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

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Abstract. Engineered materials with high hardness, great wear tolerance, high high-temperature power, and a low thermal expansion coefficient are aluminum-based composites. These materials are widely used in the automotive and aerospace industries. Friction stir processing (FSP) method used to prepare SiC reinforced aluminum alloy surface composite. Material removal rate (MRR) and surface roughness (SR) are measured with the impact of pulse on time, discharge current, and pulse off time (add one or two outcomes remark at SR and MRR optimal condition) is examined. For each of the three machining parameters, L9 orthogonal arrays (OA) of three levels were used in conducting the experiments. The validity of the Aluminum Surface Composite experiment programme is determined using MINITAB.

Keywords: EDM, Current, Surface roughness, Metal removal rate, Pulse on time and Pulse off time

1 Introduction

Metal matrix composites (MMCs) are distinct type of composite material that is increasingly being utilised in architecture and manufacturing. MMCs are utilised in many industries, including aircraft, cars, construction, electronics, defense, sports goods, and technical components. In order to meet the specific demands of MMC products, composite materials have been developed that are made up of two or more distinct physical and chemical substances. The reinforcement refers to the discontinuous phase, while the matrix refers to the continuous-phase. The advanced materials are light, have high specific power, are resistant to wear, and have a low coefficient of thermal expansion. Aluminium metal matrix composites (MMCs) are extensively utilised in the automotive (brake drum, cylinder liners, cylinder base, and drive shaft) and aerospace sectors because of their high strength, shatter resistance, wear tolerance, and endurance (helicopter components of the chassis, rotor vane, and aero-engines). Furthermore, AIMMCs reinforced by ceramics such as SiC and Al2O3 demonstrated better long-term strength [2-3]. These ceramic particles reinforced Aluminum alloy composites are utilised in applications that need both wear resistance and weight reduction. Aluminum alloy 6061-T6 composites are often used in aviation, safety, cars, and boats because of their improved corrosion and lightweight.

EDM's objectives include producing different physical and mechanical phases from a composite material. When examining these reinforcements, you will see they have different characteristics in their melting points and thermal conductivity. In EDM operations, Comosits' high thermal conductivity allows for good resistance and efficiency. M.Selvakumar et al. [4] (2012) studied EDM of sand cast 6061 Al/SiC composites. The models were developed to demonstrate the effect of machining variables such as pulse off time, pulse on time, peak current, wear intensity, and dielectric fluid on MRR and SR. The surface polish and metal removal rate (MRR) improve with increasing current, while the MRR decreases with increasing silicon content in hardened particles. M. In experimental research, Rozenek et al [5] looked at the effects of machining factors on aluminium alloy SiC and Al2O3-related composite materials. As the discharge current and pulse on-time rose, the surface roughness increased as well. TWR and MRR drop when electrical conductivity and thermal conductivity decreases. In aluminium composite content EDM, R. Karthikeyan et al. [6] established a statistical model to optimise process variables. The TWR and SR both decreased as the SiC particle concentration increased. As the volume % of SiC particles rose, the TWR and SR were observed to decrease. According to the results, MRR increases as current increases and reduces as SiC particle reinforcement increases. However, no EDM findings for FSP-fabricated Al/SiC 6061-T6 surface composite have been found. Optimizing
process parameters to enhance MMR and SR of a Al/SiC 6061-T6 surface composite was not mentioned. The Taguchi is a method to plan and evaluate studies with the goal of increasing efficiency [7-9]. It is already a commonly used realistic technique for improving performance efficiency and decreasing the number of experiments, thereby cutting the cost of testing. A Devaraju et al. [10] optimised the mechanical and wear characteristics of Al-SiC/Gr surface hybrid composites using the Taguchi method.

The FSP technique is used in this work to reinforce aluminium 6061-T6 alloy metal matrix composite of 12% SiC volume particles using the FSP method. EDM on an surface composite Al6061-SiC is carried out using dielectric solvent with EDM oil and electrolyte copper with a 10 mm diameter. The main aim of the present study is, to investigate how EDM parameters like pulse on time, discharge current and pulse off time influence SR and MRR, using the method Taguchi to identify the optimum combinations.

2 Experiment Details

2.1 FSP of Al-SiC surface composite

Aluminium alloy 6061-T6, which is 4 mm thick, was utilised as the foundation material in this study. Table-1 shows chemical structure of the basic material. On average, the SiC reinforcements are 20 metres long. A 3 mm width and 3 mm depth square groove was in tangent to the pin in the state of advancing hand with 1 mm distant from the tool rotation's centre line over the Aluminum alloy of 6061-T6 shield. Screwed taper pin profile on the aluminium alloy plate to perform FSP was manufactured from tool steel H13 and had 24 mm shoulder diameter, 8 mm pin diameter, and 3.5 mm height. At a volume percentage of 12%, the groove was filled with SiC particles. The groove hole was initially closed using a tool with a shoulder without a lock to prevent reinforcing particles from escaping during production. FSP utilised a tool with a 40 mm/min movement speed, a 5 KN axial force, and a 2.50 forward tilt angle around the centre line. The experiments are performed using vertical milling system (HMT FM-2, 10 HP, 3000 RPM) [10].

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

| Element | Mg | Si | Cu | Zn | Ti | Mn | Cr | Al |
|---------|----|----|----|----|----|----|----|----|
| Amount (W%) | .85 | .68 | .022 | .07 | .05 | .032 | .06 | Balance |

Experiments were conducted using a PSR-20 power supply and die-sinking EDM type 50. The DC servo control is used to fed electrode downwards into the workpiece. In the tests, positive polarity electrodes were utilised. The electrode is made of copper with a 10 mm diameter and 70 mm length. A workpiece of 100 mm long, 20 mm wide, and 4 mm thick is utilised. It takes 4 minutes to complete the machining operation. Before and after the commencement of machining, the workpiece weight is determined using a digital balance (manufactured by Citizen). Surface roughness is calculated with the help of the Handysurf tool. Tables-2 and Table-3 shows the usual working conditions of EDM and material characteristics of surface composites 6061-T6 Al/ SiCp.

Table 2: EDM working conditions

| Working conditions | Description |
|-------------------|-------------|
| Work piece        | 12Vol%SiC T6-6061 |
| Electrode material| Electrolyte copper |
| Electrode polarity| Reverse |
| Working time      | 4 min |
| Discharge Gap     | 70 Microns |
| Discharge current | 0-8A |
| Discharge open voltage | 110+_5V |
| Discharge gap current | 40 V |
| Pulse on time     | 0-90 μs |
| Pulse off time    | 0-60 μs |
| Dielectric oil    | EDM Oil |
| Dielectric pressure| 0.5 Mpa |

Table 3: 6061-T6 Al/ SiCp surface composite properties

| Material | Micro Hardness | UY Strength | Yield Strength | %Elongation | Density (g/cm³) |
|----------|----------------|-------------|----------------|--------------|----------------|
| 6061-T6 Al/SiCp | 125(HV) | 557(Mpa) | 115(Mpa) | 7.2 | 2.76 |

2.2 Evaluation of MRR and SR

The following parameters are typically used to evaluate EDM efficiency, regardless of the electrode material and dielectric fluid used:

- Metal removal rate (MRR) in millimeters per minute (mm³/min)
- Roughness of the Surface (Ra) (μ)

The equation below is used to calculate the MRR:
The maximum MRR is a valuable measure of the EDM process's performance and cost-effectiveness; nevertheless, in all the applications rising MRR may not be always optimal since it may compromise the integrity of workpiece's surface. Quick removal rates result in a rough surface finish. The equation below is often used to calculate the MRR value.

\[
\text{MRR} = \frac{W_b - W_a \times 1000}{\rho \times T_m}
\]  

(1)

Where,

- \( W_b \) = workpiece material weight before machining (g)
- \( W_a \) = workpiece material weight after machining (g)
- \( T_m \) = time of machining (min)
- \( \rho \) = workpiece material density (g/cm\(^3\))

2.3 Experimental Plan based on Taguchi’s Method

One of the most important parameters in EDM is current, over which MRR is highly affected on Al-SiC surface composites [4-6]. Sample experiments were carried out to establish the working range by changing the current, \( T_{on} \), and \( T_{off} \) while keeping the other variables constant. The technique parameter values that were deemed viable were chosen to produce a defect-free Al-surface composite. The existing range, \( T_{on} \), \( T_{off} \), and constant process parameter ranges are tabulated in Tables 3 and 4.

Table 4: Working range of the selected parameters

| Symbol | Parameters | Units | (1) | (2) | (3) |
|--------|------------|-------|-----|-----|-----|
| A      | Current    | A     | 4   | 6   | 8   |
| B      | \( T_{on} \) | \( \mu s \) | 25  | 55  | 80  |
| C      | \( T_{off} \) | \( \mu s \) | 16  | 38  | 56  |

Taguchi’s approach is particularly helpful when dealing with responses that are influenced by a number of variables. It’s a simple, efficient, and thorough technique for finding the optimum process parameters. It reduces the number of trials required, which makes it a good design experiments technique for modelling and refining responses. Experiments are also saved lots of time and money. Taguchi technique [7-9] was designed for optimization of the process and the determination of optimum process parameters values. The Taguchi technique is used to transform the signal-to-noise (S/N) ratio from experimental values of various responses. Maximisation retort is referred to as “higher is better,” while minimization response is referred to as “lower is better”. Taguchi calculates the mean value to the divergence of the answer from using the S/N ratio. S/N ratios are calculated using Equation 2 for 'higher the better' and Equation 3 for 'lower the better' features.
Investigational research was performed on 6061-T6 Al/ SiCp surface composite to examine the effect of machining parameters such as pulse off time, pulse on time and discharge current using electrical discharge machining.

### Table 6: S/N Response table for MRR

| Levels | Current | Pulse on time | Pulse off time |
|--------|---------|---------------|---------------|
| 1      | 10.35   | 18.72         | 21.18         |
| 2      | 21.35   | 20.91         | 18.43         |
| 3      | 25.87   | 17.94         | 17.96         |
| Delta  | 15.52   | 2.97          | 3.22          |
| Rank   | 3       | 2             | 1             |

### Table 7: S/N Response table for SR

| Levels | Current | Pulse on time | Pulse off time |
|--------|---------|---------------|---------------|
| 1      | -7.896  | -6.275        | 19.106        |
| 2      | -10.215 | -10.06        | -9.739        |
| 3      | -10.617 | -12.387       | -10.164       |
| Delta  | 2.721   | 6.111         | 1.339         |
| Rank   | 1       | 1             | 1             |

### Table 8: Optimum values of the quality characteristics

| Quality characteristics | Signal to Noise Ratio values | Predicted values | Optimun condition | Optimum value |
|-------------------------|------------------------------|------------------|-------------------|---------------|
| Material Removal Rate   | 28.268                       | 29.575           | 8-55-16(3-2-1)    | 25.906        |
| Surface Roughness       | -2.923                       | -3.844           | 4-25-16(1-1-1)    | 1.4           |

The aforementioned equations may be used to calculate the values of machining performance for each experiment of the L9 orthogonal array to determine the S/N ratio (Table 5). The major effect values obtained from the computation of the main impact for each level of the variables are shown in Tables 6 and 7. The primary effect graphic shows how each factor level influences machining efficiency. The optimum levels of a particular component are selected as person levels that contribute to the plot.

Table 5 shows how the average impact reaction valve and typical S/N response ratios for SR and MRR were calculated using experimental data and S/N ratio valves. Figures 1 and 2 shows the S/N ratio response graphs for MRR and SR. The efficiency of valves with a increased S/N ratio has increased. As a consequence, the parameter values with the high S/N ratio valves are the best. Table 8 summarises the study's results.

### 3.1 Effect of process parameters on MRR

Fig 1 shows S/N ratio of material removal rate (MRR) for the main effect plot with process parameters.

Increasing the discharge current increases the MRR because greater spark discharge pressure causes melting, evaporation, and a significant impulse force in the
The EDM of SiC-strengthened Aluminum alloy 6061-T6 material removal rate, whereas reductions in MRR lengthen the pulse off time. MRR is increased with increasing the discharge current due to the greater discharge energy of spark. Greater heat loading on both the cathode and anode resulted in increased material ejection from the workpiece as a consequence of the increased discharge current. For better material removal rate, the parametric combination is 3-2-1. With increasing current and SR, Surface roughness values increase due to the greater spark discharge energy. 1-1-1 is a strong surface completed parametric mix.

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