PARAMETRIC OPTIMIZATION OF ELECTROCHEMICAL MACHINING PROCESS FOR HARD HSSM2 MATERIAL (62-64 HRC) USING MINITAB TOOL

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Abstract

Electrochemical machining, often known as ECM, is a non-conventional machining method that is typically used for the machining of materials that are notoriously tough to work with, including super alloys, Ti-alloys, stainless steel, alloy steel, and many more. The fact that the work piece must have a nature that is electrically conductive is the most important criterion of the procedure. Both the material removal rate (MRR) and surface roughness (SR) of the components generated by ECM are influenced by a vast variety of different factors. In most cases, tool manufacturers will consult machine manuals and apply thumb rules in order to determine which parameters of the process should be optimised. In this work, Taguchi Methodology is used to investigate the influence that four significant factors have on MRR and SR for HSS M2 Hard Material (62-64 HRC). These parameters are the current, the voltage, the flow rate of electrolyte, and the inter-electrode gap. MINITAB tool is used to implement Taguchi Methodology. It is concluded that MRR and SR both values for ECM machining of HSS M2 hard (i.e. 62-64 HRC) material highly influenced by Current and Voltage parameters of ECM machine. The study is also shows that shows that Current: 280A, Voltage:36V, Flow rate: 5 m^3/min, IEG: 0.1 mm is optimum set of ECM parameters at which we get the optimum MRR i.e. 3.06 mg/min and Current: 200A, Voltage:20V, Flow rate: 9 m^3/min, IEG: 0.5 mm is optimum set of ECM parameters at which we get the optimum SR i.e. 1.93 mg/min.

Keywords: ECM, MRR, SR, HSSM2, 62-64 HRC, MINITAB, Taguchi Methodology.

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1. Introduction

Electrochemical machining (ECM) is a method of removing metal by an electrochemical process. It is normally used for mass production and is used for working extremely hard materials or materials that are difficult to machine using conventional methods. [1] Its use is limited to electrically conductive materials. ECM can cut small or odd-shaped angles, intricate contours or cavities in hard and exotic metals, such as titanium aluminides, Inconel, Waspaloy, and high nickel, cobalt, and rhenium alloys. [2] Both external and internal geometries can be machined. ECM is often characterized as "reverse electroplating", in that it removes material instead of adding it.[2] It is similar in concept to electrical discharge machining (EDM) in that a high current is passed between an electrode and the part, through an electrolytic material removal process having a negatively charged electrode (cathode), a conductive fluid (electrolyte), and a conductive workpiece (anode); however, in ECM there is no tool wear.[1] The ECM cutting tool is guided along the desired path close to the work but without touching the piece. Unlike EDM, however, no sparks are created. High metal removal rates are possible with ECM, with no thermal or mechanical stresses being transferred to the part, and mirror surface finishes can be achieved.

In the ECM process, a cathode (tool) is advanced into an anode (workpiece). The pressurized electrolyte is injected at a set temperature to the area being cut. The feed rate is the same as the rate of "liquefication" of the material. The gap between the tool and the workpiece varies within 80–800 micrometers (0.003–0.030 in.) [1] As electrons cross the gap, material from the workpiece is dissolved, as the tool forms the desired shape in the workpiece. The electrolytic fluid carries away the metal hydroxide formed in the process. [2] Electrochemical machining, as a technological method, originated from the process of electrolytic polishing offered already in 1911 by a Russian Chemist E. Shpitalsky. [3] As far back as 1929, an experimental ECM process was developed by W.Gussef, although it was 1959 before a commercial process was established by the Anocut Engineering Company. B.R. and J.I. Lazarenko are also credited with proposing the use of electrolysis for metal removal. [2] Much research was done in the 1960s and 1970s, particularly in the gas turbine industry. The rise of EDM in the same period slowed ECM research in the west, although work continued behind the Iron Curtain. The original problems of poor dimensional accuracy and environmentally polluting waste have largely been overcome, although the process remains a niche technique. The ECM process is most widely used to produce complicated shapes such as turbine blades with good surface finish in difficult to machine materials. It is also widely and effectively used as a deburring process. [2] In deburring, ECM removes metal projections left from the machining process, and so dulls sharp edges. This process is fast and often more convenient than the conventional methods of deburring by hand or non-traditional machining processes. [1]

According to Faraday 's law of electrolysis, if an electrode and work piece are placed in an electrolyte bath and a potential difference is applied, metal molecules from anode ionize to lose electrons and break free of the work piece, and travel through the electrolyte to cathode.

Mathematically, $m = Ite/F$ (Eq.1)

where, m = weight (g) of a material

I = current (A)

t = time (sec)
e = gram equivalent weight of material
F = Faraday' s constant of proportionality (=96500 coulomb)

Practically, ECM parts are subjected to less amount of thermal stress (as the operating temperature is low) or mechanical stress (as ideally no contact occurs between tool and work piece during machining) but in real practice sparks occur which is to be avoided to minimize the tool wear. ECM process is primarily used for manufacturing components of complex shape used in aerospace and defense industries, offshore petroleum industries and medical engineering.

1. Experimental Procedure

A. Experimental Setup

The experimental trails are conducted on the ECM Machine supplied by the Metatech Industry. The set up consists of three major sub systems:

1. Machining Cell

Figure 1. ECM Unit.

Figure 2. ECM Vice with Workpice.

This electromechanical assembly consists of a sturdy structure that is associated with precision machined components, servo motorised vertical up / down movement of tool, an electrolyte dispensing arrangement, illuminated machining chamber with see through window, job fixing vice, job table lifting mechanism, and sturdy stand. In order to prevent corrosion, each and every exposed component and part has been properly coated or plated, and the appropriate material has been chosen. [4]

Technical Specification:

- Tool area - 30 mm2.
- Cross head stroke - 150 mm.
- Job holder - 100 mm opening X 50 mm depth X 100 mm width.
- Tool Feed motor - DC Servo type.

2. Control Panel

Figure 3. ECM Control Panel.

The power supply is an excellent example of the seamless integration of high-current electrical, power electronics, and precision programmable microcontroller-based technologies. Because of the very low voltage at which the machine functions, there is absolutely no risk of receiving an electric shock while it is in use. [4]

Technical Specification:

- Electrical Out Put Rating - 0-300 Amps. DC at any voltage from 0 - 20 V.
- Efficiency - Better than 80% at partial & full load condition.
- Power Factor - Better than 85.
- Protections - Over load, Short circuit, Single phasing.
- Operation Modes - Manual / Automatic.
- Timer - 0 - 99.9 min.
- Tool Feed - 0.2 to 2 mm / min.
- Z Axis Control - Forward, reverse, auto forward / reverse, through micro controller.
- Supply - 415 v +/- 10%, 3 phase AC, 50 Hz.

3. Electrolyte Circulation

Figure 4. Electrolyte Circulation.

The electrolyte is pumped from a tank that has a coating that prevents corrosion with the assistance of a pump that is resistant to corrosion, and it is then supplied to the job. Electrolyte that has been used up will be poured back into the tank. The hydroxide sludge that forms will eventually fall to the bottom of the tank, where it may be drained away with little effort. The flow control valve will be responsible for controlling the electrolyte supply. The tank receives any additional electrolyte flow that is by-passed. The reservoir has distinct compartments for settling and syphoning processes. Every fitting is made of a material that is resistant to corrosion or, if required, stainless steel. [4]

B. Selection of workpiece, tool material, and electrolyte

Cylindrical blank of 30 mm diameter and 50 mm height made of HSS M2 material with high degree of hardness 62-64 HRC is selected as work piece. Tool is made of copper. 10 % NaCl along with 0.2% H_2O_2 is chosen as electrolyte such that no deposition occurs on the cathode. Unwanted machining due to stray current can be avoided on application of epoxy powder resin coating on the tool except the base of the tool.

C. Selection of machining parameters and their levels

In this experiment, four process parameters such as current, applied voltage, flow rate, inter-electrode gap (IEG) are considered as input parameters. The gap between the two electrodes (tool and workpiece) is called IEG. As the IEG decreases, current density increases and vice versa. The actual values of parameters are given in Table 1.

Table 1. Electrochemical Machining Parameters with their Levels.

Process Parameter(Unit)	Symbol	Levels		
Current(A)	A	200	240	280
Voltage(V)	B	20	28	36
Flow Rate(m^3/min)	C	5	7	9
IEG(mm)	D	0.1	0.3	0.5

D. Taguchi Methodology

Taguchi methodology is the oldest and accepted industrial method of optimization. It is a powerful tool for design high quality system. It follows systematic, simple and efficient approach to optimize designs for performance, quality and cost. Taguchi method is effective method for designing process that operates reliably and optimally over a variety of conditions. To determine the best design, it requires the use of a designed experiment. Taguchi converts the objective function values to Signal-to-Noise ratio (S/N ratio) to measure the performance characteristics of the levels of control factors. In the present work experiment is designed using Taguchi technique, which uses an orthogonal matrix to study the entire parametric space with a limited number of experiments. [5]

1. Smaller is better: Condition for SR

$$S/N = -10 \times log(\Sigma(Y^2)/n)) \qquad \text{(Eq.2.)}$$

2. Larger is better: Condition for MRR

$$S/N = -10 \times log\ (\Sigma(1/Y^2)/n) \qquad \text{(Eq. 3.)}$$

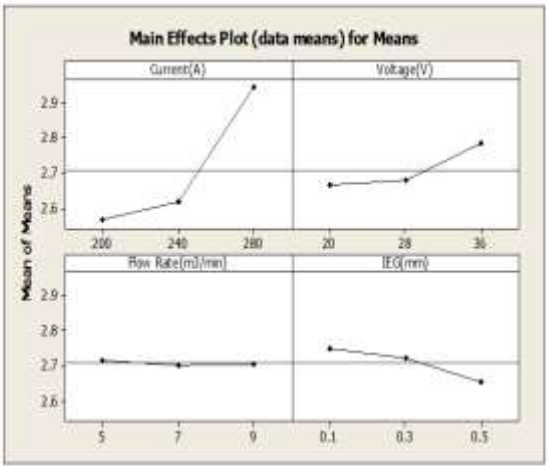
Table 2. Design of Experiments using ECM parameters and respective response signals.

Current (A)	Voltage (V)	Flow Rate (m^3/min)	IEG (mm)	MRR (mg/min)	SR (µm)
200	20	5	0.1	2.57	2.00
200	20	5	0.1	2.56	2.10
200	20	5	0.1	2.58	2.00
200	28	7	0.3	2.55	2.10
200	28	7	0.3	2.53	2.11
200	28	7	0.3	2.55	2.15
200	36	9	0.5	2.58	2.00
200	36	9	0.5	2.59	2.10
200	36	9	0.5	2.58	2.00
240	20	7	0.5	2.52	2.00
240	20	7	0.5	2.51	2.10
240	20	7	0.5	2.50	2.12
240	28	9	0.1	2.65	2.10
240	28	9	0.1	2.62	2.00
240	28	9	0.1	2.61	2.18
240	36	5	0.3	2.71	2.20
240	36	5	0.3	2.72	2.10

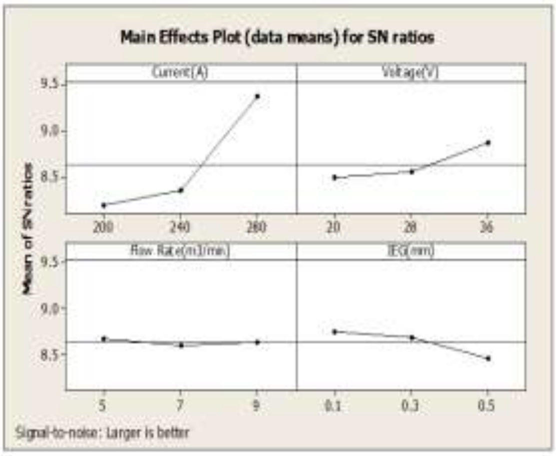
240	36	5	0.3	2.71	2.21
280	20	9	0.3	2.92	2.31
280	20	9	0.3	2.91	2.32
280	20	9	0.3	2.90	2.33
280	28	5	0.5	2.87	2.32
280	28	5	0.5	2.86	2.30
280	28	5	0.5	2.87	2.31
280	36	7	0.1	3.05	2.50
280	36	7	0.1	3.06	2.52
280	36	7	0.1	3.04	2.51

2. Results and Discussions

2.1 Results and Discussion for MRR



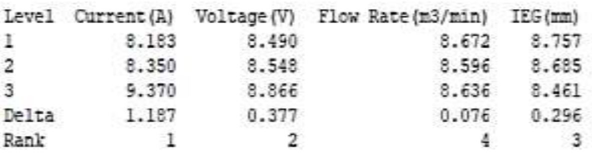
Graph No. 1 Main Effect Plot for Means of MRR.



Graph No. 2 Main Effect Plot for SN ratios of MRR.

Graph 1 shows that material removal rate (MRR) for ECM machining for HSS M2 hard material is increased with increase in current(A) values and also MRR is increased with increase in voltage (V) values. MRR is slightly decreased with increased in flow rate of electrolyte and slightly increases with decreases in flow rate of electrolyte. MRR is decreased with increase in Inter-electrode gap(IEG). Graph 2 shows that Current: 280A, Voltage:36V, Flow rate: 5 m^3/min, IEG: 0.1 mm is optimum set of ECM parameters at which we get the optimum MRR which is 3.06 mg/min. The response tables 3 and 4 shows that MRR is more influenced by current (Rank:1) and then voltage(Rank:2).

Table 3. Response Table for S/N ratios (Larger is better)



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Level  Current(A)  Voltage(V)  Flow Rate(m3/min)  IEG(mm)
1           8.183       8.490              8.672    8.757
2           8.350       8.548              8.596    8.685
3           9.370       8.866              8.636    8.461
Delta       1.187       0.377              0.076    0.296
Rank            1           2                  4        3
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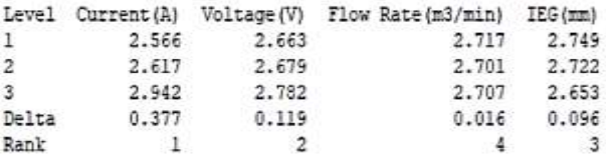
Table 4. Response Table for Means of MRR



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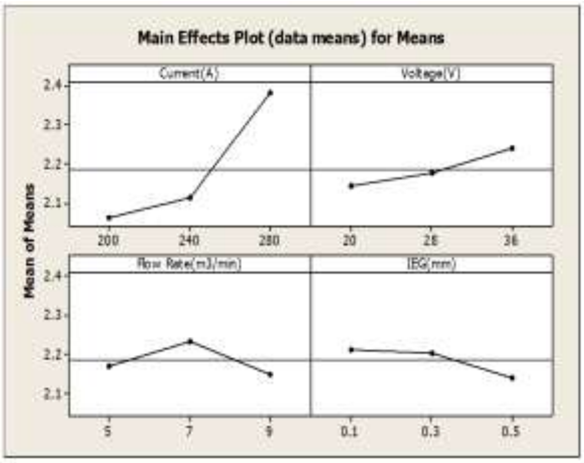
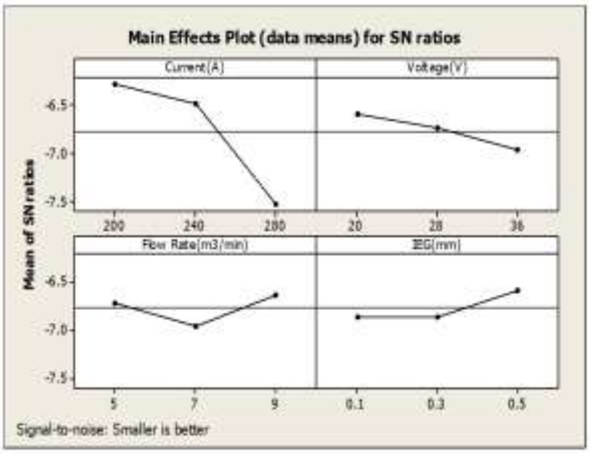
Level  Current(A)  Voltage(V)  Flow Rate(m3/min)  IEG(mm)
1           2.566       2.663              2.717    2.749
2           2.617       2.679              2.701    2.722
3           2.942       2.782              2.707    2.653
Delta       0.377       0.119              0.016    0.096
Rank            1           2                  4        3
```

2.2 Results and Discussion for SR



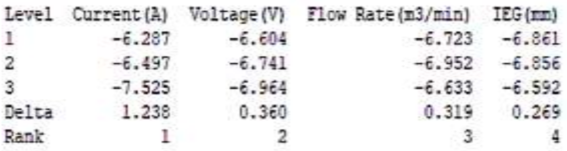
Graph No. 3 Main Effect Plot for Means of SR



Graph No. 4 Main Effect Plot for SN ratios of SR

Graph 1 shows that surface roughness (SR) for ECM machining for HSS M2 hard material is increased with increase in current(A) values and also SR is increased with increase in voltage (V) values. SR is increased up to 7 m^3/min in flow rate of electrolyte and then decreased. SR is decreased with increase in Inter-electrode gap(IEG). Graph 2 shows that Current: 200A, Voltage:20V, Flow rate: 9 m^3/min, IEG: 0.5 mm is optimum set of ECM parameters at which we get the optimum SR which is 1.93 mg/min. The response tables 5 and 6 shows that SR is more influenced by current (Rank:1) and then voltage(Rank:2).

Table 5. Response Table for S/N ratios (Smaller is better)



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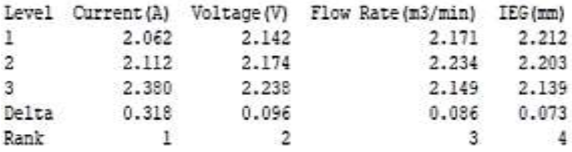
Level  Current(A)  Voltage(V)  Flow Rate(m3/min)  IEG(mm)
1          -6.287      -6.604             -6.723   -6.861
2          -6.497      -6.741             -6.952   -6.856
3          -7.525      -6.964             -6.633   -6.592
Delta       1.238       0.360              0.319    0.269
Rank            1           2                  3        4
```

Table 6. Response Table for Means of SR



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Level  Current(A)  Voltage(V)  Flow Rate(m3/min)  IEG(mm)
1           2.062       2.142              2.171    2.212
2           2.112       2.174              2.234    2.203
3           2.380       2.238              2.149    2.139
Delta       0.318       0.096              0.086    0.073
Rank            1           2                  3        4
```

3. Conclusion

From above investigation, it is concluded that MRR and SR both values for ECM machining of HSS M2 hard (i.e. 62-64 HRC) material highly influenced by Current and Voltage parameters of ECM machine. The study is also shows that shows that Current: 280A, Voltage:36V, Flow rate: 5 m^3/min, IEG: 0.1 mm is optimum set of ECM parameters at which we get the optimum MRR i.e. 3.06 mg/min and Current: 200A, Voltage:20V, Flow rate: 9 m^3/min, IEG: 0.5 mm is optimum set of ECM parameters at which we get the optimum SR i.e. 1.93 mg/min. In order to validate the results obtained, there are three confirmation experiments conducted for each of the response characteristics (MRR, Ra) at optimal levels of the process variables and at initial levels of process variables. The average values of the optimum characteristics at initial levels, predicted value levels and experimental value levels are obtained.

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