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Effects of Electrochemical Machining Parameters on Aluminum Hybrid Composites

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Abstract

In this research, the authors explore the fabrication process of a hybrid composite AA5052/TiB_2/B_4C and investigate the influence of various electrochemical machining (ECM) parameters on the material removal rate (MRR). The study employs the Taguchi L16 orthogonal array for experimentation and employs Minitab-17 software to optimize MRR and determine the individual contribution of each parameter. The results are then analyzed using ANOVA (Analysis of variance) to identify the significant factors affecting MRR, which are found to be the feed rate of electrode (FR), voltage (VE), and electrolyte concentration (EC). The relationship between these parameters is illustrated using regression analysis and interaction plots. This research provides valuable insights into the optimal process parameters required to achieve the desired MRR in ECM of aluminum hybrid composite materials.

Keywords

Aluminum alloy, Material removal rate, Taguchi method and optimization

Introduction

When fabricating components in the domains of manufacturing and industrial engineering, pure aluminum alone does not possess enough strength. Consequently, reinforcements like B_4C, TiB_2, TiC (Titanium carbide), and silicon carbide are incorporated to augment the material's strength and properties. These additions result in aluminum metal matrix composites that deliver numerous advantages across different industries and sectors [1, 2]. Al6082 stands out as a moderately strong alloy exhibiting exceptional corrosion resistance. This alloy is frequently machined in plate form. Its high strength is attributed to the careful control of grain structure and the substantial incorporation of Mn elements [3]. At elevated temperatures, a chemical reaction occurs between titanium dioxide and carbon, resulting in the formation of TiC which appears as a dark black powder. The combination of TiC with Al alloy has been discovered to impart elastic and abrasion properties to the composite [4, 5]. Zirconium silicate serves as a refractory material in scenarios requiring resistance to alkali corrosion. ECM stands out as a contemporary machining method that removes material from the workpiece by dissolving atoms [6]. De Silva et al. [7] conducted a study exploring various electrolyte concentrations and found that using lower quantities of the electrolyte resulted in increased accuracy during the process. Burger et al. [8] explored the application of the ECM method on nickel-based materials and noted that employing the same electrochemical action for dissolving can result in high-quality products. Silva et al. [9] conducted a study using various electrolytes to investigate key variables in ECM of SAEXEV-F Valve-Steels and indicated that the electrode feed rate had a significant impact on the MRR. Rao et al. [10] assessed crucial ECM process characteristics, such as electrode feed rate, applied

voltage, and electrolyte discharge rate and identifying the most effective combination of process variables to ensure optimal machining performance remains a challenging task. To address the technology gap for upcoming researchers in ECM parameter optimization, this study focuses on implementing three factors on MRR for AA5052/TiB_2/B_4C composites. The research examines different levels of parameters, and a design of experiments is performed using the Taguchi (L16) design to identify the optimal factors influencing MRR.

Experimentation

ECM process

It is a selective metal removal process that operates using a reverse electroplating mechanism. During ECM, particles from the workpiece travel from the anode to the target machine tool acting as the cathode. As a result of the current or voltage passing through the setup, a cavity is formed on the material, as depicted in figure 1.

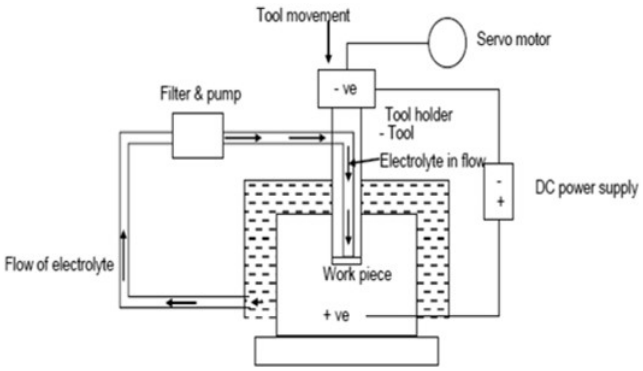

Figure 1: ECM arrangement.

Taguchi method

It is a technique employed to determine the optimal process variables and parameters that lead to a specific process response or output. Its main objective is to achieve high-quality products at a reduced cost [11-13]. It allows for the identification of variable interactions, resulting in more precise outcomes compared to other techniques. In this study, three parameters are chosen, each having four levels as presented in table 1. By using Minitab-17 software [14-16], 16 experimental combinations are generated by combining the parameter levels.

Results and Discussion

MRR

The MRR results are presented in figure 2 and table 2. It was observed that the maximum and minimum MRR were achieved with the optimal combination parameters of FR4-VE1 – EC4 (0.40 mm/min, 25 V, and 50 g/L) and FR1-VE3 – EC3 (0.25 mm/min, 45 V, and 40 g/L), respectively. Three significant factors were identified as crucial aspects of this study. The experimental tests were analyzed using ANOVA to assess the selected variables, and the S/N ratio, are shown in figure 3. The most effective parameter grouping for MRR was found to be FR2-VE2 – EC3 (i.e., FR2 - 0.30 mm/min, VE - 35 V, and EC - 40 g/L). The estimated model coefficients for S/N ratios

Table 1: ECM parameters with levels.

Parameters	Unit	Level-1	Level-2	Level-3	Level-4
Feed rate (FR)	mm/min	0.20	0.25	0.30	0.40
Voltage (VE)	V	25.0	35.0	45.0	55.0
Electrolyte concentration (EC)	g/L	20.0	30.0	40.0	50.0

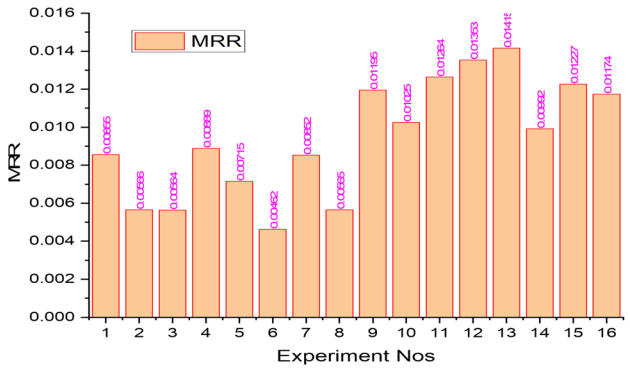

Figure 2: MRR experimental results.

Table 2: MRR results.

Exp. No.	FR	VE	EC	MRR (mg/min)	S/N ratio for MRR
01	0.25	25	20	0.00855	41.3607
02	0.25	35	30	0.00566	44.9437
03	0.25	45	40	0.00564	44.9683
04	0.25	55	50	0.00889	41.0220
05	0.30	25	30	0.00715	42.9139
06	0.30	35	20	0.00462	46.7072
07	0.30	45	50	0.00852	41.3912
08	0.30	55	40	0.00565	44.9590
09	0.35	25	40	0.01195	38.4526
10	0.35	35	50	0.01025	39.7855
11	0.35	45	20	0.01264	37.9651
12	0.35	55	30	0.01353	37.3740
13	0.40	25	50	0.01415	36.9849
14	0.40	35	40	0.00992	40.0698
15	0.40	45	30	0.01227	38.2231
16	0.40	55	20	0.01174	38.6066

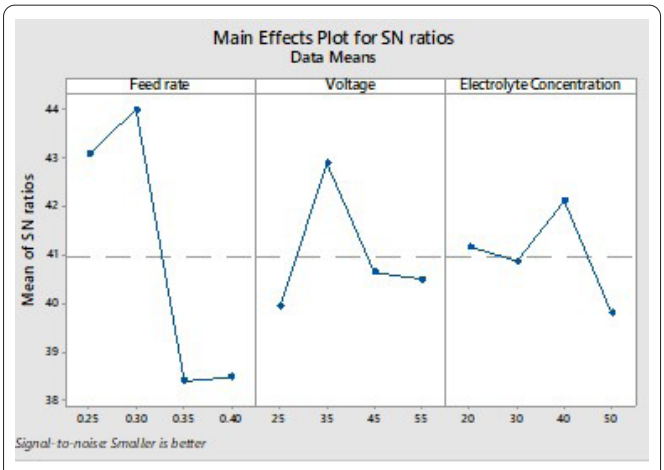

Figure 3: S/N ratio plot on MRR.

are statistical values derived from analyzing the relationship between input variables and the output response. They offer valuable insights into the impact of each input variable on the S/N ratio and aid in identifying the optimal settings for the factors to maximize the S/N ratio in table 3. Table 4 reveals the S/N response of machining factors, with level-2 of feed rate (FR) showing the most significant impact on MRR, followed by level-2 of electrolyte concentration (EC) and level-2 of voltage (VE). The analysis of variance (ANOVA) technique is employed to assess statistical differences between different parameters, with F and P values used to determine controllable and irrepressible probabilities for achieving optimum MRR. From table 5, it is observed that the p-values of process parameters are less than 0.05, indicating their significance in increasing MRR. Feed rate (FR) is the most influential factor, contributing 73.12% to the increase in MRR, followed by voltage (VE) at 13.79% and electrolyte concentration (EC) at 6.95% (Figure 4). The feed rate of the electrode plays a critical role in increasing MRR, as it enhances the contact with the composite and facilitates material removal.

Table 3: Model coefficients for S/N ratios.

Term	Coef	SE Coef	T	P
Constant	40.9830	0.2759	148.543	0.000
Feed rat 0.25	02.0907	0.4779	4.375	0.005
Feed rat 0.30	03.0099	0.4779	6.298	0.001
Feed rat 0.35	-2.5887	0.4779	-5.417	0.002
Voltage 25	-1.0550	0.4779	-2.208	0.069
Voltage 35	01.8936	0.4779	3.962	0.007
Voltage 45	-0.3461	0.4779	-0.724	0.496
Electrol 20	0.1769	0.4779	0.370	0.724
Electrol 30	-0.1193	0.4779	-0.250	0.811
Electrol 40	01.1295	0.4779	2.364	0.056

Table 4: S/N ratio reading.

Level	Feed rate	Voltage	Electrolyte concentration
1	43.07	39.93	41.16
2	43.99	42.88	40.86
3	38.39	40.64	42.11
4	38.47	40.49	39.80
Delta	05.60	02.95	02.32
Rank	01.00	02.00	03.00

Regression equation

The software Minitab-17 was employed to generate the linear regression model based on the experimental results depending on selection of input variables [17-20].

MRR = –0.000854 + 0.05045 feed rate of electrode + 0.000258 voltage + 0.000162 electrolyte concentration (1)

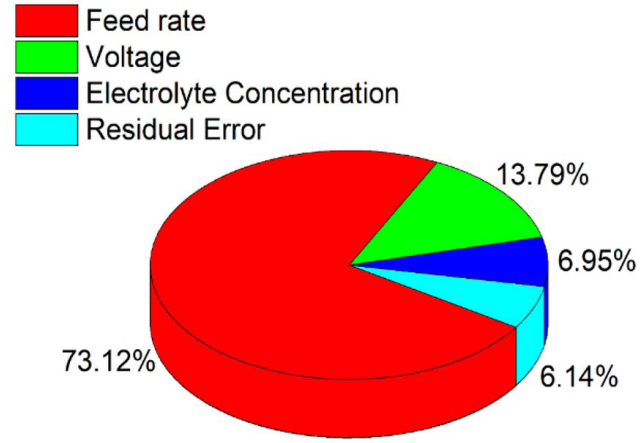

Figure 4: Influence percentages of parameters for MRR.

Interaction plots for MRR

Figure 5 depicts the impact of various factors on the MRR in the produced composites. Changes in parameters, whether in terms of their levels or interactions, result in variations in the MRR. The levels of these parameters show increased MRR values, while the interactions between FR*EC and FR*VE exhibit nearly higher values. These interactions demonstrate only slight variations and can be considered as constant deviations. However, for the interactions of VE*EC, when the values of these parameters increase, the MRR is primarily influenced by the feed rate and voltage.

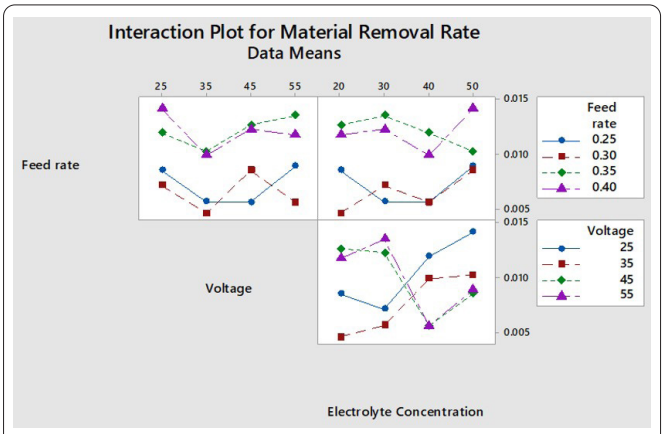

Figure 5: Interaction plots between parameters on MRR.

Conclusion

ECM parameters are electrode feed rate, voltage, and electrolyte concentration on the MRR responses is investigated using the Taguchi L16 orthogonal array optimization technique. The study observed that the maximum and minimum MRR were achieved with the optimal combination

Table 5: ANOVA result.

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Feed rate	03	105.763	35.254	28.95	0.001	73.12
Voltage	03	20.2430	06.748	05.54	0.037	13.79
Electrolyte concentration	03	10.9210	03.640	02.99	0.118	06.95
Residual error	06	7.30800	01.218			06.14
Total	15	144.235				

parameters of FR4-VE1 – EC4 (0.40 mm/min, 25 V, and 50 g/L) and FR1-VE3 – EC3 (0.25 mm/min, 45 V, and 40 g/L), respectively. The experimental tests were analyzed using ANOVA to evaluate the chosen variables. The study revealed that the most effective parameter grouping for achieving the highest MRR is FR2-VE2 – EC3 (i.e., FR2 - 0.30 mm/min, VE - 35 V, and EC - 40 g/L). The analysis revealed that the feed rate of the electrode has the most significant contribution (73.12%) to increasing the MRR, followed by the voltage with 13.79% and the electrolyte concentration with 6.95%.

Acknowledgements

None.

Conflict of Interest

None.

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