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EFFECTS OF PROCESS PARAMETERS ON SURFACE ROUGHNESS OF AL6061-SiC METAL MATRIX COMPOSITE THROUGH WIRE – CUT ELECTRO DISCHARGE MACHINING USING TAGUCHI METHOD

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ABSTRACT

The Al6061 alloy reinforced with SiC particle is proposed to be casted by stir casting technique; SiC with 36 μ size will be used. Casting will be done by varying the percentage of SiC from 3%, 6% and 9% by weight and preparing the specimens.

The wire electrical discharge machining has been used for machining characterization of Al6061/SiC composite. In this process, parameters are Pulse-on time (T_{ON}), Pulse-off time (T_{OFF}), Current (I) and Bed speed (B_s) will be varied to find their effects on Surface Roughness (Ra). The experiments were proposed to carry out as per design of experiments (DOE) according to the selected L_9 orthogonal layout. The results obtained from this study are presumed to be applicable for manufacturing engineers to choose appropriate WEDM process parameters to machine MMCs of Al6061 reinforced with SiC at various proportions and Unfilled Aluminum.

Keywords: MMC; Al6063/SiCp; ANOVA ; Response graph ; WEDM; TON; TOFF; Ra; WT; WF; SV; IP

I. INTRODUCTION

Composite Materials are a new emerging class of materials to overcome the current limits of monolithic conventional materials. MMCs are constituent materials, in which a metal is reinforced with high strength material like SiC, Al₂O₃, etc. in various proportions. This leads to MMCs with improved properties like elastic modulus, specific strength, wear resistance, stiffness, low thermal expansion coefficient, etc. Metal matrix composites (MMCs) have wide application in some industrial fields in which the parts are required to be light and heat-resistant or wear-resistant, non-continuously reinforced materials such as aluminium matrix composites reinforced by SiC particles have become practical engineering materials. However, because of the existence of hard reinforcements in their structure they are difficult to machine. So that these materials have gained importance in various fields like finishing parts for aerospace, defence, automobiles, surgical components, electronics and sports. However, the reinforcement material in various forms and greater hardness and reinforcement makes it difficult to machine using traditional machining methods and the use of traditional machinery to machine hard composite materials causes serious tool wear due to its abrasive nature of reinforcement.

Therefore, researchers have made an attempt to machine MMCs using different non-traditional machining methods like abrasive water jet, laser cutting and electrical discharge machining (EDM). However, these processes have certain limitations like linear cutting and elaborate preparation of pre-shaped electrode (tool). In order to overcome these limitations, few researchers have taken wire electrical discharge machining (WEDM) process and it has to be effective and economical tool in the machining for composite materials. WEDM is considered as one of the most versatile process for machining higher capability for intricate, complex shapes, higher precision and difficult to machine materials. But only limited attempts have been made by researchers to machine different MMCs using WEDM process.

Aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for various high performing components that are being used for varieties of applications owing to their lower



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weight, excellent thermal conductivity properties. As well as the aluminum alloy 6000 series is used in many applications like aeronautics, automotive industries, etc. because of its versatility. This Al-Mg-Si alloy enhances good corrosion resistance and high mechanical properties with appropriate thermal resistance.

Wire Electrical Discharge Machining (Wedm)

Wire EDM is a method to cut conductive materials with a thin electrode that follows a programmed path. The electrode is a thin wire. As the wire feeds from reel to reel, it uses sparks of electrical energy to progressively erode an electrically conducting material along a path determined by the relative motion of the machine's axis. Typical wire diameters range from .004" - .012". The hardness of the work piece material has no detrimental effect on the cutting speed. There is no physical contact between the wire and work material. Rather, the wire is charged to a voltage very rapidly. This wire is surrounded by de-ionized water. When the voltage reaches the correct level, a spark jumps the gap and melts a small portion of the work piece. The de-ionized water cools and flushes away the small particles from the gap.

Wire EDM can be accurate to ± 0.0001 ". No burrs are generated. Since no cutting forces are present, wire EDM is ideal for delicate parts. No tooling is required so delivery times are short. Pieces over 16" thick can be machined.

Basic principle of WEDM process

The Spark Theory on a wire EDM is basically same as the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (Electrode) and work piece. High frequency pulses of alternating or direct current is discharged from wire to the work piece with a very small spark gap through an insulated dielectric fluid.

Many sparks can be observed at a time. This is because actual discharges can occur more than 100,000 times per second, with discharge sparks lasting in the range of 10-6 seconds or less. The volume of metal removed during this short period of spark discharge depends on the speed of desired cutting and surface finish required.

The heat of each electrical spark, estimated at range of 15,000° to 21,000° Fahrenheit, erodes away a tiny bit of material that is vaporized and melted from the work material. (Some of the wire material is also eroded away) These particles (chips) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles. The water acts as a coolant, prevents heat build-up in the work material. Without this cooling, thermal expansion of the part varies size and positional accuracy. Keep in mind that, it is the Pulse ON and Pulse OFF time of the spark that is repeated again and again that removes material, not just the flow of electric current Fig. 1.

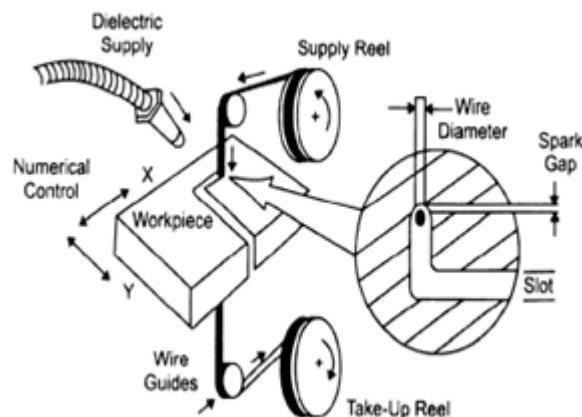


Figure 1. Schematic Diagram of the Basic Principle of WEDM Process [17]

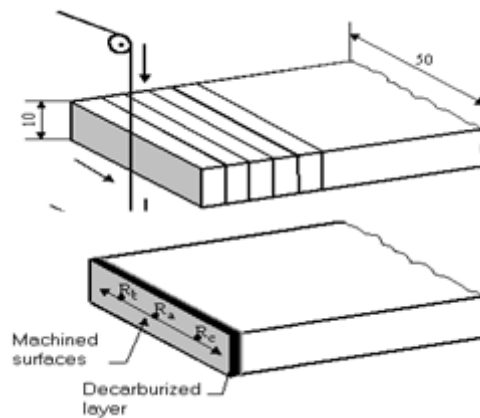


Figure 2. Schematic diagram of the cutting process and examination surfaces [13]

II. MATERIALS AND EXPERIMENTAL METHOD

Design of Experiments

Table 1. L9 Orthogonal Array

Run	P_{on} in μs	P_{off} in μs	Current in Amps.	Bed Speed in mm/min
1	12	6	2	30
2	12	7	3	40
3	12	8	4	50
4	16	6	3	50
5	16	7	4	30
6	16	8	2	40
7	20	6	4	40
8	20	7	2	50
9	20	8	3	30



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Table 2. WEDM Process Parameters and their Levels

Sl. No.	Parameters	Levels		
1	Pulse on time in μs (P_{ON})	12	16	20
2	Pulse off time in μs (P_{OFF})	6	7	8
3	Current in Amps.	2	3	4
4	Bed Speed in mm/min	30	40	50

The Taguchi's experiment provides an orderly way to collect, analyze, and interpret data to reach the objectives of the study. This design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation.. The Experiments were conducted as per the standard orthogonal array so as to investigate which design parameter significantly affects the WEDM for the selected combinations of Pulse on time, Pulse off time, Current and Bed speed. The selection of the orthogonal array was based on the condition that the degree of freedom for the orthogonal array should be greater than or equal to sum of those WEDM parameters. In the proposal work an L9 orthogonal array was chosen, this has 9 rows and 4 columns as shown in the Table 1.

Selection of Orthogonal Array and Parameter Assignment.

For this experimental work the four process parameters each at three levels has been decided to reflect the true behaviour of output parameters. The process parameters are renamed as factors, the levels of the individual process parameters are given in Table 2.

The WEDM parameters were chosen and their levels indicated in table 2. The experiments consist of 9 tests table 1 (each column in the L9 orthogonal array) and in table 2 was assigned to Pulse on time (T_{ON}) Pulse off time (P_{OFF}), Current (I) and Bed speed (B_S) 1-4 rows respectively.

Fabrication of MMC

There are different methods by which they can cast metal matrix composites. But most feasible method is stir casting technique. This technique is a primary process of composite production whereby the reinforcement material is incorporated into the molten metal by constant mixing.

Addition of SiC to the molten matrix is done in different percentages. Minimum of 0% to maximum of 9% is added. Still it can increase the percentage of reinforcement, but due to density variation, SiC will not distribute properly in matrix. It will either float or completely settle at the bottom of the crucible.

Preparation of Specimens

The test piece is a square bar of material, 60mm x 50mm x 30mm, that are milled from the casted material. The prepared specimens were composite material Al6061 reinforced with 3 % SiC, 6% SiC and 9%SiC respectively.

Preparation of Specimens from WEDM

The unreinforced Al6061 and MMCs of 60mm x 50mm x 30mm size is placed on the ELECTRONICA SPRINTCUT WEDM and specimens were cut into 5mmx50mmx30mm size. The fixtures used for cutting the specimens.



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III. RESULTS AND DISCUSSION

Effect of pulse on time on R_a for various percentage of SiC

The variation of surface roughness with respect to pulse on time for various percentage of SiC is as shown in the Fig. 3. From the Fig. it can be observed that surface roughness is increase in with increase in pulse on time but the margin of decrease in Surface Roughness is generally small irrespective of the percentage of SiC. It can also be observed that the surface roughness is higher for 9% SiC reinforcement and the variation in roughness value is smaller for remaining percentage of reinforcement. This is because at high pulse-on time (T_{ON}) the spark intensity is high, which remove the work piece material at higher depth (creates large crater size) and results in higher surface roughness [11].

The maximum surface roughness is observed to be $6.14\text{mm}^3/\text{min}$ with $20\ \mu\text{s}$, pulse on time for 9% of SiC and minimum Surface Roughness is $4.5\text{mm}^3/\text{min}$ for $12\ \mu\text{s}$, pulse on time for 0% SiC.

Effect of pulse off time on R_a for various percentage of SiC

The Variation of surface roughness with respect to pulse off time for various percentage of SiC is as shown in the Fig.4. From the Fig. it can be observed that the surface roughness is decreasing with the increase in pulse off time but the margin of decrease in surface roughness generally small irrespective of the percentage of SiC. It can also be see that the margin of decreasing surface roughness is greater with the increase in pulse of time from 6 to 7 μs as compare to 7 to 8 μs pulse of time. so it is clear that the surface roughness is generally increased with increase in percentage of SiC. The surface roughness is decreasing with the increase in pulse off time irrespective of percentage of SiC due to reducing number of pulse per cycle with increase in pulse of time. In the case of pulse-off time (T_{OFF}), higher pulse-off time (T_{OFF}) resulted in higher R_a . High pulse-off time (T_{OFF}) is required in WEDM process in order to flush the eroded materials by the dielectric fluid effectively before it gets resolidified.

The maximum Surface Roughness is observed to be $6.04\ \mu\text{m}$ with 6 μs , pulse off time for 9% of SiC and minimum Surface Roughness is $4.83\ \mu\text{m}$ with 7 μs , pulse off time for 6% SiC. So the value of pulse off time can be selected in such a way that they get the desired surface roughness.

Effect of current on R_a for various percentage of SiC

The variation of Surface Roughness with respect to current for various percentage of SiC is as shown in the Fig. 5. From the Fig. it can be observed that the surface roughness is increasing with the increase in current but the margin of decrease in surface roughness is generally small irrespective of the percentage of SiC. It can also be see that the margin of increase in surface roughness is greater with increase in current from 2 to 4 Amps for 0% and 6% of SiC. But surface roughness is greater with increase in current from 2 to 3 Amps as compare to 3 to 4 Amps, current for 3% and 9% of SiC. It can also be observed that the surface roughness is generally decreased with increase in percentage of SiC. The surface roughness is decreasing with the decrease in current irrespective of percentage of SiC due to reducing number of current per cycle with decrease in current. This may be due to the possible presence of reinforced particles (SiC) in the surface. Erratic behaviour of the curves for 9% and 6% are not known and these results are in par with the previous works [12]

The maximum surface roughness is observed to be $5.74\ \mu\text{m}$ with 4 Amps, current for 0% of SiC and minimum surface roughness is $4.3\ \mu\text{m}$ for 4Amps, current and 6% SiC. So the value of current should be high to obtain higher surface roughness.

Effect of bed speed on R_a for various percentage of SiC

The variation of surface roughness with respect to bed speed for various percentage of SiC is as shown in the Fig.6. From the Fig. can be observed that the surface roughness is increasing with the increase in bed speed but the margin of decrease in surface roughness is generally small irrespective of the percentage of SiC. From the graph shows that the margin of increase in surface roughness is greater with increase in bed speed from 30 to 50 mm/min for composition of 3%, 6% and 9% of SiC as compare to unreinforced aluminum. It can also be observed that the surface roughness is generally increased with increase in percentage of SiC. The surface roughness is decreasing with the decrease in bed speed irrespective of percentage of SiC.



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The maximum surface roughness is observed to be $5.85 \mu\text{m}$ with 50mm/min , Bed speed for 9% of SiC and minimum surface roughness is $4.55 \mu\text{m}$ for 30mm/min , Bed speed for 3% SiC. So the value of bed speed should be high to obtain higher surface roughness.

From the above study, it is observed that the average Ra obtained for the unreinforced Al6061 is found to be $5.0 \mu\text{m}$ Fig. 3, 4, 5 & 6. In the case of MMCs Al6061 with 3% , 6% and 9% SiC, the average value of Ra are found to be 5.09 , 5.25 and $5.75 \mu\text{m}$, respectively. It is seen that the machining of composite materials results in higher order roughness, due to the possible presence of reinforced particles (SiC) in the surface. It is found that the surface roughness Ra values increases with an increase in the percent volume of SiC particles.

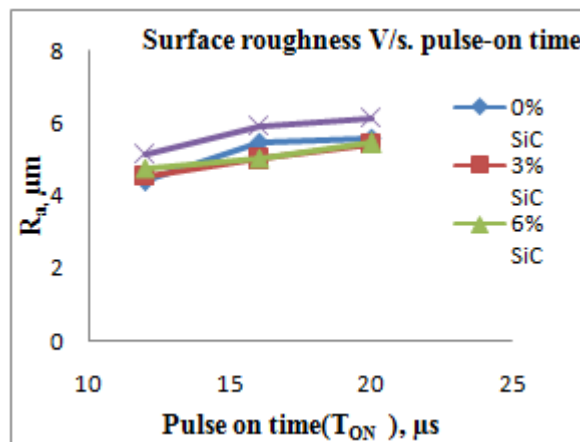


Figure 3. Effect of pulse on time on surface roughness.

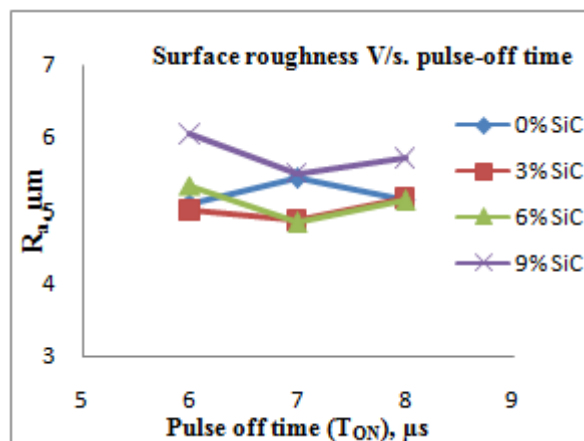


Figure 4. Effect of pulse off time on surface roughness.

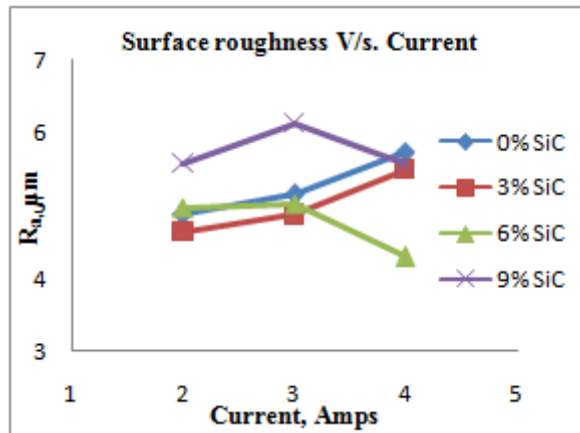


Figure 5. Effect of current on surface roughness.

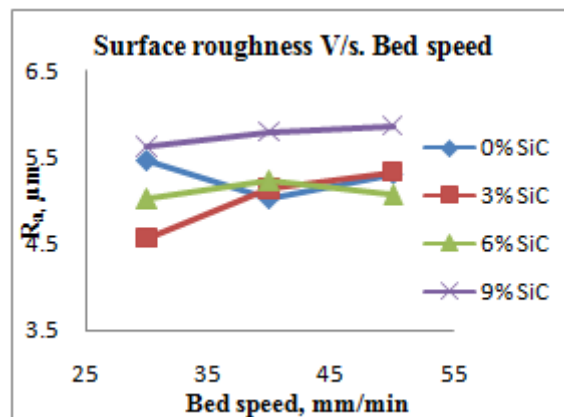


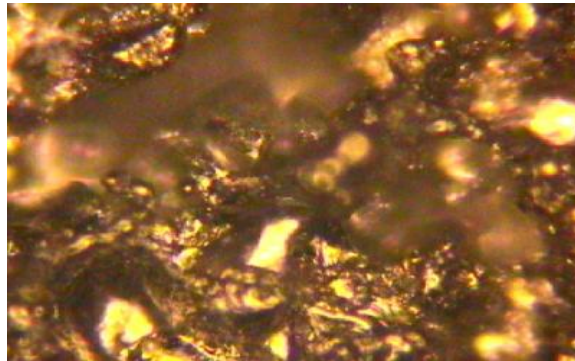
Figure 6: Effect of bed speed on surface roughness.

Image Effect System Photographs of MMCs

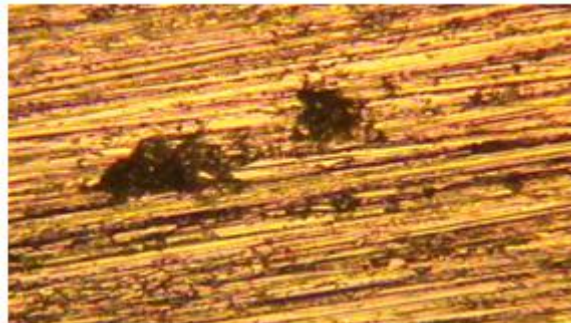
The matrix structure of the Machining Al6061 with 3, 6 and 9% SiC, and after polishing Al6061 with 3, 6 and 9% SiC composites are shown Fig. 7. By observed minute grain size than that of the 6061 Al alloy. It can also be recorded that, the distributions of reinforcements in the respective matrix are fairly uniform. The increasing percentage of Silicon Carbide particulate leads to a finer grain size. These results causes the presence of SiC particles, which acts as sites of nucleation. The photographs of this and similar composites show the absence of voids and a uniform distribution of SiC in the matrix structure. It can also be seen that the deep grooves are formed on the surface of the specimen and patches on surface are observed. The finally these photographs reveals the homogeneity of the cast composites



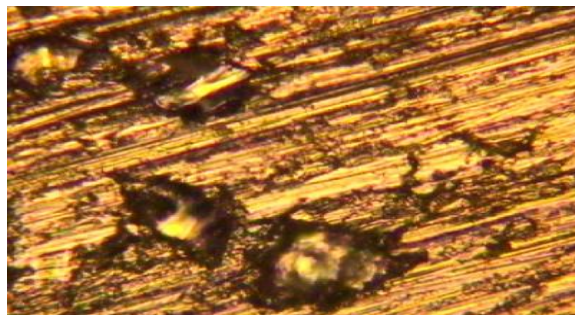
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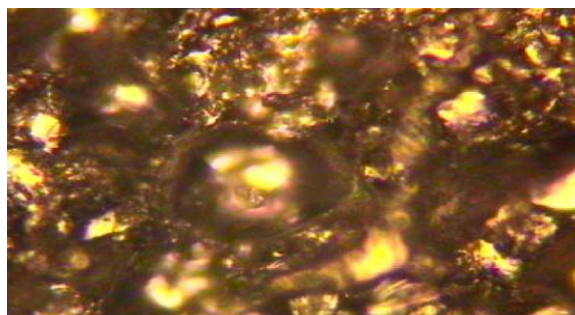
(a)



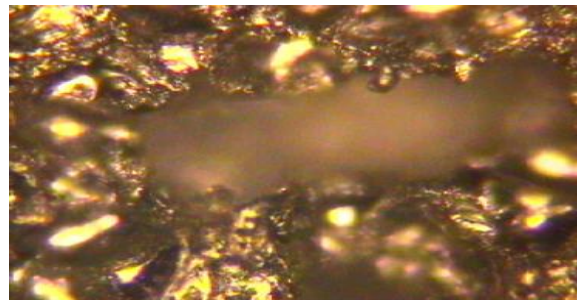
(b)



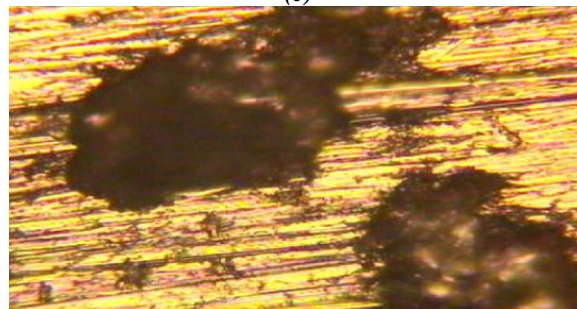
(c)



(d)



(e)



(f)

IV. CONCLUSION

Based on experimental studies and results obtained the following conclusions are drawn.

Mathematical relations between the machining parameters are Pulse On time, Pulse Off time, Current and Bed speed and performance characteristics like Surface Roughness is established by the regression analysis method. It is generally observed that the surface roughness Ra values increases with an increase in various percentages of volume fractions of Silicon carbide particles in the Metal Matrix Composites.

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