

Open
Access

Effect of Peak Current and Pulse On Time on the Coating Layer Thickness using Electrical Discharge Coating

Norhazeratul Mohammad Zainudin¹, Pay Jun Liew^{1,*}, Ching Yee Yap¹, Noraiham Mohamad¹, Jingsi Wang²

¹ Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

² Marine Engineering College, Dalian Maritime University, 1 Linghai Road, Ganjingzi District, Dalian 116026, China.

ARTICLE INFO

Article history:

Received 29 September 2021

Received in revised form 9 November 2021

Accepted 9 November 2021

Available online 30 November 2021

Keywords:

Electrical discharge coating (EDC),
coating, tungsten,

ABSTRACT

The present study focused on the surface modification of aluminum 6061 by using electrical discharge coating (EDC) with powder suspension. The effects of peak current (I_p) and pulse on time (T_{on}) on the coating layer thickness were investigated. This study used Tungsten powder as an additive and mixed it with the kerosene oil and surfactant Span 83. The results indicated that peak current and pulse on-time significantly affected the coating layer thickness. The thinnest coating layer was observed at 3A, 150 μ s, while the thickest coating layer with an average value of 17.239 μ m was obtained at parameter 4A and 250 μ s. In conclusion, the high value of peak current and longer pulse duration on time increased the thickness of the coating layer.

1. Introduction

Surface modification or also known as surface treatment is not a new process in the industry. It is widely used in the engineering field and biomedical, automotive, and aerospace [1]. The main function of surface modification is to change and enhance the material's chemical, mechanical, and physical properties. According to Oshida [2], by going through the surface modification process, the material can improve the wear resistance and resistance against degradation, biocompatibility, and surface wettability. This statement is also supported by Shibe and Chawla [3]. There are a few different techniques that can be used in surface modification. For instance, are electrical discharge machining (EDM), thermal spraying, physical vapor deposition (PVD), chemical vapor deposition (CVD), electroplating, laser coating, electron-beam irradiation, and sputtering [4].

Surface modification of workpiece by material transfer during the EDM process is known as electrical discharge coating (EDC). It is also known as a reversed method of EDM. EDC is a recent

* Corresponding author.

E-mail address: payjun@utem.edu.my (Pay Jun Liew)

technology where the polarity is reversed. The anode is connected to the electrode, and the cathode is connected to the workpiece [5]. In the EDM process, the material is removed from the workpiece, while in EDC, the electrode material is deposited on the workpiece surface with a high current electric pulse and dielectric fluid [6]. Watane and Shirbhat [7] mentioned that EDC is one of the evolving coating processes due to its comfort, usability, simplicity, reliability, and cost-effectiveness. There are many ways to perform surface modification in EDC, such as EDC with powder metallurgical (PM) electrodes, EDC with multi-layer electrode, EDC with powder suspension, and dry EDC [8].

According to Kumari [9], the surface properties such as surface hardness, wear resistance, oxidation, and corrosion resistance will be enhanced after the EDC process. A study by Liew et al. [10] revealed that, with the addition of tungsten (W) powder, the micro-hardness of the aluminum workpiece showed an increment of about 104.86%. Tijo and Masanta [11] stated that the decomposed carbon contained in the dielectric fluid will react with the powder particle added to the fluid. This reaction produced a metallic carbide that was deposited on the workpiece surface.

Panda and Kumar [12] proved that the usage of manganese as a powder addition could improve the hardness of die steel, and this method can be applied on dies and press tools to keep it long-lasting. From the experiment conducted by Kumar and Batra [13], tungsten powder was used as an additive material to modify the surface of three types of die steel material. From the microhardness test conducted after the surface modification process, it was observed that 3.25% of tungsten was deposited in the H13 die steel machined surface using the EDC technique.

In Algoti et al. [14] research, the EDC technique was used to modify the surface of 304 stainless steel by using a PM titanium carbide (TiC) tool electrode. The result shows an improvement in the mechanical performance of the workpiece where the surface hardness had increased after going through the EDC process. This condition depended on the peak current, pulse on time, and the deposited material's content [15]. According to Janmanee and Muttamara [16], the micro-cracks that occurred on EDMed surfaces were reduced. The workpiece's surface hardness was improved when the titanium powder was added to the machining gap.

In previous research, many types of powders have been used, such as aluminium, graphite, silicon, chromium, copper, etc. However, the study of tungsten powder as an additive in the surface modification of aluminum is still scarce. Therefore, in this study, tungsten powder was added to the dielectric fluid. The effects of different peak current (I_p) and pulse on time (T_{on}) on the coating layer thickness were investigated experimentally using the EDC process.

2. Experimental Methods

2.1 Equipment and Materials

A die sinking machine model Sodick AQ35L was used to conduct the EDC experiment. This die sinker machine consists of 3-axis linear motor drive system with a quick response and vibration-free servo system. Aluminum 6061 with the dimension of 30 mm x 50 mm x 15 mm was used as workpiece material. A copper rod with a 6mm diameter was selected as a tool electrode in this research. Before the tool electrode was used for the experiment, the electrode tip was dressed using 320 grit sand paper with 300 rpm to get a flat base surface.

2.2 Preparation of Mixture

Tungsten powder with a purity of 99.5% was used as an additive in this study. Figure 1 shows the scanning electron microscope (SEM) micrograph of tungsten powder. Before the EDC experiment, the tungsten powder, surfactant span 83, and kerosene oil were mixed together by sonication using

a Labsonic ultrasonic homogenizer type P series. The mixing was performed at an amplitude of 50% with an interval of 0.5.

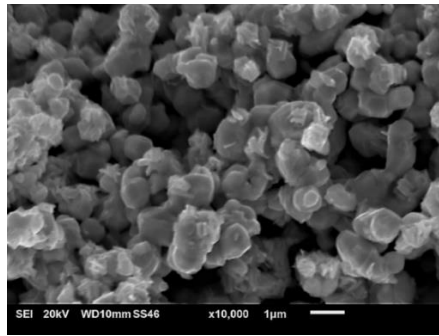


Fig. 1. SEM micrograph of tungsten powder

2.3 EDC Conditions

During the EDC experiment, the polarity was reversed. The aluminum 6061 workpiece was connected to the cathode, and the copper electrode was attached to the anode. The flushing system was used to circulate the dielectric fluid with the addition of tungsten particles. The duration for each test was set to 30 minutes. Peak current and pulse on time were varied while the other parameters such as voltage, pulse off time, and machining time were kept constant. Table 1 shows the experimental conditions for the process.

Table 1

Experiment conditions

Parameters	Conditions
Workpiece material	Aluminum 6061
Tool electrode	Copper
Dielectric fluid	Kerosene oil
Powder materials	Tungsten
Polarity	Aluminum 6061 Workpiece - Negative Copper Electrode - Positive
Surfactant	Span 83
Voltage (V)	40
Current (A)	3 and 4
Pulse on time (μ s)	150, 200 and 250
Pulse off time (μ s)	20
Machining time (minutes)	30

2.4 Measurement and Analysis

The deposited layer thickness was measured by using SEM model Zeiss EVO 50. Ten measurements of coating layer thickness were taken at different spots to ensure data accuracy. Before the measurement, the sample was cut in half using Miracut 151 Low-Speed Precision Cut Off Machine and then cleaned by an ultrasonic cleaning machine with ethanol. The cross-section was ground using 600, 800 and 1200 grit sandpaper to remove the burr. The polishing process was performed by a 1.0 μ m diamat polycrystalline diamond suspension followed by a 0.05 μ m nano-polish alumina suspension manufactured by PACE Technologies Corporation.

3. Results and Discussion

3.1 Coating Layer Thickness

The thickness of the coating layer on the aluminum 6061 workpiece was investigated after the EDC process. Figure 2 shows the SEM image of the sample with the magnification of 2000X at the cross-section area. From Figure 2, it can be seen that a thin layer was coated on the aluminum 6061 machined surface with different thicknesses. According to Liew et al. [10], the coated layer mainly consists of five elements, which were carbon (C), aluminum (Al), tungsten (W), oxygen (O), and copper (Cu). The coated layer becomes thicker as the peak current and pulse on-time increase. The thinnest coating layer was obtained at a peak current of 3A and a pulse on-time of 150 μ s. In contrast, the thickest coating layer was obtained using 4A of peak current with a pulse on-time of 250 μ s. This trend is in line with the findings of Algodí et al. [14].

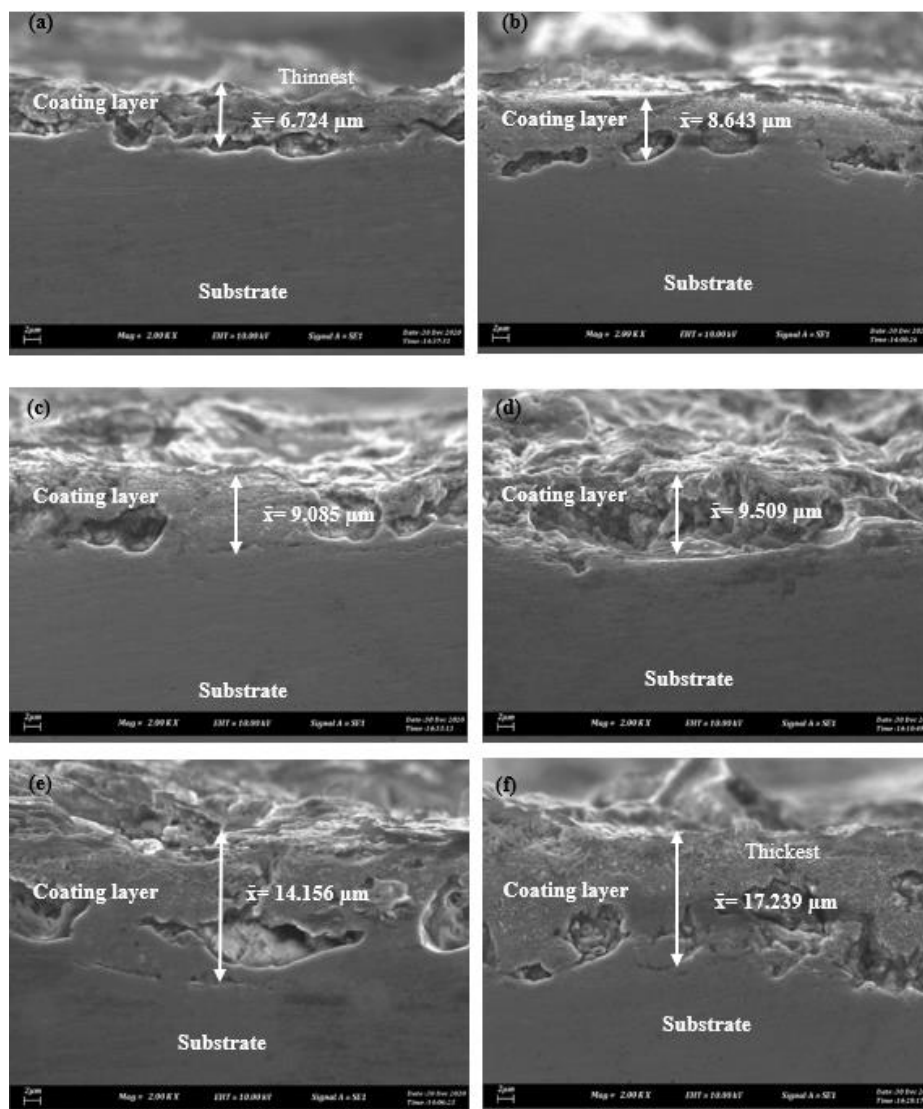


Fig. 2. SEM image of coating layer of tungsten powder deposited on aluminium 6061 workpiece with condition (a) $I_p=3A$, $T_{ON}=150 \mu s$ (b) $I_p=3A$, $T_{ON}=200 \mu s$ (c) $I_p=3A$, $T_{ON}=250 \mu s$ (d) $I_p=4A$, $T_{ON}=150 \mu s$ (e) $I_p=4A$, $T_{ON}=200 \mu s$ (f) $I_p=4A$, $T_{ON}=250 \mu s$

3.2 Effect of Peak Current and Pulse On Time on the Coating Layer Thickness

The effect of peak current and pulse on time on the coating layer thickness is shown in Figure 3. It is clearly seen that the average thickness of the coating layer increases when the value of peak current increases from 3A to 4A under different pulses on time. The thinnest average value of 6.724 μm was observed at 3A, and the thickest average value of 17.239 μm was observed at parameter 4A. Generally, peak current was the most influencing factor and helped initiate spark between the electrode and workpiece [17]. According to Tyagi et al. [18], when a high peak current was used, more material was melted in the plasma channel by the stronger spark produced during the EDC process. Therefore, a higher amount of tungsten powders will be deposited on the aluminum 6061 surfaces, leading to a thicker coating layer.

Besides that, it can be seen that also the coating layer thickness increased significantly when a higher pulse on time was used. These results agree with those obtained by Chakraborty et al. [5] and Elaiyaran et al. [19]. At a low pulse on-time value, the material deposition was lower due to the smaller plasma channel diameter. In this situation, only a small particle volume was present in the spark gap, resulting in a limited volume of material that melted and deposited on the workpiece. However, at a high pulse on-time value, the plasma channel expanded, and the volume of melted material will be higher, leading to a thicker coating layer.

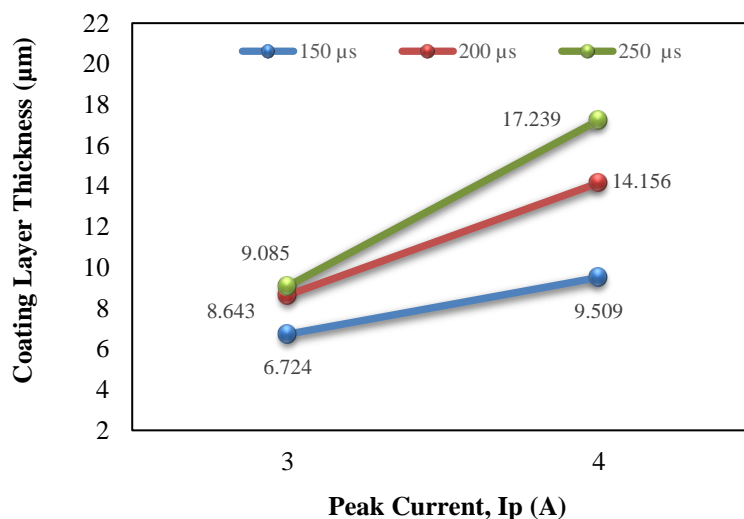


Fig. 3. Effect of peak current on the coating layer thickness

4. Conclusions

This research conducted surface modification of aluminum 6061 using the EDC process with tungsten powder as a powder additive. Peak current and pulse on time were varied, and their effects on the coating layer thickness were investigated. The important findings are concluded, as below:

- When the value of peak current and pulse on-time increase, the coating layer thickness also increases.
- The thinnest coating layer was observed at $I_p=3\text{A}$ and $T_{on}=150\ \mu\text{s}$ with the average thickness of 6.724 μm . In comparison, the thickest coating layer was observed at parameter $I_p=4\text{A}$ and $T_{ON}=250\ \mu\text{s}$ with the average coating layer thickness of 17.239 μm .

Acknowledgment

The authors greatly acknowledged the financial and equipment support from the Ministry of Higher Education (MOHE) and Universiti Teknikal Malaysia Melaka (UTeM) through the PJP grant, PJP/2018/FKP(6A)/S01587.

References

- [1] E.K. Mussada and P.K. Patowari, "Characterisation of Layer Deposited by Electric Discharge Coating Process," *Surface Engineering* 31, no. 10 (2015):796–802.
<https://doi.org/10.1179/1743294415Y.0000000048>
- [2] Y. Oshida, *Surface Modifications: Bioscience and Bioengineering of Titanium Materials* (Amsterdam: Elsevier, 2013), 341-456.
<https://doi.org/10.1016/B978-008045142-8/50011-6>
- [3] V. Shibe and V. Chawla, "A Review of Surface Modification Techniques in Enhancing the Erosion Resistance of Engineering Components," *International Journal of Research in Mechanical Engineering and Technology* 4, no.2 (2014) : 92-95.
<http://www.ijrmet.com/vol4issue2/spl2/19-Vineet-Shibe.pdf>
- [4] V. Richhariya, "Surface Modification of AISI 1020 Mild Steel by Electrical Discharge Coating with Tungsten and Copper Mixed Powder Green Compact Electrodes" (MSc Thesis, National Institute Of Technology Rourkela, 2013).
- [5] S. Chakraborty, S. Kar, V. Dey and S. K. Ghosh, "The Phenomenon of Surface Modification by Electro-Discharge Coating Process: A Review," *Surface Review and Letters* 25, no.1 (2018): 1830003.
<https://doi.org/10.1142/S0218625X18300034>
- [6] J.W. Murray, S.J. Algodí, M.W. Fay, P.D. Brown and A.T. Clare, "Formation Mechanism of Electrical Discharge Ti-Fe Composite Coatings," *Journal of Materials Processing Technology* 243, (2017):143–151.
<https://doi.org/10.1016/j.jmatprotec.2016.12.011>
- [7] K. Watane and A.D. Shirbhate, "Enhancement of Surface Hardness of Mild Steel by using EDC," *International Engineering Journal for Research and Development* 4, No. 7 (2019): 6–6.
<https://doi.org/10.17605/OSF.IO/8DERU>
- [8] P. J. Liew, C. Y. Yap, J. Wang, T. Zhou and J. Yan, "Surface Modification and Functionalization by Electrical Discharge Coating - A Comprehensive Review," *International Journal of Extreme Manufacturing* 2, no.1 (2020) : 012004.
<https://iopscience.iop.org/article/10.1088/2631-7990/ab7332>
- [9] S. Kumari, "Study of TiC Coating on Different Type Steel by Electro Discharge Coating" (PhD Thesis, National Institute Of Technology Rourkela, 2015).
- [10] P.J. Liew, C.Y. Yap, Z.Nurlishafiq, I.S. Othman, S.Y. Chang, A.R. Toibah and J. Wang, "Material Deposition on Aluminium by Electrical Discharge Coating (EDC) with a Tungsten Powder Suspension," *Journal of Advanced Manufacturing Technology (JAMT)* 12, No. 2 (2018): 133–146.
<https://jamt.utem.edu.my/jamt/article/download/4875/3617>
- [11] D. Tijo and M. Masanta, "Mechanical Performance of In-Situ TiC-TiB₂ Composite Coating Deposited on Ti-6Al-4v Alloy by Powder Suspension Electro-Discharge Coating Process," *Surface and Coating Technology* 328,(2017): 192–203.
<https://doi.org/10.1016/j.surfcoat.2017.08.048>
- [12] B.K. Panda and S. Kumar, "Impact of Powder-Mixed Electrical Discharge Machining on Surface Hardness of AISI D3 Die Steel" (PDF, *2019 the 10th International Conference on Mechanical and Aerospace Engineering (ICMAE 2019)*, Brussels, Belgium, July 22-25, 2019).
<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8880966>
- [13] S. Kumar and U. Batra, "Surface Modification Of Die Steel Materials By Edm Method Using Tungsten Powder-Mixed Dielectric," *Journal Of Manufacturing Processes* 14, no. 1 (2012): 35–40.
<https://doi.org/10.1016/j.jmapro.2011.09.002>
- [14] S.J. Algodí, J.W. Murray, M.W. Fay, A.T. Clare, and P.D. Brown, "Electrical Discharge Coating Of Nanostructured Ti-Fe Cermets On 304 Stainless Steel," *Surface And Coatings Technology* 307, (2016): 639–649.
<https://doi.org/10.1016/j.surfcoat.2016.09.062>
- [15] S. J. Algodí, J. W. Murray, A. T. Clare, and P. D. Brown, "Characterisation of TiC Layers Deposited using an Electrical Discharge Coating Process," *Journal Of Physics: Conference Series* 644, no. 1 (2015): 012008.
<https://iopscience.iop.org/article/10.1088/1742-6596/644/1/012008/pdf>

- [16] P. Janmanee and A. Muttamara, "Surface Modification of Tungsten Carbide by Electrical Discharge Coating (EDC) using a Titanium Powder Suspension," *Applied Surface Science* 258, no. 19 (2012) : 7255–7265.
<https://doi.org/10.1016/j.apsusc.2012.03.054>
- [17] A. Das and J. P. Misra, "Experimental Investigation on Surface Modification of Aluminum by Electric Discharge Coating Process using Tic/Cu Green Compact Tool-Electrode," *Machining Science and Technology* 16, no. 4 (2012): 601-623.
<https://doi.org/10.1080/10910344.2012.731951>
- [18] R. Tyagi, N. K. Mahto, A. K. Das and A. Mandal, "Preparation of MoS₂+Cu Coating through the EDC Process and its Analysis," *Surface Engineering* 36, no. 1 (2020): 86–93.
<https://doi.org/10.1080/02670844.2019.1615744>
- [19] U. Elaiyarsan, V. Satheeshkumar and C. Senthilkumar, "Experimental Analysis of Electrical Discharge Coating Characteristics of Magnesium Alloy using Response Surface Methodology," *Materials Research Express* 5, no. 8 (2018): 086501.
<https://iopscience.iop.org/article/10.1088/2053-1591/aad11f>