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Electric Discharge Coating on Aluminium-6351 Alloy with Green Compact Silicon Carbide and Copper Tool using EDM Oil as Dielectric

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Abstract: This study presents electric discharge coating of SiC-Cu on Al-6351 alloy using EDM oil as dielectric. The electrode is made by green compaction powder metallurgy process. A Taguchi design of experiments is used to study the sensitivity of EDC response parameters like Material Deposition Rate (MDR) and Surface Roughness (SR) by changing process parameters such as pulse-on time, peak current, compaction load and composition. A Taguchi L16 orthogonal array with mixed levels is used as a DOE (Design of Experiment) in this present study. To explore the effect of significant process parameters, the Analysis of Variance (ANOVA) is used. Moreover, SEM and EDX analysis has been carried out to characterize the deposited layer and also to confirm the ubiquity of electrode materials on the substrate surface.

Key words: Electric discharge coating, powder metallurgical tool, process parameter, material deposition rate, surface roughness, electrode, Taguchi

INTRODUCTION

From the literature study, it has been found that several research have been done to modify the workpiece surface by EDM process. Surface alteration by EDM is completely a new practice which is not yet industrialized (Chakraborty *et al*., 2017a, b). It is still under evolvement stage. The main working principle of EDM is to remove materials from the workpiece. It is basically done by erosion process where a series of sparks are taking place between the tool and workpiece. In EDM, the tool is allied to the cathode and the workpiece is allied to the anode. This system not just precedes the material confiscation from the top surface of the workpiece but also material confiscation from the tool (Chakraborty *et al*., 2017a, b). From the literature study, it has been noticed that a white layer forms over the upper surface of the workpiece whose properties match with the properties of electrode material (Murray *et al*., 2013). This took to the practice of surface alteration by EDM which is also recognized as Electro Discharge Coating (EDC). The coating of a hard material over the top surface of the substrate is made more gargantuan by proper transfer of tool materials with the use of powder metallurgical compaction technique, either in semi sintered or green state (Chakraborty *et al*., 2017a, b). To get a fine deposition during the coating process, zero flushing pressure or minimum flushing pressure of dielectric medium has to be maintained (Chakraborty *et al*., 2017a, b). EDC is basically done in reverse polarity to that of EDM, i.e., workpiece is connected to cathode and tool to the anode. This is made to alleviate the coating process by eroding more amounts of material from the electrode (Chakraborty *et al*., 2017a, b). Many researchers have worked on EDC process with different composition of powder materials like Cu-W, TiC-Cu, WC-Co, TiC and Ti, etc. by powder metallurgy method in semi sintered or in green state.

In this present research, an exertion has been made to deposit silicon carbide on the top surface of aluminium 6351 alloy by EDC process in EDM oil. The electrode has been made by green compaction powder metallurgy technique which consists of SiC (Silicon Carbide) and Cu (copper) of 44 μ (325 mesh size) each (Chakraborty *et al*., 2017a, b). The operating parameters chosen in this study are tool composition, compaction load, pulse duration and peak current. The output responses of this study are MDR (Material Deposition Rate) and SR (Surface Roughness).

MATERIALS AND METHODS

In this present study, die sinking EDM machine has been used to carry out the whole experiments. The machine setup is shown in Fig. 1. For tool electrode materials, SiC (Silicon Carbide) and Cu (Copper) powders of 44 μ each (325 mesh size) has been used and also assorted, it properly in requisite quantity by weighing to fulfill the actual composition (Chakraborty *et al*., 2017a, b).

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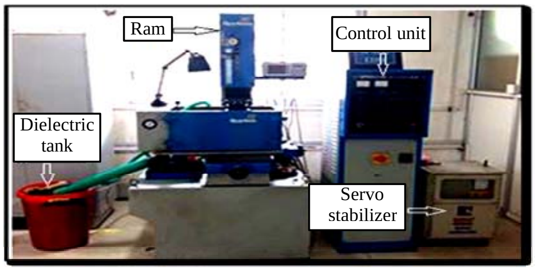

Fig. 1: Experimental setup

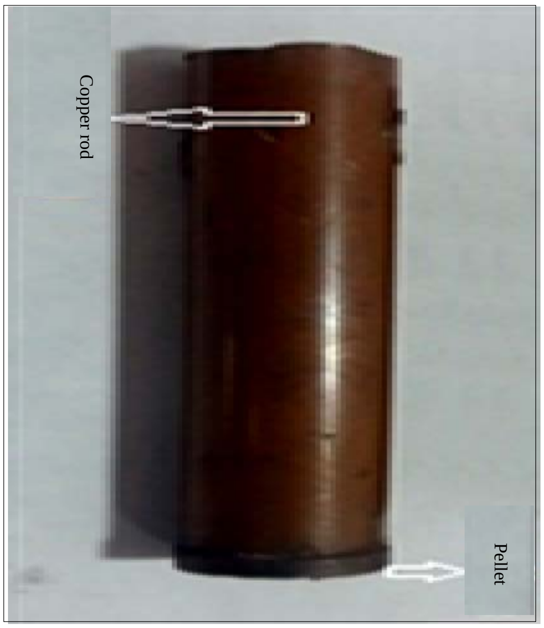

Fig. 2: Pellet joined with copper

The pellet press machine is used to prepare the pellets by changing the compaction load and also to control the response bonding strength between silicon carbide and copper powders at different composition. Then to make the tool electrodes, the pellets are being joined with a copper rod of same diameter by electrically conductive glue which is shown in Fig. 2 (Chakraborty *et al.*, 2017a, b). In this study, Al-6351 alloy is used as a substrate. The dimension of this substrate is 25×25×5 mm. EDM oil is being used as dielectric fluid in this coating process. A precision weight measuring balance has been used for measuring the weights of workpiece and tool before and after experiments to calculate the material deposition rate and Taylor Hobson 3D Profilometer for surface roughness measurement.

Pilot runs (experiments) have been done to select the effective operating parameters and also their corresponding levels (Rahang and Patowari, 2016). The input process parameters with their different levels are stated in Table 1 (Kar *et al.*, 2017). To contain this type of unevenly discrete level of factors, mixed level design of Taguchi has been taken and a modified L-16 orthogonal array (Roy, 2001; Krishnaiah and Shahabudeen, 2012) is accordingly chosen which is shown in Table 2. A photograph of some specimens after EDC process is shown in Fig. 3.

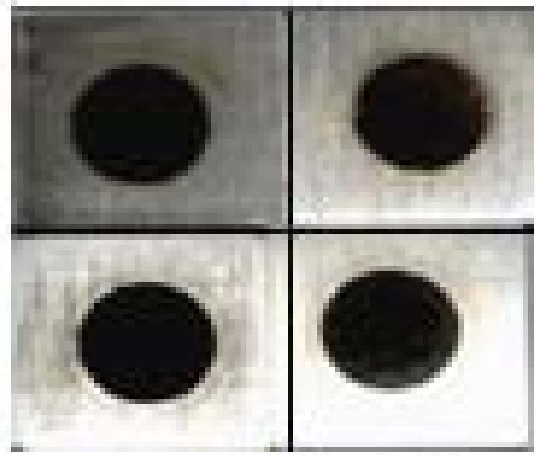

Fig. 3: Coated specimen

Table 1: Process parameters and their levels (Kar *et al.*, 2016)

Parameters	Code/Units	Levels 1	2	3	4
Compaction load	P (Ton)	50	10	15	20
Current	I_p (A)	20	40	60	80
Pulse on time	T_{on} (μs)	11	21	50	100
Tool composition	C_t (SiC:Cu)	30:70	50:50	-	-

Table-2: L-16 orthogonal array and experimental results for MDR (mg/min) and SR (μm)

Exp. No.	Compaction Load (ton)	Current (A)	Pulse duration (μs)	Composition (SiC:Cu)	MDR (mg/min)	SR (μm)
1	50	2	110	30:70	0.25	2.11
2	50	4	210	30:70	0.27	2.79
3	50	6	500	50:50	0.78	3.70
4	50	8	100	50:50	0.73	3.97
5	10	2	210	50:50	0.43	2.68
6	10	4	110	50:50	0.50	2.40
7	10	6	100	30:70	0.35	3.58
8	10	8	500	30:70	0.36	3.47
9	15	2	500	30:70	0.13	2.13
10	15	4	100	30:70	0.19	2.24
11	15	6	110	50:50	0.37	2.71
12	15	8	210	50:50	0.48	3.11
13	20	2	100	50:50	0.27	2.20
14	20	4	500	50:50	0.20	2.44
15	20	6	210	30:70	0.10	2.41
16	20	8	110	30:70	0.12	2.61

RESULTS AND DISCUSSION

Experimental results are given in Table 2. A wide range of material deposition rate (0.10-0.78 mg/min) and

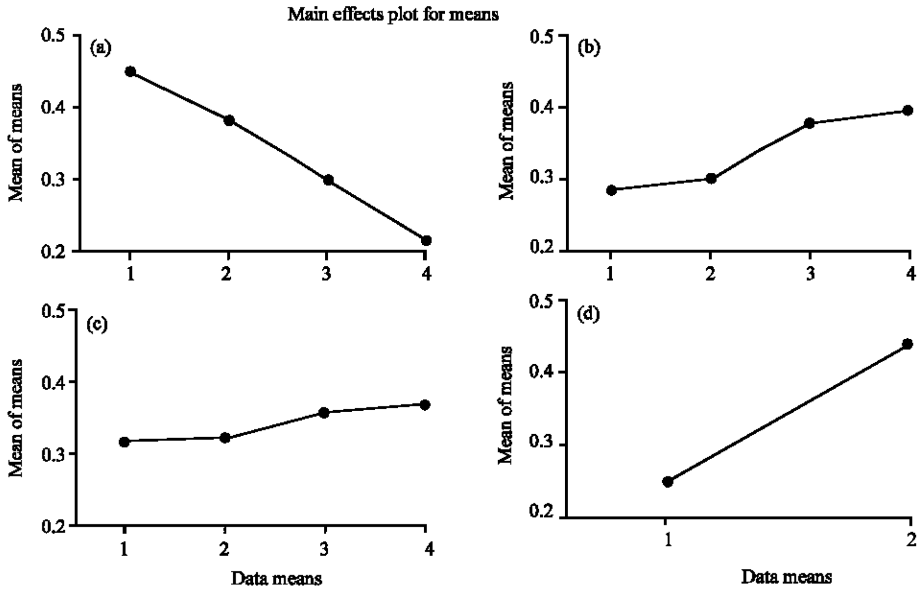

Fig. 4: Mean effect of operating parameters on material deposition rate: a) Compaction; b) Current; c) Pulse duration and d) Composition

surface roughness (2.11-3.97 μm) has been obtained with different amalgamation of process parameters. The mean effects of the operating parameters on the two output responses (MDR and SR) are explained.

Mean effect of operating parameters on Material Deposition Rate (MDR) is shown in Fig. 4. Here, "larger the better type" characteristic for MDR is selected. From the Fig. 4, it is clearly seen that, at lower compaction load, MDR is high and it gradually decreases with the increase of compaction load. This may be due to the fact that at lower compaction load, the powder materials are loosely bonded that means the binding strength is less and it is increasing with the increase in compaction load. But, at lower current and pulse duration, MDR is low and it increases with increase in current and pulse duration which is due to the high energy of current with high magnitude applied for longer duration. Copper restrains high binding strength with high thermal conductivity also. Thus, higher percentage of copper (70%) confines quicker deposition of electrode materials on the substrate surface.

Mean effect of operating parameters on SR is shown in Fig. 5. Here, "smaller the better type" characteristic for SR is selected. From Fig. 5, it is clearly observed that, with the increase of compaction load, the surface roughness value decreases. This may be due to the fact that the compact tool electrode's density increases with increase in compaction load (Krishna and Patowari, 2014) which lead to less number of pores. It is also seen that with the increase in current, average surface roughness value also increases. This may be due to the fact that the usable energy of current which increases also leads to increase in crater formation on the substrate surface (Patowari *et al*., 2011a, b). Increase in pulse duration augments the duty cycle of operation which results in more spark-erosion with better deposition of tool electrode material. This may be due to the increase in spark intensity as well as number of sparks hitting the tool material and development of profound craters on the workpiece surface (Patowari *et al*., 2011a, b). Thus, SR will be higher due to this development of profound craters. Moreover, surface roughness also gets increased with increased percentage of silicon carbide which is nothing but the better deposition of tool materials and thus development of more craters on the workpiece surface.

The output characteristics like material deposition rate and surface roughness is also analyzed by Analysis of Variance (ANOVA) using Software Minitab-16. It shows the percentage contribution of each influencing factors on MDR and surface roughness. This also shows that which factor is more effective during the coating process. The ANOVA results are shown in Table 3.

From the ANOVA table, it has been noticed that the most significant factor influencing MDR is compaction load. It's affecting the MDR by 41.41%, followed by composition, current and pulse duration as they contribute 40.58, 11.59 and 2.59%, respectively. Similarly, the most significant factor influencing SR is current. It's affecting the SR by 52.33%, followed by compaction load, pulse duration and composition as they contribute 28.18, 13.00 and 4.03%, respectively.

Table 3: ANOVA results for MDR and SR

	Percentage contribution (%)						
Response	Compaction load	Current	Pulse duration	Composition	Error	R^2	R^2(adj)
MDR	41.41	11.59	2.590	40.580	3.83	96.17	88.50
SR	28.18	52.33	13.000	4.030	2.46	97.54	92.61

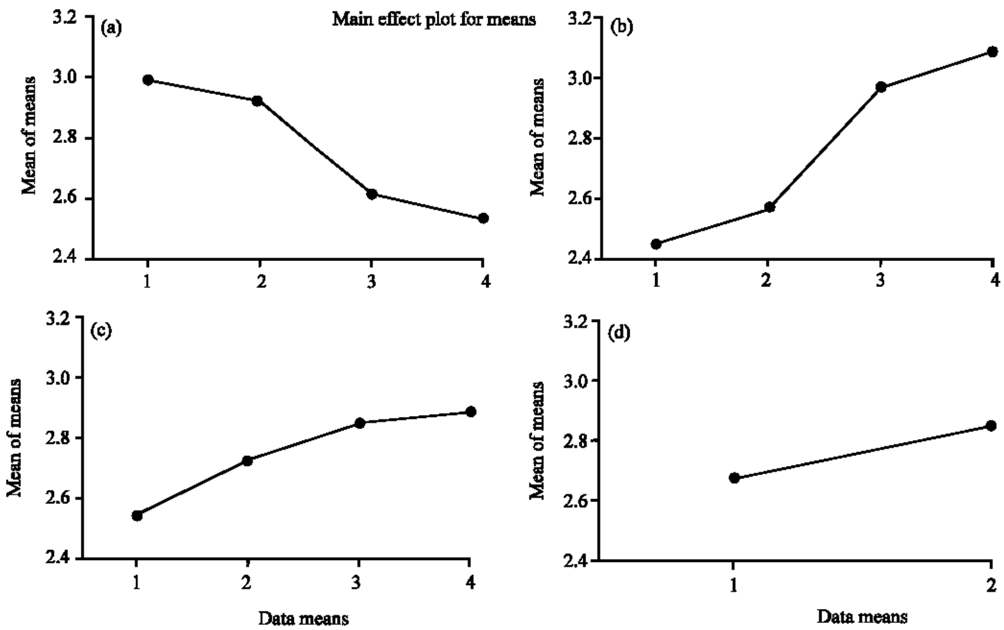

Fig. 5: Mean effect of operating parameters on surface roughness: a) Compaction; b) Current; c) Pulse duration and d) Composition

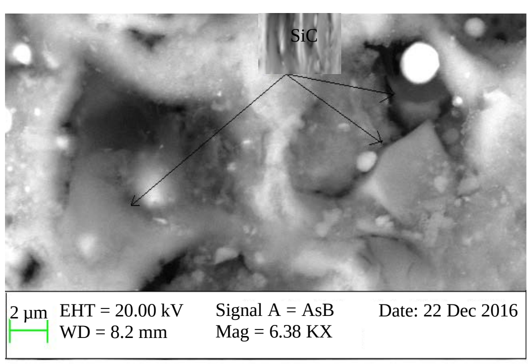

Fig. 6: SEM micrograph of the top surface of a sample

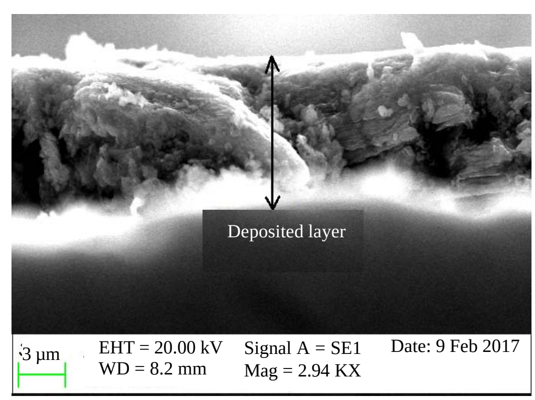

Fig. 7: SEM micrograph of the deposited layer

Analysis of the coated layer: The coated layer of the substrate's surface is analyzed by Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray (EDX) techniques to validate the presence of any Foreign particle other than the workpiece material. Figure 6 shows the SEM photograph of the top surface of one sample (Ghosh *et al*., 2010). From Fig. 7, it is clearly seen that a particle like phase is scattered over the coated layer (Patowari *et al*., 2011a, b). A cross sectional view at high magnification is shown in Fig. 7. From Fig. 8, the deposited layer is clearly identified. The EDX plot of a coated layer is also shown in Fig. 8 (Chakraborty *et al*., 2017a, b). The Al, Si, C and Cu peaks along with the Mg and Mn peaks are clearly seen from Fig. 8 (Patwari *et al*., 2011a, b). Therefore, it helps to confirm the ubiquity of electrode materials on the workpiece surface (Chakraborty *et al*., 2017a, b).

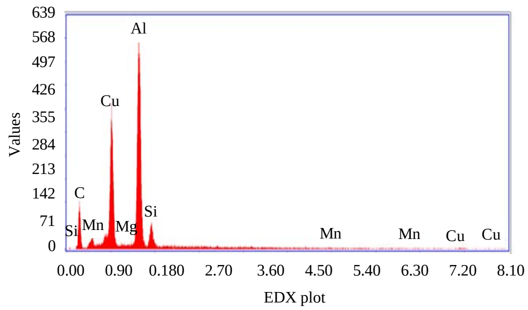

Fig. 8: EDX plot of a coated layer

CONCLUSION

The present study demonstrated the surface modification of Al-6351 alloy with SiC/Cu green compact powder metallurgical tool by EDC process using EDM Oil as dielectric. The output responses of this study were Material Deposition Rate (MDR) and Surface Roughness (SR). Mean effect and ANOVA was used to investigate the effect of relevant process parameters and also percentage contribution of each input parameter on MDR and SR. Based on the ANOVA analysis, it was found that the most significant factor influencing MDR was compaction load (41.41%) followed by composition (40.58%), current (11.59%) and pulse duration (2.59%) respectively and the most significant factor influencing SR was current (52.33%) followed by compaction load (28.18%), pulse duration (13.00%) and composition (4.03%), respectively. Moreover, Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray (EDX) testing was done to typify the deposited layer which also confirmed the ubiquity of electrode materials on the upper surface of the workpiece.

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