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Effect Of Process Parameters On The Machining Characteristics Of Stir Casted Work Piece Aluminum 6061 With Sic Using Sinker Edm

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ABSTRACT

The electrical discharge machining (EDM) is a one of an electrical energy based unconventional machining technique. The EDM is used in mould and die making industries, automobile industries and also making of Aerospace components. The present work is to investigate surface modification and the effects of the various EDM process parameters on the machining quality and obtain the optimal process parameters. The optimization is done by using Taguchi technique considering L9 orthogonal array and experiments are conducted on the pieces varying input parameters like pulse on time pulse off time peak current with constant time. The work piece and electrode materials used for machining are Stir casted aluminum 6061 with SiC (6.5%) and copper (12 mm diameter rod). The process parameters are pulse on time 75 μ sec, 150 μ sec, 225 μ sec, Pulse off time 40 μ sec, 80 μ sec, 120 μ sec and peak current 5 amps, 10 amps, 15 amps with constant time 5 minutes, flushing pressure and spark gap (0.2 mm). Find out the MRR, TWR, surface roughness, hardness of work piece before and after stir casting process and scanning electron microscopy (SEM) analysis was performed to investigate the surface topography of the EDM job.

KEYWORDS

EDM, Stir Casting, Al 6061, MRR, TRR, Microstructure Evaluation, Surface Roughness.

INTRODUCTION

Sinking-electrical discharge machining (EDM) is a non-traditional machining technique used to cut metal workpieces by utilising thermal energy obtained from electric sparks in the narrow gap between the electrode and workpiece [1]. This machining is considered one of the most competitive non-conventional machining processes and widely used in modern industries (aerospace, automotive, mould, microelectronics, and biomedical industry) due to its unique features, such as the ability to process any electrically conductive material, independent of its strength and hardness, as well as the ability to achieve complex geometry with high dimensional accuracy [2,3]. The cutting process involves erosion caused by a high frequency electric spark that occurs on a regular basis in the narrow gap between the workpiece and the electrode in the dielectric fluid [4]. This spark represents discharge energy that has been converted to high temperature and absorbed by the workpiece material, resulting in melting and evaporation [5]. During the pulse-off time, a portion of the melted and evaporated material particle located at the workpiece-electrode gap is flushed and removed away by dielectric fluid [6].

There are numerous studies on the use of EDM for metal and alloy cutting, but soft metals such as aluminium (Al) are rarely found in the literature [7]. Because of its lower strength when compared to common ferrous metals, it is sufficiently processed by conventional machining; however, in the modern automotive and aerospace industries, this conductive and lightweight material is extensively used for complex and precision parts, in the form of monolithic or composite, and thus EDM is suitable to meet the geometrical requirements [8,9]. Khan compared the machinability of mild steel and Al on EDM using brass and copper (Cu) electrodes [10]. EDM is frequently included in the "non-traditional" or "non-conventional" group of machining methods, alongside processes such as electrochemical machining (ECM), water jet cutting (WJ, AWJ), laser cutting, and in contrast to the conventional group, which includes (turning, milling, grinding, and any other process whose material mechanism is essentially based on mechanical forces) [11,12]. EDM is best viewed as a series of breakdown and restoration of the liquid dielectric in-between the electrodes.

However, such a statement should be approached with caution because it is an idealised model of the process introduced to describe the fundamental ideas underlying the process. However, any practical application involves numerous factors that must be considered [13,14]. For example, the removal of debris from the inter-electrode volume is almost always partial. As a result, the electrical properties of the dielectric in the inter-electrode volume can deviate from their nominal values and even change over time [15]. The inter-electrode distance, also known as the spark-gap, is determined by the control algorithms of the specific machine used [16]. Controlling such a distance appears to be central to this process. Furthermore, not all of the current flowing between the dielectrics is of the ideal type described above: debris can short-circuit the spark-gap [17]. The electrode's control system may fail to react quickly enough to prevent the two electrodes (tool and work piece) from coming into contact, resulting in a short circuit [18]. This is undesirable because a short circuit contributes to material removal in a different manner than in the ideal case [19].

The flushing action may be insufficient to restore the insulating properties of the dielectric, causing the current to always occur at the point of the inter-electrode volume (this is known as arcing), resulting in an unwanted change in shape (damage) of the tool-electrode and work piece. Finally, to obtain a specific geometry, the EDM tool is guided along the desired path very close to the work; ideally, it should not touch the work piece, although this may occur due to the performance of the specific motion control in use [20,21]. As a result, a large number of current discharges (also known as sparks) occur, each contributing to the removal of material from both the tool and the work piece, where small craters form [22]. The size of the craters is determined by the technological parameters set for the job at hand. They can have dimensions that range from the nano scale (in micro-EDM operations) to hundreds of micrometres in roughing conditions [23].

The commercial CuCr electrode wear rate was investigated in this study for cutting Cu-electroplated Al alloy material using Sinking EDM under discharge current and pulse-on time variation. The results were then compared to the results of untreated Al alloy EDM. SEM analysis was performed on selected samples to examine the electrode surface after the EDM process.

MATERIAL AND METHODS

Al 6061 Aluminium Alloy

The various types of aluminium alloys are commercially available, each with its own distinct advantage and applications. This paper focuses on Al 6061 aluminium alloys, which are heat treatable, can be significantly strengthened, and are used for a variety of applications requiring strength, weldability, and corrosion resistance [19,20]. The Al 6061 chemical composition and material composition of stair casted with SiC as shown in Table 1 and Table 2.

Table 1. Material composition of Aluminum 6061 (without SiC)

Elements	Al	Si	Mg	Fe	Cu	Ti	Mn	Cr
Amount (wt %)	98.9752	0.2990	0.4174	0.1301	0.0488	0.0100	0.0049	0.0038

Table 2. Material composition of Stir casted Al6061 with SiC(6.5%)

Elements	Al	Si	Mg	Fe	Cu	Ti	Mn	Cr
Amount (wt %)	98.7712	0.5162	0.4196	0.1381	0.0445	0.0103	0.0047	0.0043

Stir Casting Process

It is a liquid phase technique used to make composite materials in which an isolated phase (ceramic particles, short fibres) is mixed with a molten matrix metal using mechanical stirring. Stir casting is the simplest method and also the most cost-effective method of producing liquid phase as shown in the Figure 1. The liquid composite material is then cast using standard casting procedures and can also be handled using standard metal forming machines. The casting process is stirred as shown in the Figure 2. The aluminum 6061 with SiC Work pieces and after machining of stir casted Aluminum 6061with SiC as shown in the Figure 3.

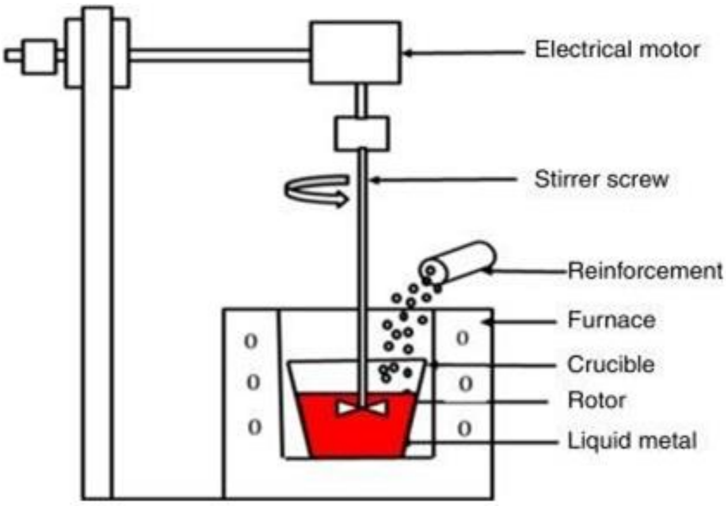

Figure 1. Schematic diagram of stir casting.

Figure 2. Furnace and Cast Iron Die, liquid aluminum metal matrix pouring in to cast iron die.

Figure 3. Aluminum 6061 with SiC Work pieces and after machining of stir casted Aluminum 6061with SiC

Experimental Procedure

The machine process difficult to machine materials and contours, EDM uses high-frequency sparks as shown in the Figure 4. The tool and work piece form a pair of electrodes separated by approximately 20 to 200 m in a liquid dielectric medium through which spark discharges occur. EDM comes in two varieties. The tool in one is rigid and preformed to the desired contour of the machined surface. This is known as sinking type EDM (SEDM). Modern advanced SEDM systems do not require a fully pre-shaped electrode and instead use a CNC programmed electrode that operates similarly to the die sinking process. The other method uses a flexible wire with a diameter of less than 0.25 mm as the electrode, which continuously passes through the machining zone of the work piece. Another distinction between these two processes is the dielectric fluid, which in SEDM is kerosene and in WEDM is deionized water.

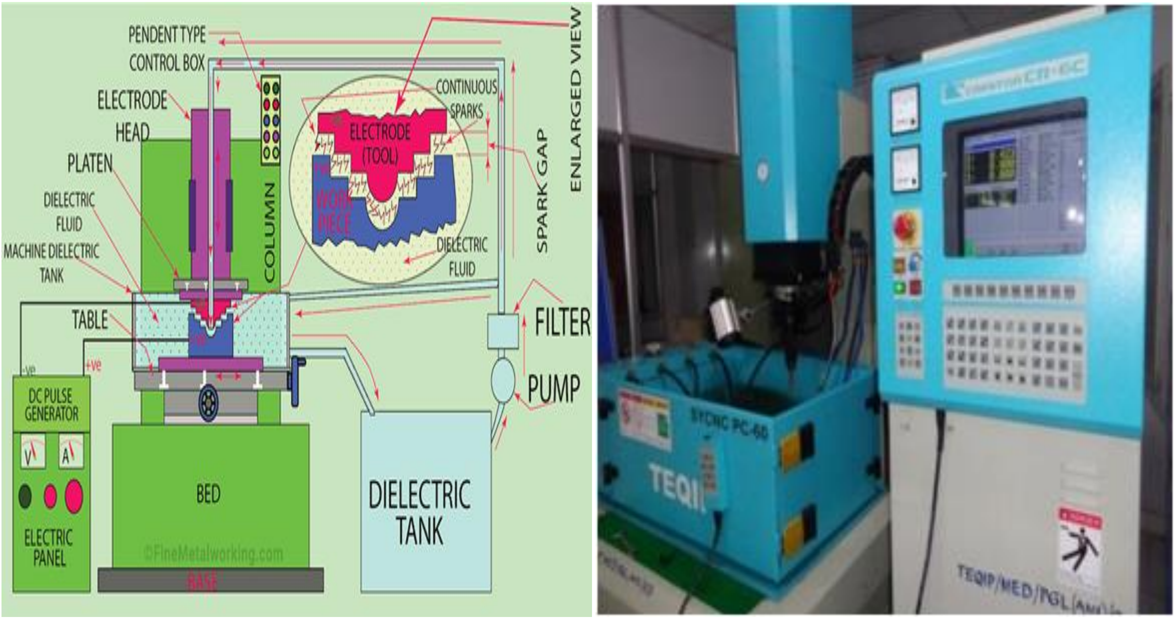

Figure 4. Die sinker EDM working diagram and CNC EDM CREATOR CR-6C die sink EDM Machine.

A series of experiments were carried out to investigate the effects of various machining parameters on the Sinker EDM process. The purpose of these studies was to look into the effects of current, pulse on time, and pulse off time on the MRR, TWR, Surface Roughness, and morphology of an EDM surface. The copper tool is used to machine the stir casted Al 6061 alloy with SiC (20 mm×20 mm×5 mm). The dielectric medium is ED30. The displays the input parameters used as shown in the Table 3. After used minitab and generated 3 levels & 3 factors of Taguchi OA L9 (3^3) as shown in the Table 4 and Table 5.

Table 3. Input parameters.

Process Parameters	Level1	Level2	Level3
Current (Amps)	5	10	15
Pulse On time (μ sec)	75	150	225
Pulse Off time (μ sec)	40	80	120

Table 4. Taguchi orthogonal array L9 (3^3).

Expt. No.	A Current (A)	B Ton (μ sec)	C Toff (μ sec)
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

Table 5. Taguthi orthogonal array L9 input Parameters.

Expt. No.	A Current (A)	B Ton(μ sec)	C Toff (μ sec)
1	5	75	40
2	5	150	80
3	5	225	120
4	10	75	80
5	10	150	120
6	10	225	40
7	15	75	120
8	15	150	40
9	15	225	80

RESULTS AND DISCUSSION

Experimentation is used to evaluate the machining characteristics of a process. The overall goals are to investigate the mechanism of the basic process as well as the effect of process parameters on the major machining characteristics and optimize.

Material removal rate and tool wear rate

In EDM, erosion is caused by melting from spark energy, which results in two opposing effects. Lower melting enthalpy leads to faster erosion, whereas higher thermal conductivity reduces heat concentration. Whichever of these effects is greater, the erosion rate is affected. Higher current and pulse on times result in faster erosion rates for Al6061 with SiC. Higher erosion rates are also a result of increasing pulse energy. However, the effect of current is greater than the effect of pulse times. The reason for this is a decrease in energy concentration caused by the expansion of the plasma channel with longer pulse times. The reason for this is a decrease in energy concentration caused by the expansion of the plasma channel with longer pulse times. Longer spark gaps cause plasma channel expansion due to mutual repulsion of similar charge carriers. It's not surprising that pulse off time has an effect. Lowering the pulse off time improves the utilisation of spark energy while increasing erosion rates. The polarity setting has the greatest impact of all the variables. Higher machining rates are achieved when the electrode is positive (anode). Despite the fact that the charge carriers have the same energy and release at the same electrodes, their density levels are very different. Sparks are ionic discharges in which electrons are absorbed at the anode and ions are absorbed at the cathode via the plasma channel. Because electrons and ions have similar charge carriers, there is mutual repulsion, which is very strong for electrons due to their negligible mass. As a result of the very low expansion of ions of higher mass, the energy concentration at the cathode (work electrode) is very high. Naturally, this leads to extremely high cathode erosion rates, so electrode positive and work piece negative polarity is preferred. TWR increases as peak current and polarity increase. The corrosive effect of an electrical spark can be seen at both the cathode and the anode. As a result, tool wear is unavoidable and must be minimised. In Minitab 17, the first Taguchi Orthogonal Array is created to calculate the S/N ratio of MRR and TWR as shown in the Table 6. The greater the material removal rate (MRR), the lower the tool wear rate (TWR).

The time spent machining and the weights of the work piece are measured to calculate material removal rates, as shown in the Table 7 and Table 8.

The Initial weight of the piece before cutting = $\rho * V$ (1)

Where, ρ = density in g/mm^3, V = Volume in mm^3.

Material removal rate (MRR) = $(W_b - W_a) / t * \rho$ (2)

Where, W_b = Weight of work piece before machining (gms)W_a = Weight of work piece after machining (gms), t = Machining Time (Secs), ρ =Density of work piece (g/mm^3) = 0.00275g/mm^3 MRR = 4.9529-4.8649/0.00275*300, MRR = 0.10667 mm^3/sec.

Tool Wear Rate for the copper tool used for machining = $(W_b - W_a) / t * \rho$ (3)

Where, W_b = Weight of Tool before machining (gms)W_a = Weight of Tool after machining (gms), t = Machining Time (Sec) =5minutes =300 seconds ρ =Density of Tool (g/mm^3) = 0.00896g/mm^3 TWR = 120.7128-120.7118/0.00896*300, TWR = 0.000037 mm^3/s.

Table 6. Results of MRR, TWR and its corresponding S/N Ratio of EDM of stir casted workpiece Al6061 with SiC

Job No.	Pulse on time (µ sec)	Pulse off time (µ sec)	Current (Amps)	MRR (mm^3/sec)	TWR (mm^3/sec)	S/N Ratio of MRR	S/N Ratio of TWR
1	75	40	5	0.10667	0.000037	-19.4392	88.6360
2	150	80	5	0.07321	0.000110	-22.7086	79.1721
3	225	120	5	0.05091	0.000110	-25.8639	79.1721
4	75	80	10	0.51600	0.001500	-5.7470	56.4782
5	150	120	10	0.45916	0.000330	-6.7607	69.6297
6	225	40	10	0.66970	0.000930	-3.4824	60.6303
7	75	120	15	0.78230	0.005600	-2.1325	45.0362
8	150	40	15	1.12450	0.003400	1.0192	49.3704
9	225	80	15	1.24400	0.004600	1.8964	46.7448

Table 7. Response table for S/N Ratio of MRR of stir casted work piece Al6061 with SiC

Level	Pulse on time(µ sec)	Pulse off time(µ sec)	current(Amps)
1	-22.6706	-9.1062	-7.3008
2	-5.3300	-9.4834	-8.8531
3	0.2610	-9.1500	-11.5857
Delta	22.9316	0.3771	4.2849
Rank	1	3	2

Table 8. Response table for S/N Ratio of TWR of stir casted work piece Al6061 with SiC

Level	Pulse on time (µ sec)	Pulse off time (µ sec)	Current (Amps)
1	82.33	63.38	66.21
2	62.25	66.06	60.80
3	47.05	62.18	64.61
Delta	35.28	3.87	5.41
Rank	1	3	2

The rate of material removal Taguchi method emphasises the importance of studying response variation using the signal-to-noise (S/N) ratio, which results in less variation in quality characteristics due to uncontrollable parameters. The MRR is regarded as a quality characteristic, with the notion that "the larger, the better." The analysis and debate a higher S/N value corresponds to better performance regardless of the category of the performance characteristics. As a result, the optimal level of machining parameters is the one with the highest value. Figure 4 depicts the effect of parameter current on MRR. So the optimal current rate is 15 amps, the optimal pulse on time is 75 µseconds, and the optimal pulse off time is 40 µseconds as show in Figure 5.

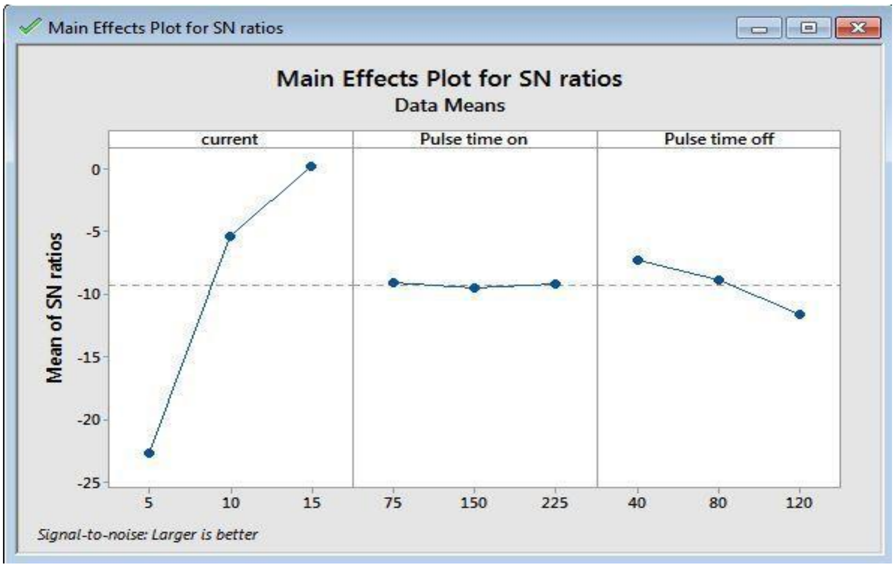

Figure 5. Effect of machining parameters on MRR for S/N ratio for Larger is better.

The Tool wear rate Taguchi method emphasises the importance of studying response variation using the signal-to-noise (S/N) ratio, resulting in the minimization of quality characteristic variation due to uncontrollable parameters. The TWR is regarded as a quality characteristic with the concept of "the smaller, the better." According to the analysis and discussion, regardless of the category of the performance characteristics, a higher S/N value corresponds to better performance. As a result, the optimal level of the machining parameters is the one with the highest value. So the optimal current rate is 5Amps, the optimal pulse on time is 150 µseconds, and the optimal pulse off time is 40 µseconds as shown in Figure 6.

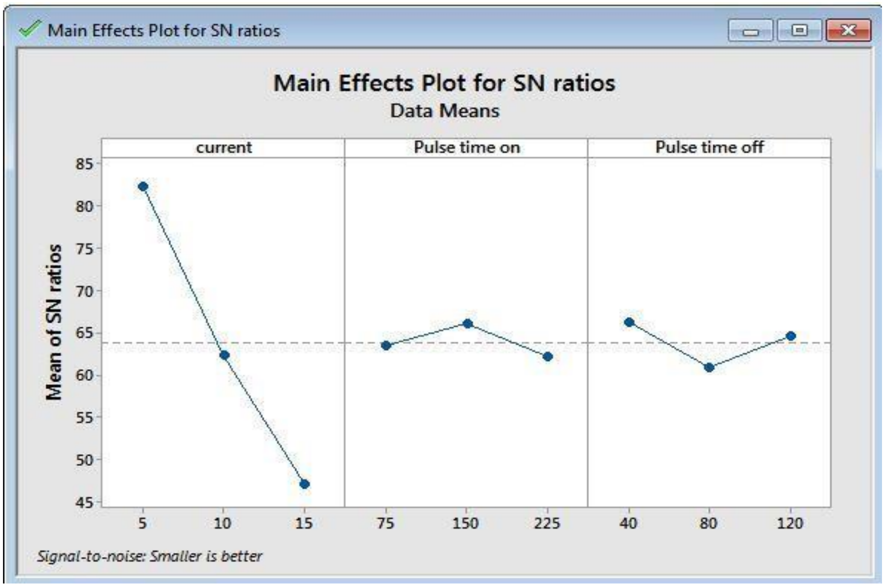

Figure 6. Effect of machining parameters on TWR for S/N ratio for smaller is better

Surface Roughness

The Taguchi method is used in this project to optimise the process parameters pulse on time, pulse off time, and current for lower surface roughness. Minitab 17 software is used for optimization as shown in Table 9, Table 10 and Table 11.

Table 9. Calculated SR values for experimental data

EXPT. NO	SR 1(µ m)	SR 2(µ m)	SR 3(µ m)	Average SR(µ m)
1	4.11	3.87	4.13	4.0367
2	3.77	4.87	4.08	4.2400
3	4.01	4.34	3.98	4.1100
4	9.15	8.69	7.69	8.5100
5	7.96	8.75	7.82	8.1767
6	9.86	8.53	8.63	9.0067
7	7.49	8.01	9.23	8.2433
8	11.70	10.17	11.66	11.1767
9	12.10	11.04	11.72	11.6200

Table 10. Results of Surface Roughness and S/N Ratios for Smaller is better

Expt. No.	Current (Amps)	Pulse on time (µ sec)	Pulse off time (µ sec)	Surface Roughness (R_a) µ m	S/N Ratio
1	5	75	40	4.0367	-12.1242
2	5	150	80	4.2400	-12.5988
3	5	225	120	4.1100	-12.2837
4	10	75	80	8.5100	-18.6208
5	10	150	120	8.1767	-18.2624
6	10	225	40	9.0067	-19.1108
7	15	75	120	8.2433	-18.3559
8	15	150	40	11.1767	-20.9838
9	15	225	80	11.6200	-21.3103

Table 11. Response table for S/N Ratio of Surface Roughness of stir casted work piece Al6061with SiC

Level	Pulse on time(µ sec)	Pulse off time(µ sec)	current(Amps)
1	-12.34	-16.37	-17.41
2	-18.66	-17.28	-17.51
3	-20.22	-17.57	-16.30
Delta	7.88	1.20	1.21
Rank	1	3	2

The Taguchi method emphasises the importance of studying response variation using the signal-to-noise (S/N) ratio, which results in less variation in quality characteristics due to uncontrollable parameters. Surface Roughness is regarded as a quality characteristic, with the notion that "the smaller, the better." According to the analysis and discussion, a higher S/N value corresponds to better performance regardless of the category of the performance characteristics. As a result, the optimal level of machining parameters is the one with the highest value. So the optimal current rate is 5 amps, the optimal pulse on time is 75µ seconds, and the optimal pulse off time is 120 µseconds as shown in the Figure 7.

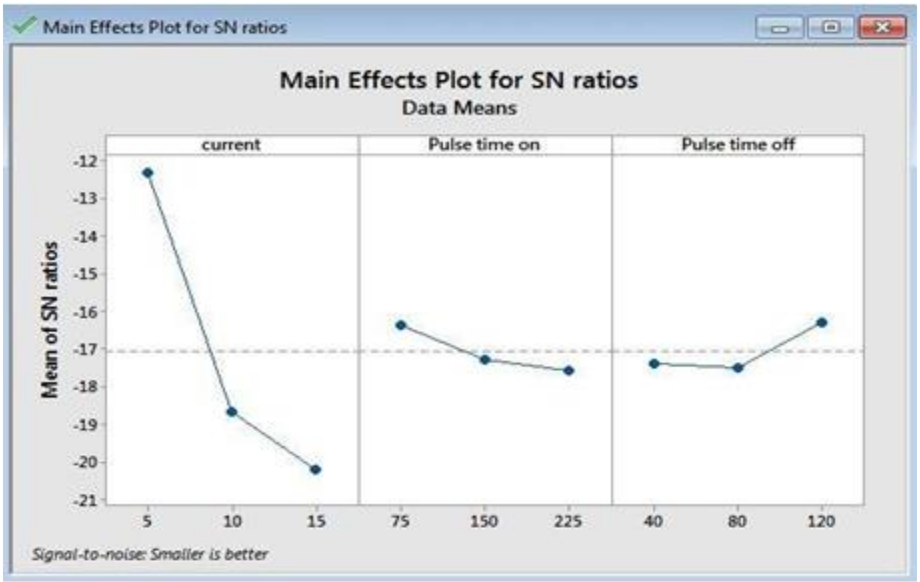

Figure 7. Effect of machining parameters on SR for S/N ratio for Smaller is better.

Morphology of spark eroded surfaces

SEM was used to examine the overall morphology and distinguishing features of the spark-eroded surfaces. Surface integrity research focuses on the induced effects of spark erosion on the resulting surfaces. The typical depictions of spark craters on work surfaces for their relative characteristics. Cracks form in the solidified layer and, when melted, can promote mechanical separation. Evaporation as a mode of spark erosion is unrealistic due to metal thermal conduction and dielectric quenching. The suspended debris in the spark gap, on the other hand, is subjected to the extremely high temperatures of the spark channel, which can cause evaporation and coalescence. This could also explain the relatively large size of erosion debris. These findings can be validated by using scanning electron microscopy (SEM) techniques to examine the appearance of machined surfaces. The surface texture observed by SEM as the current intensity increases. The SEM images from nine experiments are shown in Figure 8 and the effect of input parameters on the eroded surface can be seen.

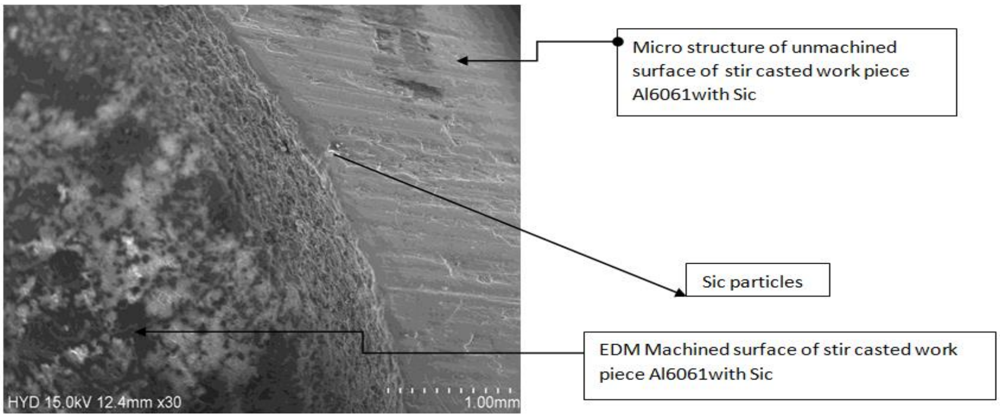

Figure 8. The morphology of stir casted work piece Al6061 with SiC after EDM process(15 A, Ton 75 µ sec, T off 120µ sec) coated surface and uncoated surface at X30

The morphology of stir casted Al6061 with SiC without EDM process reveals silicon carbide flakes, whereas after EDM process grain structure changes and craters form due to the spark between the work piece and tool as shown in the Figure 9 and Figure 10.

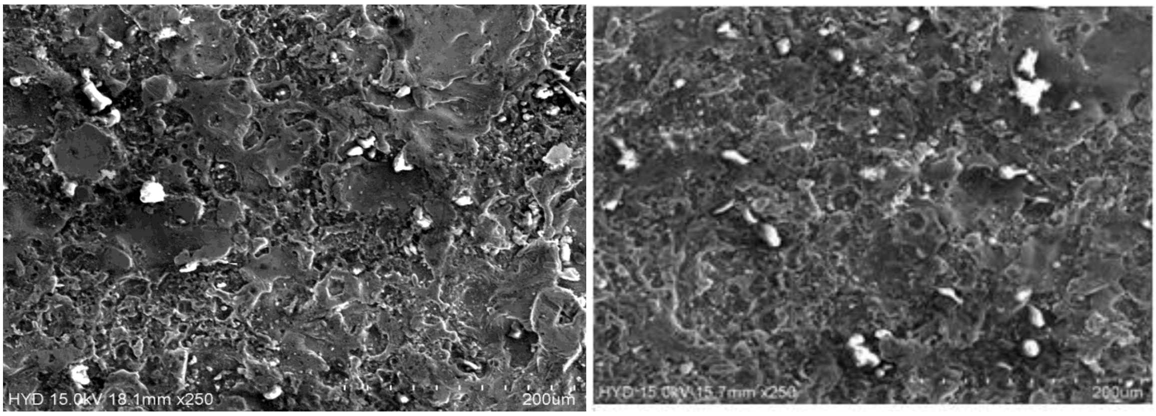

Figure 9. The morphology of Al6061with SiC after EDM process (5A, T_{on} 75µ sec, T_{off} 40 µsec) surface at X250 and The morphology of Al 6061with SiC after EDM process (5A, T_{on} 150µ sec, T_{off} 80 µsec) surface at X250.

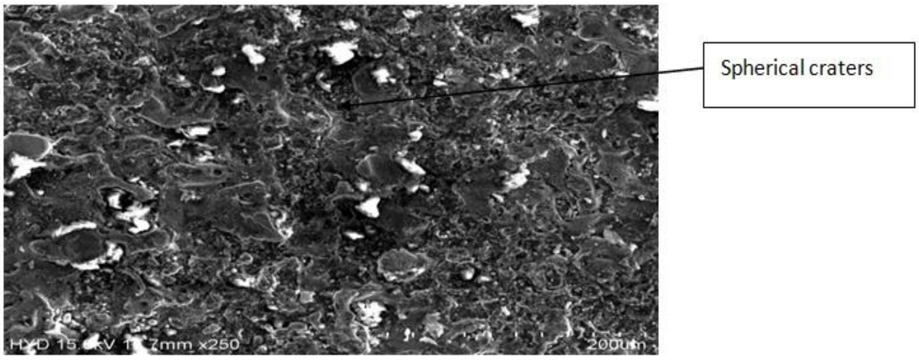

Figure 10. The morphology of Al6061with SiC after EDM process (5A, T_{on} 225µ sec, T_{off} 120µsec) surface at X250

The low pulse on time spark energies are concentrated with small dimensions of plasma for removal of metal from spark craters as shown in Figure 11, which is also facilitated by heat transfer and quenching by dielectric fluid in the Figure 12. The surface craters are less and shallower at lower pulse current and pulse on time, and thus the work piece surface finish is better as shown in Figure 13 and Figure 14.

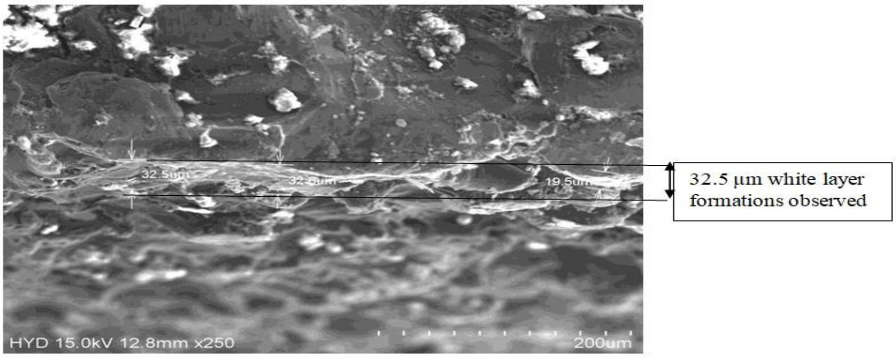

Figure 11. The morphology of Al6061with SiC after EDM process (10 A, T_{on} 75µ sec, T_{off} 80µ sec) White layer (32.4 µm) at X250.

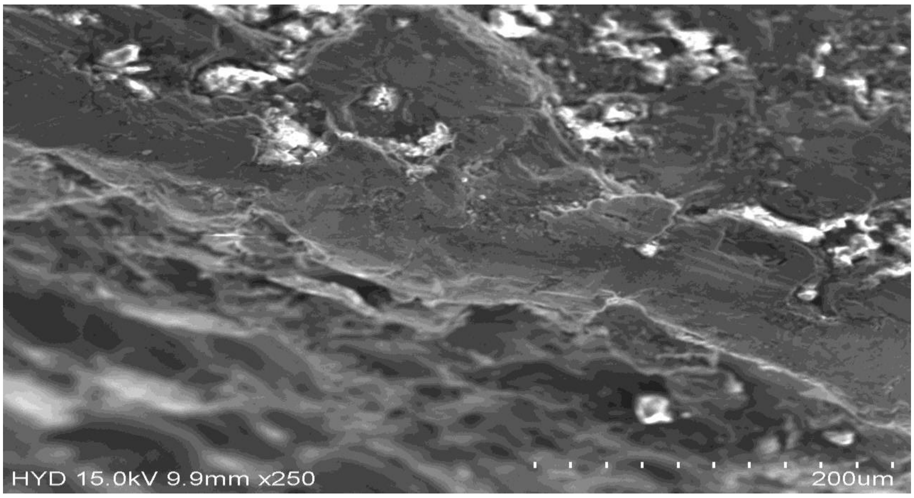

Figure 12. The morphology of Al6061with SiC after EDM process (10 A, T on 150μ sec, T off 120μsec) thickness at X25

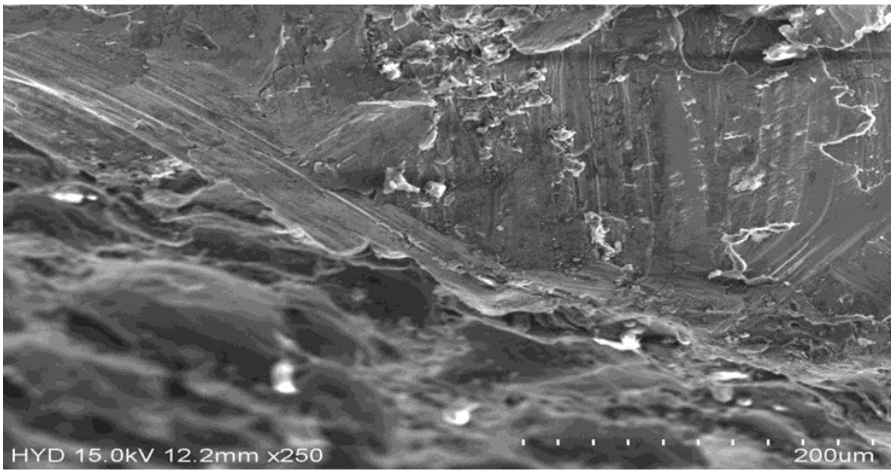

Figure 13. The morphology of Al6061with SiC after EDM process. (10 A, T on 225μ sec, T off 40μsec) thickness at X250.

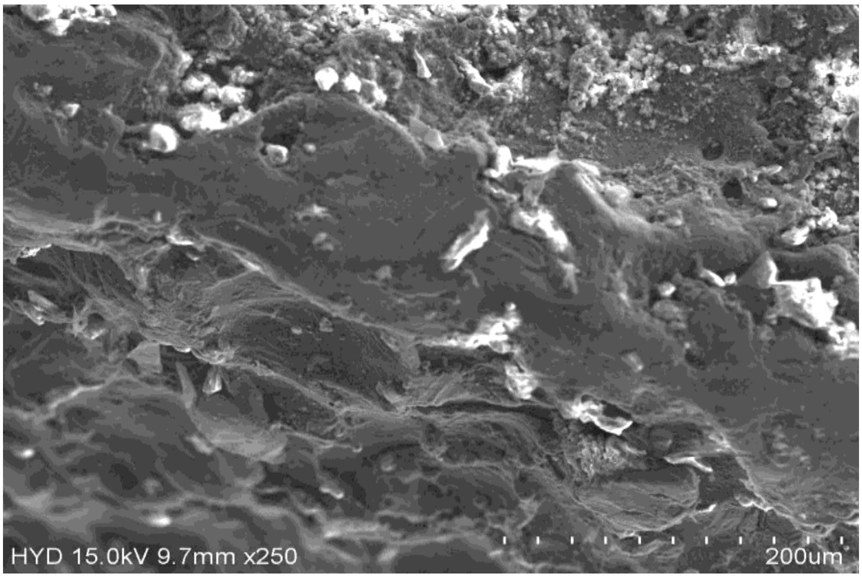

Figure 14. The morphology of Al6061with SiC after EDM process.(15 A, T on 225 μ sec, T off 80μ sec) thickness at X250.

The high-intensity machining produces more craters, which increases surface roughness. A large amount of energy discharged causes violent sparks and impulsive forces, resulting in a deeper and larger erosion crater on the surface. High energy intensity machining causes machined surfaces to crater more than lower intensity machining.

CONCLUSION

In this study, a newly developed stir casted work piece Al 6061 with SiC outperformed a traditional metal alloy Al 6061 in terms of mechanical properties. Experimental investigation of electric discharge machining in relation to a newly developed stir casted work piece Al 6061 SiC, which is manufactured using the stir casting process.

- It was discovered that adding SiC particles to a composite material resulted in superior mechanical properties. When compared to the base Al 6061 hardness value, the hardness of stir casted work piece Al6061 SiC 29% increased rapidly.
- The material removal rate of a new aluminium metal matrix composite increases as the current and pulse on time increase, while it decreases as the current decreases. With increasing current, the surface roughness decreases. When the current increases, the pulse on time increases, and so does the MRR.
- When the current increases, the TWR decreases. This means that when the current is low, melting begins earlier because the heat generated is greater. The tool wear decreases as the pulse-on-time increases from 75 s to 225 s.
- Higher pulse off time can lead to higher MRR in some cases due to effective deionization and gap flushing. The Taguchi method leads us to the conclusion that the optimum condition for MRR is A3B1C1, the optimum condition for TWR is A1B2C1, and the optimum condition for SR is $A_1B_1C_3$.

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