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Research Paper

Experimental Study on the Surface Modification by Electrical Discharge Process

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Abstract. The creation of modified layer on metal surfaces using new methods is one of the procedures in surface engineering which can improve the surface mechanical properties. The electrical discharge process is a new method that can form a modified layer on the metal surfaces. This study aims to improve of pure aluminum surface properties through Electrical Discharge process with Monel 400 electrode. In order to design the experiments, the pulse on time and the pulse current were considered as input parameters. The SEM images indicated that the increase in the pulse on time and the pulse current can increase the thickness of the modified layer. Based on the obtained results, the thickness of improved layer varied between 35 to 75 microns. The results of the EDX analysis showed the diffusion of the copper and nickel to the aluminum surface. Moreover, the results of microhardness testing of the surface layer showed that after Electrical discharge process, the surface hardness has increased and the surface hardness as 35 Vickers has reached more than 400 Vickers.

Keywords: Microardness; Electrical discharge; Pulse on Time; Pulse current.

1. Introduction

A surface is the outermost binding layer of a certain object. It plays a vital role in determining the behavior of a substrate as it is the first layer of contact between a substrate and the environment in which it functions. In recent years, a significant progress has been occurred regarding the usage of Electrical Discharge Machining (EDM) in micromachining and surface modification. EDM is the one of the non-traditional machining methods which is widely used in electrically conducting materials. The thermal action of EDM process is known to yield a relatively poor surface integrity, therefore, after EDM process, in order to improve the EDM-induced surface integrity, surface treatments is necessary for the EDMed parts [1,2,3].

Therefore, in order to harden and coat the surface of products which are produced by EDM, first, the recast layer which has low mechanical properties should be removed then coating or material surface deposition should be done. But the alternative solution is to anticipate surface modifying or electrical discharge alloying (EDA), which eliminates the need for secondary operations of the surface modification [4].

This kind of surface modification is performed by selecting suitable materials for the electrode with the aim of increasing the work piece surface integrity. In This process, discharge current, pulse-on time, pulse-off time, and voltage are the most

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commonly used input parameters. The T_i is the duration of pulse on time during which the electrical energy is supplied to the electrode and the workpiece. The duration of T_i plays a very important role in machining performance. Apart from this, the pulse current (I) is another very important process parameter on which the machining efficiency depends [5-6 and 7].

A few studies are available of EDA process. Simao et al. studied the surface modifying of H13 tool steel using the composite electrode WC/ Co inside a hydrocarbon fluid. Based on their results, the surface hardness increased after the EDA process compared to the base material hardness (640HK) and reached to1319HK. Moreover, surface cracks decreased at the workpiece surface [4]. Kumar et al. evaluated the surface modifying of AISI D2, AISI H13, and OHNS tool steel by adding the tungsten powder to a dielectric fluid. The results of the XRD analysis indicated that the diffusio n of tungsten powder with carbon to the surface alloyed increases the surface hardness up to 100% for all three typ es of tool steel. Based on the results of this study, tungsten carbide (WC, W_2C) was produced at the surface which is the sign of its formation inside the plasma channel [8]. Mir et al. investigated the surface roughness modeling in EDM process of AISI H11 tool steel with the addition of powder (aluminum) to the dielectric fluid. In their research, the pulse on time, the puls, current, and the concentration of aluminum powder were considered as input parameters and the Response Surface Methodology (RSM) was used to optimize the output parameters. Based on the results of this research, the RSM is a suitable method for modeling the EDM process and among the selected input parameters, the pulse current and powder concentration were the most important parameters affecting the surface roughness of the workpiece [9]. Khedkar et al. studied the alloying and improving the surface quality of OHNS tool steel through adding the tungsten powder into the dielectric fluid. They considered the pulse current, the pulse on time, and the pulse off time as input parameters and the surface hardness as the output parameter. The testing hardness results showed an increase in the hardness of the workpiece surface from the initial value of 506 Vickers to 1090 Vickers [10].

Based on the above-mentioned literature, the aim of present study is to use an electrical discharge process to create a modified layer at the aluminum surface using copper and nickel. Therefore, to be precise, it investigates the influence of the EDA input parameters with Monel 400 electrode on the aluminum surface microhardness and thickness of the modified layer.

2. Experimental procedure

In experiments, aluminium was selected as a workpiece material with the purity of 99.98% and the tool material was Monel 400. Tables (1) and (2) represent the chemical analyses of the aluminum workpiece and the Monel 400 electrode.

Table 1. Chemical composition of pure aluminum (%wt).

Al	Mn	Fe	Ni	Si	Mg	Cr
99.80	0.003	0.118	0.006	0.04	0.003	0.004

Table 2. Chemical composition of Monel 400 (%wt).

Ti	Zr	Al	Cr	Fe	Ni	Cu
0.032	0.035	0.14	0.095	1.65	66.64	28.09

In order to prepare the aluminum specimens, the cutting, turning, and grinding were carried out on the raw material and 16 cylindrical aluminum with the dimensions of $12\times14mm^2$. In order to prepare 16 cylindrical electrodes with the dimensions of $18\times20mm^2$, cutting, machining, and grinding were done on Monel 400. Figure 1 shows the aluminum workpiece and the Monel electrode.

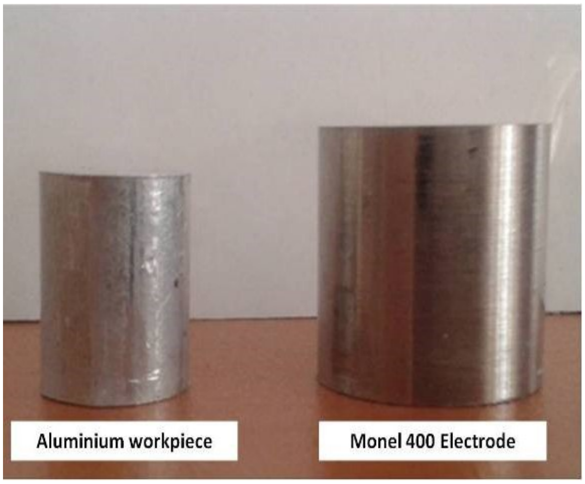


Fig. 1. Monel electrode and aluminum workpiece.

During these experiments, the pulse on time (T_i) and the pulse current (I) each were considered as an input parameter of four levels. All samples were machined by the use of die sinking EDM machine (CNC- Charmilles Roboform 200) with an iso-pulse generator. Each test was performed for 20 minutes. In order to create the same conditions for flushing during all experiments, the normal submerged flushing method was used. Table (3) provides test conditions and Fig. 2 indicates the setting of electrodes before EDA process.

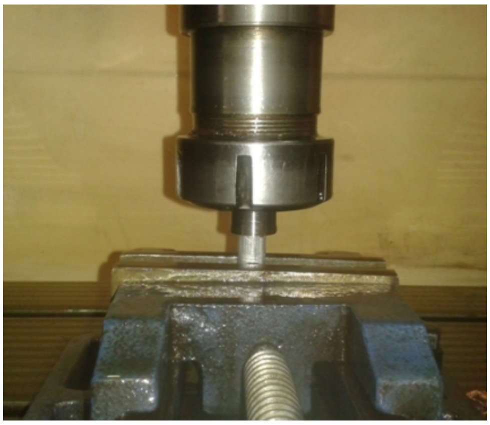


Fig. 2. Setting the electrode and workpiece to EDA process

Table 3. Experimental test conditions.

Parameters	Conditions
Dielectric fluid	Kerosene oil
Pulse on-time (µs)	50,100,200,400
Voltage (V)	160
Pulse current (A)	12,16,24,32
Pulse of time (µs)	800
Tool Polarity	Negative

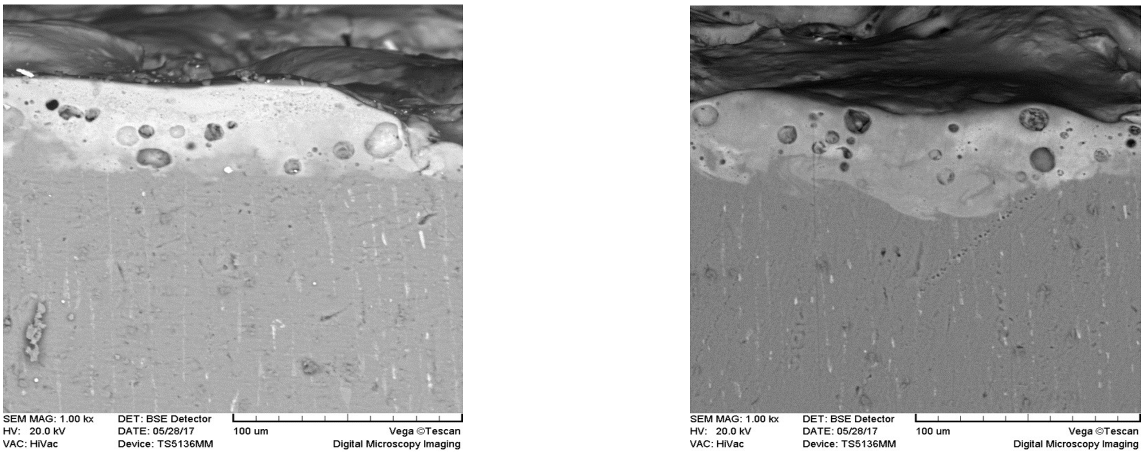
A digital balance (CP2245-Surtorius) with the resolution of 0.1 mg was used for weighing the Monel 400 before and after the EDA process. Furthermore, an optical microscope (Olympus PMG3) was used to provide microscope images. The hardness of modified layer was measured by using a hardness measuring an instrument, namely Olympus LV 700 hardness tester. Therefore, the modified specimens were sectioned transversely and prepared under a standard procedure for metallographic observation by utilizing Cam Scan MV2300 scanning electron microscopy (SEM).

3. Results and discussion

3.1. The effect of pulse current on the surface layer thickness

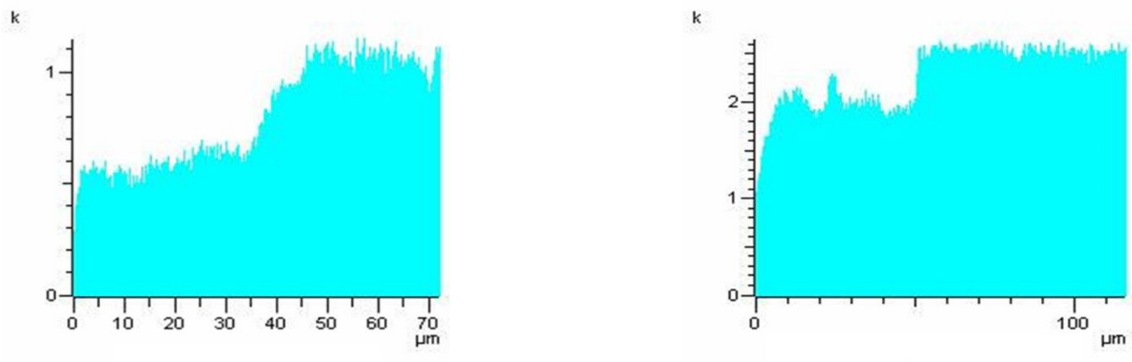
Figure 3 shows the modified layers after EDA process. According to this figure, by an increase pulse current, the average thickness of the modified layer increases. The results of EDX analysis (line scan) of these specimens show that in T_i=100µs, I=16A has a thickness of 35µm but in T_i=100µs, I=24A improved layer thickness becomes 50 µm (Fig. 4). The pulse current is one of the important parameters affecting the energy of sparks in EDA process. Increasing the current through the gap increases electric flows which increases the surface temperature and causes deeper melting at surface [11]. Consequently, by increasing the size of the melt carters at the aluminum surface the thickness of the modified layer increases.

Figures 5 and 6 show the effect of pulse current on the diffusion depth of nickel and copper at the aluminum surface. By increasing the pulse current due to the increase in discharge strike, bigger craters are created on the surface of the Monel 400 [12]. Figure 7 shows the effect of pulse current on the surface carters of Monel 400 surface after EDA process. This results in the larger erosion of the Monel 400 electrode and simultaneously by an increase in the pulse current, the Material Removal Rate (MRR) from the Monel 400 increase (Fig. 8). Increasing MRR from the negative pole (Monel 400) in high temperature conditions causes higher diffusion of nickel and copper at the aluminum surface.



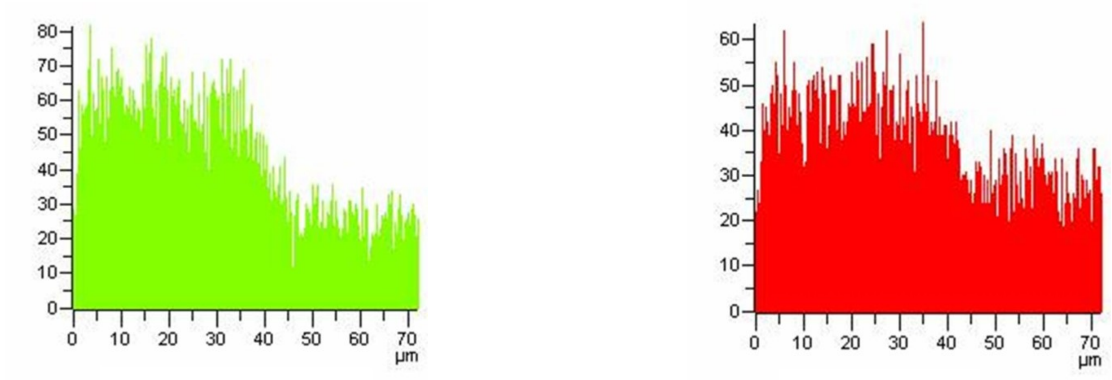
(a) (b)

Fig. 3. SEM micrograph showing cross-section of EDAed piece. a) T_i=100, I=16A, b) T_i=100, I=24A



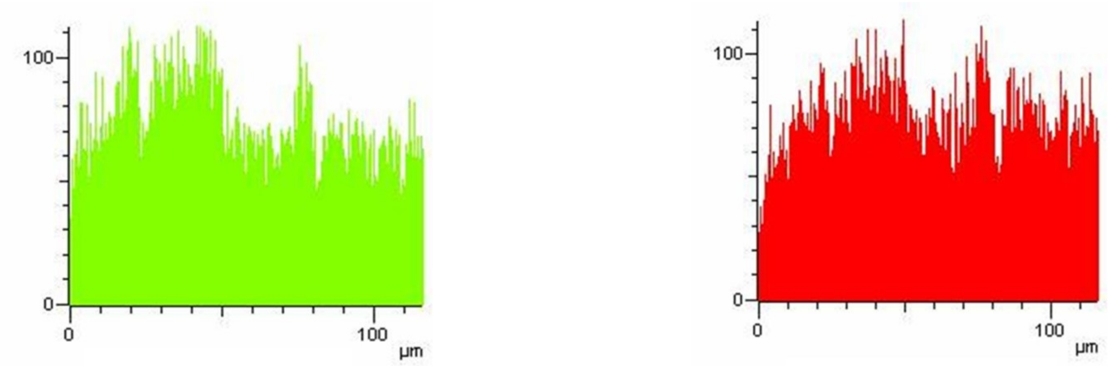
(a) (b)

Fig. 4. Energy dispersive Spectroscopy (Line scan) results of workpiece cross-section after EDA a) T_i=100, I=16A, b) T_i=100, I=24A



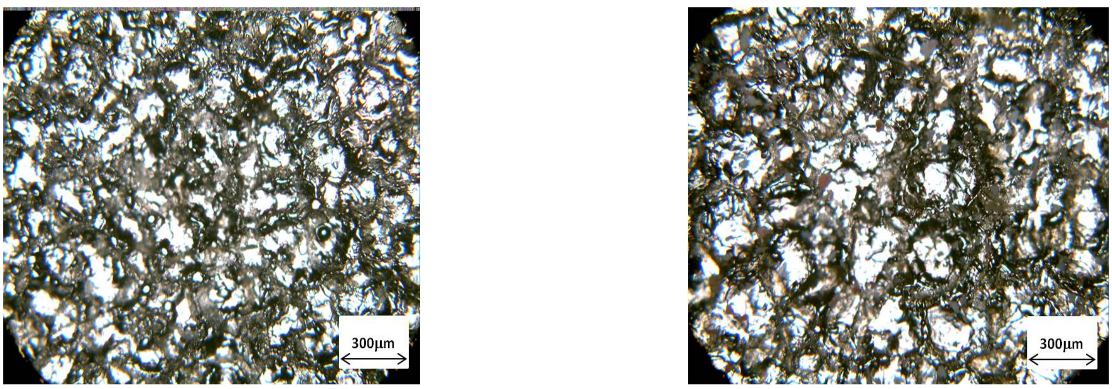
(a) (b)

Fig. 5. Energy dispersive Spectroscopy (Line scan) results of workpiece cross-section after EDA. (T_i=100, I=16A) a) Depth of Nickel diffusion (µm), b) Depth of copper diffusion (µm)



(a) (b)

Fig. 6. Energy dispersive Spectroscopy (Line scan) results of workpiece cross-section after EDA. (T_i=100, I=24A) a) Depth of Nickel diffusion (µm), b) Depth of copper diffusion (µm)



(a) (b)

Fig. 7. Effect of pulse current on the surface topography of Monel 400 electrode after EDA. (100 X) a))T_i=50,I=16A, b) T_i=50,I=32A

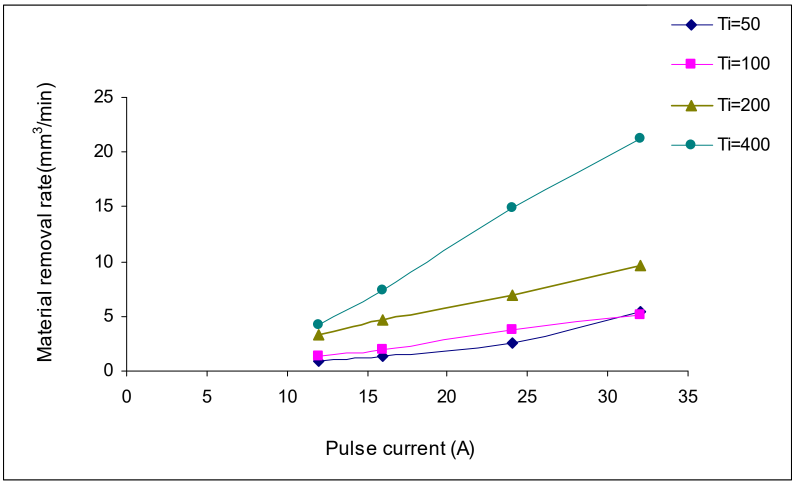
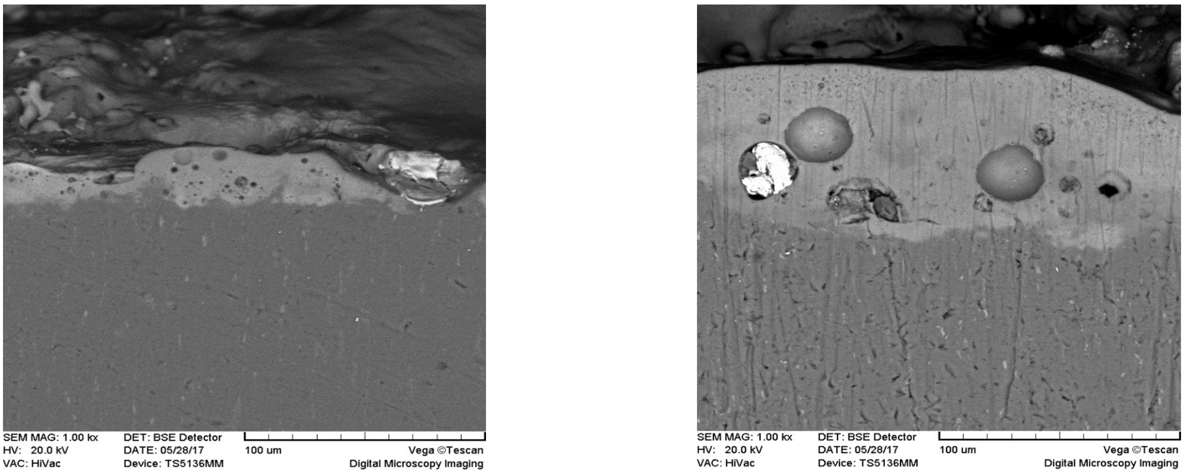


Fig. 8. Material removal rate from the Monel 400 electrode in EDA process.

3.2. The effect of pulse on time on the surface layer thickness

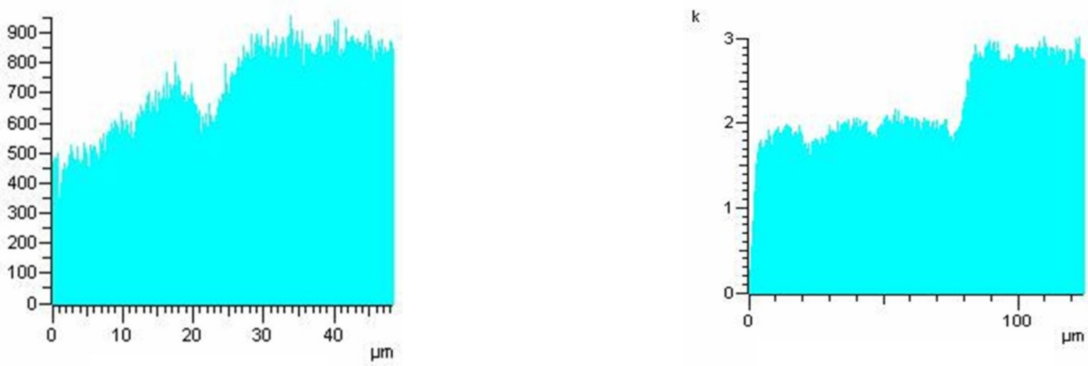
Figure 9 shows the effect of pulse on time on the modified layer thickness after EDA process. According to this figure, by an increase in the pulse on time, the thickness of the modified layer increases. The results of EDX analysis indicates that the thickness of modified layer for T_i=100µs, I=32A is 25µm while in T_i=400µs, I=32A the thickness has reached 75µm (Fig. 10). The pulse on time is one of the most important factors affecting the energy of sparks. As the pulse on time increases, the energy of sparks and the melting depth of surface increases [13, 14]. Moreover, by increasing the pulse on time, the process efficiency increases by increasing the number of useful sparks over time.

Figures 11 and 12 show the effect of pulse on time on diffusion depth of nickel and copper at the aluminum surface. According to the microscopic images of the surface of the Monel 400 electrode (Fig. 13), by increasing the pulse on time due to increased spark energy, larger craters are created on the negative pole; furthermore, MRR from the Monel 400 electrode is associated with an increased pulse on time (Fig. 8). The higher erosion of Monel 400 increases the efficiency of the EDA process so that diffusion depth of copper and nickel reaches over 70 micrometers.



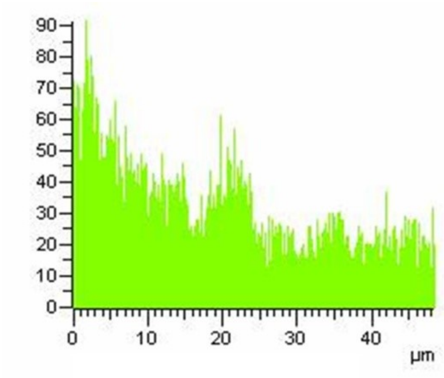
(a) (b)

Fig. 9. SEM micrograph showing cross-section of EDAed workpiece. a) T_i=100,I=32, b) T_i=400,I=32A

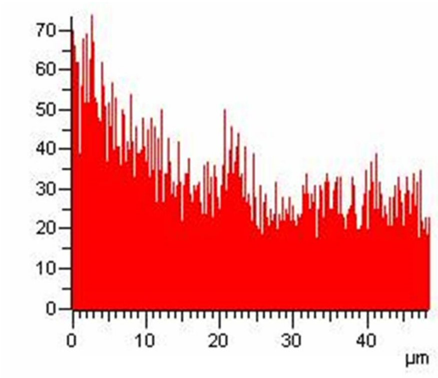


(a) (b)

Fig. 10. Energy dispersive Spectroscopy results of workpiece cross-section after EDA. a) T_i=100, I=32A, b) T_i=400,I=32A

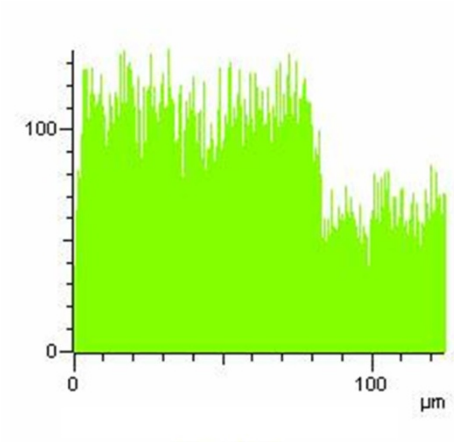


(a)

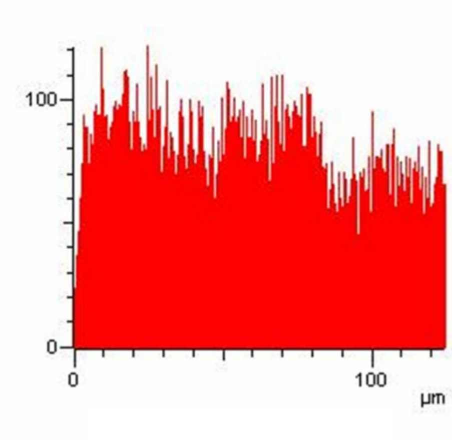


(b)

Fig. 11. Energy dispersive Spectroscopy (Line scan) results of workpiece cross-section after EDA. (T_i=100,I=32A) a) Depth of Nickel diffusion (µm), b) Depth of copper diffusion (µm)

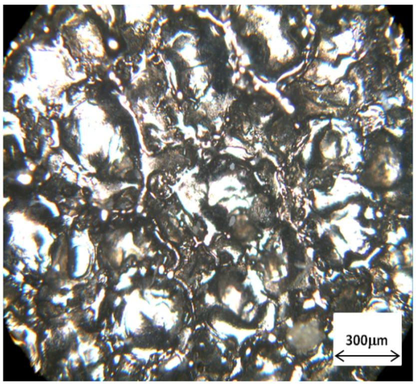


(a)

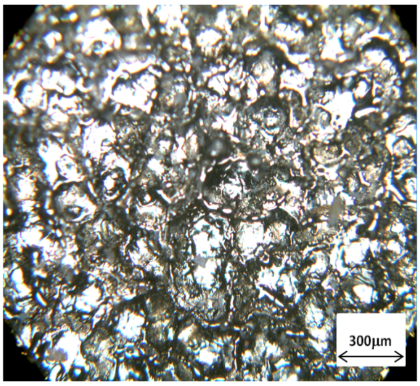


(b)

Fig. 12. Energy dispersive Spectroscopy (Line scan) results of workpiece cross-section after EDA. (Ti=400,I=32A) a) Depth of Nickel diffusion (µm), b) Depth of copper diffusion (µm)



(a)



(b)

Fig. 13. Effect of pulse on time on the surface topography of Monel 400 after EDA (100 X) a) T_i=100,I=16A, b) T_i=400,I=16A

3.3. The effect of pulse on time on the surface hardness

Figure 14 shows the effect of pulse on time on the depth of the hardened layer of aluminum specimens. As it can be seen, the surface hardness increased as the pulse on time increased, so that from initial value of 35 Vickers (before EDA), it reached more than 300 Vickers. The main factor in the increase of surface hardness is the diffusion of copper and nickel into aluminum surfaces. Figure 15 shows the results of EDX analysis from the surface layer. An increase in the pulse on time increases the diffusion of alloying elements on the aluminum surface. That is because of the increase in MRR of the Monel 400 electrode, which is due to the creation of a more energetic spark.

In other words, by an increase in the pulse on time, the greater erosion of the Monel 400 happens. As a result, due to the increase of the Monel particles between the electrode and the workpiece, a series of discharge starts under the electrode area. These series of discharge which modifies the plasma channel between the electrode and the workpiece. Subsequently, increasing the concentration of Monel particles on the aluminum surface increases the diffusion depth (hardened layer) of copper and nickel to aluminum surface [15].

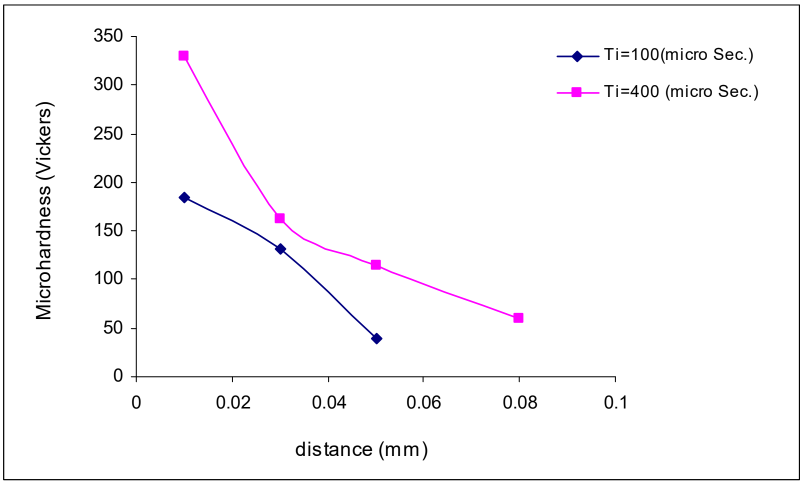


Fig. 14. Microhardness profiles alonge EDA treated sample cross section. (I=16A)

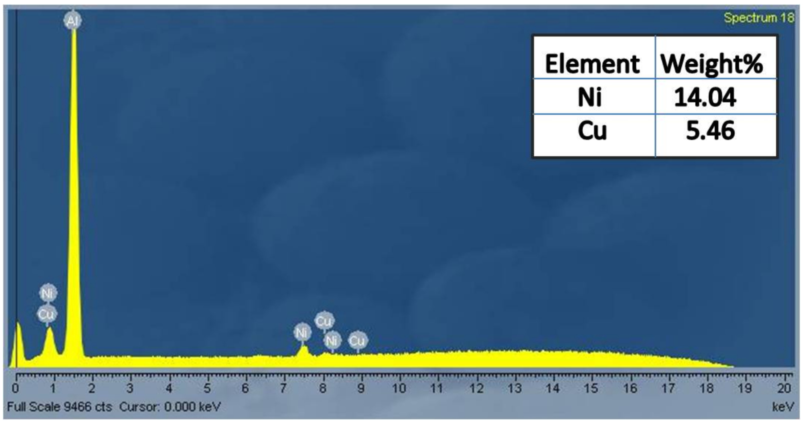


Fig. 15. EDX analysis of alloyed layer after EDA process. (T_i=100s, I=16A)

3.4. The effect of pulse current on the surface hardness

According to Fig. 16, by increasing the pulse current, the surface hardness and depth of the improved layer increases. Therefore, regarding the diffusion of copper and nickel in the setting of T_i=400µs, I=24A, the surface hardness reaches more than 450 Vickers (Fig. 17). As mentioned in the previous section, one of the main parameters of the energy of the sparks is the pulse current. Therefore, increasing the pulse current increases the electrical discharge energy, which causes the higher melting of the Monel 400. Increasing the surface temperature and increasing the concentration of copper and nickel on the surface increases the diffusion of these elements to the aluminum surface; therefore, the surface hardness and hardened depth increase [16].

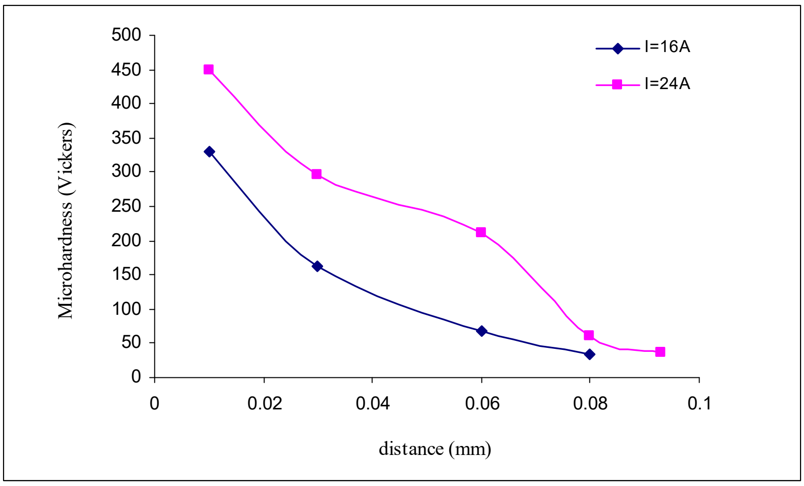


Fig. 16. Microhardness profiles alonge EDA treated sample cross section. (T_i=400µs)

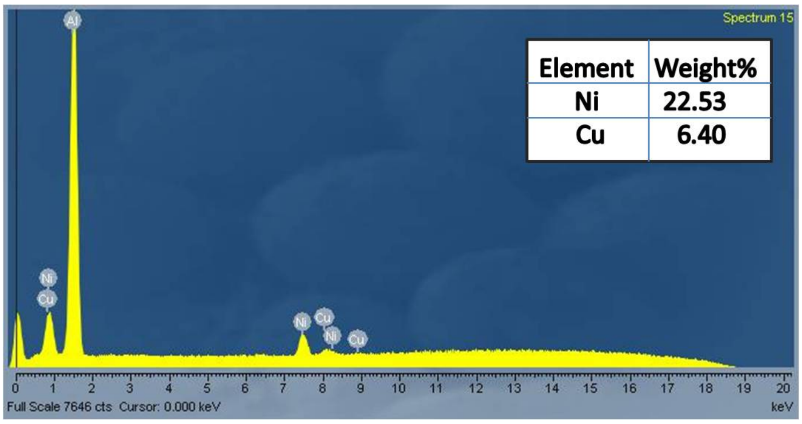


Fig. 17. EDX analysis of alloyed layer after EDA process (T_i=400s, I=24A)

4. Conclusion

In this research, the Monel 400 electrode was used to identify the effect of EDA input parameters on the surface property of the pure aluminum. The most important findings of this study are as follows:

1. Improving the surface properties by the use of EDA method is a useful procedure for increasing the surface properties of manufactured components. Therefore, using the Monel 400 electrode increases the surface properties of aluminum.
2. The thickness of the modified layer increased by an increase in the pulse on time and the pulse current and its thickness reached 75 microns.
3. The results of EDX analysis from the alloyed layer indicated that the increase in the pulse on time and the pulse current increase the diffusion of copper and nickel to the surface.
4. Increasing the pulse on time and the pulse current increases the erosion rate of the Monel 400 electrode, which results in higher efficiency of alloying process.
5. The results of microhardness testing indicated that by an increase in the pulse on time and the pulse current, the surface hardness increases, and in the setting of T_i=400µs, I=24A, the initial hardness from 35 Vickers reaches more than 400 Vickers.

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Conflict of Interest

The authors declare no conflict of interest.

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