Performance Analysis of Copper Coated Aluminum Tool in Electrode Discharge Machining of Ti-6Al-4V Alloy

Huu-Phan Nguyen[1], Tien-Long Banh[2,3], Shailesh S. Shirguppikar[4,5], Maharudra S. Patil[5], Thi-Bich Mac[2], and Quang-Dung Le[2](✉)

[1] Faculty of Mechanical Engineering, Hanoi University of Industry, Ha Noi, Vietnam
[2] Faculty of Mechanical Engineering, Hung Yen University of Technology and Education, Hung Yen, Vietnam
ledung202@gmail.com
[3] School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam
[4] Department of Mechanical Engineering, KLS GIT, Belagavi Affiliated to VTU, Belagavi, India
[5] Department of Mechanical Engineering Department, RIT, Rajaramnagar Affiliated to SUK, Rajaramnagar, Maharashtra, India

Abstract. Electric Discharge Machining (EDM) is one of the most popular non-traditional machining processes applied for machining very hard conductive materials with desired shape, size and dimensional accuracy. In this paper, copper-coated aluminium alloy is applied as EDM electrode instead of copper electrode. Electrodeposition, simple a nd economical process, was used for preparation of copper coating on aluminium alloy. The method of anodization was applied in order to get a strong adhesive copper coating on aluminium alloy substrate. Taguchi based design of experiment technique were used to form relationship of process parameters and response variables. The copper-coated surface was characterized with XRD report. Lower tool wear rate (TWR), surface roughness (SR) and higher material removal rate (MRR) were found for copper-coated aluminium alloy EDM electrode compare to uncoated aluminium alloy electrode. The micro-crack formation on machined surface was significantly decreased by using copper coated aluminum electrode.

Keywords: EDM · Coated electrode · MRR · TWR

1 Introduction

Electrical discharge machining (EDM) has become one of the most important production technologies to manufacture very accurate three-dimensional complex components on any electrically conductive material [1]. The cost of a part manufactured by EDM is essentially determined by the electrode cost, which consists of the raw material cost and the tool production [2]. The contribution of the electrode cost to the total EDM operation cost can be more than 70%. The electrode production is a major cost and time spent in

B. T. Long et al. (Eds.): AMAS 2021, LNME, pp. 520–526, 2022.
https://doi.org/10.1007/978-3-030-99666-6_75

the EDM process cycle, which can account for over 50% of the conventional machining costs [3]. The thermo-physical properties of the electrode, such as thermal and electrical conductivity, thermal expansion and heat needed to vaporize from room temperature, melting and boiling temperature have a considerable influence on the EDM process performance in terms of material removal rate, electrode wear and surface integrity of the workpiece [4]. When the surface temperature of the electrode is not over the boiling or melting point, electrode material removal does not occur, so materials with higher melting point are suitable as tool electrodes [5]. Electrical properties are also important, as the current is responsible for the material erosion. Higher electrical conductivity (low electrical resistivity) generally leads to lower tool wear. In addition, although the EDM process does not involve mechanical forces, the sparks produced act in a violent way, inducing stresses in a microscopic scale [6]. Thus, the structural integrity of the electrode is a significant factor determining the electrode performance. The nickel-tungsten alloy coating has good erosion resistance performance, which can effectively reduce the side wear of the tool, especially at the end and edge, maintaining the shape of the tool and improving the shape precision of the machined microhole [7, 8]. Researchers were proposed a wear-variation EDM (WV-EDM) approach to fabricate a laminated disc electrode (LDE) with stable-shape microchannels on the outer edge surface [9].

In this paper, in order to reduce the significant problem of tool wear in EDM, thin film coated copper tools were made by electroplating technique. Experiments were performed as per Taguchi based design of experiment method. The effects of the thin film coated tools on tool wear, surface roughness, and material removal rate were analyzed. It provides a new tool preparation method for EDM, and the research results have certain guiding significance for the actual production in EDM.

2 Experimental Details

Experiments were performed on titanium alloy (Ti-6Al-4V) and undergone drilling operation using EDM. Two types of electrodes were used; uncoated aluminum electrode and copper coated aluminum electrode. Selection of process parameters and its levels were selected as per literature review and machine capabilities, three input process parameters with four levels were selected for the final experimentation, as shown in Table 1. Taguchi based orthogonal array were used for experimental work with four levels of Current (I), Gap Voltage (Vg), Pulse-ON Time (TON) and L16 design of experiment were planned and conducted experiments with uncoated aluminum electrode and copper coated aluminum electrode.

Table 1. Selection of process parameters & levels

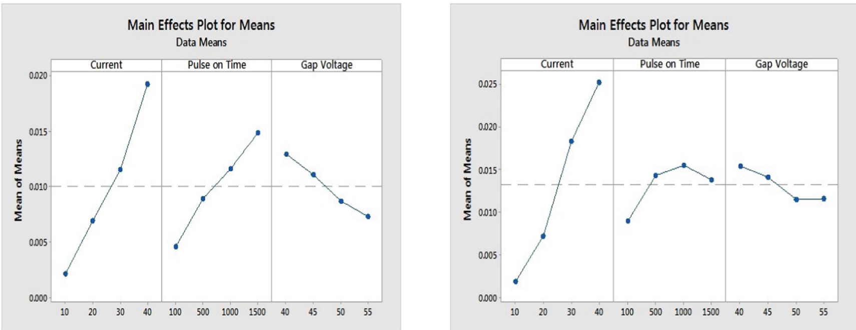
Parameters	Symbol	Levels				Unit
Peak current	I	10	20	30	40	A
Gap voltage	Vg	40	45	50	55	V
Pulse-ON time	TON	100	500	1000	1500	μS

3 Experimental Results

In this experimental work study has been conducted to investigate effect of coated and uncoated electrodes on the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) by using Ti-6Al-4V as workpiece material, Table 2.

3.1 Performance Analysis of Material Removal Rate (MRR)

Main effect plots were plotted with help of Minitab 17 software. These graphs show the behavior of process parameters in relation to response variables. Main effect plot of MRR with uncoated & Cu coated Al electrode is shown in Fig. 1. The MRR chart is a linear graph that increases from 10 to 40 amps in both cases.



(a) MRR using Al Electrode (b) MRR using Coated Electrode

Fig. 1. Main effect plots for MRR with uncoated & Cu coated Al electrode

Table 2. Results for Ti-6Al-4V using uncoated and copper coated Al electrode

Expt. No.	Process parameters			Uncoated Al electrode			Copper coated Al electrode		
	(I)	(Vg)	(TON)	MRR gm/min	TWR gm/min	SR μm	MRR gm/min	TWR gm/min	SR μm
1	10	40	100	0.002	0.0023	6.664	0.0033	0.003	6.23
2	10	45	500	0.0022	0.0028	6.683	0.0004	0.0042	6.28
3	10	50	1000	0.0019	0.0041	6.691	0.0019	0.0034	6.34
4	10	55	1500	0.0027	0.0029	6.815	0.0021	0.0045	6.44
5	20	45	100	0.0019	0.005	7.781	0.0062	0.0064	7.112
6	20	40	500	0.0073	0.0058	8.325	0.0088	0.0092	7.354
7	20	55	1000	0.0075	0.0076	8.662	0.0092	0.0126	7.641
8	20	50	1500	0.0111	0.0087	8.981	0.0048	0.0174	7.664

(*continued*)

Table 2. (*continued*)

Expt. No.	Process parameters			Uncoated Al electrode			Copper coated Al electrode		
	(I)	(Vg)	(TON)	MRR gm/min	TWR gm/min	SR µm	MRR gm/min	TWR gm/min	SR µm
9	30	50	100	0.0053	0.0068	9.116	0.0114	0.011	8.021
10	30	55	500	0.0097	0.0098	9.203	0.0201	0.0137	8.331
11	30	40	1000	0.0141	0.0118	9.412	0.0214	0.0159	8.689
12	30	45	1500	0.0172	0.0124	9.665	0.0204	0.021	8.911
13	40	55	100	0.0093	0.0106	9.706	0.0151	0.0148	8.978
14	40	50	500	0.0164	0.0145	9.783	0.028	0.0214	9.011
15	40	45	1000	0.0229	0.0177	10.112	0.0296	0.0262	9.241
16	10	40	100	0.0282	0.0212	10.391	0.0281	0.0281	9.511

High pulse time values, the drop may be explained, due to pulse-OFF values. As the duty cycle was kept constant during the experimentation, at higher values of TON corresponding TOF values are also higher due to which reduction in the MRR was observed. This phenomenon was been observed by few researchers which support our statement. The calculated MRR for two electrodes is shown in bar chart shown in Fig. 2. About 12% higher MRR is achieved for copper-coated Al electrode than uncoated Al electrode.

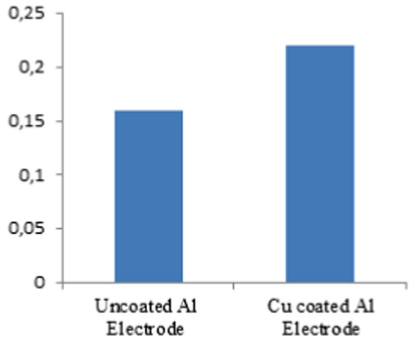
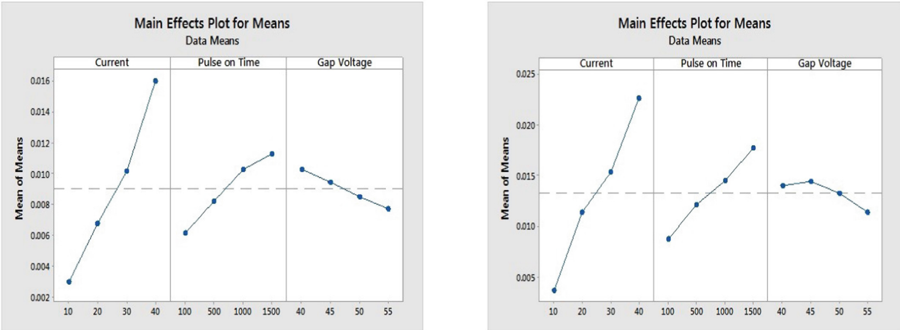


Fig. 2. Influence of electrode material on MRR

The higher value of electrical conductivity is the main reason for the increasing of material removal rate. The higher value of electrical conductivity can increase more energy transfer into workpiece and it causes more material removal from the workpiece. Though the electrical conductivity of Al is improved by copper coating on it, it does not reach the electrical conductivity as much as copper.

3.2 Performance Analysis of Tool Wear Rate (TWR)

The absolute values of tool wear show that there are two phenomena that regulate the wear characteristics of the tools: the erosion of the tool electrode material and the deposition of the workpiece material on the tool electrode. When high MRR conditions occur, large quantities of debris are produced and the quantity of material deposits increases on the tool electrode. In such conditions, the amount of actual material removed from the tool electrode also increases. Main effects plot for TWR is shown in Fig. 3.



(a) TWR using Al Electrode (b) TWR using Coated Al Electrode

Fig. 3. Main effect plots for MRR with uncoated & Cu coated Al electrode

Figure 4 shows the calculated electrode wear rate (EWR) for uncoated & Cu copper electrodes. The EWR is decreased by 22% after applying copper coating on Al electrode. The thermal conductivity is mainly responsible for electrode wear rate. The higher thermal conductivity of electrode material can be driven out more heat from sparking zone more quickly. This is reduced the electrode erosion. Thermal conductivity of copper-coated Al is higher compared to uncoated Al alloy. The higher thermal conductivity of copper-coated 6061Al electrode can reduce the electrode wear compared to the uncoated Al electrode.

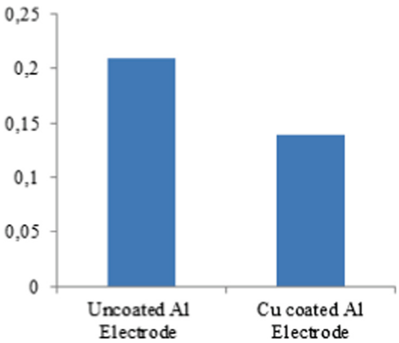
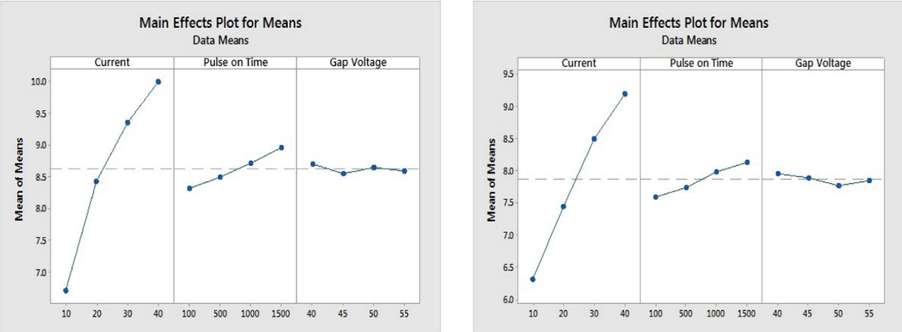


Fig. 4. Influence of electrode material on TWR

3.3 Performance Analysis of Surface Roughness (SR)

Increase in current and pulse on time shows the increase in the surface roughness (SR) which can be determined from main effects graph, thereby increasing temperature leading to premature melting of the tool electrode. Therefore, as the current level is increased the surface roughness is increased due to increment in the spark energy. Main effects plot for SR is shown in Fig. 5.



(a) SR using Al Electrode (b) SR using Cu Coated Al Electrode

Fig. 5. Main effect plots for SR with uncoated & Cu coated Al electrode

Figure 6 shows the influence of three different electrodes on the surface roughness of workpiece. The results show that better surface is achieved using copper-coated Al electrode compared to uncoated Al electrode. The higher wear rate caused the degradation of surface of electrode. The degraded surface of electrode has generated more rough surface.

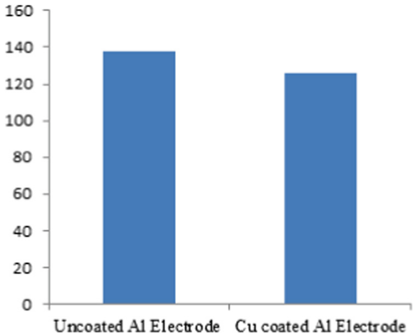


Fig. 6. Influence of electrode material on SR

4 Conclusion

Copper-coated aluminium electrode was developed using electrode position process. Prior to electrode position, the surface of aluminium was prepared by anodizing process. The EDM operations were performed with newly developed electrodes. The performance of two electrodes was compared on the basis of MRR, TWR and SR. The results show that copper coating on aluminium has enhanced the performance compared to uncoated aluminium. The result shows that copper coating on aluminium alloy has significantly improved the applicability and sustainability of Al as an EDM electrode. The copper-coated aluminium can be used as EDM tool in a large scale in industry.

References

1. Ho, K.H., Newman, S.T.: State of the art electrical discharge machining (EDM). Int. J. Mach. Tools Manuf. **43**, 1287–1300 (2003)
2. Klocke, F., König, W.: Fertigungsverfahren - Abtragen, Generieren und Laser material bearbeitung (1997)
3. Ozgedik, A., Cogun, C.: An experimental investigation of tool wear in electric discharge machining. Int. J. Adv. Manuf. Technol. **27**, 488–500 (2005)

4. Jha, B., Ram, K., Rao, M.: An overview of technology and research in electrode design and manufacturing in sinking electrical discharge machining. J. Eng. Sci. Technol. Rev. **4**, 118–130 (2011)
5. Kunieda, M., Lauwers, B., Rajurkar, K.P., Schumacher, B.M.: Advancing EDM through fundamental insight into the process. CIRP Ann. Manuf. Technol. **54**, 64–87 (2005)
6. Kern, R.: Sinker electrode material selection. EDM Today **4**, 32–38 (2008)
7. Teng, D.: Preparation of Cr-Cu composite electrode an research of simulation and experiment. Taiyuan University of Technology, Taiyuan, China (2012). (in Chinese)
8. Lv, Q.C.: Simulation and experimental study on the fabrication of the composite electrode for MEDM. Dalian University of Technology, Dalian, China (2009)
9. Zhang, J.: Fabrication of TiN-Cu electrical discharge machining electrode by gel injection molding. Chin. J. Vac. Sci. Technol. **39**(2), 169–173 (2019). (in Chinese)