Electrical Discharge Machining of SiC and Gr Reinforced 6061-T6 Aluminum Alloy Hybrid Composite Fabricated by Friction Stir Processing

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ELECTRICAL DISCHARGE MACHINING OF SiC & Gr REINFORCED 6061-T6 ALUMINUM ALLOY HYBRID COMPOSITE FABRICATED BY FRICTION STIR PROCESSING

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ABSTRACT

Aluminum based hybrid composites are advanced materials having the properties of high hardness, superior wear resistance, strength, high elevated temperature and low thermal expansion co-efficient.These hybrid composites are widely used in industries like automobile and aerospace. In this present paper 6061-T6 Aluminum alloy reinforced with SiC and Gr particles, hybrid composites are fabricated by using Friction stir processing (FSP) technique. It prevents the further development of hybrid composites for machining by nonconventional methods like water jet and laser cutting process. Electrical discharge machining (EDM) is used for machining the complex shapes of the material. This paper presents an overview of EDM studies conducted on the Al-SiC/Gr hybrid composites using a copper electrode in EDM.The EDM experiment machining parameters such as the dielectric fluid, peak current, pulse on, pulse off times are changed to explore their effects on machining performance, material removal rate (MRR), Tool wear rate (TWR), and surface roughness (SR). It is observed that the MRR and SR of the Al-SiC/Gr hybrid composites increase with an increase in the current.

NOMENCLATURE

A	Current
MRR	Metrial Removal Rate
MPa	Mega pascal
OA	Orthoganal Array
R_a	Roughness average
S/N	Signal to Noise Ratio
SEM	Scanning Electron Microscope
SR	Surface Raughness
TWR	Tool Wear Rate
T_m	Machining Time
T_{on} =B	Pulse on time
T_{off} =c	Pulse off time
WWL	Workpiece Weight Loss
TWL	Tool Weight Loss
W_a	Weight of workpiece material aftermachining
W_b	Weight of workpiece material beforemachining
ρ_w	Density of work piece material
ρ_t	Density of tool material
µ	Roughness symbol
µs	Micro seconds
η	Signal to Noise Ratio values symbol

INTRODUCTION

In past three decades aluminium composites materials demand increases in various industries of aerospace, automobile, aviation, electrical, military, sports and engineering components. These materials have light weight, high specific strength hardness, good wear resistance and low thermal expansion coefficient. Due to high hardness of these Al Metal Matrix Composites (MMCs) , it was observed that difficulty in machining, which causes serious tool wear due to the abrasive nature of reinforcing particles and hence shortens the life of the tool. For the machining of MMCs advanced machining techniques are used such as water jet, laser beam and plasma. But the above processes have proven to highly expensive for that reason electrical discharge machine is selected as this process is low in cost and has high MRR and low surface roughness(1).

EDM in composite materials has various goals in the formation of phases with different physical and mechanical properties. The matrises of MMCs have a high thermal conductivity and low melting point at the same time the brittle reinforcement is considered by a low thermal conductivity and high melting point. The high thermal conducting of composites had good resistivity and more efficiency of EDM processes (2).

B. H. Yan et al (3) studied experimental results of Al_2O_3 composite materials, surface roughness depends on the quantity of reinforcement particles with both conductivity (electrical and thermal). Such that the usage of increasing the discharge energy can procludes increasing the discharge craters.

P. Cichosz et al (4) investigated, the influense of different machining parameters on the performance of mixed fibres and matrix material in the affects surface area of the EDM of Al matrix composites. It was found that the low discharge current parameters existed in a thin layer with a recast layer structure of increased hardness. It was also found that the increasing the material removal rate formed a very rough finishing with poor surface integrity.

B.Mohan et al (5) studied analysis the effect of electrical discharge machining of Al-SiC composite materials .It was observed that MRR increased with increasing discharge current and for a specific current it decreased with increase in pulse on times. High amount of volume percentage of SiC has an inversely proportional to MRR and TWR. N.P.Hung et al (6) observed increasing the pulse-on time generates high discharge energy, expansion and deep discharge craters of work piece surface.

Sameh S. Habib et al (7) reported the analysis of the control input parameters required for the control of output parameters of the material removal rate, electrode wear ratio, gap size and surface roughness. It was observed that the pulse on time and peak current increases with increasing the electrode wear ratio.

Velusamy senthilkumar et al (8) investigated the effect of different EDM process parameters like discharge current, pulse on time and flushing pressure on MRR, TWR, EWR and SEM analysis of 6061-Al/TiC composite. It was observe that the MRR was increases with increasing values of discharge current, MRR was decreased as increasing the volume percentage of titanium carbide particles due to the bridging effect of titanium carbide particle in the composite**.**

However, it has not been found that there is no result reported for EDM of 6061-T6 Al-SiC/Gr surface hybrid composite fabricated by FSP. The optimization of process parameters for improving the MRR, SR, TWR of 6061-T6 Al-SiC/Gr surface hybrid composite was not reported. Taguchi method is a systematic methodology intended for design and analysis of experiments for improving the quality characteristics (9-11). Nowadays, it has become a very popular practical tool for improving the quality of output without increasing the cost of experimentation by reducing the number of experiments. A Devaraju et al. (12) optimized the FSP process parameters for maximizing wear and mechanical properties of Al-SiC/Gr surface hybrid composites by using Taguchi method.

In this present investigation,influence of EDM process parameters has been studied on 6061-T6 aluminium alloy metal matrix hybrid composite reinforced with 6% of SiC and 3% Gr particles fabricated via FSP technique. The electrical discharge machining is done on Al6061-SiC/Gr hybrid composite using 10 mm diameter electrolyte copper and EDM oil as dielectric fluid. The objective of the present investigation is to study the influence of machining parameters, such as discharge current, pulse on time and pulse off time on MRR ,SR and TWR and to obtain the optimum combinations using Taguchi method.

EXPERIMENTAL DETAILS

Surface composite preparation by FSP

The base material employed in this study is 4 mm thick Aluminium alloy 6061-T6. The chemical composition of the base material is given in Table 1. The average sizes of the SiC and Gr reinforcements are 20 µm. The square groove was made with dimensions of 3 mm width and 3 mm deep tangent to the pin on the advancing side and which is 1 mm far away from the center line of the tool rotation on the Aluminum alloy 6061-T6 plate. H13 tool steel is used for FSP, having screwed taper pin profile with shoulder diameter of 24 mm, pin diameter of 8 mm and 3.5 mm height. The volume percentages of SiC (i.e 6%) and Gr (i.e 3%) particles were packed in the groove. The groove opening initially closed by means of the tool which is having shoulder without pin to avoid the escapement of reinforcement particles from groove while processing. The Tool travelling speed of 40 mm/min, axial force 5 KN and tool onward tilt angle of 2.5^0 along the centre line were used in FSP. The experiments are carried out on a Vertical milling machine (Make HMT FM-2, 10 hp, 3000 rpm)(13).

Table 1 . Chemical composition of Aluminum 6061-T6 alloy (Wt. %).

Element	Mg	Si	Cu	Zn	Ti	Mn	Cr	Al
Amount (%)	.85	.68	.22	.07	.05	.32	.6	Balance

The experiments were performed on a Formatics EDM 50 die sinking machine with Electronica PRS-20 controller. The electrode fed downwards under DC servo control into the work piece. Electrol EDM oil is used as the dielectric fluid for machining, which is used in die-sinking machines for high machining speed and good surface finished. Experiments were conducted with positive polarity electrode. The electrolyte copper with dimensions 10 mm diameter and 70 mm length is selected as an electrode. The workpiece with dimensions of 100 mm length, 20 mm width and 4 mm thickness is employed. Each experiment was conducted for four minutes duration. Prior to machining, the work pieces and electrode were cleaned and polished. The workpiece was firmly clamped in the vice and immersed in the electrol EDM oil. The die sinking EDM machine experimental set up and 6061-T6 Al-SiC/Gr work piece properties details shown in Table 2 and Table 3. The weight of the workpiece and the electrode tool has been measured using a digital weighing balance make (citizen) before and after the commencement of machining to calculate the MRR and TWR respectively. Surface roughness of the machined work pieces were measured using Handysurf equipment.

Table 2. Al-SiC/Gr hybrid surface composite properties.

Material	6061-T6Al-Sic/Gr
Micro Hardness	125 (HV)
UT Strength	210 (MPa)
Yield Strength	175 (MPa)
% Elongation	9.4
Density (g/cm^3)	2.78

Evaluation of MRR and TWR

EDM performance, regardless of the type of the electrode material and dielectric fluid is measured usually by the following criteria:

- Metal removal rate (MRR) (mm^3/min)
- Tool wear rate (TWR) (mm^3/min)
- Surface Roughness (R_a)

The MRR is the workpiece weight loss (WWL) under a period of machining time in minutes, i.e.

$$MRR = \frac{WWL \times 1000}{\rho w \times Tm} \quad (1)$$

WWL (mm^3/min) = (W_b – W_a)

Where:

W_b = weight of workpiece material before machining (g)

W_a = weight of workpiece material after machining (g)

Tm = machining time (min)

ρ_w = density of work piece material (g/cm^3)

Table 3. EDM Working conditions.

Working conditions	Description
Work piece	Al-SiC/Gr surface composite
Electrode material	Electrolyte copper
Electrode polarity	Reverse
Working time	4 min
Discharge Gap	70 Microns
Discharge current	0-8A
Discharge open voltage	110 ± 5 V
Discharge gap current	40 V
Pulse on time	0-90 µs
Pulse off time	0-60 µs
Dielectric Fluid	EDM OIL
Dielectric pressure	0.5 Mpa

Maximum of MRR is an important indicator of the efficiency and cost effectivness of the EDM process, however increasing the MRR is not always desirable for all applications since this may scarify the surface integrity of the workpiece. A rough surface finish is the outcome of fast removal rates. In terms of the TWR value, the equation below is usually used;

The TWR is the tool weight loss (TWL) under a period of machining time in minutes, i.e.

$$TWR = \frac{TWL \times 1000}{\rho t \times Tm} \quad (2)$$

Where:

T_b = weight of tool material before machining (g)

T_a = weight of tool material after machining (g)

T_m = machining time (min)

ρ_t = density of tool material (g/cm^3)

The concept of TWR can also be defined in different ways, and in this study the TWR is defined according to the weight loss of the electrode, as this definition is the most commonly used among the researchers. The minimum value of TWR always becomes an objective in many studies, where it indicates a minimum change in the shape of electrode, which leads to the better accuracy of the product.

Surface Roughness

In this study SR is calculated by using Handysurf instrument. Surface roughness are referred to the roughness or smoothness of a given surface. It was measured in terms of R_a (Roughness average), which is an arithmetic average of peaks and valleys of a workpiece surface measured from the centerline of evaluation length and measured by using the surface roughness tester.

Planning of Experiments based on Taguchi's Method

Current is the most important process parameter in EDM which has greater influence on MRR of Al-SiC/Gr surface composite (5,7-8,14-15). Trial experiments were conducted by varying the current, T on and T off, keeping the others constant to find the working range. Feasible levels of the process parameters were selected in such a way that the surface composites should be free from defects. The levels range of the current, Ton, Toff and the process parameters were presented in Table 4 and Table 5 respectively.

Table 4. Control parameters for EDM.

Symbol	Parameters	Units	Levels		
			1	2	3
A	current	A	4	6	8
B	T_{on}	µs	25	55	80
C	T_{off}	µs	16	38	56

Table 5. Experimental layout L_9 (3^3) orthogonal array.

Exp No	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Taguchi's method is very effective to deal with responses influenced by many parameters. It is a simple, efficient and systematic approach to determine the optimal process parameters. It is a powerful design of experiments tool which reduces drastically the number of experiments that are required to model and optimize the responses. Also, it saves a lot of time and experimental cost. The Taguchi method is devised for process optimization and identification of optimum levels of process parameters for given responses (9-11). In Taguchi method the experimental values of various responses are further transformed to signal to noise (S/N) ratio. The response that is to be maximized is called 'higher the better' and the response that is to be minimized is called 'lower the better'. Taguchi uses the S/N ratio to measure the deviation of the response from the mean value. S/N ratios for 'higher the better' and 'lower the better' characteristics are calculated using equations 3 and 4 respectively,

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{\,2}}\right] \qquad (3)$$

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \qquad (4)$$

where η denotes s/n ratio of experimental values, y_i represents the experimental value of the i^{th} experiment and n is total number of experiments.

In this present study, Taguchi method is applied to experimental data using statistical software Minitab-16. The number of process parameters considered under this study is three and the level of each factor is three. The degree of freedom of all the three factors is 6. Hence, L_9 (3^3) orthogonal array is selected. The condition of each experiment was repeated thrice in order to reduce the noise/error effects. The selected orthogonal array is presented in Table 5. The quality characteristics such as MRR, TWR and SR of Al-SiC/Gr hybrid surface composite was evaluated for all the trials. The optimum element combinations were predicted and verified.

Table.6 Experimental results with S/N Ratios of MRR,SR and TWR.

Exp No	MRR	S/N Ratio MRR	SR	S/N Ratio SR	TWR	S/N Ratio TWR
1	2.355	7.439	1.8	-5.106	1.629	-4.234
2	2.360	7.459	2.6	-8.299	1.601	-4.088
3	1.895	5.553	4.4	-12.869	1.675	-4.479
4	5.097	14.146	2.8	-8.943	2.163	-6.701
5	9.702	19.737	3.2	-10.103	2.449	-7.761
6	13.710	22.741	4.6	-13.256	1.557	-3.841
7	17.419	24.821	2.9	-9.248	0.556	5.097
8	22.742	27.137	3.8	-11.596	0.524	5.612
9	10.968	20.802	4.9	-13.804	0.500	6.026

RESULTS AND DISCUSSIONS

By using above (3) and (4) equations the S/N ratio values of machining performance for each experiment of L_9 orthogonal array can be calculated for the MRR, SR, and TWR values and it is presented in Table 6. From the calculation of main effect for each level of the factors,the response to values are presented in below Table. The main effect plot shows the influence of each level of factors on the machining efficiency .The individual levels are contributing are selected the plot and are the optimized levels of the particular factor.

By using the experimental data results and worked out values of the S/N ratios, average effect response value and the average S/N response ratios are calculated for MRR, SR and TWR presented in Table 7. The S/N ratios response graphs for MRR,SR and TWR are shown in Fig 1,Fig 2 and Fig 3 respectively. A greater S/N ratio value corresponds to a better performance. The optimum level of parameters is the level with the highest S/N ratio values. Hence,the optimum levels of parameters are the levels with the highest S/N ratio values. Based on the analysis, results were given in the Table 8.

Table 7.Response tables for Signal to Noise Ratios .

Material Removal Rate (Larger is better)			
Levels	Current	Pulse on time	Pulse off time
1	7.779	15.468	19.105
2	18.874	19.073	15.098
3	24.253	16.365	16.703
Delta	16.474	3.604	4.008
Rank	3	2	1
Surface Roughness (Smaller is better)			
Levels	Current	Pulse on time	Pulse off time
1	-8.758	-7.766	-9.985
2	-10.767	-9.999	-10.349
3	-11.549	-13.309	-10.740
Delta	2.791	5.544	0.755
Rank	1	1	1
Tool Wear Rate (Smaller is better)			
Levels	Current	Pulse on time	Pulse off time
1	-4.269	-1.948	-0.823
2	-6.101	-2.083	-1.589
3	5.576	-0.767	-2.381
Delta	5.576	1.313	1.559
Rank	3	3	1

Table 8. Optimum values of the quality characteristics

Quality charactrstics	Signal to Noise Ratio values	Predicated values	Optimum Condition	Optimum Condition values
Material Removal Rate	27.137	28.173	3-2-1	22.742
Surface Roughness	-5.106	-5.798	1-1-1	1.8
Tool Wear Rate	6.026	7.183	3-3-1	0.50

Effect of process parameters on MRR

Figure 1 shows the effect of discharge current on MRR . It is observed that the increase in discharge current increases the MRR due to the higher spark discharge energy, which results in enhancing the discharge energy channel diameter and an increase in the crater diameter and depth, which attributes to higher materials being evicted from the work piece(7,14,16). EDM spark discharges are more affected on the percentage of hybrid reinforced particles. Effect of pulse duration on MRR is presented in the fig 1. It is observed that the MRR is increasing with in increasing in pulse duration, then after reaching the optimum condition the MRR gradually decreases.

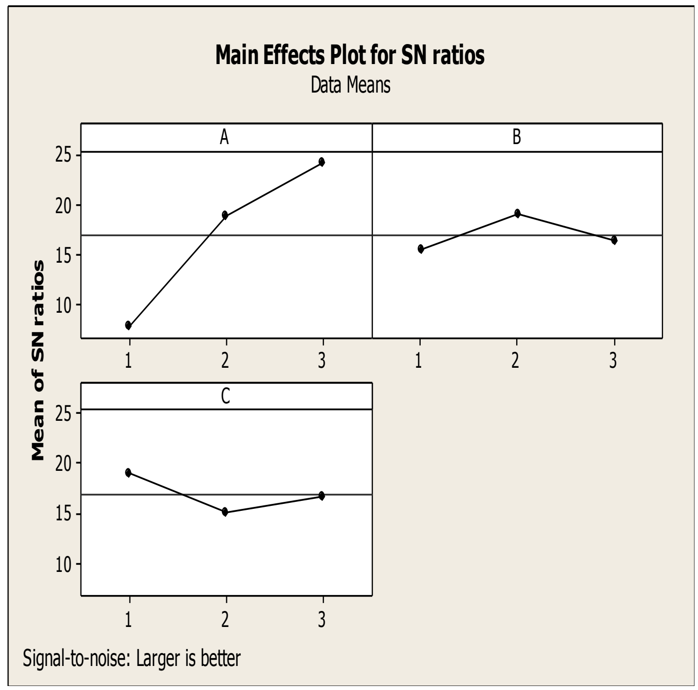

Figure 1. MRR Response graph for Signal to Noise Ratios

An increasing the pulse on time implies spark discharge energy for a long duration time. This is due to increase in the diameter of the discharge volume causes reduce the energy at the discharge spot of the work piece (16). This is impacted on pulse on time which increases the melting and the evaporation rate of the gas bubbles, eject the high pressure force on the work piece(5,7,14,16). In addition to this, MRR is decreased due to the presence of hybrid reinforcement particles entrapment in to the spark gap.

It is also observed that the increase in the pulse off time resulted in decreases the MRR due to lower discharge current this attributed to the short pulse (i.e. 16 μs to 38 μs) off time duration causes less vaporisation on the machined surface of the work piece. While the longer pulse (i.e. 38 μs to 56 μs) duration causes expansion of the plasma channel, thereby decreasing the energy density in the machining process. As earlier mentioned, improving the hybrid reinforcement particles entrapment in to the spark gap which reduces the MRR.

Effect of process parameters on Surface Roughness

The main effect plot for S/N ratio of SR with process parameters is shown in Figure 2. It is found that the increase in the discharge current decreases the SR. This is due to series of successive spark discharge which resulted in higher diameter and depth of craters causes high material removal rate and low surface finish on the workpiece (5,7-8,14).

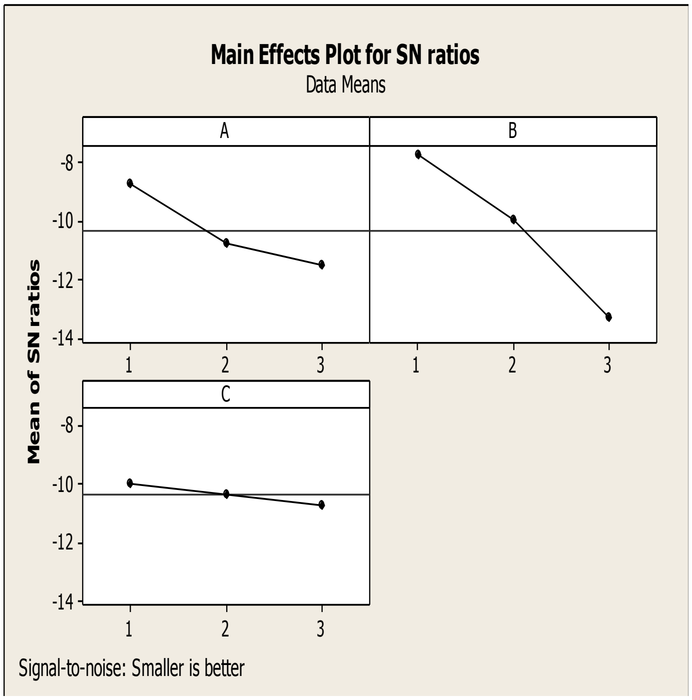

Figure 3. SR Response graph for Signal to Noise Ratios

It is also found that the increase in the pulse on time decreases the SR. This is due to high discharge energy (i.e. high energy has spent more time in the machining zone) which resulted in higher plasma channel diameter and impulse forces causes more material melts and burning (T on 80, T off 56 micro Sec) and vaporizes large shallow craters are formed on the work piece (7,14,16). In addition, as earlier mentioned, improving the SiC reinforcement particle entrapment in to the spark gap which reduces the SR.

It is revealed that the increase in the pulse off time decreases the SR. This is due to lower discharge current in the pulse off time duration which causes less vaporization (i.e. no material is removed) on the machined surface of the work piece obtained the lesser surface finishing. The lower machining resulted in high surface finish and the SR, MRR is a directly proposal to the pulse duration**.**

Effect of process parameters on Tool Wear Ratio

The results indicated that the tool wear rate increases with increasing the discharge current. In the initial stage of the machining process, it is observed that the tool wear rate decreases with increase in initial discharge current. After that the result depicts that the tool wear increases along with an increase in discharge currents. The reason for this phenomenon is due to the complex structure of hybrid composite. The work piece consists of reinforcement particles on the surface layer and also, the matrix phase and the reinforcement have different melting temperatures which serious effect on the Tool Wear Ratio.Initially low discharge current was applied so less heat generated which is insufficient for melting and evaporation of the composite is very less will resulted in low tool wear ratio. Later the discharge current increases, higher thermal loading on both electrodes (tool and work piece) leading to higher amount of material being removed from both electrodes. This causes higher MRR and high debris at the gap, which increases the wear on the electrode (5,14-16).

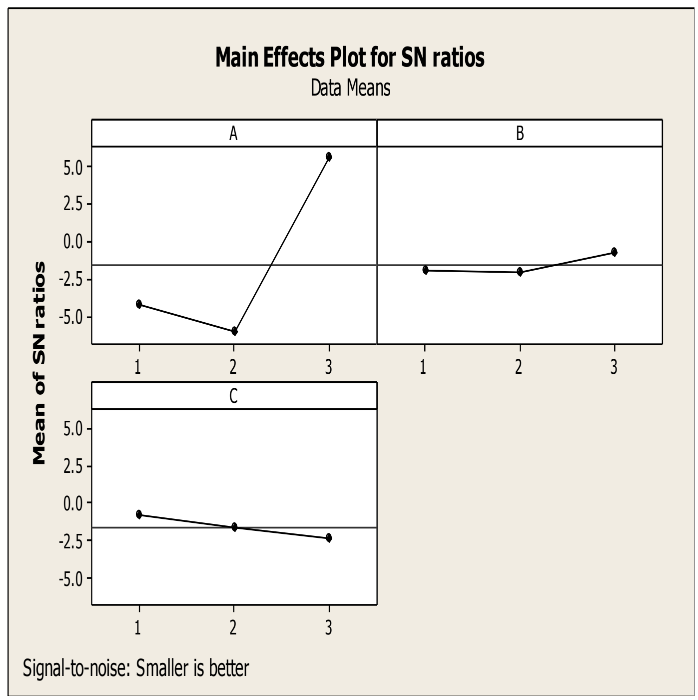

Figure 3.TWR Response graph for Signal to Noise Ratios

Figure 3 observe that the value of TWR is quickly changing with an increase of pulse on time. But, the increase is diminished after 86 (1) and the values of tool wear stags constant. This trend is an aspect to the electrolyte copper electrode has a good thermal conductivity. It easily removes for the generation of high heat. These phenomena the heat removals facilitate a reduction of the temperature around the surface of the electrode for a long pulse duration cause the less TWR (5,7-8,14). The TWR decreases in an inverse relation with pulse duration as similarly observed .

CONCLUSINS

Electrical discharge machining of SiC&Gr reinforced 6061-T6 Aluminum alloy surface hybrid composite fabricated by Friction stir processing was successfully carried out. Based on the experimental results the following conclusions can be drawn.

- The material removal rate of the hybrid surface composite increases with an increase in current , pulse off time increase with decreases in MRR. The MRR predicted value 28.1731 equivalent the experimental values 27.1365.
- Surface roughness value increases with an increase in current the SR due to the higher spark discharge energy. The SR predicted value-5.7975 equivalent the experimental values -5.1055.
- The tool wear rate of the developed hybrid composite decreases with increasing the pulse off time and it decreases with increase in pulse on time. The TWR predicted 7.1827 value equivalent the experimental values 6.0260.

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