ELECTRICAL DISCHARGE MACHINING OF SILICON CARBIDEAND REINFORCED 6061-T6ALUMINUM ALLOY HYBRID COMPOSITE FABRICATED BY STIR CASTING PROCESSING

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Abstract

The primary goal of this research was to prepare a Metal Matrix Composite (MMC) aluminum 6061 reinforced with 10Wt% silicon carbide particles using a stir casting procedure. It limits the further advancement of hybrid metal matrix composites for machining using unconventional processes such as Electrical Discharge Machining (EDM), which are utilized to machine the material's complex forms. The machining is carried out by altering the three input process parameters peak current (IP), pulse on time (Ton), and pulse off (Toff) in order to investigate their special impacts on two output process metrics machining performance such as material removal rate (MRR) and tool wear rate. The Taguchi approach was used to analyze the significant effect of process parameters on performance measurements and to determine the ideal parameters for the Electrical Discharge Machining process. Minitab version 17.0 was used for the analysis and explanations. In addition, the surface character of the machined specimen is examined using a scanning electron microscope. Different process parameters were experimentally tested and statistically analyzed, and the results revealed that the copper electrode maximizes material removal rate (MRR) while lowering tool wear rate.

Key words: Electrical Discharge Machining (EDM), Metal Matrix Composites (MMC), Stir Casting Techniques, Taguchi method, Material Removal Rate (MRR), Tool Wear Rate (TWR).

1. Introduction

Most aluminum-based hybrid composites are sophisticated materials with qualities such as high hardness, superior wear resistance, strength, high raised temperature, and low thermal expansion coefficient. These hybrid composites are frequently used in the automotive and region sectors [1-3]. Industrial uses. Graphite is quickly becoming the preferred electrode material for sinking EDM. Graphite electrodes have significant advantages over copper electrodes, particularly for roughing. Optimized settings result in very low tool wear and high material removal rates [4].The three input parameters considered are current, pulse on time, and pulse off time, which are used for experimental work and their effects on Material Removal Rate, Tool Wear Rate, and Surface Roughness [5]. Electrical discharge machining is one of the oldest unconventional machining techniques, widely used in industry for the production of components with unusual features and low precision [6]. The trials produce output responses such as material removal rate (MRR) and tool wear rate (TWR). The parameters pulse on-time, pulse off-time, and water pressure were investigated for optimal machining characteristics. This study describes the use of the Taguchi technique for higher MRR in drilling of Al-6061-based composites. The tests were performed supported L27orthogonal array, according to Taguchi's approach of experiment creation [7]. The current experimental effort aims to optimize the discharge machining parameters of a metallic element alloy (Al 6351) matrix strengthened with 5wt.% (SiCp) and 10wt.% boron carbide (B4C) using the stir casting process. Multi-response optimization was performed using gray relative analysis (GRA) with the goal of reducing machining parameters such as conductor wear magnitude relation, surface roughness, and power consumption [8].The surface roughness characteristics were recorded, and scanning microscopy was used to investigate surface integrity due to the migration of conductor material pieces onto the machined surface [9]. The value of SR increases with an increase in pulse current and pulse on time, whereas in voltage cares, SR reduces up to 50 V and then increases with an increase in voltage. The optimal combination configuration for Al and 5wt% SiC set is Voltage 50 V, Pulse current 8 A, Pulse on time 9 µs, and Pulse off time 9.00 µs to maximize Material Removal Rate, minimize electrode wear rate, and SR [10]. The Taguchi methodology was used to study the multiple effects of method parameters on performance measures as well as the optimal parameters of the EDM method. For analysis and explanations, Minitab version 17 software was utilized. Completely different parameter approaches were studied and statistically assessed, and the results revealed that the copper conductor has the best MRR and lowest EWR%, while the brass conductor has the lowest SR [11]. The Metal Removal Rate (MRR) and surface roughness of the workpiece will increase as the current rises. The MRR reduces as the percentage weight of carbide increases. The surface end of the machined work piece improves with the percentage of carbide [12].The distribution of carbon and chemical element inorganic compounds on the matrix was reasonably uniform, indicating reduced porosity and good bonding between the matrix and the reinforcements. Microwave heat treatment was intended to be more affordable and energy efficient than traditional heat treatment [13]. The casted specimen with an adequate proportion was analyzed by cutting it according to the approved procedure. The holes (10 millimeter diameter and a pair of millimeter depth) on the specimens were made by electrical discharge machining by varying the flushing rates of 0.5, 0.6, 0.7, 0.8, 0.9, and one kg/cm2 [14].The unusual machining process EDM is the best alternative to machine tangled forms in MMC [15].The Nano composite was created utilizing an ultrasonic cavitation-based solidification technique, and machining investigations were carried out using an experimental design matrix developed using Response Surface Methodology's central composite approach [16].

2. Materials and Experimentation

2.1 Experimental Materials Details

In this study, the MMC is Al 6061 alloy. Silicon particulate is the most essential alloying ingredient in Aluminium 6061, which has good weld ability and mechanical qualities. Tables 1 and 2 illustrate the chemical compositions and attributes of the aluminum 6061-T6 alloy.

Table 1 Chemical Composition of Al6061 by Weight percentage

Element	Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
Weight (%)	0.9	0.7	0.27	0.22	0.10	0.07	0.06	0.04	Balance

Table 2 Properties of Al 6061 alloy

S.No	Properties	Al 6061 alloy
1.	Hardness	95 BHN
2.	Elongation	18%
3.	Density	2.7g/cc
4.	Yield Strength	302Mpa
5.	Ultimate Tensile Strength	334 Mpa
6.	Modulus Of Elasticity	70 Gpa
7.	Melting Point	650 °C
8.	Proof Stress	240 MPa
9.	Tensile Strength	260 MPa

2.2 Fabrication of Metal Matrix Composites (MMC)

The Al6061 and SiCp composites were made utilizing the stir casting technique, as shown in figure 1, which is a liquid state method of manufacturing composite materials by putting small pieces of Aluminium 6061 alloy from ingots into the crucible. The percentage of SiC added to melt in volume proportion is 10 Wt%. In this technique, the matrix alloy Aluminium 6061 was first superheated to its melting point of 8000C, and then progressively cooled below the liquid temperature to maintain the matrix alloy's semisolid state. At this point, the silicon carbide particles were added to the slurry and blended. After mixing, the temperature of the composite slurry was increased to achieve a fully liquid state, and stirring was continued for approximately five minutes at an average speed of 550-600 rpm. The study employed Aluminium6061 and Silicon Carbide as specimens since Al6061-SiC has a wide application in various fields. Figure 2 shows a specimen sample.

Fig: 1Stir Casting Method

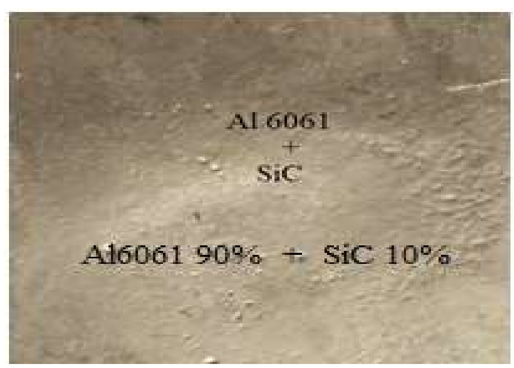


Fig: 2 Aluminium-Silicon Carbide (Al6061-SiC)

2.3 Mechanism of Electrical Discharge Machining (EDM)

Electrical discharge machining (EDM) is based on the erosion of fabric caused by repeated sparks between the workpiece and the tool submerged in a tub of nonconductor medium. The workpiece and tools are two electrodes connected by a direct current generator. A conductor tool may be a formed tool with the required profile to be cut on the work piece. The work piece and conductor are separated by a niche, resulting in a pulsated spark across which the nonconductor fluid flows. The servo drive mechanism maintains the spark gap for continuous operation while feeding the tool.

2.4 Machining Of Metal Matrix Composite (MMC)

During the machining process, a copper electrode with a diameter of seven millimeters was utilized as an anode, and the created composite was used as the cathode. The current peak current, pulse on time, and pulse off time are the machining method's input parameters. Current is varied from 10, 15, and 20 amps, while pulse on and off time are varied from 3, 5, 7, and 6, 8, 10 microseconds, respectively. Figures 3 and 4 demonstrate the electrical discharge machining (EDM) setup. The provision of nonconductor fluid (Electrical Discharge Machining Oil) is achieved by proper configuration. The material removal was enabled by a spark generated between the tool (anode) and also the work piece (cathode) a relentless gap of 0.009 – 0.09 millimeter was maintained by means that of a servo motor.

Fig.3 Experimental set up of EDM process

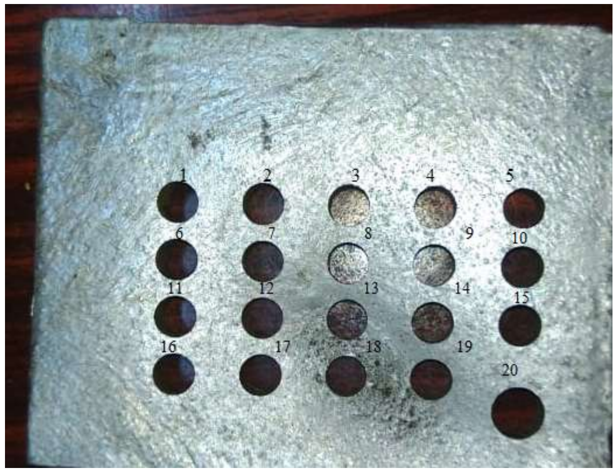


Fig: 5 Typical image of the machined specimen

2.4.1 Metal Removal Rate (MRR)

The invented square plate metal matrix composite (MMC) specimen is secured within the fixture (Work holding device) that is mounted over the machine table, and the circular hole is trained by feeding the electrode at a consistent pace. The time spent cutting each hole was noted. The Metal Removal Rate is frequently computed using equation (1).

$$MRR = \frac{Wbm - Wam}{Tav} X\ 1000\ \frac{\mathrm{mm}^3}{min} \dots\dots\dots\dots\dots.(1)$$

Where:
W_{bm} = Weight of the work piece before machining (mm)
W_{am} = Weight of the work piece after machining (mm)
T_{av} = Machining average time (min)

2.4.2 Tool Wear Rate (TWR)

Tool wear is an important issue because it impacts both dimensional accuracy and the form formed. Tool wear is extended to the freezing point of the materials. Carbon from the organic compound nonconductor precipitates on the conductor surface during sparking, causing tool wear. The Tool Wear Rate is calculated using equation (2), which is a quantitative relationship between the difference in tool weight before and after machining and the machining time and fabric density.

$$TWR = \frac{Wtbm - Wtam}{\rho \times t} \times 1000\ \frac{\mathrm{mm}^3}{\mathrm{min}} \dots\dots\dots\dots\dots..(2)$$

Where:
W_{tbm}= Weight of the tool before machining (mm)
W_{tam} = Weight of the tool after machining (mm)
t= Machining time (minute)
ρ= Density of copper (8.96 gm/cm^3)
2.5 Analysis of Experiments

Input parameters: pulse on time, pulse off. The effects of time and current on the machining process were investigated using different response values such as Metal Removal Rate and Tool Wear Rate. The primary goal of any machining process is to remove the required material in the shortest amount of time possible, hence increasing material removal rate while decreasing tool wear. As a result, the greatest approach for lowering tool wear rate value is to make the output value smaller. The Design of Experiment employs Taguchi's recommended orthogonal array concept. The statistical tool Analysis of Variance is utilized to calculate the percentage contribution of each parameter to the indicated degree of confidence. Signal to noise ratio (S/N) can be used to calculate the divergence of performance parameters from the desired values.

2.6. Design of Experiments (DOE)

The tests followed the supported central composite design (CCD) of response surface methodology. The factorial portion of the central composite style can be a full factorial design with all combinations of the factor at two levels (High +1 and Low-1) and composed of eight star purpose and six central points coded (Level 0), which is the midpoint between the high and low level and corresponds to an α value of one. The face focused (CCD) method entails twenty experimental observations with three distinct input parameters. The technique parameter values and levels are shown in Table 3.

Table: 3 Machining process parameters and their levels

S.No	**Symbols**	**Factors**	**Unit**	**Codes**		
				Level -1	**Level 0**	**Level 1**
1	A	Pulse on time	μs	3	5	7
2	B	Pulse off time	μs	6	8	10
3	C	Current	A	10	15	20

2.6.1 Experimental Details

The base metal matrix composite used in the current study is aluminum 6061, with silicon carbide as the component. Stir casting procedures were used to cast an aluminum 6061 matrix supplemented with 10Wt% SiC and an average particle size of 10 microns. The investigations were carried out on a die sinking electrical discharge machining based on Table 4.The work material was 100 × 100 millimeters in dimension and 10 millimeters thick, and an electrolytic copper electrode with a diameter of 7mm was employed. All experiments include one hour of machining. The Metal Removal Rate and Tool Wear Rate data were calculated by weighing the work piece and electrode material before and after machining on a computerized Weighing scale with a precision of 0.001grm.

Table: 4 Design Layout and Experimental Results.

Ex. No	**Factor: 1 A:T_{on}**	**Factor:2 B:T_{off}**	**Factor:3 C:Current**	**Experimental value**	
				Response : 1 MRR (mm^3/ min)	Response: 2 TWR (mm^3/ min)
1	-1	-1	-1	0.0341	0.072
2	1	-1	-1	0.0422	0.061

3	-1	1	-1	0.0413	0.060
4	1	1	-1	0.1431	0.059
5	-1	-1	1	0.1573	0.057
6	1	-1	1	0.1781	0.055
7	-1	1	1	0.2732	0.050
8	1	1	1	0.2314	0.080
9	-1	-1	0	0.2245	0.077
10	1	-1	0	0.2208	0.075
11	0	1	0	0.372	0.071
12	0	1	0	0.3741	0.069
13	0	0	-1	0.4341	0.064
14	0	0	1	0.4583	0.062
15	0	0	0	0.589	0.090
16	0	0	0	0.5201	0.087
17	0	0	0	0.6314	0.085
18	0	0	0	0.7391	0.084
19	0	0	0	0.8013	0.082
20	0	0	0	0.937	0.080

3. Result and discussion

3.1 Effect of Process Parameters on Material Removal Rate (MRR)

The mathematical relationship for correlating the Machining Rate with the Considered Process Variables is as follows.

$$MRR = 0.5352 + 0.0098*A + 0.0285*B + 0.0625*C - 0.339\,C^2 + 0.0031\,A*B + 0.0426\,A*C + 0.0175\,B*C \quad \text{……….} (3)$$

The fit summary indicated that the quadratic model is statistically significant in the analysis of Material Removal Rate. Table 5 shows the ANOVA results for the quadratic model for Material Removal Rate.

Table: 5 The analysis of variance for main and interaction effects of parameters on MRR.

Source	DOF	SS	MS	F-value	Prob >Value	At 95% CI
Model	7	0.65372	0.093389	1.66	0.210	Significant
A	1	0.00186	0.001855	0.03	0.859	Significant
B	1	0.01539	0.015392	0.27	0.610	Significant
C	1	0.03648	0.036475	0.65	0.436	Significant
C^2	1	0.54308	0.543078	9.66	0.009	Significant
AB	1	0.00018	0.000184	0.00	0.946	Significant
AC	1	0.01714	0.017141	0.30	0.591	Significant
BC	1	0.00287	0.002870	0.05	0.825	Significant
Total	19	1.32838				
Lack of fit	4	0.07549	0.018872	0.25	0.901	NonSignificant
R^2		49.21%				
Adjusted R^2		19.59%				
Predicated R^2		0.00%				

CI: confidence interval; DOF: degrees of freedom; MS: mean sum of squares; SS: sum of squares.

This model was created with a 95% assurance level. The model's F value of 1.66 indicates that it is significant for MRR. There is only a 0.21% chance of a model F value. This big event could be caused by noise. A value of prob > F smaller than 0.07 implies that the model terms are important. In this scenario, A, B, C2, C, AB, and BC are important model terms. The lack fit F value of 0.901 indicates that it is not statistically significant in comparison to the pure error. The expected R2 of 0.00% is reasonably consistent with the "Adjusted R2" of 19.59%. "Adequate precision" measures the signal-to-noise ratio. Show table 6. Figure 6 depicts the impact of various input parameters (pulse on/off time, current) on the response parameter Material Removal Rate. Figure 7 depicts a contour plot of Material Removal Rate vs pulse on and pulse off time, whereas Figure 8 depicts the dimensional interaction response surface for Material Removal Rate in relation to the input parameters of pulse on and pulse off time. Figure 9 shows that MRR increases with increased current.

Table: 6 Response for Signal to Noise Ratios(S/N) on MRR

Level	Pulse On Time	Pulse Off Time	Current
1	2.2611	1.9652	6.4182
2	3.1047	3.4005	-0.1272
3	-	-	1.7577
Delta	0.8436	1.4353	6.5454
Rank	3	2	1

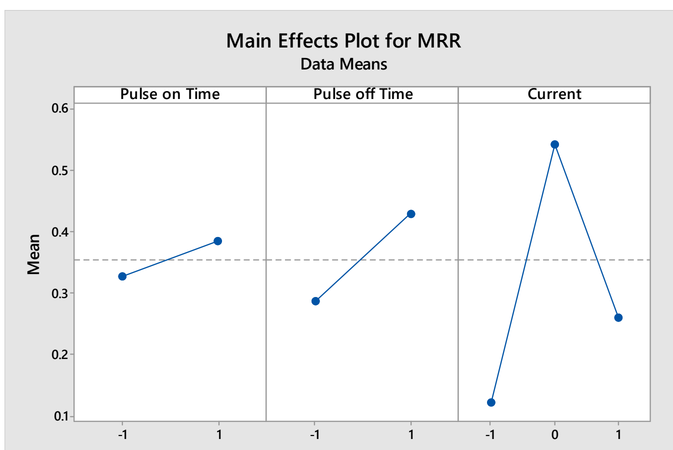
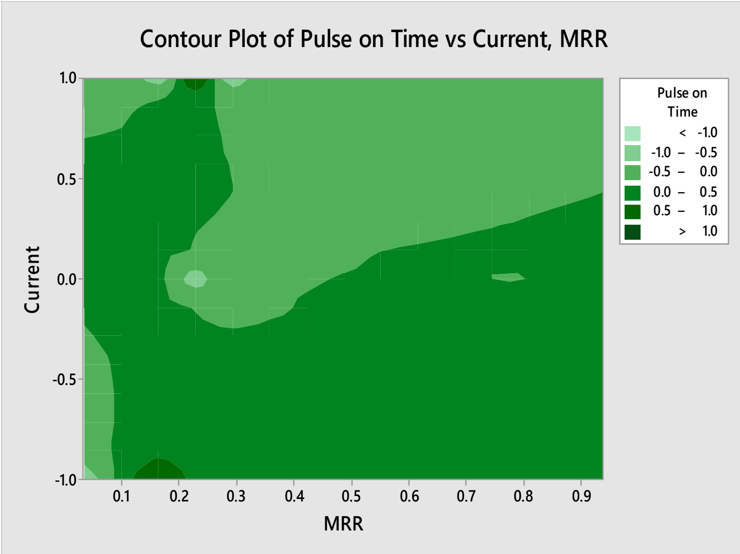


Fig: 6 Main effects plot for MRR



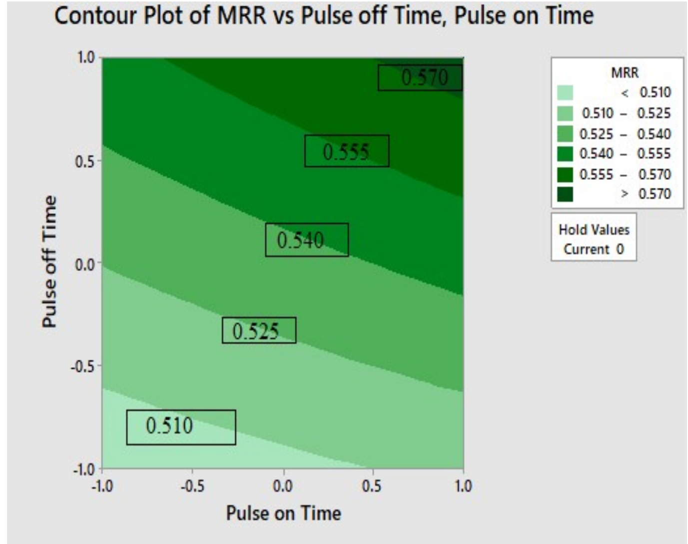
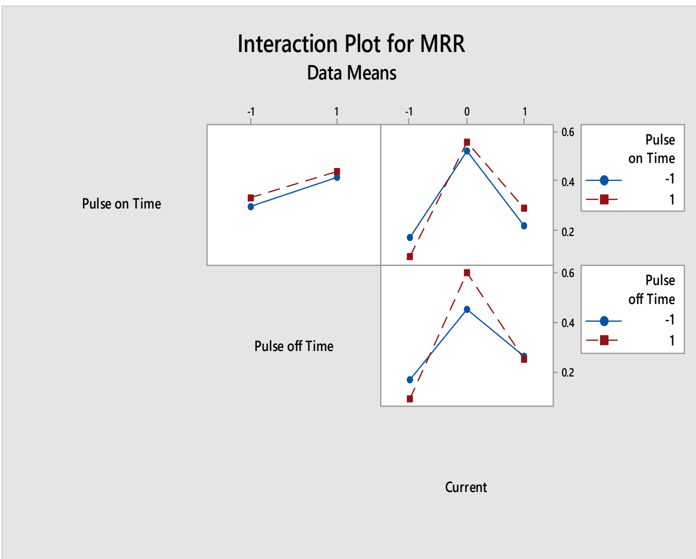


Fig: 7 Contour plots of MRR verse pulse on time and pulse off time



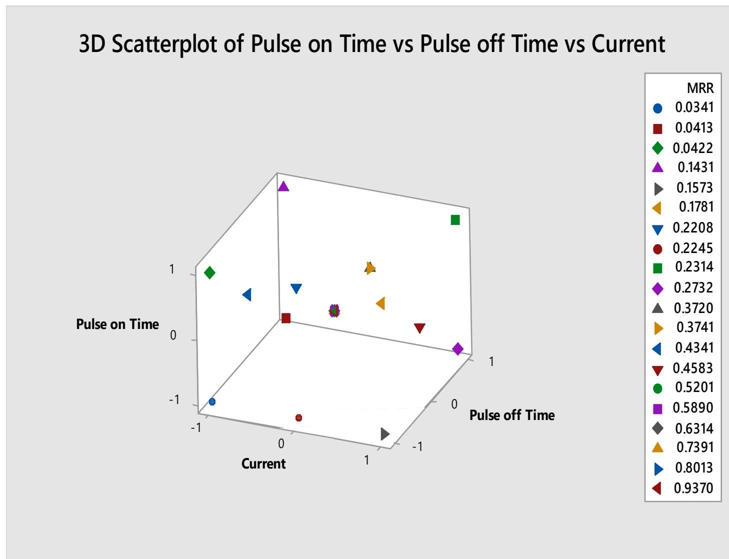


Fig: 8 Interaction plot graph for MRR

Fig: 9 3D Interaction plot graph for MRR

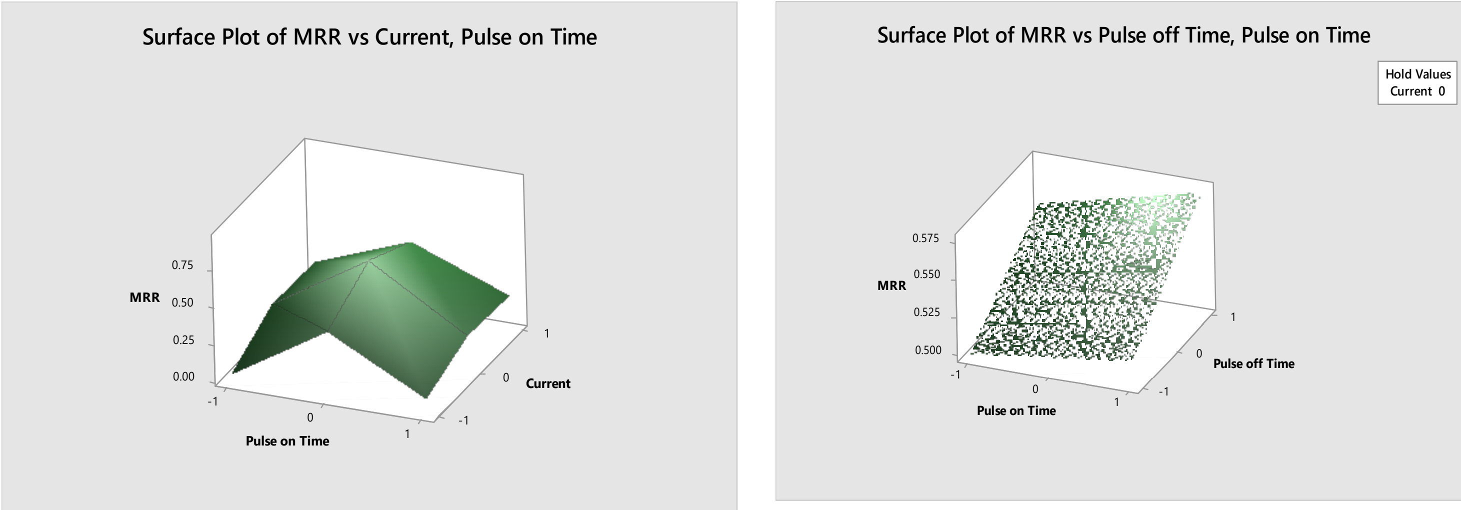


Fig: 10 Graphs in 3D for EDM

The maximum material removal rate is achieved with a high current of 20A and a pulse on time of 7µs.This can be explained by an increase in the rate of discharge energy, since high absorption of discharge energy in the spark gap causes rapid melting and vaporization of metal, resulting in an increase in the MRR. The graphs demonstrated that MRR increased from 0.372 to 0.937 mm^3/min when current and pulse on time increased (figure 10). Display the residuals from the normal probability plot as well as the residual versus anticipated plot for MRR. It was observed that the residuals often fall on a straight line, implying that the mistakes are normally dispersed.

3.2 Effect of Process Parameters on Tool Wear Rate (TWR)

The mathematical relationship for correlate the tool wear rate and the measured process variables are obtained as follows:

$$TWR = 0.07993 + 0.00055 *A + 0.00037 *B - 0.00036 *C - 0.01874 *C^2 + 0.00165\ A*B + 0.00444\ A*C + 0.00311\ B*C \qquad \ldots (4)$$

The fit summary recommended that the quadratic model is statistically significant for analysis of TWR. The results of the quadratic model for TWR in the form of ANOVA are given in Table7.

Table: 7 The analysis of variance for main and interaction effects of parameters on TWR

Source	DOF	SS	MS	F-value	Prob >Value	At 95% CI
Model	7	0.001985	0.000284	4.69	0.010	Significant
A	1	0.000006	0.000006	0.10	0.763	Significant
B	1	0.000003	0.000003	0.04	0.840	Significant
C	1	0.000001	0.000001	0.02	0.891	Significant
C^2	1	0.001662	0.001662	27.50	0.000	Significant
AB	1	0.000053	0.000053	0.87	0.368	Significant
AC	1	0.000186	0.000186	3.08	0.105	Significant
BC	1	0.000090	0.000090	1.49	0.246	Significant

Total	19	0.002710				
Lack of fit	4	0.000250	0.000062	1.05	0.439	NonSignificant
R^2		73.23%				
Adjusted R^2		57.62%				
Predicated R^2		16.41%				

CI: confidence interval; DOF: degrees of freedom; MS: mean sum of squares; SS: sum of squares.

This model was created with a 95% assurance level. The *F*value of 4.69 indicates that the model is significant. Noise has a 0.35% possibility of causing such a huge "model *F*value" to occur. Values of "Prob >*F*" less than 0.05 indicate significant model terms. In this scenario, A, C, B2, and AB are important model terms. The "lack of fit *F* value" of 1.05 indicates that the lack of fit is not significant compared to the pure error. The expected R2 of 73.23% is reasonably consistent with the "adjusted R2" of 57.62%. "Adequate precision" measures the signal-to-noise ratio. Show table 8. Figures 11 and 12 demonstrate the impact of various input parameters (pulse on time, pulse off time, and current) on the response parameter TWR. Figure 15 depicts a contour plot, whereas Figure 16 depicts three-dimensional interaction response surfaces for TWR in respect to the input parameters peak current and pulse off time. The contour figure shows that the minimal tool wear rate is 0.050 mm3/min with a low current of 20A and a pulse off time of 10 μs. In addition, Figures 13 and 14 indicate that the normal plot of residuals data is normally distributed.

Table: 8 Response for Signal to Noise Ratios(S/N) on TWR

Level	Pulse On Time	Pulse Off Time	Current
1	0.17108	0.16661	0.08042
2	0.18683	0.19129	0.30324
3	-	-	0.15320
Delta	0.01575	0.02468	0.22282
Rank	3	2	1

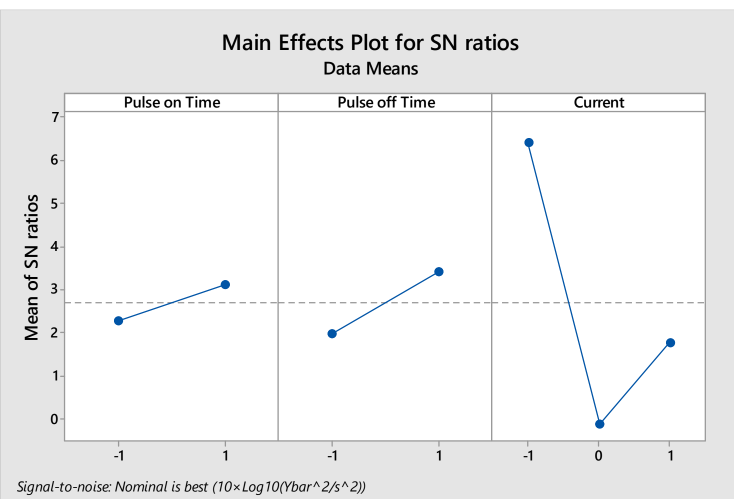


Fig: 11 Main effects plot for TWR (S/N)

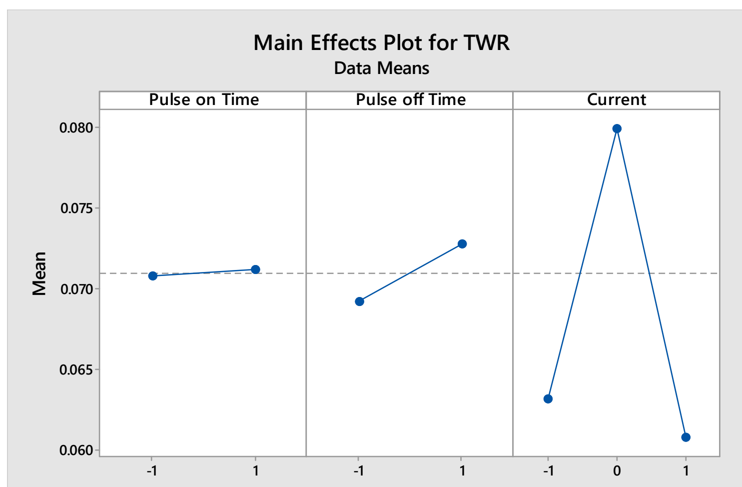


Fig: 12 Main effects plot for TWR

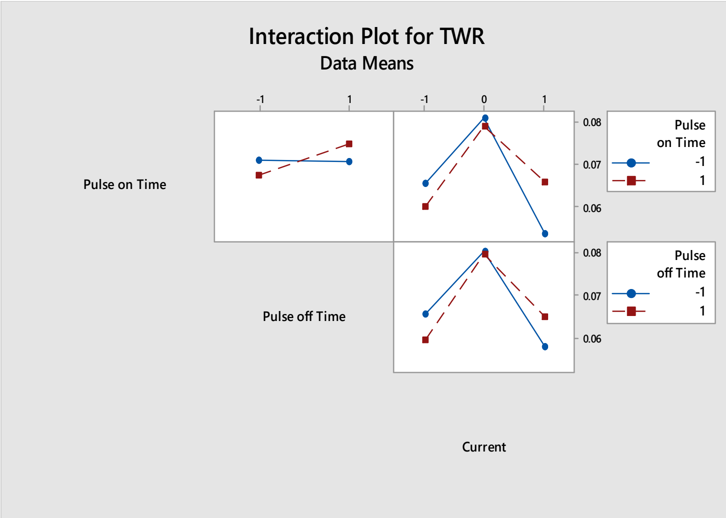


Fig: 13 Interaction plot graph for TWR

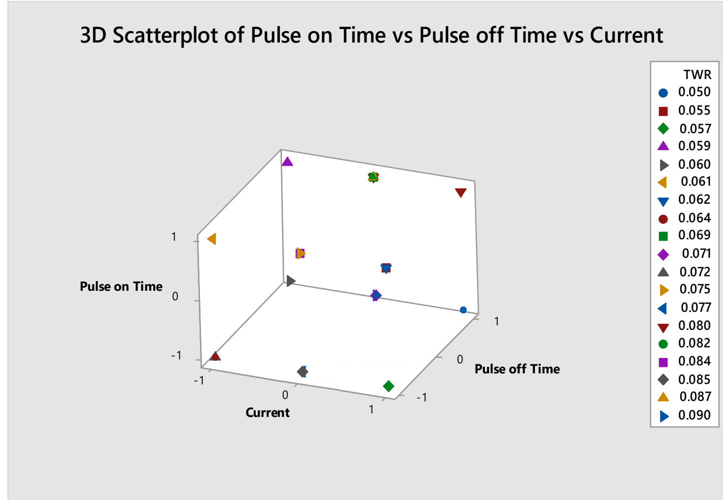


Fig: 14 3D Interaction plot graph for TWR

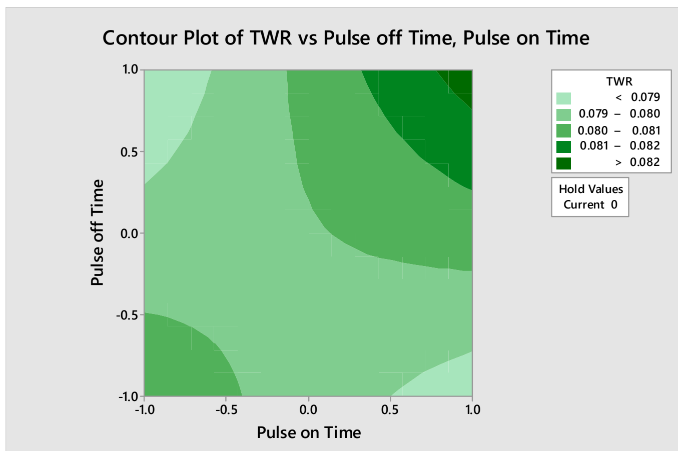


Fig:15 Contour plot of TWR verse pulse on time and pulse off time

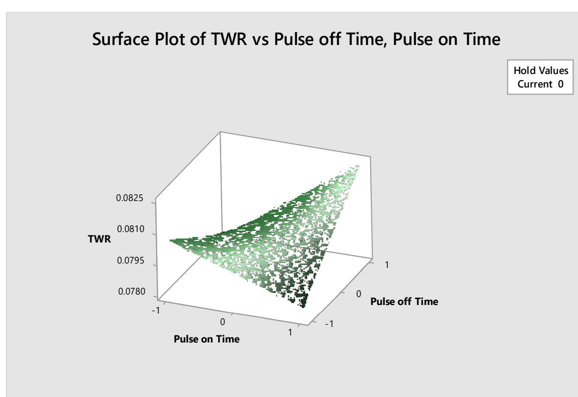


Fig: 16 Surface plot Graph in 3D for EDM

3.3 Micro structural analysis

Figure 17 depicts the microstructure of Al6061 and silicon carbide composites. Micrographs show that Silicon Carbide particles were distributed uniformly throughout the matrix alloy, with decreased porosity. It is also stated that high stiffness is always associated with smaller porosity in metal matrix composites. It can be demonstrated experimentally that there is good quality bonding between the matrix and the reinforcement particles, resulting in improved load transfer from the matrix to the reinforcement material.

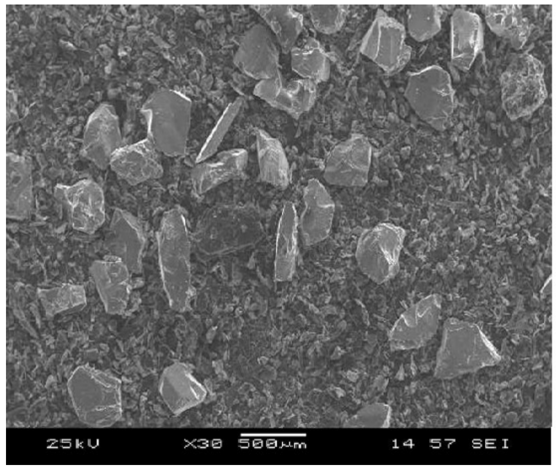


Fig: 17SEM of Al6061 reinforced with 10 wt% of SiCp

4. Conculsion

In this study, EDM performance parameters such as MRR and TWR of AA6061 MMC were examined, and statistical models were created. An ANOVA was performed, and the derived models were judged to be sufficient.

(i) Line plots were created for various EDM settings and their output performances. The response plot clearly shows that MRR improves with increasing pulse on time and current. This could be ascribed to the fact that a significant quantity of heat energy is generated and sustained for an extended period of time, causing melts and vaporization on the workpiece surface. However, for pulse off time, MRR drops. This is linked to that a higher pulse off-time supply of spark energy is interrupted, there is no creation of the conductive route in the IEG, resulting in lesser

(ii) As the pulse on time and applied current grow, so does TWR. Higher pulse on-time and applied current values resulted in a high temperature due to the mobility of positive ions in IEG striking the electrode surface with a high spark energy. Furthermore, copper electrode melts in drops absorb more heat during EDM and are quickly evaporated, resulting in a greater TWR.

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