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Optimization of process parameter in electrochemical machining Of Inconel 718 by Taguchi analysis

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Abstract— Electrochemical machining (ECM) is a non-contact, electrochemical dissolution process that is used to shape the anode metal, namely the work piece, the cathode, namely the tool, is normally moved toward the anode at constant feed rate, and the electrolyte flows at high speed through the gap to carry away the dissolved metal . ECM is mainly used to cut hard or difficult to cut metals, where the application of a more traditional process is not convenient. Being a complex process, it is very difficult to determine optimal parameters for improving cutting performance. Proper selection of manufacturing conditions is one of the most important aspects in the Electrochemical Machining process, as these conditions determine important characteristics such as Material Removal Rate and Surface Roughness. The material used in the Study was Inconel 718. Four parameters were chosen as process variables: Voltage, Feed rate, Pressure and electrolyte concentration. Experiments have been carried out to establish an Empirical relationship between process parameters and responses in ECM process using Taguchi Methodology. The contour plots are generated to Study the effect of process parameters as well as their interactions. MRR is influenced by applied Voltage and tool feed rate rather than other parameters. There is no single optimal combination of cutting parameters, as their influences on the metal removal rate are quite opposite.

KEY WORDS: ELECTROCHEMICAL MACHINING, TAGUCHI METHOD, OPTIMIZATION, MRR, INCONEL 718

1. INTRODUCTION

Electrochemical Machining (ECM) has tremendous potential because of versatility of its applications, and it is expected that it would be a promising, successful, and commercially viable machining process in the modern manufacturing industries. ECM was developed initially to machine the hard alloys, although any metal can so be machined [1]. It is an electrolytic process and its basis is the phenomenon of electrolysis, whose laws were established by Faraday in 1833. ECM has more advantages over other machining processes such as no tool wear, absence of stress/burr, high material removal, smooth surface finish and the ability to machine complex shapes in materials regardless of their hardness. ECM is an imaging process, where the cathode tool moves with a certain feed rate (0.1 to 2 mm/min) towards the work piece and its negative mirror shape is reproduced in the work piece [1]. The purpose of this work is to investigate the optimum process parameter in the material removal rate of electrochemical machining of Inconel718 by using Taguchi method. The effect of Voltage, Feed rate, Pressure and electrolyte concentration on Inconel 718 is also presented.

2. WORKING PRINCIPLE OF ECM

ECM is a controlled anodic dissolution process which is shown in fig. 1. Here, workpiece & tool are anode and cathode respectively, separated by an electrolyte [4]. When an electric current of high density and low voltage is passed through the electrolyte, the anode work piece dissolves locally. So the final shape of the generated work piece is approximately a negative mirror image of the tool.

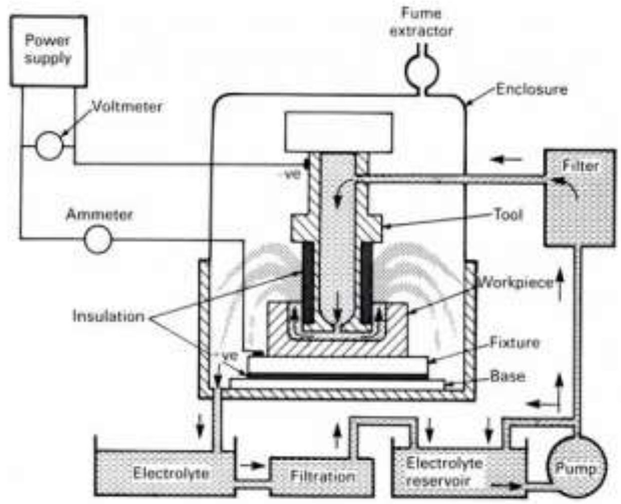

Fig. 1 Principle of ECM

The electrolyte, which is generally a concentrated salt solution flows through the inter electrode gap with high velocity to intensify the mass transfer through the sub layer near anode and to remove the sludge, heat and gas bubbles generated in the gap. Machining performance in ECM is governed by the anodic behavior of the work piece material in a given electrolyte. When a potential difference is applied across the electrodes, several possible reactions can occur at the anode and cathode. The salt is not consumed in the electrochemical processes; therefore, for keeping constant concentration level of electrolyte, it may be necessary to add more water. With this metal-electrolyte combination occurs, due to electrolysis the dissolution of iron from the anode, and the generation of hydrogen at the cathode. No other action takes place at the electrodes [4]

3. EXPERIMENTATION

The experimental setup includes an electrochemical machining unit, control panel and electrolyte tank. The power is supplied to the machining unit through a control panel. The control panel consists of LED's showing current, voltage, feed rate and time. The electrolyte used is NaNO3 aqua solution. The electrolyte is filled in the electrolytic tank and is supplied to the machining unit through a pump. A rotameter is employed to measure the discharge rate of the electrolyte. Copper tool has been used as an electrode and the pressurized electrolyte passes through the electrode. The arrangement is shown in fig. 2.

Fig.-2 Experimental setup of electrochemical machine

The machining unit includes a spindle through which the electrode is inserted. The work piece is fixed in a vise and moved to the appropriate position using hand wheels. The maximum permissible current is set and the inter electrode gap is accurately set by touching the electrode and then feeding the electrode in reverse direction for a specified time [3]. The performance of ECM is observed in terms of material removal rate with respect to Voltage, feed rate, Pressure and electrolyte concentration [4]. IEG of 0.3mm and a tool of dia.2 mm were set throughout the experiments. Then the machining was done for the set values. The chemical composition of work material is presented in Tab.1.The experiments were conducted by seating different level of parameters and the results were recorded. Sartorius electronic weighing machine with1 mg accuracy was used for measuring the metal removal(g). The complete working environment of the experiments shown in Tab. 2.

3.1 Design of Electrode:

The material to be used as tool or electrode should posse's desirable properties like easily machinable, low wear rate, good conductor of electricity and heat, cheap and readily available. In this experiment we have taken cupper as electrode material at cathode. It is designed in circular shaped so as to cut the cavity in workpiece in the similar profile.

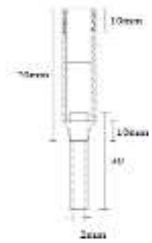

Fig.-3. Design of electrode

Work piece material: Inconel 718

Table-1. Material Composition

Elements	Ni	Co	Cr	Mo	Fe	Al	Nb+T
Weight %	52.50	1.00	19.00	3.05	17.00	0.900	5.125

3.2 Design of Experiment Using Taguchi Approach:

Taguchi parameter design is based on the concept of fractional factorial design. The two major goals of parameter design are
(1) To minimize the process or product variation and
(2) To design robust and flexible processes or products that is adaptable to environmental conditions.

3.3 Control factors and levels

The factors affecting are defined thus:
Controllable factors:

1. Voltage(V)
2. Tool Feed rate (f)mm/min
3. pressure (kg/cm^2)_1
4. Electrolyte conc (mMhos/cm

Table 2 Factors and level combination

Factor / **Level**	**Voltage (V) A**	**Feed rate mm/mn B**	**Pressure (kg/cm2) C**	**Electrolyte conc . (g/L) D**
1	9	0.7	0.8	85
3	14	0.8	0.9	105
3	20	0.9	1.0	125

3.4 Experimental observation:

Experiments were conducted according to Taguchi method by using the machining set up and the designed circular-shaped electrodes. The control parameters like applied voltage, feed rate, electrolyte concentration, and pressure, were varied to conduct nine different experiments and the weights of the work piece were taken for calculation of MRR. MRR is calculated as given by the following formula**: MRR = (initial weight-final weight) / Time**

During each drilling operation based on Taguchi L9 orthogonal array, the machining time was noted down. The weight of the work pieces were measured by the digital weighing machine before and after each drilling operation. Based on Taguchi L9 orthogonal array the values of input factors are placed in design matrix and each experiment was conducted twice to get the response more correctly and it is shown in table 3.

Table3. Experimental observations and calculation based on L9 array

S N	**Voltage (V)**	**Feed rate mm/min**	**Pressure (kg/cm^2)**	**Electrolyte conc.(mMhos/cm**	**MRR Response 1st**	**MRR Response 2st**
1	1	1	1	1	0.028	0.036

2	1	2	2	2	0.032	0.052
3	1	3	3	3	0.036	0.042
4	2	1	2	3	0.028	0.036
5	2	2	3	1	0.062	0.074
6	2	3	1	2	0.052	0.056
7	3	1	3	2	0.04	0.038
8	3	2	1	3	0.043	0.053
9	3	3	2	1	0.070	0.058

4. RESULT ANALYSES

From the result table 3, two responses are taken for further analysis to find out the optimum combination, which can yield into higher MRR. Statistical analysis was performed on the calculated values and the mean change in strength and signal to noise ratio values were calculated for the 9 experiments conducted.

Determination of S/N Ratio:

S/N Ratio = -10 $\log_{10}$ (1/n∑ 1/y_i2)

Table 3.4 Calculation of Signal to Noise ratio for various Response Factors:

Sr. No	MRR Response		Total Test Response	Mean MRRG (g/min)	S/N Ratio
	1st	2st			
1	0.028	0.036	0.064	0.032	-30.10
2	0.032	0.052	0.084	0.042	-28.28
3	0.036	0.042	0.078	0.039	-28.25
4	0.028	0.036	0.064	0.032	-30.10
5	0.062	0.074	0.136	0.068	-23.45
6	0.052	0.056	0.108	0.054	-25.36
7	0.04	0.038	0.078	0.039	-28.18
8	0.043	0.053	0.096	0.048	-26.51
9	0.070	0.058	0.128	0.064	-23.99

Table 4.the response table for mean change for material removal rate (MRR) is shown

Level	A	B	C	D
1	0.0376	0.0343	0.0446	0.053
2	0.0523	0.0526	0.0453	0.045
3	0.049	0.047	0.0486	0.0396
Delta	0.0147	0.0183	0.004	0.0134
Rank	**2**	**1**	**4**	**3**

The response table for signal to noise ratio for material removal rate (MRR) is shown in table ….

Table 5. Taguchi analysis response table for signal to noise ratios:

Level	A	B	C	D
1	28.87	29.46	27.32	25.84
2	26.30	26.07	27.45	27.27
3	26.22	25.86	26.62	28.28
Delta	2.65	2.84	0.7	2.44
Rank	**2**	**1**	**4**	**3**

Calculation of Delta:

Delta = (Maximum S/N Ratio – Minimum S/N ratio)

Rank is ordered on the basis of delta, higher the delta; greater is the influence of that parameter on material removal rate. Thus the material removal rate is highly influenced by feed rate then voltage, pressure and electrolyte concentration.

Also after calculating the S/N ratio of three levels of voltage, feed rate, pressure and electrolyte concentration the optimum parameter setting for MRR is obtained for those levels having higher S/N ratio value.
The optimum parameter setting for MRR is shown in table

Table 5. Optimal combination for MRR

	Voltage (V)	Feed rate)mm/min	Pressure (kg/cm^2)	Electrolyte concn. (mMhos/cm)
Max. MRR	14	0.8	1.0	85

5. RESULTS AND DISCUSSION

5.1 Effect of Machining Parameters on Material Removal Rate (MRR):

The machinability of ECM depends on the voltage, feed rate of electrode, pressure of the electrolyte, electrolyte concentration.

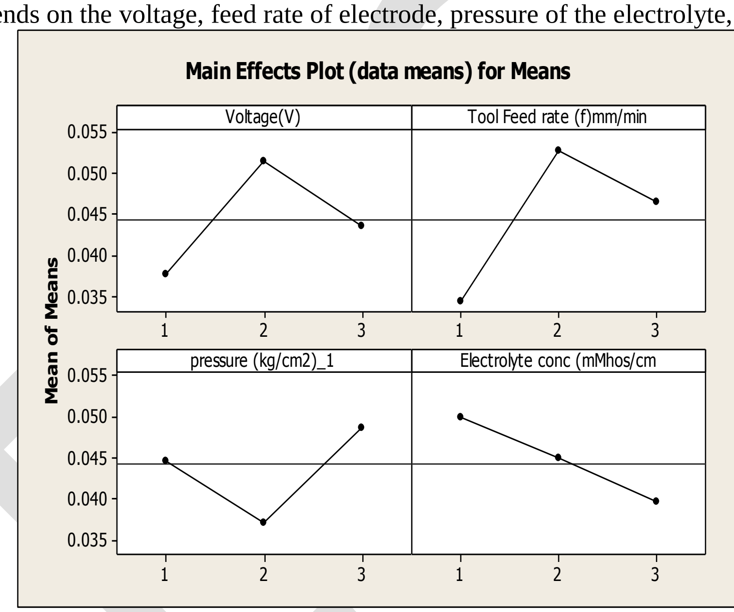

Fig. -3 Main effects plot for MRR (mean)

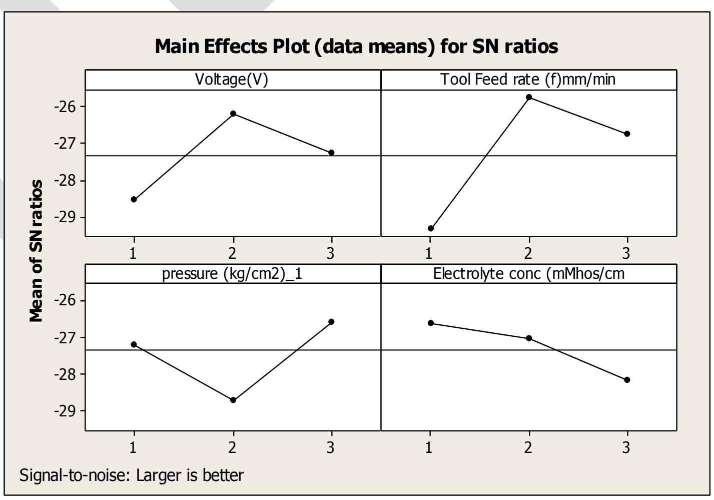

Fig.-4. Main effects plot for S/N Ratio

From the figure it is observed that the MRR increases as the voltage increases from first to second level (i.e. From 9 to 14 volts) but it decreases as it further increases to third level (20 volts). Similar trends are shown by the plot of main effects for SN ratios on MRR. The applied voltage has considerable contribution in affecting the material removal rate; also from the graph it is clear that the optimum cutting parameter for applied voltage is 14 volts (A2).

Similarly From the figure it is observed that the electrode feed rate has enormous effect on MRR and it increases with increase in feed rate up to second level (0.8 mm/sec) and then decreases as the feed rate increases to the third level .
The feed rate has larger contribution in affecting the material removal rate Larger the contribution of any factor, larger is the ability of the factor to influence material removal rate (MRR). Also from the graph it is clear that the optimum cutting parameter for feed rate is 0.8 mm/sec (B2).

Also, it is observed that the electrolyte Pressure has little effect on MRR. MRR increases from second level to third level (i.e. from 0.9 to 1 kg/cm^2) pressure of electrolyte; however, it decreases from first to second level (i.e. from 0.8 to 0.9 kg/cm^2). Similar trends are shown by the plot of main effects for SN ratios on MRR.

Also from the figure it is observed that the MRR decreases as the electrolyte concentration increases from first to second to third level (i.e. From 85 to 125 mMhos/cm) similar trends are shown by the plot of main effects for SN ratios on MRR. The electrolyte concentration has considerable contribution in affecting the material removal rate; also from the graph it is clear that the optimum cutting parameter for applied voltage is 85 mMhos/cm (D1).

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CONCLUSIONS

The paper presented the optimization of the electrochemical machining of Inconel 718 by using Taguchi analysis. The optimal process parameters that have been identified to yield the best combination of process variables are (A2,B2,C3,D1) i.e. voltage at 14 V feed rate at 0.8mm/min, Pressure 1.0 kg/cm^2 and. electrolyte concentration at 85 mMhos/cm, As a result, the target performance characteristics, i.e. material removal rate can be maximized through this method. The effectiveness of this approach is verified by experiment and analysis of variance.

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