80A material but electrochemical machining of many alloys have been reported. Bhattacharyya and Sorkhel [2] have conducted study on EN8. A cylindrical work piece of 19 mm diameter was used. The brass tool was used as anode. Material removal rate and over-cut were analysed. The technique used for generating the design of experiment was RSM, central composite design. NaCl was the electrolyte. Neto et. al [3] studied the electrochemical drilling of SAE-XEV-F Valve-Steel.

The tool material is electrolytic copper. Munda et. al [4] has performed the electrochemical micromachining of bare copper plates as workpiece. A stainless-steel wire of diameter with coating of synthetic material of thickness 20 µm was used as tool.

$NaNO_3$ was used as electrolyte. Klocke et. al [5] studied the machinability of nickel-based alloys and modern titanium such as Ti-6Al-4V, Ti-6Al-2Zn-4Zr-6Mo, Ti-5Al-2Sn-4Mo-2Zr-4Cr (abbr: Ti-17), Inconel 718, Inconel 718 DA, Waspaloy, Waspaloy gatorized, René 88, IN 100 and MAR-M-247. These all alloys are commonly used in aerospace industry. Wang et. al [6] studied the electrochemical dissolution behaviour of Inconel 718 and stainless steel at low current densities in a $NaNO_3$ electrolytic solution. Mukhrjee et. al [7] carried out the electrochemical machining of pure aluminium at constant electrolyte feed rate of 12 l/min, tool feed rate less than 1.75mm/min and a constant potential difference of 40V. The electrolyte used was a freshly prepared 1.5 M NaCl. The experiments were performed in order to determine the actual valency during anodic dissolution. Tam et. al [8] applied RSM technique to study the electrochemical-abrasive machining of mild steel. Considered three process variables to study the effect on Surface roughness as there are several parameters can be considered when two techniques are applied in combination but it is not possible to simultaneously study the all

II. Experimental Details

A. Process Parameters

The various parameters which plays influential role in the electrochemical machining process are-.

- Voltage
- Current
- Inter-electrode gap
- Electrolyte concentration
- Tool feed rate
- Electrolyte feed rate

In the present research work out of these process parameters voltage, inter-electrode gap, electrolyte concentration and tool feed rate were selected as input process parameters for electrochemical machining of Nimonic 80A alloy. Three levels of process parameters are shown in table 1.

TABLE 1. VARIOUS PARAMETERS AND THEIR LEVELS

S.No.	Factors	Unit	L-1 (-1)	L-2 (0)	L-3 (+1)
1	Voltage	V	10	15	20
2	Tool Feed Rate	mm/min	8	10	12
3	Electrolyte Concentration	gm/litre	200	250	300
4	Inter Electrode Gap	mm	0.2	0.3	0.4

B. Design of Experiment

In the present work, Response Surface Methodology (RSM)-based Box Behnken Design (BBD) technique was used for experimentation using Design Expert Software. Three levels of each input parameters were taken for experimentation. A total of 29 experiments were conducted to study the effect of input parameters on response parameters i.e. material removal rate, surface roughness and radial over-cut. The table 2 illustrates the experimental scheme according to RSM.

TABLE 2 DESIGN OF EXPERIMENTS FOR ECM OF NIMONIC 80A

S.no.	Factor 1	Factor 2	Factor 3	Factor 4
	Voltage (V)	Tool Feed Rate (mm/min)	Inter Electrode Gap (mm)	Electrolyte Concentration (gm/l)
1	20	10	0.3	200
2	15	12	0.3	200
3	15	8	0.2	250
4	15	10	0.4	300
5	15	12	0.2	250
6	15	10	0.4	200
7	20	10	0.3	300
8	20	10	0.4	250
9	20	10	0.2	250
10	10	12	0.3	250
11	20	12	0.3	250
12	15	8	0.4	250
13	15	10	0.3	250
14	15	12	0.4	250
15	10	10	0.4	250
16	15	10	0.2	200
17	15	12	0.3	300
18	10	8	0.3	250
19	15	10	0.3	250
20	15	10	0.3	250
21	15	10	0.3	250
22	10	10	0.3	200
23	15	10	0.3	250
24	15	10	0.2	300
25	10	10	0.2	250
26	15	8	0.3	300

27	10	10	0.3	300
28	15	8	0.3	200
29	20	8	0.3	250

III. RESULT AND DISCUSSION

Output response parameters are measured after performing the experiments and the values obtained are then further used for optimization of process in order to obtain the optimized values of process parameters. Three response parameters which were measured during the experimentation were surface roughness, material removal rate. The experimental values obtained for Material Removal Rate and Surface Roughness are given in table 3

TABLE 3. EXPERIMENTAL RESULTS SHOWING MRR AND SURFACE ROUGHNESS

Run	A:Voltage (V)	B:Feed Rate (mm/min)	C:Inter-electrode Gap (mm)	D:Electrolyte Concentration (gm/l)	MRR (gm/min)	Surface Roughness (μm)
1	20	8	0.3	250	0.25	0.14
2	15	12	0.2	250	0.3	0.15
3	15	10	0.3	250	0.24	0.2
4	10	8	0.3	250	0.2	0.21
5	10	12	0.3	250	0.3	0.21
6	10	10	0.3	200	0.2	0.17
7	15	10	0.4	300	0.42	0.25
8	15	12	0.3	200	0.48	0.2
9	15	10	0.3	250	0.24	0.22
10	15	10	0.3	250	0.26	0.21
11	10	10	0.2	250	0.24	0.18
12	15	8	0.2	250	0.24	0.17
13	20	10	0.4	250	0.3	0.13
14	20	12	0.3	250	0.28	0.15
15	10	10	0.4	250	0.2	0.14
16	15	8	0.4	250	0.18	0.16
17	15	10	0.2	200	0.24	0.18
18	15	8	0.3	200	0.16	0.16
19	15	8	0.3	300	0.18	0.22
20	15	10	0.4	200	0.22	0.15
21	20	10	0.2	250	0.26	0.19
22	15	10	0.2	300	0.24	0.25
23	10	10	0.3	300	0.28	0.26
24	15	12	0.3	300	0.3	0.28
25	15	10	0.3	250	0.24	0.17
26	15	10	0.3	250	0.22	0.2
27	20	10	0.3	300	0.4	0.26
28	20	10	0.3	200	0.24	0.19
29	15	12	0.4	250	0.36	0.14

A. Material Removal Rate

Multiple regression models were developed for material removal rate. The mathematical equation obtained for material removal rate is given below.

Sqrt (material removal rate + 1.00) = 3.46675 + (-0.1103 * Voltage) + (-0.897954 * Feed Rate) + (2.06618 * Inter-electrode Gap) + (0.0119532 * Electrolyte Concentration) + (0.0184927 * Voltage * Feed Rate) + (0.017893 * Voltage * Inter-electrode Gap) + (0.0666122 *

Feed Rate * Inter-electrode Gap) + (0.00146973 * Feed Rate * Electrolyte Concentration) + (-0.0306012 * Inter-electrode Gap * Electrolyte Concentration) + (0.00157999 * Voltage2) + (0.0586777 * Feed Rate2) + (0.463265 * Inter-electrode Gap2)
(1)

The results were represented in the form of multi-dimensional curves representing varied slopes, thus indicating variation in influence on material removal rate. The perturbation plot is shown in figure 2.

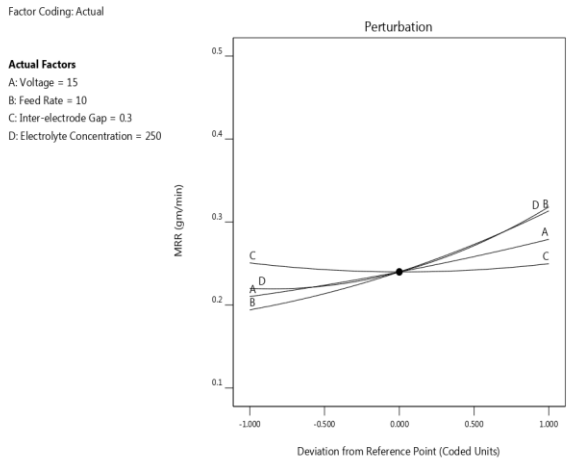


FIGURE 2 PERTURBATION PLOT OF MRR

The optimized process parameters so obtained from machining are shown in Table

B. Surface Roughness

Multiple regression models were developed for surface roughness. The mathematical equation obtained for surface roughness is given below.

Sqrt/(Surface Roughness+1.00) = -2.83721 + (0.11864 * Voltage) + (0.268938 * Feed Rate) + (5.84951 * Inter-electrode Gap) + (0.0225525 * Electrolyte Concentration) + (-0.184078 * Voltage * Inter-electrode Gap) + (-0.289452 * Feed Rate * Inter-electrode Gap) + (-0.0155698 * Inter-electrode Gap * Electrolyte Concentration) + (-0.00873771 * Feed Rate2) + (-2.85993 * Inter-electrode Gap2) + (0.299058 * Voltage * Inter-electrode Gap2) + (0.0232011 * Feed Rate2 * Inter-electrode Gap) + (-0.291034 * Feed Rate * Inter-electrode Gap2) (2)

The results were represented in the form of multi-dimensional curves representing varied slopes, thus indicating variation in influence on surface roughness. The perturbation plot is shown in figure 3.

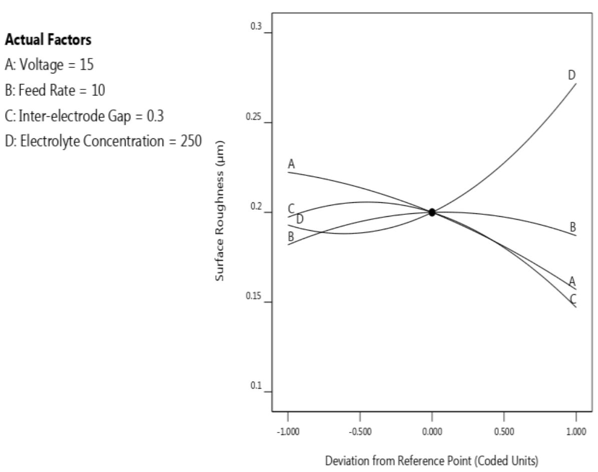


FIGURE 3 PERTURBATION PLOT OF SURFACE ROUGHNESS

The optimized process parameters so obtained from machining are shown in Table 4.

TABLE 4 OPTIMIZED VALUES FOR MRR AND OVERCUT

Voltage (V)	Feed Rate (mm/min)	Inter-electrode Gap (mm)	Electrolyte Concentration (gm/l)	MRR (gm/l)	Surface Roughness (m)
10.317	11.947	0.394	200.049	0.48	0.12

IV. CONCLUSION

The machining of Nimonic 80A was successfully done with copper tool by the optimizing of process parameters viz. voltage, tool feed rate, inter-electrode gap and electrolyte concentration. The following conclusions are drawn on the basis of experimental work and analysis of the result.

- The optimum combination for machining was found to be voltage = 10.317 V, tool feed rate = 11.947 mm/min, inter-electrode gap = 0.394 mm and electrolyte concentration = 200.049 gm/l.
- Most influential factor is tool feed rate in controlling the material removal rate, as the slope is found to be maximum. In this case electrolyte concentration, voltage and inter-electrode gap are the next influential factors respectively.
- Electrolyte concentration is the most influential factor in controlling the radial overcut, as the slope is found to be maximum. In this case voltage, inter-electrode gap and feed rate are the next influential factors respectively.

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