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Research Article

STUDIES ON ELECTROLYTE EFFECT ON SS316 USING MULTICRITERIA DECISION METHODS

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Abstract

Electrochemical Machining (ECM) is an innovative non-traditional machining technology that is commonly used to machine hard and complicated materials with great precision. This study compares the performance of two electrolytes, sodium nitrate (NaNO_3) and dilute sulphuric acid (H_2SO_4), in the ECM of stainless steel (SS316). Experiments were designed with an L18 mixed orthogonal array to alter important process parameters such as electrolyte concentration, voltage, duty cycle, and frequency. The machining performance was assessed using material removal rate (MRR), overcut (OC), and conicity. The ideal parameter combination was determined using multi-criteria decision-making techniques, specifically CRITIC (Criteria Importance Through Intercriteria Correlation) and Simple Additive Weighting (SAW). The findings show that sulphuric acid electrolyte has a larger MRR, whereas sodium nitrate provides superior control over dimensional accuracy and surface properties. The best machining conditions were 0.2 M H_2SO_4 electrolyte concentration, 12 V, 80% duty cycle, and 90 Hz frequency.

Keywords: Dilute Sulphuric Acid, Simple Additive Weighting, Material removal rate, Conicity, Sodium nitrate.

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1. INTRODUCTION

Electrochemical Machining (ECM) is a Stochastic process and useful in many industries especially for finishing process. In recent years, ECM was considered for machining complex shapes and features with the advent of 3d printing technologies. Research on ECM is pursued by many researchers and Soundarajan and Thanigaivelan (2018) have investigated the ECM of copper using Ultraviolet rays heating. The study reveals the electrolyte concentration shows major contribution of 65% among the other process parameters. Saravanan et al. (2021) have comparatively optimised the ECM parameters using multi-criteria decision-making methods. They verified that all MCDM methods shows same level of optimum combinations. Vinod Kumar et al. (2022) have suspended the copper powder in the electrolyte and considered the stirring effect. The outcome of the results indicates that at upper parameter levels, the larger,

material removal rate (MRR) and modest overcut (OC) are attained for suspended electrolyte with stirrer effect. Vinod Kumar et al. (2022) have used various strong electrolytes to machine SS316L and study reveals that the overcut of tartaric acid electrolyte is 179% less compared to the mixed electrolyte. On the other hand, the mixed electrolyte shows 114.2% higher MRR than the tartaric acid electrolyte at experiment combinations of 25%, 11 V, and 20 g/l. Benjamin Lazarus Simon et al. (2024) have used salt free composite electrolyte and optimised the process parameters. The higher MRR, i.e., $1.8887\mu\text{m/s}$ is attained in mixed electrolyte with the parameter grouping of 7 V, 90% and 38°C electrolyte temperature which is 98.23% higher than the sodium nitrate electrolyte. Priya et al. (2021) have used mixed electrolyte to machine SS 316L workpiece and result show that electrolyte concentration plays significant role on MRR and OC.

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Venugopal & Thanigaivelan (2023) have considered magnetised tool on scrapped aluminium alloy. The use of magnetic effect increases the MRR and reduces the OC. Muthurajan et al (2019) have machined boron carbide reinforced composite using induction heated electrolyte ECM. It is evident that research on ECM is pursued worldwide to understand clearly the effect of various parameters on the machining speed, accuracy and surface quality. In this research ECM experiments are planned with Sodium nitrate and dilute sulphuric acid electrolyte. The L_{18} mixed orthogonal array (OA) combination of experiments were considered and process parameters are optimised using CRITIC (Criteria Importance Through Intercriteria Correlation) and Simple Additive weighting method. This method is an objective weighting method that estimates criteria importance as per the contrast intensity and conflict. It is generally attached with the SAW (Simple Additive Weighting) method, a ranking method that determines alternatives by multiplying normalized criteria values by these CRITIC-derived weights.

2. EXPERIMENTAL SETUP

The ECM setup (Figure 1) comprises electrolyte supply system, tool electrode feeding system, and power supply. The electrolyte system consists of filter, pump and machining chamber made of Perspex materials. The tool feeding arrangement engulf with stepper motor, lead screw and microcontroller unit to control the feed. The pulse power supply with variable voltage and frequency is used to vary the input process variables. The electrolytes are prepared by mixing the sodium nitrate salt in the 1 liter of distilled water and used for the experiments. Dilute sulphuric acid of 0.1,0.2

and 0.3 Mole is used for the experiments. The stainless steel (316 SS) is used a workpiece and thickness of workpiece is 750 μ m. The Material removal rate is calculated by measuring the time taken to complete the through hole and dividing the same with thickness of the workpiece. The overcut is calculated by finding the difference between the tool electrode diameter (500 μ m) and machined hole diameter. The conicity degree is calculated by measuring the large diameter at the hole entry and small diameter at the hole exit and finding the difference. The difference value is divided by 2 times the length of the hole gives the conicity. The experiment plan used is mixed L_{18} (Table 1) OA and the degrees of freedom is calculated based on the number of parameters and levels [9-13].

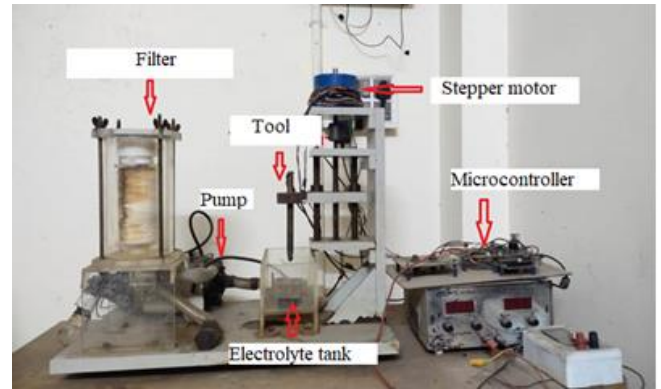


Figure 1: Experimental setup

The whole experiments are conducted at the room temperature and weighing system, stop watch are calibrated. The tool electrode is stitching needles are used and it is insulated on the circumference using adhesive paste.

Table 1: Experimental Plan

S. No	Electroyte	Electrolyte Concentration	Voltage (V)	Duty Cycle (%)	Frequency (Hz)	MRR in μ m/sec	Overcut in μ m	Conicity in degree
1	SODIUM NITRATE	22(g/l)	10	70	70	0.568	391.67	4.267
2		22(g/l)	11	75	80	0.625	414.15	3.817
3		22(g/l)	12	80	90	0.521	400.02	4.140
4		26(g/l)	10	70	70	0.391	234.66	7.327
5		26(g/l)	11	75	80	0.543	353.55	5.029
6		26(g/l)	12	80	90	0.568	80.95	10.261
7		30(g/l)	10	65	70	0.625	222.01	7.040
8		30(g/l)	11	75	80	0.658	251.46	7.071
9		30(g/l)	12	80	90	0.568	220.50	7.800
10	H ₂ SO ₄	0.1 M	10	65	70	0.833	494.93	1.141
11		0.1M	11	75	80	0.735	410.67	3.250
12		0.1M	12	80	90	0.781	318.87	3.450
13		0.2M	10	65	70	0.694	263.72	5.226
14		0.2M	11	75	80	0.893	142.13	6.557
15		0.2M	12	80	90	1.250	150.54	6.489
16		0.3M	10	65	70	1.042	246.88	4.162
17		0.3M	11	75	80	1.042	270.74	5.085
18		0.3M	12	80	90	0.781	156.58	5.268

3. OPTIMIZATION OF ECM PARAMETERS USING CRITIC AND SAW METHOD

CRITIC method is proposed by Diakoulaki et al (1995). The CRITIC method is applied to resolve objective weights of criteria as per the data variability and conflict between criteria. It allocates higher weight to criteria that have elevated variation are fewer associated with others [14-18].

Steps to determine CRITIC Ranking

1. Create decision matrix: Alternatives $\times$ Criteria
2. Normalize the matrix
Usually using min-max normalization
3. Compute standard deviation (σ)
Measures variability of each criterion
4. Calculate correlation matrix (M)
Between criteria
5. Estimate information measure (E_j)
$$E_j = \sigma_j \times \sum (1 - M_{jk})$$
6. Determine weights (D_j)
$$D_j = \frac{E_j}{\sum_{k=1}^n E_j}$$

Steps to determine SAW

1. Construct decision matrix
2. Normalize values

Benefit criteria:

$$Z' = \frac{z}{\max z}$$

Cost criteria:

$$Z' = \frac{\min z}{z}$$

3. Apply weights

Multiply normalized values by weights

4. Calculate total score

$$S_i = D_j \times Z_{ij}'$$

5. Rank alternatives

Highest score = best alternative

Table 2 to 5 presents the estimated values from the CRITIC and SAW methods. The weights determined using SAW methods are 0.2318, 0.4173 and 0.3510. As per the table 3, the best combination for the higher MRR, lower OC and lower conicity is 0.2M H₂SO₄ electrolyte concentration, 12 V, 80% duty cycle and 90 Hz frequency. The second-best combination is 0.1 M H₂SO₄ electrolyte concentration, 10V, 65% duty cycle and 70 HZ frequency. Electrochemical Machining (ECM) is commonly utilized for machining hard and complex materials where traditional methods fail. The method is based on Faraday's electrolysis laws, with the workpiece acting as an anode and the tool as a cathode. The

electrolyte promotes ion transport and the elimination of dissolved metal. Sodium nitrate and sulphuric acid are popular electrolytes due to their different electrochemical characteristics. Sodium nitrate is a neutral electrolyte with moderate electrical conductivity. It is chemically stable and less corrosive than acidic electrolytes. In ECM, sodium nitrate allows for regulated anodic dissolution with minimum adverse effects. Gas evolution is relatively minimal, resulting in stable machining conditions and homogenous material removal. Sulphuric acid is an extremely acidic electrolyte with excellent electrical conductivity and chemical reactivity. The use of sulphuric acid produces rapid anodic dissolution, resulting in a high material removal rate. It does, however, produce substantial amounts of gas and heat, which may have an impact on process stability. The electrolyte used in ECM is chosen to strike a compromise between machining rate and surface quality. Sodium nitrate is preferable for applications that require precision and low environmental impact, whereas H₂SO₄ is useful in high-speed machining despite its operational challenges. Sodium nitrate and H₂SO₄ electrolytes behave quite differently in the ECM. Sodium nitrate provides improved control, safety, and surface polish, making it perfect for precise applications. In contrast, H₂SO₄ increases MRR but at the expense of surface quality, equipment longevity, and safety. As a result, the electrolyte used should be determined by the individual machining needs and operational limits.

Table 2: Normalization of decision matrix using CRITIC method

Normalization of decision matrix using CRITIC			
S. No	MRR	OC	Conicity
1	0.2061	0.2494	0.6572
2	0.2724	0.1951	0.7066
3	0.1513	0.2293	0.6712
4	0.0000	0.6287	0.3217
5	0.1769	0.3415	0.5737
6	0.2061	1.0000	0.0000
7	0.2724	0.6593	0.3532
8	0.3108	0.5881	0.3498
9	0.2061	0.6629	0.2698
10	0.5146	0.0000	1.0000
11	0.4005	0.2035	0.7688
12	0.4540	0.4253	0.7468
13	0.3527	0.5585	0.5521
14	0.5844	0.8522	0.4061
15	1.0000	0.8319	0.4136
16	0.7579	0.5992	0.6688
17	0.7579	0.5415	0.5675
18	0.4540	0.8173	0.5475

Table 3: Normalization of decision matrix using SAW method

Normalization of decision matrix using SAW			
S. No	MRR	OC	Conicity
1	0.1764	0.3078	0.1740
2	0.1941	0.3255	0.1556
3	0.1618	0.3144	0.1688
4	0.1214	0.1844	0.2987
5	0.1686	0.2778	0.2050
6	0.1764	0.0636	0.4183
7	0.1941	0.1745	0.2870
8	0.2043	0.1976	0.2883
9	0.1764	0.1733	0.3180
10	0.2587	0.3890	0.0465
11	0.2283	0.3227	0.1325
12	0.2425	0.2506	0.1406
13	0.2155	0.2073	0.2131
14	0.2773	0.1117	0.2673
15	0.3882	0.1183	0.2645
16	0.3236	0.1940	0.1697
17	0.3236	0.2128	0.2073
18	0.2425	0.1231	0.2148

Table 3: Ranking of experiments

S. No.	S_i	Ranking
1	0.3216	15
2	0.3451	13
3	0.3078	17
4	0.2771	18
5	0.3089	16
6	0.5266	3
7	0.3586	11
8	0.3553	12
9	0.3369	14
10	0.6049	2
11	0.3953	9
12	0.4218	8
13	0.3784	10
14	0.5109	4
15	0.6134	1
16	0.5105	5
17	0.4869	6
18	0.4716	7

Table 4: Relation between the output performances

Output Performance	MRR	OC	Conicity
MRR	1	0.213956	0.220895
OC	0.213956	1	-0.83566
Conicity	0.220895	-0.83566	1

Table 5: Weight of the output performance

Output Performance	MRR	OC	Conicity	E_j	D_j
MRR	0	0.7860	0.7791	0.3973	0.2318
OC	0.7860	0	1.8356	0.7153	0.4173
Conicity	0.7791	1.8356	0	0.6017	0.3510

4. CONCLUSIONS

This work conducted a comparative examination of sodium nitrate and sulfuric acid electrolytes in electrochemical machining of SS316 using CRITIC and SAW optimization approaches. The results showed that electrolyte type has a substantial impact on machining performance metrics such as MRR, overcut, and conicity. Sulphuric acid electrolyte shows higher MRR performance due to its high conductivity and reactivity, making it appropriate for high-speed machining applications. However, it resulted in significantly more instability and dimensional aberrations. In contrast, sodium nitrate electrolyte provides more stable machining conditions with better control over overcut and conicity, making it more appropriate for precision-oriented applications. After multi-criteria optimization, the optimal parameter combination was 0.2 M H₂SO₄, 12 V, 80% duty cycle, and 90 Hz frequency, resulting in balanced performance across all response metrics. The data confirm that sulphuric acid increases productivity, whereas sodium nitrate improves machining quality and operating safety. As a result, the electrolyte should be chosen based on the individual needs of machining precision, surface integrity, and production rate. Future research can concentrate on hybrid electrolytes and sophisticated control mechanisms to enhance ECM performance.

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CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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