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SCIENTIFIC PAPER

UDC

PERFORMANCE OPTIMIZATION OF ECM PARAMETERS FOR PALLADIUM COATED TOOL ELECTRODE USING MULTI-CRITERIA DECISION ANALYSIS METHOD

Highlights

- A palladium-coated electrode with an ascorbic acid mixed electrolyte is used for the ECM experiments.
- The optimal factors are 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency.
- Significant factors for higher MR and overcut are machining voltage and electrolyte concentration.

Abstract

Electrochemical machining is an important process for fabricating difficult-to-cut materials. It is a much more advantageous process for creating excellent surface quality on a wide range of conductive materials. In this research, the electrode (cathode) is coated with less resistive palladium material through a sputtering process, and sodium electrolyte is added with 10 gl^{-1} ascorbic acid to improve Local electrolysis and reduce the sludge generation. The process parameters, specifically electrolyte concentration, machining voltage, duty cycle, and frequency, were varied on machining rate and overcut using the L_{27} orthogonal array experimental plan. ÉLimination Et Choix Traduisant la REalité (ELECTRE) is employed to find a suitable solution. Based on the ELECTRE method, the best factor combination is 29 g L^{-1}electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency. The analysis of variance shows that machining voltage and electrolyte concentration are the considerable factors, with contribution percentages of 43.93% and 23.34%, respectively. As per the mean effect plot, the optimal combination is 29 g L^{-1}electrolyte concentration, 12 V, 90% duty cycle, and 80 Hz frequency.

Keywords: Machining rate, overcut, orthogonal array, ANOVA, ascorbic acid, sputtering.

INTRODUCTION

Electrochemical machining (ECM) is a metal finishing process that works on Faraday's law of electrolysis, in which the tool electrode is the cathode and the workpiece is the anode, separated by a small gap and immersed in an electrolyte bath. By way of application of a potential difference between the electrodes, the dissolution of the workpiece takes place. Apart from the finishing process, the ECM is now considered for the development of holes/dimples and intricate shapes, which finds application in aerospace, biomedical, and automobile components. In ECM, the factors and optimized levels of factors play the major role in performance measures such as material removal rate (MRR)/machining speed/machining rate (MR), overcut (OC), delamination factor, surface corrosion factor, circularity, cylindricity, and surface roughness (SR). Srividya *et al.* [1] have optimized the ECM parameters on aluminum composite using the Taguchi-ANN method. For the experiment dataset, the Artificial Neural Network (ANN) predictions produce an R^2 value of 0.98003 and a mean squared error in the range of 0.02413. The regression study's findings clearly show that the ANN model is capable of accurately and consistently predicting both MRR and SR [1].

Saranya *et al.* [2] have utilized a ceramic-coated tool and optimized the ECM performance for machining aluminum composite. They used ethylene glycol mixed with sodium nitrate electrolyte, and the ideal combination, according to the Grey Relational Analysis (GRA), is 30%

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ethylene glycol, 9 V of voltage, 70% duty cycle, and 35 g L^{-1} of electrolyte. The most encouraging factor, according to the analysis of variance (ANOVA), is electrolyte concentration, which displays 46.36%. The predicted values of the ANN model are 0.17 and 1.14, respectively, which are quite near to the GRA-optimized values of surface corrosion factors and MR, or 0.17 and 1.14, respectively [2]. Venugopal *et al.* [3] have used a polytetrafluoroethylene (PTFE)-coated electrode in ECM for machining Hastelloy C22. The ideal levels of variables for better MR, lower OC, and conicity were found by using inter-criteria correlation and basic additive weighting techniques. The investigation indicated that a PTFE-coated electrode with 20 g L^{-1} mixed electrolyte, 8 V, 85% duty cycle, and 90 Hz frequency was the ideal parameter combination. As per the results of an ANOVA, the electrode type affects MR and OC by 21.15% and 41.26%, respectively. With a 64.32% contribution, the electrolyte content is the most important element for conicity [3].

Thangamani *et al.* [4] have used a heat-treated copper electrode on aluminum 8011 alloy. The best parameters were found using the artificial bee colony (ABC) algorithm, and the error difference on the machining process was then assessed using the confirmation test. For the ECM process, the voltage (14 V), electrolyte concentration (30 g L^{-1}), frequency (60 Hz), and duty cycle (33%) for the annealed tool electrode and the voltage (14 V), electrolyte concentration (20 g L^{-1}), frequency (70 Hz), and duty cycle (33%) for the quenched tool electrode are the ideal combinations of input process parameters that were discovered using TOPSIS and the ABC algorithm. It was verified that the ideal parameter combination produced 95% of the demonstrated accurate response values [4]. Arul *et al.* [5] examined how square-shaped stainless steel (SS) and aluminum metal matrix composite tools affect the creation of square holes. The electrochemical micromachining process's performance is assessed in terms of OC and MR. At parameter combinations of 8 V, 85%, and 23 g L^{-1}, the AMC tool displays 43.22% less OC than the SS tool [5]. An ECM experiment with a persistent magnetic field effect has been planned by Palaniswamy and Rajasekaran [6]. According to the study, the MR grew quickly for voltage levels between 9 V and 10 V, although the pace of change in OC was less noticeable for voltage levels between 6 V and 10 V. A duty cycle range of 70 to 90% exhibits greater MR and a high rate of OC change in conjunction with the magnetic field effect. Higher MR is produced by an electrolyte concentration of 30 to 35 g L^{-1}, whilst an increased rate of change in OC is noted in the range of 15 to 30 g L^{-1} [6].

Palaniswamy *et al.* [7] studied the impact on the copper plate of the graphite electrode with a magnetic force. For these studies, four different tools are used: the graphite tool, the permanent magnet graphite tool (PMGT), the electromagnetic graphite tool (EMGT), and the SS tool. The primary determining parameters on MR and OC are electrolyte content in g L^{-1}, duty cycle in %, and machining voltage in volts. At a parameter level of 23 g L^{-1}, 15 V, and 85%, respectively, the results showed that EMGT, PMGT, and graphite electrodes yield MR of 106.4%, 74.6%, and 44.5% over the SS tool. Furthermore, at parameter levels of 8 V, 95%, and 28 g L^{-1}, graphite and EMGT electrodes produced, respectively, 11.9% and 3.41% lower OC than the SS tool [7]. Maniraj and Thanigaivelan [8] have used a heated electrode in ECM for improving the MRR, reducing the OC, and reducing the conicity factor. The results of the performed studies show that at 8 V, 90% duty cycle, 35 g L^{-1} electrolyte concentration, and 60 °C electrode temperature, the heated electrode increases the MR by 88.37%, lowers the radial OC by 37.03%, and lowers the conicity factor by 33.33% [8]. Cercal *et al.* [9] have experimented with ECM for the reduction of sludge during electrolysis. To accomplish this, complexing and reducing (ascorbic acid) agents were added to the electrolyte composition, resulting in parallel processes that prevented metallic ions from precipitating. They suggest that ascorbic acid is suitable to be added to the electrolyte for the ECM process [9].

It is apparent from the above literature that the research on ECM mainly focuses on the enhancement of output performances such as MRR, accuracy, and surface quality with additional energy and tool design improvement. Literature in the recent past focuses on coating the tool electrode with insulating material towards the deceleration of stray current, and it is the first attempt at coating the ECM electrode with the lowest electrical resistance material, namely palladium. The use of a high electrical conductivity tool electrode induces the enhancement of electrochemical performance. A further L27 orthogonal array (OA) experiment was conducted, and the multi-criteria decision analysis method, namely ÉLimination Et Choix Traduisant la REalité (ELECTRE), was employed to find the suitable solution.

METHODOLOGY

The ECM setup shown in Figure 1 is used for machining, and it consists of a machine structure, an electrode feeding system, an electrolyte supply system, and a power supply. The electrolyte is prepared by using sodium nitrate salt along with distilled water. The varying concentration of electrolyte was considered for the study. Along with the sodium nitrate electrolyte, a concentration of 10 g L^{-1} of ascorbic acid is used as a reducing agent to minimize the sludge formation during the electrolysis process. The stitching needle is used as a 500 µm diameter tool electrode, and a 304 SS workpiece of 0.5 mm thickness was used for the study. The needle is coated with palladium using a sputtering process. The electrode is first submerged in isopropyl alcohol, double-distilled water, and ultrasonicated acetone to remove any minute particles that may have accumulated on the electrode's surface. The ultra-high vacuum chamber was loaded with this cleaned electrode. The argon gas flow was kept at 0.12 m^3/s while the UHV DC magnetron sputtering power was fixed at 30 W, 4×10^{-5} Nm^{-2} was the base pressure, while 0.53 Nm^{-2} was the deposition pressure. The electrode was rotated at 10 rpm and pre-sputtered for 10 minutes, with a gap of 10 cm between it and the target [10,11]. An electrode was covered in palladium. The prepared coated electrode is stored in a base vacuum (high vacuum) for one day. The profile of the palladium-coated tool electrode is shown by field emission scanning electron microscope. Figure 2 depicts the SEM picture of palladium-coated electrodes before and after machining. Table 1 presents the L_{27} OA experiments with factors, levels, and output performances. The MR is measured by noting the time taken to machine the complete hole. The thickness of the workpiece divided by the time noted provides the MR. The OC is the difference between the hole diameter and the tool diameter after coating [12].

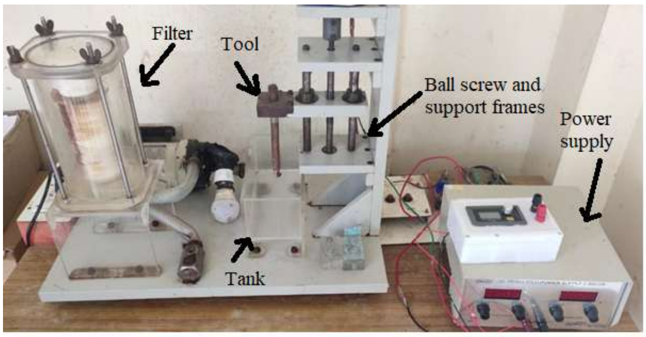

Figure 1. The ECM setup.

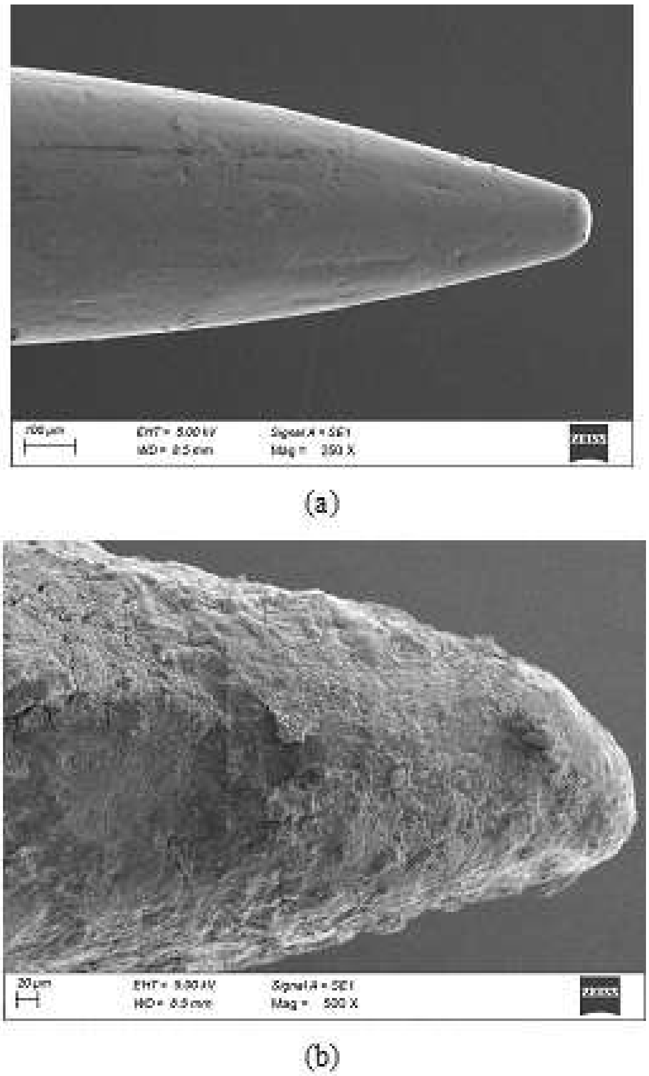

Figure 2. The SEM image of the palladium-coated tool (a) before and (b) after machining.

RESULTS AND DISCUSSION

ELECTRE Method

Decision-making techniques help in investigating multiple process attributes and optimizing the process quality [13,14]. The ELECTRE method is linked to a variety of fields to address multi-measure difficulties. In this procedure, decisions are made by comparing options pairwise depending on each appropriate criterion. The alternatives that do not meet the requirements are then discarded, allowing viable alternatives to be developed [15-18].

The goal is to rank the alternatives based on the two criteria, namely MR and OC. The steps in the multi-criteria decision analysis method are as follows:

1. Define the alternatives.
2. Construct the decision matrix for the criteria.
3. Normalize the decision matrix.
4. Assign weights to MR and OC.
5. Construct the Concordance and Discordance matrices.
6. Apply thresholds for concordance and discordance indices.
7. Determine outranking relations based on the concordance and discordance dominance.
8. Rank the alternatives.

Step 1: Define the alternatives.

Each data point is an alternative, so 27 alternatives corresponding to the pairs of MR and OC were defined.

Step 2: Construct the decision matrix.

A matrix with each row representing an alternative and each column representing a criterion (MR and OC) is formed.

$$\textbf{Decision Matrix} = \begin{bmatrix} \mathbf{0.208} & \mathbf{184} \\ \mathbf{0.278} & \mathbf{166} \\ \mathbf{0.333} & \mathbf{154} \\ \vdots & \vdots \\ \mathbf{0.490} & \mathbf{88} \\ \mathbf{0.556} & \mathbf{84} \end{bmatrix}$$

Criterion 1: MR–to be maximized.

Criterion 2: OC–to be minimized.

Step 3: Normalize the decision matrix

To normalize the decision matrix, each element is divided by the square root of the sum of squares of the corresponding criterion (for benefit criteria, such as MR) or divided by the maximum value (for cost criteria, such as overcut).

For MR (benefit criterion), vector normalization is done using the following relation:

$$x_{ij}^{'} = \frac{x_{ij}}{\sum_{i=1}^{n}(x_{ij})^2}$$

where x_{ij}' is the normalized value of the j^{th} criterion for the i^{th} alternative, x_{ij} is the actual value of the j^{th} criterion for the i^{th} alternative, i is the index for alternatives (i = 1, 2, ..., n), j is the index for criteria, and n is the total number of alternatives.

Table 1. L_{27} OA.

Expt.No	Electrolyte concentration (gl^{-1})	Machine voltage (V)	Duty cycle (%)	Frequency (Hz)	MR (µm/s)	OC (µm)
1	23	8	50	60	0.208	184
2	23	8	70	70	0.278	166
3	23	8	90	80	0.333	154
4	23	10	50	70	0.379	150
5	23	10	70	80	0.417	112
6	23	10	90	60	0.417	115
7	23	12	50	80	0.439	106
8	23	12	70	60	0.417	100
9	23	12	90	70	0.463	95
10	26	8	50	70	0.225	175
11	26	8	70	80	0.231	146
12	26	8	90	60	0.238	142
13	26	10	50	80	0.253	152
14	26	10	70	60	0.269	160
15	26	10	90	70	0.287	162
16	26	12	50	60	0.333	150
17	26	12	70	70	0.362	140
18	26	12	90	80	0.463	100
19	29	8	50	80	0.347	143
20	29	8	70	60	0.379	123
21	29	8	90	70	0.397	110
22	29	10	50	60	0.362	118
23	29	10	70	70	0.379	150
24	29	10	90	80	0.417	105
25	29	12	50	70	0.463	110
26	29	12	70	80	0.556	84
27	29	12	90	60	0.490	88

For OC (cost criterion), the normalization is divided by the maximum value:

$$x_{ij}^{'} = \frac{\text{Min}\left(x_{ij}\right)}{x_{ij}}$$

Step 4: Weigh the criteria.

The weights for MR and OC were assigned as 0.5 based on the importance.

Step 5: Construct the concordance and discordance matrices.

Concordance matrix:

For each pair of alternatives, A_i and A_j, the concordance index was calculated. The concordance index is the sum of the weights of the criteria where A_i performs better than or equal to A_j.

$$\begin{array}{cccccc} & A1 & A2 & A3 & L & A27 \\ A1 & 0.0 & 0.5 & 0.5 & L & 0.5 \\ A2 & 0.0 & 0.0 & 0.5 & L & 1.0 \\ A3 & 0.0 & 0.0 & 0.0 & L & 1.0 \\ M & M & M & M & O & M \\ A27 & 0.0 & 0.0 & 0.0 & L & 0.0 \end{array}$$

Discordance matrix:

For each pair A_i and A_j, the discordance index was computed, which reflects the maximum relative difference for the criteria where A_i performs worse than A_j.

$$\begin{array}{cccccc} & A1 & A2 & A3 & \cdots & A27 \\ A1 & 0.0 & 0.00735 & 0.01359 & \cdots & 0.04202 \\ A2 & 0.02162 & 0.0 & 0.00624 & \cdots & 0.04298 \\ A3 & 0.04143 & 0.02162 & 0.0 & \cdots & 0.05763 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ A27 & 0.05027 & 0.03946 & 0.03321 & \cdots & 0.0 \end{array}$$

Step 6: Apply thresholds.

The concordance threshold c^* and discordance threshold d^* were applied to filter the pairs for which A_i outranks A_j. The threshold values are set based on the average concordance and discordance values.

c^*: 0.514

d^*: 0.176

Based on these thresholds, the dominance matrix is constructed, and the dominance scores are calculated for each alternative. The alternatives were ranked according to their dominance scores (higher dominance scores indicate better performance).

Step 7: Determine outranking relations.

As per the concordance and discordance indices, dominating alternatives were determined. An alternative Ai will outrank Aj if:

c(Ai,Aj) ≥ c^* (sufficient concordance)

d(Ai,Aj) ≤ d^*(acceptable discordance)

Step 8: Rank the alternatives

Aggregate the dominance matrix by combining the concordance and discordance dominance matrices to identify the final dominance for each pair. Using the outranking relations, the ranking of the alternatives is done. The alternative that dominates the most others will be ranked highest. Hence, based on the multi-criteria decision analysis method, the best combination for obtaining optimal output performance is 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency, and the next best combination is 29 g L^{-1} electrolyte concentration, 12 V, 90% duty cycle, and 60 Hz frequency (Table 2). It can be concluded that 29 g L^{-1} of electrolyte concentration, 12 V, a 70-90% duty cycle range, and a 60-80 Hz frequency are the best parameter combinations for achieving better MR and OC.

Table 2. Ranking of attributes.

Alternative	Dominance score	Rank
A26	26	1
A27	25	2
A25	24	3
A18	24	3
A9	24	3
A8	23	6
A7	22	7
A24	22	7
A5	20	9
A6	20	9
A21	19	11
A20	15	12
A22	15	12
A23	13	14
A17	13	14
A4	13	14
A12	12	17
A19	12	17
A16	11	19
A11	10	20
A3	9	21
A13	8	22
A14	6	23
A15	5	24
A2	4	25
A10	1	26
A1	0	27

Analysis of Variables on the ECM Performance

Figure 3 depicts the mean effect plot, and an increase in electrolyte concentration first reduces the MR. A further increase in the concentration enhances the ECM performance because the ionic strength raises the electrolyte conductivity, which leads to higher current density, more heat generation, rapid gas evolution, and passive film generation, which blocks the machining performance. Further increase in electrolyte concentration improves the electrolyte's buffer capacity, leading to a slight increase in the electrolyte's viscosity. This phenomenon stabilizes the gas layer and prevents localized overheating. At a higher voltage, the sludge generation will be affected, which invariably affects the ECM dissolution process. To avoid this effect, the addition of ascorbic acid causes a parallel reduction reaction for metal ions dissolved in the electrolyte. The major goal is to lower the cation valence of metal ions by oxidizing ascorbic acid into dehydroascorbic acid [9].

The ANOVA helps in analyzing the effects of process characteristics on the performance of the process [22-24]. Based on the *F*-value, the ANOVA table (Table 3) shows that electrolyte concentration is the second-best parameter that affects the MR next to voltage. Table 4 shows the ANOVA for the OC, and it is evident that voltage is the most significant factor with an *F*-value of 12.90.

The increase in voltage levels increases the MR. As per Faraday's law of electrolysis, the rise in voltage augments the current density required for machining. The rise in voltage level accelerates the ions during the electrolysis, and the palladium-coated electrode and the addition of ascorbic acid complement the higher MR and lower OC. Moreover, based on the ANOVA table, voltage is the most significant factor that influences the machining performance, with a contributing percentage of 33.83. Figure 2(b) shows the SEM of the coated electrode after the ECM process, and the coatings are delaminated during the electrolysis process. Hence, it is evident that although the coated surface was delaminated, it was not detached from the electrode surface, leading to increased local conducti vity, which accounts for higher output performance. Figure 4 depicts the mean effect plot of OC. An increase in the electrolyte concentration decreases the OC.

Table 3. ANOVA table for MR.

Symbol	Machining parameters	Degrees of freedom	Sum of squares	Mean sum of squares	*F*-value	% contribution
A	Electrolyte concentration (gl^{-1})	2	0.072	0.0359	23.73	0.000
B	Machining Voltage(V)	2	0.103	0.0512	33.80	0.000
C	Duty Cycle(%)	2	0.004	0.0022	1.46	0.258
D	Frequency(Hz)	2	0.007	0.0043	2.84	0.084
E	Error	18	0.027	0.0015		
	Total	26	0.215			

Table 4. ANOVA table for OC.

Symbol	Machining parameters	Degrees of freedom	Sum of squares	Mean sum of squares	F-value	% contribution
A	Electrolyte concentration (gl^{-1})	2	4868	2434.1	7.92	0.003
B	Machining Voltage(V)	2	7928	3964.1	12.90	0.000
C	Duty Cycle(%)	2	1308	654.1	2.13	0.15
D	Frequency(Hz)	2	1069	534.3	1.74	0.20
E	Error	18	5531	307.3		
	Total	26	20705			

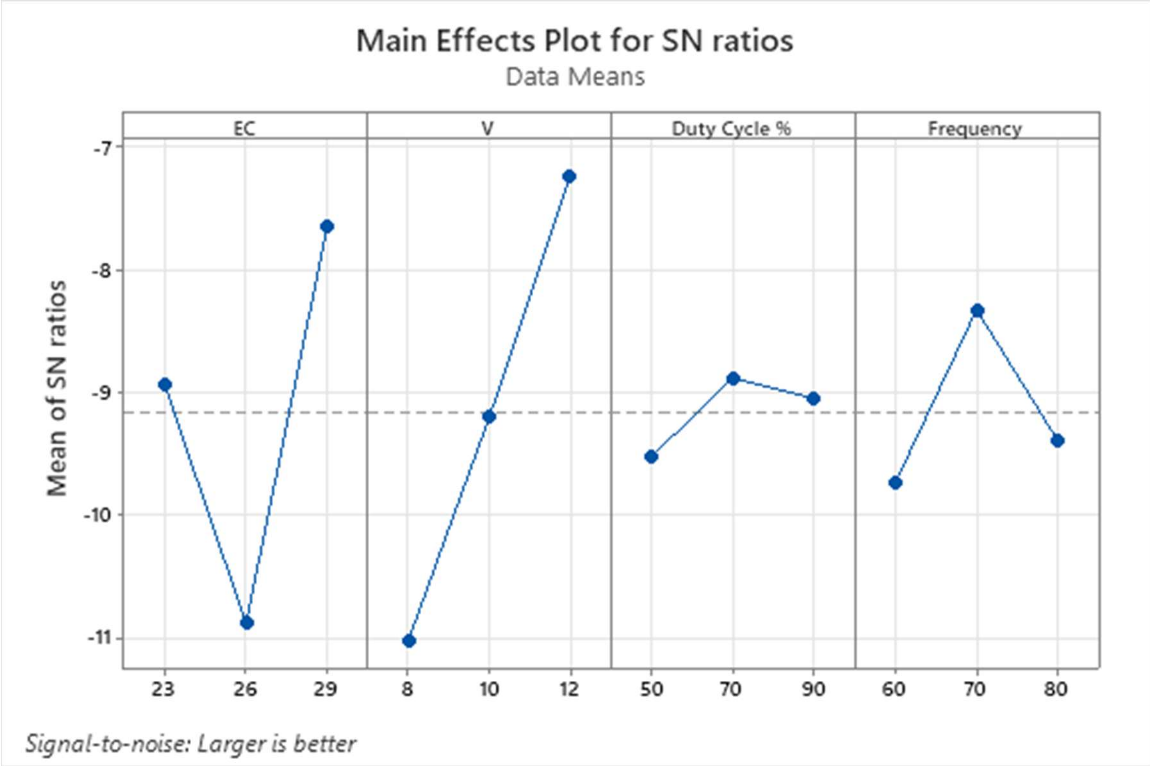

Figure3. The mean effect plot for MR.

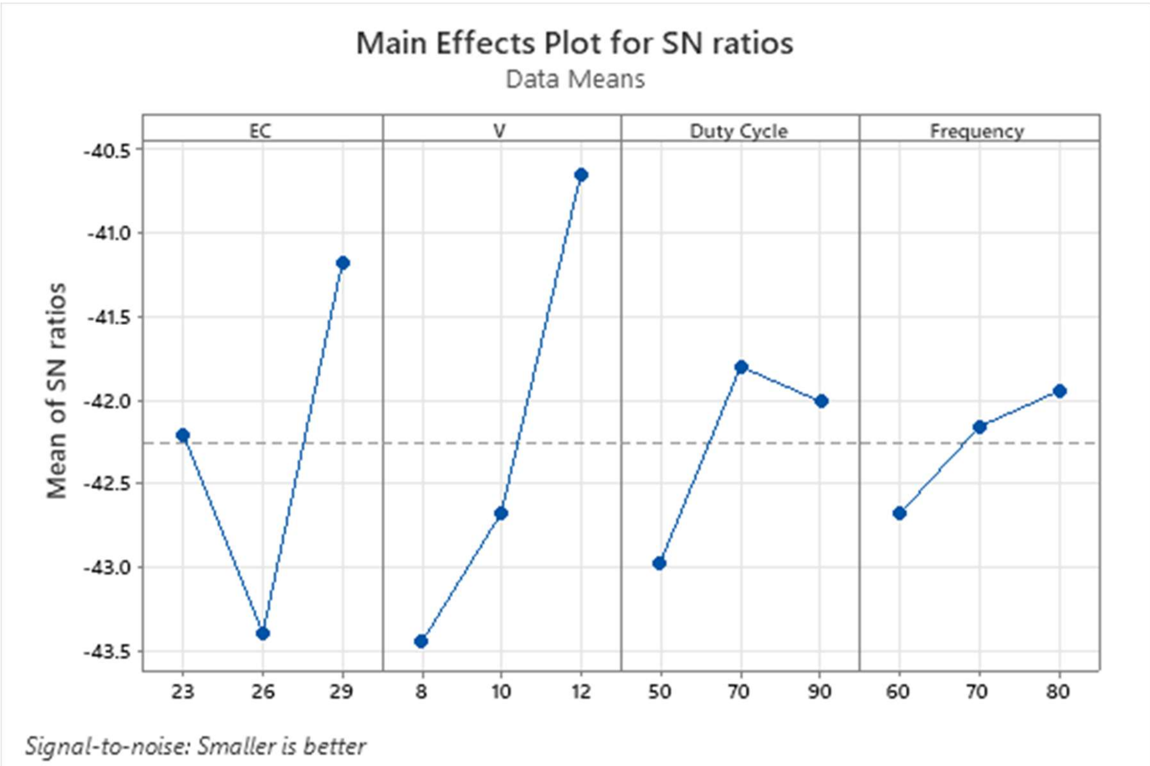

Figure 4. The mean effect plot for OC.

In ECM, to ensure stable machining, a uniform inter-electrode gap (IEG) is maintained in the range of 200μm to 300μm. Hence, during machining at a lower electrolyte concentration, the proximity of the electrodes helps to develop the required current density in the machining zone. This phenomenon contributes tostable machining without stray cuts. While an increase in electrolyte concentration beyond 26 g L^{-1}, the presence of more ions develops an intense current density between the IEG. This phenomenon develops more dissolute products in the machining zone. This debris builds up in time, resulting in micro-sparking and a stray cut effect. The OC tends to increase with electrolyte concentration; at higher concentrations, the debris produced increases the frequency of micro-sparking. An increase in voltage level shows a significant effect on OC, which is because at a higher voltage, the current density available between IEG is more, leading to higher material removal. A huge volume of debris from the machining attributes for increased OC. The OC tends to increase with duty cycle, and the optimum range of duty cycle is 70-90%. An increase in the frequency of the pulse increases the OC. With respect to Figure 4, the points for the frequency are closer to each other, hence the optimum range of frequency is 60-80 Hz.

It is also evident from the SEM micrograph shown in Figure 5(a) that the hole generated during the ECM process at a parameter combination of 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 70 Hz. As per the mean effect plot, the former factor combination is the best combination for obtaining high MR [19]. The influence of ascorbic acid is witnessed on the whole profile and the hole surface. The perfect circular hole profile with fewer stray current-affected regions and white layers. Localized heating can still happen at the electrode-workpiece interface even though ECM mostly removes material by an electrochemical reaction. This results in a tiny area of changed microstructure close to the surface, known as the white layer. This white layer might cause residual stresses and perhaps weaken the machined component's fatigue strength; it is usually preferable to minimize its thickness. The palladium-coated electrode accounted for the reduction of stray current-affected regions on the hole due to its high electrical conductivity [20,21]. Figure 5(b) shows the hole machined at the best combination of 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency. The increase in duty cycle increases the MR, as shown in Figure 3, and a further increase in duty cycle percentage reduces the material removal performance. The proper balance of pulse-on-time and pulse-off-time attributes for higher machining performance. It is evident from the optimal parameter setting that 70% duty is the best level for achieving the best performance. Out of the total duty cycle, 1/3rd of the percentage is used for debris settlement and de-electrification of the high-conductive electrode. This phenomenon helps to improve the electrolysis in the ECM process. Although frequency is the least significant factor as per the ANOVA, the higher frequency of the pulse is good to achieve the best performance.

The developed regression equations for MR and OC are shown in Eqs.(1) and (2), respectively:

$$MR = 0.36304 + 0.0093\ EC\_23 - 0.0674\ EC\_26 + 0.0581\ EC\_29 - 0.0701V\_8 - 0.0097\ V\_10 + 0.0799V\_12 - 0.0147\ \text{Duty Cycle}\%\_50 + 0.0165\ \text{Duty Cycle}\ \%\_70 - 0.0018\ \text{Duty Cycle}\ \%\_90 - 0.0145\ \text{Frequency}\_60 + 0.0252\ \text{Frequency}\_70 - 0.0107\ \text{Frequency}\_80 \quad (1)$$

and

$$OC = 131.11 + 0.22\ EC\_23 + 16.33\ EC\_26 - 16.56\ EC\_29 + 18.11\ V\_8 + 4.89\ V\_10 - 23.00\ V\_12 + 9.67\ \text{Duty Cycle}\_50 - 6.44\ \text{Duty Cycle}\_70 - 3.22\ \text{Duty Cycle}\_90 + 8.89\ \text{Frequecny}\_70 - 4.78\ \text{Frequency}\_80 \quad (2)$$

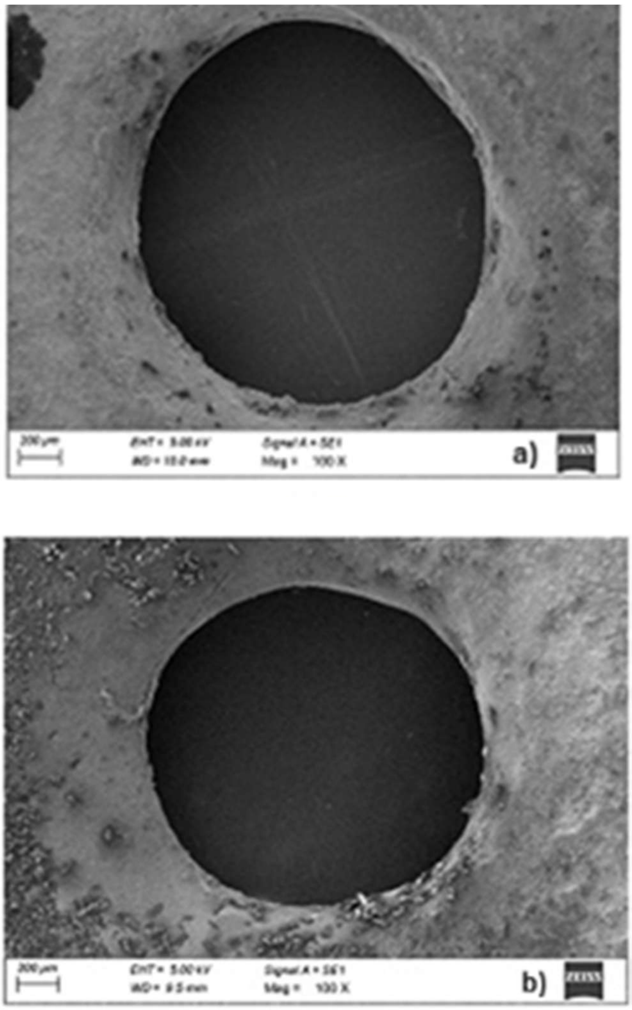

Figure 5. (a) Hole machined at the 29 g L^{-1} electrolyte concentration,12 V, 90% duty cycle, and 80 Hz frequency, and (b) hole machined at the 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency.

CONCLUSIONS

The tool electrode is successfully coated using palladium through the DC magnetron sputtering process.

The L_{27} OA experiment was conducted successfully with sodium nitrate electrolyte mixed with 10 g L^{-1}ascorbic acid, and the multi-criteria decision analysis, namely ELECTRE, is employed to find the suitable solution.

Based on the multi-criteria decision analysis method, the best combination for obtaining the optimal output performance is 29 g L^{-1}electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency, whereas the next best combination is the 29 g L^{-1}electrolyte concentration, 12 V, 90% duty cycle, and 60 Hz frequency. It can be concluded that the 29 g $L^{-1}$of electrolyte concentration, 12 V, a 70-90% duty cycle range, and a 60-80 Hz frequency are the best parameter combinations for achieving better MR and OC.

As per the mean effect plot, the 29 g L^{-1} electrolyte concentration, 12 V, 70% duty cycle, and 70 Hz frequency factor combination is the best combination for obtaining a higher MR, while the 29 g L^{-1}electrolyte concentration, 12 V, 70% duty cycle, and 80 Hz frequency factor combination is the best combination for obtaining a lower OC.

The most important factor is the machining voltage, with *F*-values of 33.80 and 12.90 for MR and OC, respectively, while the next best factor is the electrolyte concentration, with *F*-values of 23.73 and 7.92, respectively.

Future work may include industry-scale validations with varying concentrations of ascorbic acid to further establish scalability.

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NAUČNI RAD

OPTIMIZACIJA PARAMETARA ELEKTROHEMIJSKE OBRADE ZA ALATNU ELEKTRODU OBLOŽENU PALADIJUMOM KORIŠĆENJEM METODE VIŠEKRITERIJUMSKE ANALIZE ODLUČIVANJA

Elektrohemijska obrada je važan proces izrade teško obradivih materijala. To je mnogo povoljniji proces za dobijanje odličnog kvaliteta površine na širokom spektru provodljivih materijala. U ovom istraživanju, elektroda (katoda) je obložena manje otpornim paladijumskim materijalom kroz proces raspršivanja, a natrijumov elektrolit je dodat sa 10 g/l askorbinske kiseline kako bi se poboljšala lokalna elektroliza i smanjilo stvaranje ulja. Parametri procesa, posebno koncentracija elektrolita, napon obrade, radni ciklus i frekvencija, varirani su u zavisnosti od brzine obrade i prerez korišćenjem eksperimentalnog plana sa ortogonalnim nizom L27. Metoda ÉLimination Et Choix Traduisant la Realité (ELECTRE) je korišćena za pronalaženje odgovarajućeg rešenja. Na osnovu ELECTRE metode, najbolja kombinacija faktora je koncentracija elektrolita od 29 g/L, napon obrade od 12 V, radni ciklus od 70% i frekvencija od 80 Hz. Analiza varijanse pokazuje da su napon obrade i koncentracija elektrolita značajni faktori, sa procentima doprinosa od 43,9% i 23,3%, redom. Prema grafikonu srednjeg efekta, optimalna kombinacija je koncentracija elektrolita od 29 g/L, napon obrade od 12 V, radni ciklus od 90% i frekvencija od 80 Hz.

Ključne reči: Brzina obrade, prerezivanje, ortogonalni niz, ANOVA, askorbinska kiselina, raspršivanje.