

Surface Integrity of Aluminium Processed with Cu-SiC Powder Metallurgy Green Compact Tools in EDM

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Abstract: EDM is an unconventional machining process widely used for machining tough material. A special aspect of EDM is surface modification by transferring the tool electrode material to work piece surface. In the present work electrode prepared with copper (Cu) and silicon carbide (SiC) by powder metallurgy route as tool and Aluminium plate is the workpiece material. A comprehensive experimental study was carried out. Material transfer rate (MTR), surface roughness, scanning electron microscopy (SEM), energy dispersive x-ray (EDX) was used to demonstrate the effect of various process parameters on surface characteristics. The pulse on time during electrical discharge coating (EDC) on metal transfer rate (MTR) and surface roughness (Ra) have been studied. From the experiment results, it can be revealed that the MTR is higher at high current and pulse on time. Surface roughness diminished at low current, and pulse on time. The surface integrity of the workpiece was determined to change with the desired deposition of a hard composite layer of SiC and copper over the work surface.

Keywords— EDM; Powder metallurgy; Surface integrity; Surface modification.

1. INTRODUCTION

Machining is the execution of an automated method to cut material into the desired shape and size. When the same operation is performed using electrical discharges for high-precision machining, the process

is known as electrical discharge machining (EDM) [1]. The EDM process has proven useful in machining dies and press tools, as well as in automotive and aerospace applications. The growing demand for miniature components in every industry has resulted in the development of sub micrometer components, with Micro- EDM emerging as one of the most

prominent machining processes [2-5]. These efforts can be classified into two types. The first attempt involved the addition of powder particles of various materials to the dielectric fluid, while the other involved the use of powder metallurgy (P/M) compact tools. P/M tools are divided into two categories: the green compact type and sintered type [6,7]. The following represent a few of the related study results concerning the surface modification associated with EDM. Several attempts were made using P/M tools, with both green and sintered forms. Gangadhar et al. [8] used electro discharge utility in industrial applications can be analyzing to transfer bronze onto a steelworks surface for work through bronze compacts containing 90% Cu and 10% Sn.

The aluminium is a promising metal that is widely used in the production of mould and die materials [9,10]. Molds and dies benefit from excellent properties such as high hardness, tensile and yield strength [11]. To improve the hardness and thickness of the coated surface, material deposition on the aluminium workpiece is required. It's investigated for surface treatment of dies and punches, gear teeth, coating of cutting tools, parts with flat sliding surfaces, selective treatment of parts, and so on.

In the present investigation, Silicon carbide (SiC) P/M green compacts were used as EDM tools, and aluminum was selected as the workpiece material. The objective was to deposit a layer of Silicon carbide with an increased surface hardness on the surface of the workpiece to transfer the tool material. Green compact P/M tools were selected as the material source to be transferred to the work surface. Green compacts have a lower bonding strength than partially or fully sintered compacts, which allows for easy tool material transfer. In addition to the SiC powder, Cu powder was added as an adhesive for adding strength to the compacts. Cu, as a good conductor of electricity, increases the frequency of discharges. In fact, the occurrence of good discharges is the primary requirement in EDM. A detailed experimental study was conducted with the combinations to determine the effects of different controlling process parameters on the output parameters.

2. Materials and Methods

2.1 Taguchi design of Experiments

The Taguchi method is a popular robust design philosophy which enhances engineering productivity [12]. There are three S/N ratios of common interest for optimization of static problems; Nominal-the-Best (NB)/ Target-the-Best (TB), three levels and three

parameters were chosen for the experiments as shown in table 1. The analyzed and generated design was done by mathematical software called MINITAB 17.

Table 1: Process Parameter

Parameter	Level 1	Level 2	Level 3
Pulse on time (μ s)	20	30	40
Pulse off time (μ s)	6	8	10
Current (A)	4	6	8

2.2 Experiment

The experiment was carried out in a 5030 EDM E-series machine with the dielectric fluid of EDM oil and a semi sintered electrode equipped with servo head and electrode having positive polarity. The electrode consists of 70% Cu and 30% SiC powders made through powder metallurgy (P/M).

Table 2: Experimental Result

Experimental Run	Current (A)	Pulse on time (μ s)	Pulse off time (μ s)	MTR (gm/min)	Surface Roughness (Ra)
1	20	6	4	0.0010	5.5614
2	20	8	6	0.0087	5.2409
3	20	10	8	0.0039	6.4109
4	30	6	6	0.0242	4.5797
5	30	8	8	0.0265	6.6542
6	30	10	4	0.1556	7.867
7	40	6	8	0.2493	5.867
8	40	8	4	0.0103	6.8
9	40	10	6	0.2008	7.93

Before starting the experiment, the top and bottom faces of the workpieces were ground to create a flat

surface. To remove the debris, side flushing technique through jet were used. The selected Machining parameters are Pulse on time, Pulse off time and current, polarity – reverse polarity; electrode tool – polarity positive; workpiece – polarity negative [13]. Before each experiment, the electrode was polished and buffed. For each experiment, the machine was run for a fixed time interval of about 10 minutes. To determine MTR, an SF400D weighing machine with a 0.01g accuracy was used to weigh the workpiece before and after EDC. Handy surf E-35A surface roughness measuring instrument has been used to measure the surface roughness Ra. The machined workpiece is shown in figure 1. The Taguchi L9 orthogonal array was selected for the experimentation and the experimental results are shown in table 2.

$$MRR = \frac{\text{Before machining of the work Piece (gm)} - \text{After machining of the workpiece (gm)}}{\text{Time taken for the experiment (min)}} \quad \dots (1)$$

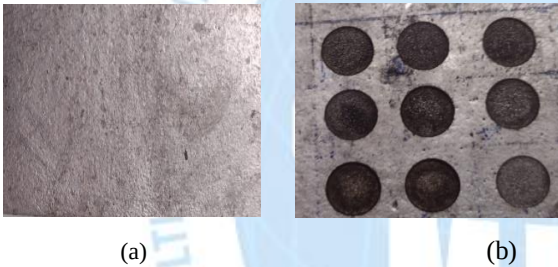


Fig. 1. Workpiece (a) Before Machining (b) After Machining

2.3 ANOVA

The ANOVA table for the quadratic model for MTR is shown in Table 3 and 4. The value of R² is over 91.98%, which means that the regression model provides an excellent explanation of the relationship between the independent factors and the response (MTR). The associated P value for the model is lower than 0.05 (i.e., p=0.05, or 95% confidence) which indicates that the model is statistically significant. Similarly, the R² value of surface roughness is 92.60%, which regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (Ra) [14]. The associated P value for the model is lower than 0.05 (i.e., p=0.05 or 95% confidence), which of fit are smaller than the standard value. Thus, both the models are adequate. It is also seen that from the P

values, for both metal transfer rate and surface roughness of linear and square effects are significant.

2.4. Mathematical modelling for MTR and Ra

The response function of metal transfer rate and surface roughness are the function of pulse of time (μs), current (A) and pulse on time (μs). The mathematical relationship obtained for examining the effect of the various EDC process parameters on the MTR and Ra is given in equation 2 and 3.

$$\begin{aligned} MTR = & 0.0757 - 0.0710 \text{ Pulse ON } (\mu s)_{20} + 0.0068 \text{ Pulse ON } (\mu s)_{30} + 0.0779 \text{ Pulse ON } (\mu s)_{40} + 0.0159 \text{ Pulse OFF } (\mu s)_{6} - 0.0604 \text{ Pulse OFF } (\mu s)_{8} + 0.0445 \text{ Pulse OFF } (\mu s)_{10} - 0.0199 \text{ Current (A)}_{4} + 0.0023 \text{ Current (A)}_{6} + 0.0176 \text{ Current (A)}_{8} \quad \dots (2) \end{aligned}$$

$$R^2 = 91.98\%$$

Table 3: Analysis of variance for MTR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pulse ON (μs)	2	0.03346	0.01673	1.43	0.412
Pulse OFF (μs)	2	0.01764	0.00882	0.75	0.571
Current (A)	2	0.00214	0.00107	0.09	0.916
Error	2	0.02345	0.01172		
Total	8	0.07671			

The mathematical model for the influences of the dominant parameters on the surface roughness is given in equation. 2.

$$\begin{aligned} Ra = & 6.323 - 0.586 \text{ Pulse ON } (\mu s)_{20} + 0.044 \text{ Pulse ON } (\mu s)_{30} + 0.542 \text{ Pulse ON } (\mu s)_{40} - 0.987 \text{ Pulse OFF } (\mu s)_{6} - 0.092 \text{ Pulse OFF } (\mu s)_{8} + 1.079 \text{ Pulse OFF } (\mu s)_{10} + 0.419 \text{ Current (A)}_{4} - 0.407 \text{ Current (A)}_{6} - 0.013 \text{ Current (A)}_{8} \quad \dots (3) \end{aligned}$$

$$R^2 = 92.60\%$$

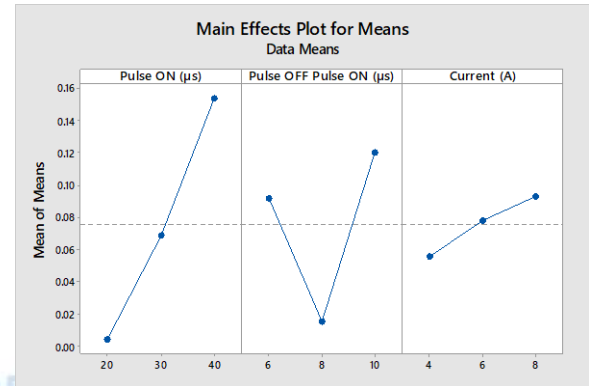
Table 4: Analysis of Variance for Ra

Source	F	Adj SS	Adj MS	F-Value	P-Value
Pulse ON (μ s)	2	1.9169	0.9584	2.07	0.325
Pulse OFF (μ s)	2	6.4440	3.2220	6.97	0.125
Current (A)	2	1.0239	0.5120	1.11	0.474
Error	2	0.9243	0.4622		
Total	8	10.309			

3 RESULT AND DISCUSSION

3.1. Effect of current, pulse on time and pulse off time on MTR

The influence of input parameters Figure 2 depicts MTR. This figure clearly shows that MTR increases with an increasing pulse on time and current and that MTR decreases initially and then increases with increasing pulse off time. It could be because the binding strength of the electrode increases, resulting in an increase in MTR from the powder-compacted electrode. MTR denotes the proportional current supplied during the EDC process. The transfer rate increases as the peak current increases from 4A to 8A. The reason for this is that more material is disintegrated from the powder compacted electrode and deposited on the substrate surface during the electro discharge process at high current [15]. Furthermore, a higher current induces a stronger spark and aids in the melting of greater amounts of tool material, and this is deposited in the surface of the substrate in the form of coating, resulting in an overall increase in transfer rate. MTR increases as a pulse on time increases from 20 to 40s. This could be due to the amount of material that will be melted away from the tool-electrode and deposited on the workpiece surface [16].

**Fig. 2.** Effects of Process parameters on MTR

When the pulse on time is increased from 30 to 40 seconds, the deposition rate remains nearly constant. Due to the strong spark, a higher pulse on time with the same energy applied for a longer duration has the potential to remove some pre-deposited coating layer or substrate material, resulting in an overall reduction.

3.2 Effect of current, pulse on time and pulse off time on Ra

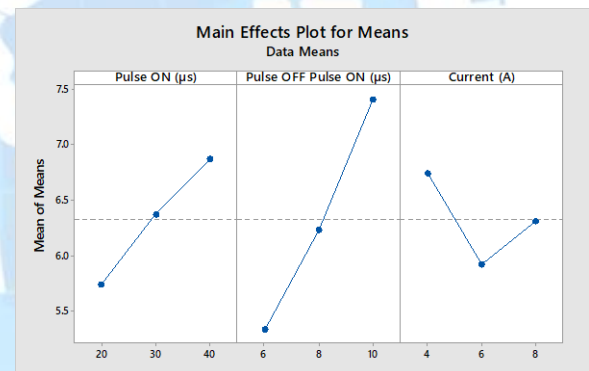
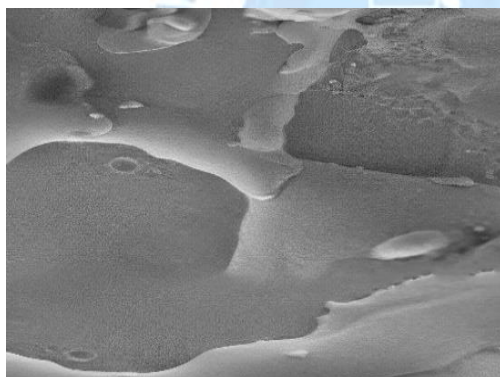
**Fig. 3.** Effects of Process parameters on Ra

Figure 3 shows the effect of input parameters on Ra. The figure clearly shows that Ra increases as the pulse-on-time and pulse-off time increase. Ra decreases initially and then increases as the current increases. The tool-electrode acts like a denser tool with a lower wear rate and fewer pores [17]. As a result, as surface roughness decreases, the amount of material deposited decreases. Increased current aids in the formation of strong electric sparks, which raises the spark temperature and causes the tool-electrode material to be deposited on the workpiece surface, resulting in crater formation at greater depths and an increase in surface roughness. Similarly, as pulse-on-time increased, surface roughness increased, most likely due to the prevalence of arcing rather than sparking [18]. Higher pulse on time results in higher

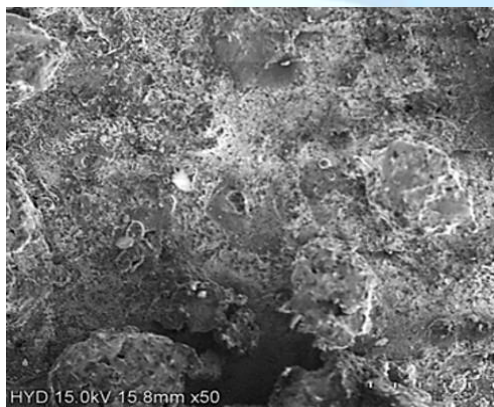
pulse energy per spark impinged on the workpiece surface, resulting in the formation of deep craters that remove a large amount of material and deposit powder particles on the substate, causing increased roughness.

4. SCANNING ELECTRON MICROSCOPE ANALYSIS

The SEM (Scanning electron microscope) micrographs of the machined surface of the tested specimen of the aluminium as shown in figure 4.. SEM micrographs for the machined surface of tool steel at different machining parameters are shown in Figure 4. Some irregularities on the machined surface such as craters, ridges of re-deposited molten metal, debris particles, micro-voids, and micro-cracks have been observed. The high discharge energy affects the size of the craters and the density of ridges on the machined surface [19].



(a)



(b)

Fig.4. SEM micrographs of the machined surface

5. CONCLUSION

Surface modification of Aluminium alloy (Al7075) with cu-SiC powder metallurgy sintered electrode by EDC process was carried out. Influence of compaction load, current, and pulse on time on material transfer rate and surface roughness have been studied. The following conclusions can be drawn from the experimental results obtained.

- From the result it can be concluded that MTR increases at high current, pulse on time and pulse off time. This is attributed ai low compaction load bonding between the electrode particle is low and high current and pulse on time initiating the effective spark which melts and vaporize the electrode material and deposited the workpiece. Conversely at high compaction load with low current and pulse on time MTR decrease. This is owing to higher compaction load, bonding strength of powder particle is high and low current and pulse on time supplies the electric density and diameter of the plasma is minimum, which is not sufficient to melt the electrode, hence MTR decreases.
- For Surface roughness the most significant factor was again current followed by pulse on time and lastly the duty cycle. SR increased significantly with increase in current in a nonlinear fashion. For increase in pulse on time SR increased up to 100 and then there was no significant increases. In case of duty cycle, SR first increased up to 70% and then started decreasing.

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