INTERNATIONAL JOURNAL OF ADVANCED RESEARCH IN ENGINEERING AND TECHNOLOGY (IJARET)

ISSN 0976 - 6480 (Print)
ISSN 0976 - 6499 (Online)
Volume 5, Issue 1, January (2014), pp. 18-23
© IAEME: www.iaeme.com/ijaret.asp
Journal Impact Factor (2013): 5.8376 (Calculated by GISI)
www.jifactor.com

IJARET
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ANALYSIS OF ELECTROCHEMICAL MACHINING PROCESS PARAMETERS AFFECTING MATERIAL REMOVAL RATE OF HASTELLOY C-276

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ABSTRACT

The difficulties in machining super alloys and other hard materials by conventional processes are largely responsible for the development of non traditional machining processes. Electrochemical machining (ECM) is a non-traditional process used mainly to machine hard or difficult to cut metals such as Ni-base super alloys, composites, stainless steels etc. Three parameters are changed during experiments: feed rate, electrolyte flow rate and voltage. Taguchi L9 orthogonal array is used for parameter setting during the experimental runs. Aqueous solution of sodium nitrate ($NaNO_3$) is used as an electrolyte of concentration 200 g/l. The results show that the high material removal rate is obtained at high feed rate (1 mm/min), minimum electrolyte flow rate (150 L/hr) and high voltage (16 V). The feed rate is observed to be the main parameter affecting the material removal rate.

Keywords: Electrochemical Machining Process, Material Removal Rate, Optimization, Taguchi Methodology

1. INTRODUCTION

The difficulties in machining super alloys and other hard materials by conventional processes are largely responsible for the development of non traditional machining processes. Electrochemical machining (ECM) is a non-traditional process used mainly to machine hard or difficult to cut metals such as Ni-base super alloys, composites, stainless steels etc. The difficult to cut metals require high energy to deform material in chips resulting into thermal stresses due to the high temperatures. In traditional processes, the heat generated during the machining is dissipated to the tool, chip, workpiece and environment, affecting the surface integrity of the workpiece. [2, 4, 5, 6, 9]

In Electrochemical machining process the tool is not touching the workpiece [8]. Electrochemical reactions (electrolysis) are responsible for the material removal mechanism. Main components of ECM system are voltage, a high current power supply and an electrolyte. The electrolyte is normally solution of inorganic salts, like sodium chloride (NaCl) or sodium nitrate ($NaNO_3$), acids, bases or combinations of salt, acid and base [10]. The objective of this work is to optimize and analyze the process (cutting) parameters in electrochemical machining of Hastelloy C-276 (Ni-Base Superalloy) to get high material removal rate. C-276 alloy is a nickel-molybdenum–chromium wrought alloy that is generally considered a versatile corrosion-resistant alloy. This alloy resists the formation of grain-boundary precipitates. Hastelloy C-276 alloy has excellent resistance to localized corrosion and to both oxidizing and reducing media. It also has excellent resistance to pitting and stress- corrosion cracking. It is one of the few materials that withstand the corrosive effects of wet chlorine gas, hypochlorite and chlorine dioxide. Because of its versatility, C-276 alloy can be used where “upset” conditions are likely to occur or in multipurpose plants [3]. A prototype specimen developed at the laboratory is used for experimentation. Three parameters are changed during the experiments: feed rate, electrolyte flow rate and voltage. Aqueous solution of sodium nitrate ($NaNO_3$) is used as an electrolyte of concentration 200 g/l of H_2O to machine Hastelloy C-276 [10]. Twenty-seven experimental runs are carried out using the equipment developed, with different parameter combinations. Taguchi methodology is used for optimization of the process. To combine parameters at different levels L9 orthogonal array is used [1, 7].

2. DESIGN OF EXPERIMENTS

Fig. 1 shows a schematic diagram of the electrochemical machining system used in this work. The workpiece is held in fixture containing two metal plates; one fixed and other movable. The fixture is kept in a plastic box to avoid loss of current and shock during experimentation. A nut and bolt assembly is used to move the plate for tightening the workpiece. During the process, tool electrode moves according to feed movement while the workpiece is stationary. A threaded shaft is used to provide linear motion to the tool with a gear mounted to rotate shaft through a pinion and a stepper motor. It is welded to steel frame by means of bearing assembly. The shaft is supported in two ball bearings at the ends to ensure free rotation of the shaft. Feed is given manually as well as automatically by means of stepper motor. The tool is of copper and used to supply current through negative pole of power supply. The electrolyte is supplied for machining through the hole drilled at its centre. Acrylic plate of 10 mm thickness is used to hold the tool and to avoid loss of current and shock during manual feeding. The electric unit is used to supply voltage and current at desired level during experiments. It supplies current in regulated DC mode and has calibrated voltmeter and ammeter to set values of voltage and current in the range 0-30 V and 0-60 A respectively. The hydraulic unit is used to supply electrolyte at high and desired pressure or flow rate to facilitate removal the material. It consists of a pump, PVC pipes, fittings and a rotameter. Rotameter is used to measure electrolyte flow rate in liters per hour. To calculate material removal rate an electronic weight balance with a least count of 10 mg is used.

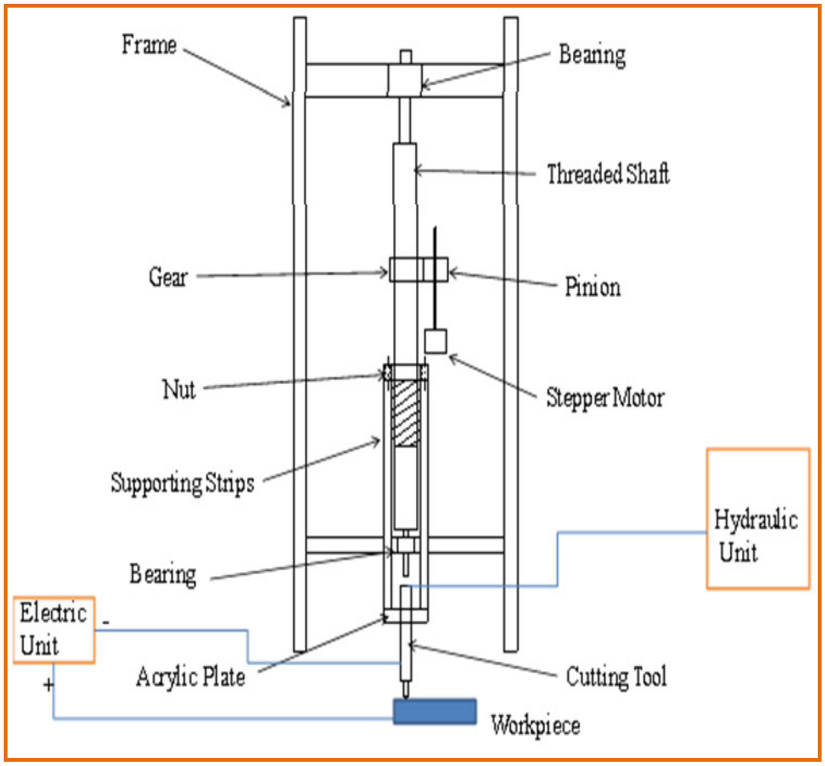

Figure 1: Experimental Set up

The metal removal rate (MRR) is given by,

$$MRR = \frac{(Wb - Wa)}{T} \qquad (1)$$

Where Wb = weight before machining and
Wa = weight after machining and
T = machining time.

During experimentation (1) is used for calculation of the material removal rate (MRR).

3. RESULTS AND DISCUSSION

Optimization of parameters is done by means of Taguchi method. The first step in this method is to select the number of parameters and their levels. The methodology for optimization is given below: (i) Selection of number of parameters and their levels (ii) Selection of orthogonal array (iii) Selection of criteria (Higher-The- Better, Lower-The-Better, Nominal-the-Best) (iv) Determination of signal to noise ratio (S/N ratio), (v) Selection of best combination of parameters for maximum material removal rate. In case of the material removal rate the Higher-The-Better criterion is selected. For increasing productivity of the process the material removal rate needs to be high hence this criterion is selected. S/N ratio for Higher-The-Better criterion is calculated by means of (2).

$$S/N = -10 \log \frac{1}{n}\left\{\frac{1}{\sum_{i=1}^{n} Yi^2}\right\} \qquad (2)$$

Table 1 shows general results for MRR. From the table the optimized combination of parameters high feed rate, minimum flow rate and high voltage is seen. S/N ratio is calculated from (2) and S/N7 has highest value and hence results into optimized combination of parameters for high material removal rate. For this condition, the voltage is 16V and the flow rate of the electrolyte is 150 L/hr.

Table 1: Experimental Results and S/N ratio

Sr. No.	Feed Rate Mm/min (P1)	Electrolyte Flow Rate L/hr (P2)	Voltage V (P3)	MRR mg/min	S/N ratio	
1	0.5	150	12	30	29.54	S/N1
2	0.5	250	14	40	32.04	S/N2
3	0.5	350	16	28	28.49	S/N3
4	0.7	150	14	58	35.26	S/N4
5	0.7	250	16	56	34.96	S/N5
6	0.7	350	12	36	31.12	S/N6
7	**1.0**	**150**	**16**	**78**	**37.84**	**S/N7**
8	1.0	250	12	52	34.32	S/N8
9	1.0	350	14	48	33.62	S/N9

The mean effect of parameters on material removal rate is shown in the following figures. Graphs are plotted to show relation between mean S/N and process parameters from Table 2.

Table 2: Mean S/N values of MRR

Level	Feed Rate	Electrolyte flow rate	Voltage
-1/1	30.02	34.21	31.66
0/2	33.78	33.77	32.8
+1/3	35.26	31.07	33.76

3.1 Effect of Feed Rate

In Fig. 2 the effect of feed rate is shown. As feed rate increases material removal rate increases because tool is forwarding fast towards the workpiece and removes more material. Material removal rate increases because the gap between tool and workpiece is maintained and thus current efficiency are increased which results in high material removal.

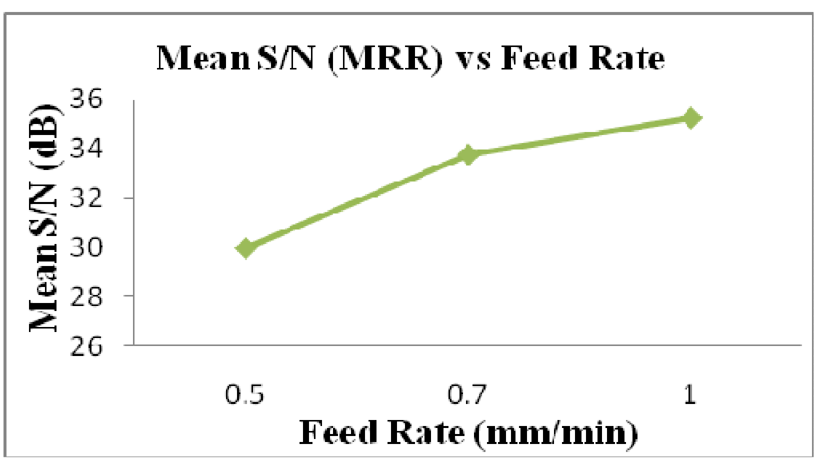

Figure 2: Effect of Feed Rate on MRR

It is the main parameter which affects MRR on large extent because it is varied in fractions (0.2 mm/min).

3.2 Effect of Electrolyte flow rate

In Fig. 3 effect of electrolyte flow rate is shown. As flow rate increases material removal rate decreases because the electrolyte is flowing at fast rate without contacting surface of workpiece. Contact of the electrolyte is needed to react with the material hence at minimum flow rate material removal rate is high.

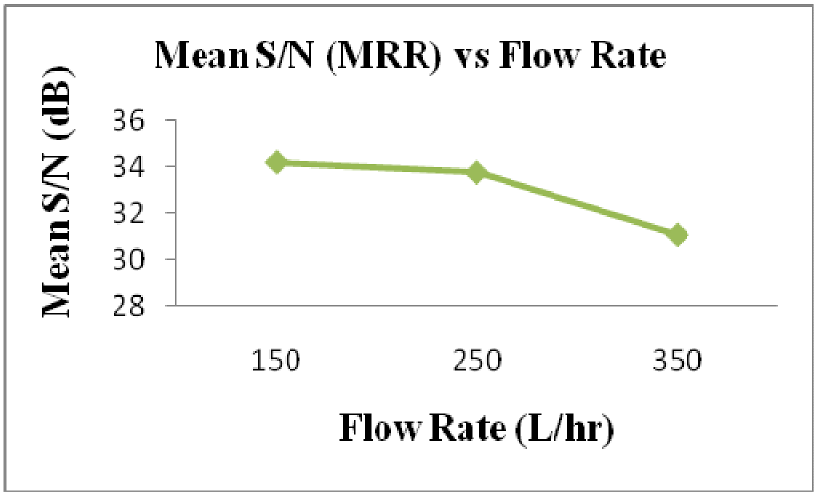

Figure 3: Effect of Flow Rate on MRR

3.3 Effect of Voltage

In Fig. 4 effect of voltage is given and it has almost linear relation with material removal rate. The effect of voltage on material removal rate is negligible because it is varied by two units as compared with feed rate.

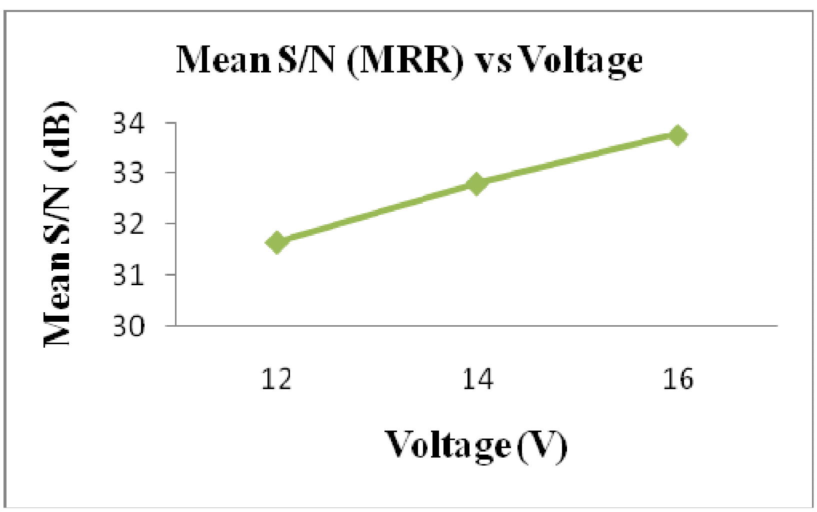

Figure 4: Effect of Voltage on MRR

4. CONCLUSIONS AND FUTURE SCOPE

In this case the best combination is high feed rare at minimum electrolyte flow rate and maximum voltage. The input parameters are termed as Signal and Error in the response/result is termed as Noise. The main component which needs to be tight controlled is feed rate. As voltage and feed rate increases MRR increases. It requires low flow rate to complete the reaction between electrolyte and workpiece to remove maximum material.

It is concluded that:

(i) The MRR is affected by tool feed rate to the greater extent.
(ii) At low feed rates irregular removal of material is more likely to occur.
(iii) The effect of voltage on MRR is almost linear.
(iv) At low electrolyte flow rate (150 L/hr) more material is removed from the workpiece due to longer contact with the workpiece.

In this paper only cutting parameters are optimized and analyzed. Along with these controllable parameters some non controllable parameters are affecting the process characteristics (MRR) and hence optimization of those parameters is challenging. Study of reaction kinetics is broad area for research to increase productivity.

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