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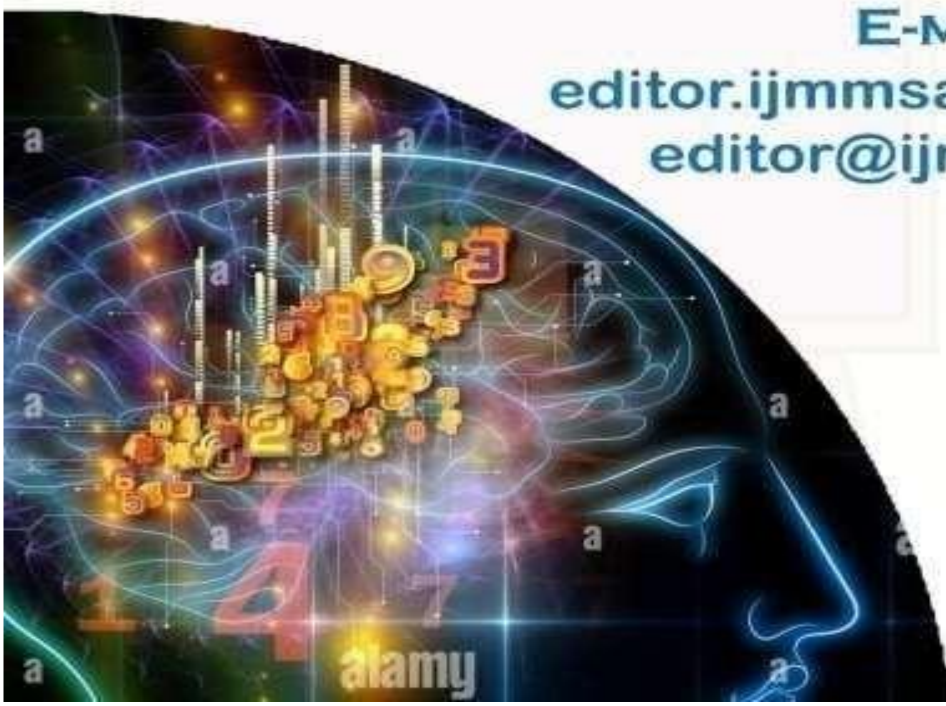

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A Comparative Study on Surface Roughness and Recast Layer Behavior of Al-7075/Al_2O_3 MMCs Under Controlled EDM Cooling Conditions

Lade Jayahari[1], A. Seshappa[2], Prassana P[3]

Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad 500072, India

Department of Mechanical Engineering, Siddartha Institute of Technology and Science Puttur, A.P 517583, India

Department of Mechanical Engineering, JNTUH, Hyderabad, 500072, India.

ABSTRACT

Metal matrix composites (MMCs) have been the subject of much research because of the growing need for lightweight, strong components in the automotive and aerospace industries. The inconsistent hardness, matrix of composites, and undesirable tool life of MMCs make traditional machining procedures challenging. As a non-contact technique, Electric Discharge Machining (EDM) can manufacture very hard materials and complex shapes and improve surface polish and tool life. This advantage makes it an alternative to traditional machining methods for MMCs. As the leftover molten material on the machined surface re-solidifies during the EDM process, it leaves behind recast layers that are very dense and brittle, as well as the generated heat from the process and the flushing of machined debris. Using the Taguchi techniques, this work optimizes process parameters during EDM machining to minimize surface roughness of the quickly resolidified layer of Al 7075/Al_2O_3 composite MMC. Among the process parameters taken into account were the pulse on-time, pulse off-time, and gap current. Using surface roughness as a response variable both within and outside the hole, researchers examine the creation of resolidified layers during EDM drilling.

Keywords: *MMCs, EDM, Recast layer, Taguchi Technique.*

1. Introduction

While electrical discharge machining (EDM) typically involves the melting and vaporization of the workpiece material to remove material, the presence of a dielectric flushing foil causes the material to rapidly cool near the machined surface, which causes it to resolidify as layers on the surface. The recast layer's thickness changes depending on machining factors such as pulse on-time and peak current [1-3]. When the peak current, pulse on-time, and dielectric flushing effect are all increased, the recast layer thickness also rises [1]. As the pulse energy, discharge current, and pulse-on time are increased, the average recast layer thicknesses also rise. Using a hydrocarbon-based dielectric fluid causes microcracks on the recast layers [2]. The majority of fractures either ended inside the recast layer or at its interface, and changes in pulse on-time durations had a greater impact on variations in recast layer thickness than changes in peak current [3]. According to [4], the layer thickness was found to be around 10 μm when parameters such as a pulse current of 8 amps and a pulse on-time of 8 microseconds were used. While EDM machining a 2124 Al alloy matrix reinforced with SiC in volume fractions of 15% and 25%, a brass electrode demonstrates a superior material removal rate compared to a copper electrode. At lower cutting speeds, EDM is a practical procedure that softens surfaces; but, at higher speeds, it causes micro damage to both the surface and subsurface regions [5]. Using EDM statistical models, researchers looked at how different process factors affected the rate of metal removal, the thickness of the recast layer, and the surface finish; they found that pulse current was the most important component in determining the surface finish [6]. Researchers found that under certain circumstances, the EDM method could be used to machine Al/SiC MMCs, despite its slowness, and that the resulting crater-like surface grew in size as the discharge energy rose [7]. Raising the flushing pressure improves the Material Removal Rate (MRR), which in turn improves the Tool Wear Rate (TWR) and the surface finish [8]. Milling 6061 Al-MMC reinforced with 10% SiC results in taper, radial overcut, and poor surface quality but increases MRR and TWR with increasing pulse current and pulse on-time levels [9]. Pulse on-time increases machining instability owing to greater rates of melting and solidification and leads to poor surface finish in the tungsten carbide-cobalt (WC-Co) composite material, which has very high hardness and great resilience to shock wear [10]. Rough EDM machining causes thermal spells and poor surface integrity, and increasing the discharge current and pulse on-times increases surface roughness and recast layer thickness, according to research into the machining characteristics, surface integrity, and material removal mechanisms of an advanced ceramic composite (Al_2O_3-SiC-TiC) using an EDM process [11]. Additional research on the surface integrity of materials treated by EDM is necessary.

The current research utilizes the electrical discharge machining (EDM) procedure to process holes in Al 7075/Al_2O_3 MMC workpieces. The experiment was designed using Taguchi techniques that incorporated gap current. The control variables were pulse on-time and pulse off-time, and the response was surface roughness. We look at the recast layer's surface roughness both within and outside the hole. An analysis of variance (ANOVA) was performed to examine the surface roughness both inside and outside the hole. Variables in the process have been optimized.

2. Materials Selection

One of the ineffective steps in conducting any kind of study that takes into account current trends and their potential final uses is material selection. For this study, we just investigated Al-7075/Al_2O_3 MMCs with a hardness of 120.9 HV at a load of 100 g since they are used exclusively in automotive components. In Table 1 you can see what makes up Al-7075/Al_2O. For this study, we employed 6 mm electrolytic copper electrodes and spark fusion oil with a 450 rating as the dielectric fluid for the EDM procedure.

Table1. Composition of Al-7075

Content	Mn	Si	Cr	Mg	Ti	Zn	Cu	Fe	Al
Wt.%	2.9	0.5	0.28	3.1	0.2	5.6	2.1	5	Bal

3. Experimentation

In this study, the Al-7075/Al_2O_3 metal matrix composite is machined using an EDM machine (a small kind, Model No. EMS-5030). At first, the die-cast Al 7075 is placed on the machine table after being cut to dimensions of 50 mm x 20 mm x 5 mm. Auto positioning involves setting the electrode and workpiece in a specified location relative to each other, while the electrolytic copper electrode is fixed to the Z-axis. The 2 mm depth of cut is now permanent. To ensure that the tests were adequate, they were performed twice and carried out according to Taguchi's standard orthogonal array L-9. Table 2 shows the process parameters and their values for machining Al-7075/Al_2O_3 metal matrix composites. This helps to establish the ideal combination of these parameters, such as pulse current, pulse on-time, and pulse off-time, that minimises the surface roughness of the recast layer. Table 3 displays the results of the surface roughness measurements taken using a perthometer within and outside the holes on the EDM-machined surface.

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Table 2. Experimental parameters and their levels

Level	Gap current (I)	Pulse-On time (T_{on})	Pulse-Off time (T_{off})
	Amp	µs	µs
1	5	10	3
2	15	15	6
3	25	20	9

The experimental setup was operated under a supply voltage of 420 V, three-phase, 50 Hz, ensuring stable power delivery to the EDM system. The open gap voltage was maintained at 140 V with a tolerance of ±5%, providing consistent discharge energy during machining. An electrolytic copper electrode of cylindrical shape and 6 mm diameter was used as the tool material due to its excellent electrical and thermal conductivity. The dielectric medium employed was spark fusion oil (Rated 450), which offers superior insulation and cooling characteristics during the discharge process. The dielectric pressure was set at 250 N/m² to ensure efficient flushing of debris from the machining zone. The machining operation was performed to achieve a depth of cut of 2 mm, maintaining a spark gap width of 0.05 mm between the tool and the workpiece to ensure precise and stable spark generation throughout the process.

Table 3. Experimental Results for Recast Surface Roughness (Ra values) for both Inside and Outside Hol

Ex. No	Gap Current(A)	Pulse ON time(µs)	Pulse OFF time(µs)	Inside Hole Ra (µm)
1	5	10	3	2.61
2	5	15	6	1.53
3	5	20	9	2.23
4	15	10	6	2.18
5	15	15	3	2.24
6	15	20	9	2.36
7	25	10	9	2.49
8	25	20	3	2.31
9	25	15	6	2.39

3.1. Analysis of Recast Layer Surface Roughness Inside the Hole

To find out how different process factors affect the surface finish within the hole, an analysis of variance was performed. According to the data presented in Figure 1, the factors are ranked in order of importance as follows: pulse off-time has the maximum impact at 39.47%, followed by gap current at 17.35%, and pulse on-time at 11.78%.

Table 4. ANOVA S/N Ratio (Inside the Holes)

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Sources	SS	DOF	V	P	F-Ratio
Gap Current(A)	17.5981	2	8.8965	17.3512	0.5527
Pulse ON time (µs)	11.9475	2	5.9863	11.7856	0.3754
Pulse OFF time(µs)	40.0125	2	20.0106	39.4738	1.2589
Error	31.8563	2	15.1929	31.9605	
Total	101.3859	8		100	
SS=Sum of squares, DOF=Degree of Freedom, V=Variance, P=Percentage,					

Figure 2 displays the impact of gap current on surface roughness. The first trend indicates that as the gap current rises, the roughness somewhat increases. When the current goes over 15A, the roughness goes down because the high energy in the gap creates a stable environment where all of the composites' alloys can be removed. Figure 3 shows that machining Al-7075/Al_2O_3 metal matrix composites requires a lot of energy, and this observation is further supported by the fact that extending the pulse on-time by only 15 µs somewhat improves the surface quality. Many composite alloys may not melt or evaporate at low energy states, making them difficult to drain out. Because a longer flushing time eliminates dirt and reduces the creation of recast layers, a lower on-time level indicates a superior surface quality. Decreased flushing time results in a high rate of recast layer generation; reduced off-time implies greater on-time and a worse surface finish quality as a result of a high melting rate (Figure 4).

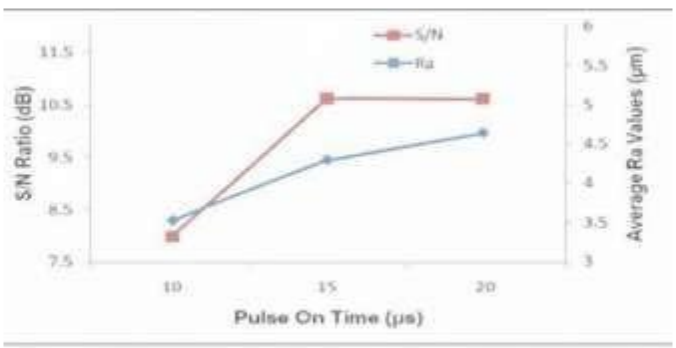

Figure 2. Gap Current Vs Ra and S/N ratio

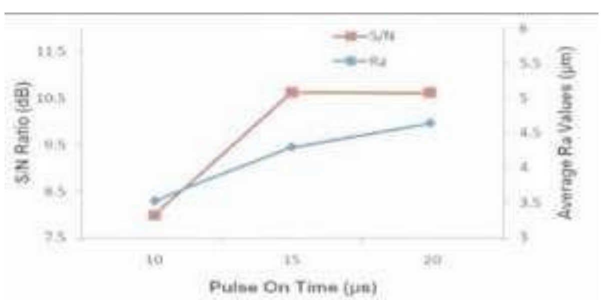

Figure 3. Pulse on-time Vs Ra and S/N ratio

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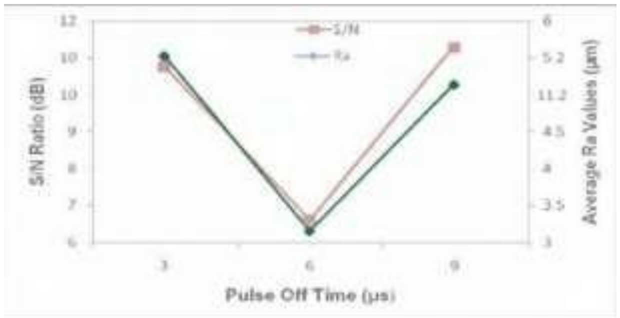

Figure 4. Pulse off-time Vs Ra and S/N ratio

3.2 Analysis of Recast Layer Surface Roughness Near the Hole

Table 5 displays the results of an analysis of variance (ANOVA), an analysis of signal-to-noise ratio (SNR), and the mean influence on surface quality close to the hole. As indicated in Figure 5, the most significant factors influencing surface finish are pulse off-time (35.34%), pulse on-time (16.21%), and gap current (9.19%).

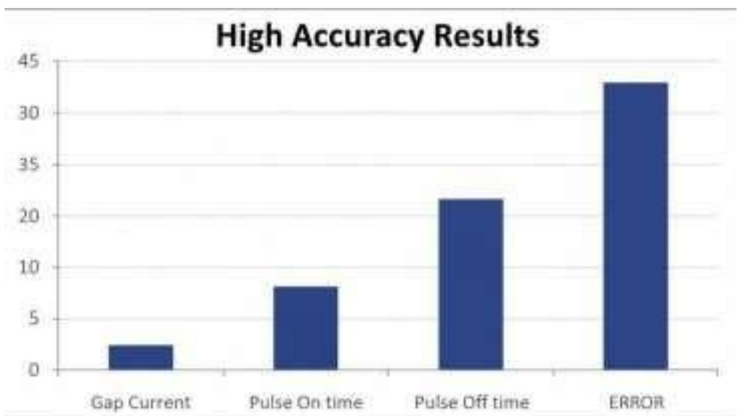

Figure 5. Effect of parameters on the recast layer surface layer roughness near the hole

Figure 6 shows the surface quality drop caused by the casting out of hot debris from the hole and its rapid solidification at the surface as a result of the increased gap current. This decline is due to the analysis of the influence of process parameters near the hole. Surface roughness decreases somewhat as the duration of pulse on-time rises, and surface quality improves with additional increases in pulse on-time (Figure 7). Figure 8 shows that when the pulse off-time goes beyond 6 µs, the near-hole solidifies and the roughness increases.

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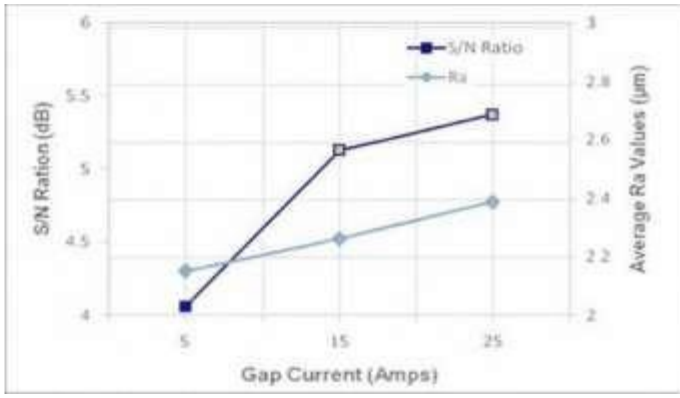

Figure 6. Gap Current Vs R_a and S/N ratio

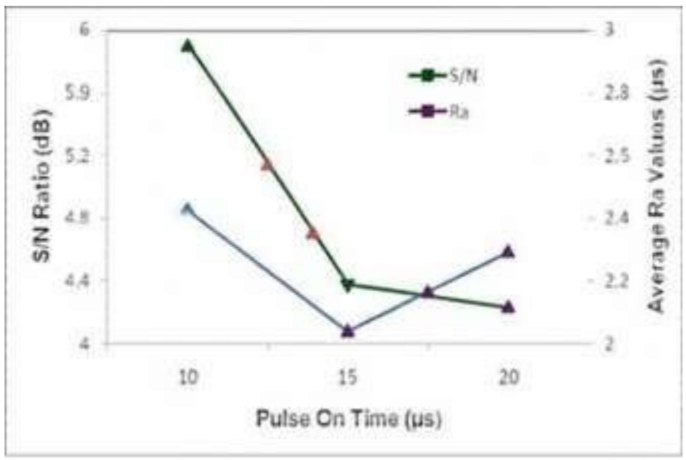

Figure 7. Pulse on-time Vs R_a and S/N ratio

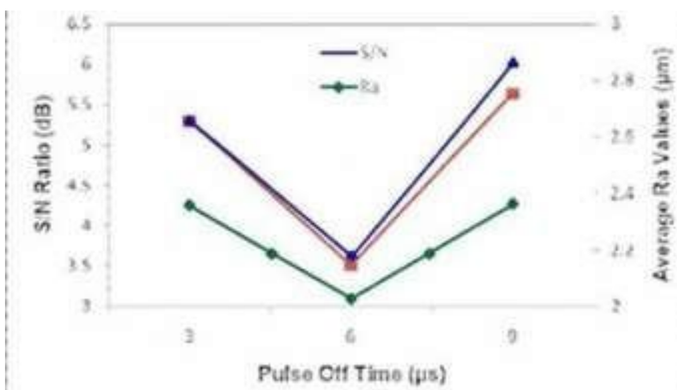

Figure 8. Pulse off-time Vs R_a and S/N ratio

3.3. Confirmation Experiments

At the sweet spot for the process parameters, three confirmation tests were run. Within the confidence range of the projected optimum values of quality features was the mean value of the recast layer's surface roughness within and around the hole, as determined by the optimal configuration of the process parameters. Table 6 displays the optimised processes for both the interior and outside of the hole.

Table 6. Optimum value of Process Parameters for both Inside and Near the Hole

Process Variables	In side Hole	Near to the Hole
Gap Current(A)	25	05
Pulse ON time (µs)	20	15
Pulse OFF time(µs)	06	06

4. RESULT AND DISCUSSION

An analysis was conducted to determine the impact of control parameters on the recast layer and surface roughness both within and around the hole in an Al 7075/ metal matrix composite during EDM machining. Both examples demonstrate that the three factors significantly affect the surface roughness of the recast layer.

At a gap current of 25 Amps and 5 Amps, the average value of the recast layer's 'Ra' is at its lowest both inside and outside the hole. This could be because the metal matrix composite is recast in layers after being machined, with more of the material remaining in the hole than near its surface. This causes the dielectric fluid to flush ineffectively, leading to ineffective material removal in the hole. As a result, at higher gap currents, the surface finish is poor at the surface closest to the holes because of the high rate of material removal.

The recast layer's average 'Ra' value with pulse on-time is 10 µs for locations within the hole and 20 µs for locations around the hole. Spark energy is directly proportional to the pulse on time. Ra rises with increasing pulse on-time within the hole due to the increased material removal rate, while it drops with increasing pulse on-time outside the hole due to the repeated removal of the same recast layer rather than new material. Increasing the pulse on-time close to the hole significantly decreases the effective material removal compared to within the hole. This is due to the increased recasting of removed material.

In both the inside and near the hole scenarios, the pulse off time has a minimum Ra value of 6µs. At first, it was noticed that pulse off-time reduced surface roughness. This could be because the molten metal matrix composite did not have enough time to be recasted in large quantities. However, after 6 µs, there was enough time for recasting, and surface roughness began to increase with an increase in pulse off-time.

The nominal levels of pulse on-time and gap current for the optimal recast layer surface layer are reasonable because, out of the three parameters, pulse on-time has the least impact on the recast layer surface roughness inside the hole and the gap current has the least impact on the recast layer surface roughness near the hole surface.

5. CONCLUSION

The Taguchi technique was used to examine the surface roughness of recast layers in Al-7075/Al_2O_3 metal matrix composites. We optimised the method by studying the effect of process parameters on surface roughness, such as pulse on-time, pulse off-time, and gap current. The research led to the following findings:

1. For the purpose of achieving the minimal recast layer surface roughness during EDM machining of an Al-7075/Al_2O_3 metal matrix composite, the ideal values for the gap current (25A), pulse on-time (20 µs), and pulse off-time (6 µs) have been determined.
2. The ideal values for the gap current (5A), pulse on-time (15µs), and pulse off-time (6µs) have been determined for achieving the lowest possible recast layer surface roughness when EDM machining an Al-7075/Al_2O_3 metal matrix composite near the hole.
3. The combination of a 15 Amp gap current, 10 µs pulse on-time, and 6 µs pulse off-time inside the hole produces the smoothest recast layer surface. The near-hole example has a current of 15 amps, a pulse on-time of 15 µs, and a pulse off-time of 6 µs.
4. Roughness profiles show that at run 4, both within and around the hole, the least values of Ra and Rz are seen.
5. At first, the surface roughness grows quickly in relation to the pulse off-time, but later on, it grows slowly.

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