Improving the Surface Wear Resistance of Aluminum by Electrical Discharge Process

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ABSTRACT

In this study, electrical discharge process was used to increase surface wear resistance of pure aluminum. Pulse-on-time and pulse current were considered as the input parameters of the electrical discharge process. Experimental results revealed that the electrical discharge process is a successful method for improving the surface wear resistance of aluminum, to the effect that it has greatly increased the surface wear resistance of aluminum parts. The results indicate that with increasing the input parameters (pulse-on-time and pulse current), weight loss of the aluminum specimens is reduced and wear resistance increases. The XRD analysis demonstrated that Al_3Ni_2 and AlCu intermetallic compound and Al_4C_3 were formed on the alloyed surface. The presence of these compounds and hard particles on the surface increases the wear resistance. Also, friction coefficient measurements showed that after electrical discharge process and improving surface wear resistance, the friction coefficient slightly increased due to the presence of hard particles on the alloyed surface.

1-Introduction

The advancement of technology has made the need for metal materials with better surface properties. Therefore, with the development of materials science, materials with new structures and special functions have been considered by researchers. Aluminum alloys are used in a variety of structures, aerospace and marine industries, electronic equipments, etc. due to their unique properties such as high strength to weight ratio, good weld ability, excellent formability, fairly well corrosion resistance, [1, 2]. Compared to other metals such as steel, the most noticeable weaknesses of aluminum are low hardness, low wear resistance. Therefore, due to poor mechanical properties, the use of aluminum alloys has limitations despite the stated advantages. But a significant characteristic of aluminum is the formation of intermetalic compounds with other elements such as Fe, Ni, Co, Cr, Ti and Cu. Therefore, in recent researches, the creation of intermetallic compounds in aluminum with these elements is interest [3-6].

The traditional methods used to increase the surface properties of machined parts are the secondary methods that increase the time and production cost.

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In the case of work pieces that are produced by electrical discharge machining (EDM), for the purpose of hardening and coating, at first, the recast layer which has low mechanical properties should be removed and then the secondary coating operation on the surface should be done. But the alternative solution is to anticipate surface modifying or surface alloying with electrical discharge process, which eliminates the need for secondary operations for surface modification. The results of the researches indicated that the wear resistance of the alloyed layer by Electrical Discharge Alloying (EDA) method is more than the work piece that does not have the modified layer. This method has a lot of flexibility and low cost [7].

EDM is classified under thermo-electric methods in which material removal takes place through the process of controlled spark generation. Although electrical discharge machining is a material removal and machining process, the researchers use the capabilities of this method to carry out surface engineering processes [8]. Research results show that the surface layer after an EDM operation is a high-speed cooled, and the depth of this layer depends on the energy and the pulses of duration. Below this layer, there is a layer affected by EDM, and its chemical composition has been changed and phase changes can be seen.

Therefore, the composition of the recast layer by materials in the dielectric or electrodes is an effective way to improve the surface quality. This kind of surface alloying is performed by selecting suitable materials with the aim of increasing the surface hardness, increasing wear resistance and improving the corrosion resistance [9, 10].Due to the improvement of surface quality with the use of electrical discharge process, it is one of the latest research areas in the manufacturing engineering, but not much work has been done in this field and the conducted studies have only focused on the tool steel. Simao et al. studied surface alloying of H13 tool steel using composite electrode WC/ Co inside a hydrocarbon fluid. Based on their results, surface cracks decreased and surface hardness increased after the alloying process compared to the base material hardness [7]. Kumar et al. investigated the surface alloying of AISI D2, AISI H13 and OHNS tool steel using tungsten powder. In their research, Taguchi method was used to design the experiments, and the pulse-on time and pulse-off time and pulse current were considered as the input parameters and the surface micro hardness was considered as the output parameter. The results of the XRD analysis indicated that the diffusion of tungsten powder with carbon to the surface alloyed increases the surface hardness up to 100% for all three types of steel. Based on the results of their study, tungsten carbide (WC, W2C) was formed on the surface which is the sign of its formation inside the plasma channel [11]. Mir et al. investigated surface roughness modeling in EDM process of AISI H11 tool steel with the addition of powder (aluminum) to dielectric fluid. In their research, parameters of pulse on time, pulse current and concentration of aluminum powder added to the dielectric fluid were considered as the input parameters and the Response Surface Methodology (RSM) was used to optimize the output parameters. Based on the reported results, the RSM is a suitable method for modeling the EDM process and among the selected input parameters, the pulse current and powder concentration are the most important parameters affecting the surface roughness of the work piece [12]. Tsunekawa et al. investigated aluminum surface alloying using titanium electrodes by electrical discharge method. They produced TiC-TiAl composite layer at the aluminum surface [13]. Khedkar et al. studied the alloying and improving the surface quality of OHNS tool steel using the addition of tungsten powder into the dielectric fluid. The pulse current, pulse on time and pulse off time were considered as the input parameters and surface hardness as the output parameter. Hardness testing results indicated the increase in the surface hardness from 506 to 1090 Vickers [14]. Khan et al. studied the surface properties of mild steel using TiC and Al2O3 powder mixed in dielectric fluid. The results showed that increasing the current leads to increase in the recast layer thickness and the cracks. The Al2O3 powder gave higher layer thickness than the TiC powder [15].

Based on the literature review it can be concluded that very little work has been done regarding surface modification of aluminum and its alloys using electrical discharge method. Thus the objective of this study is to investigate the improvement in the surface wear resistance of pure aluminum by Monel 400 elcetrode.

2- Experimental procedure

In this study, in order to improve wear resistance of pure aluminum (99%), monel 400 which is the alloy of copper and nickel was used as an electrode. Before doing the process, to ensure the chemical composition of the specimens, the samples analysis was carried out using spectroscopy method. Table 1 shows the chemical composition of the pure aluminum and Table 2 demonstrates the chemical composition of the electrode (Monel 400).

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))

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

In order to prepare the aluminum specimens, cutting, turning and grinding were done on the raw material and 16 cylindrical aluminum samples with the dimensions of 12×14 mm2 were prepared. Also, for the preparation of Monel 400 electrodes, cutting, machining and finishing were done and 16 cylindrical electrodes 18×20mm^2 were prepared. Fig. 1 shows the aluminum work piece and the Monel electrode.

All of the tests were designed by DOE method; in this way full factorial technique was developed for performing experiments (pulse on time and pulse current in four levels). Considering that this research has been done with the aim of improving the aluminum wear resistance, it was intended to reduce the erosion of the aluminum specimens and increase the erosion of the alloying electrode at negative pole to the monel 400 and the positive pole to the aluminum. All specimens were alloyed by EDM apparatus (CNC- Charmilles Roboform 200) which contains an Iso-pulse generator. Each test was performed for 20 minutes. In order to create the same conditions for flushing in all experiments, the normal submerged flushing method was used.

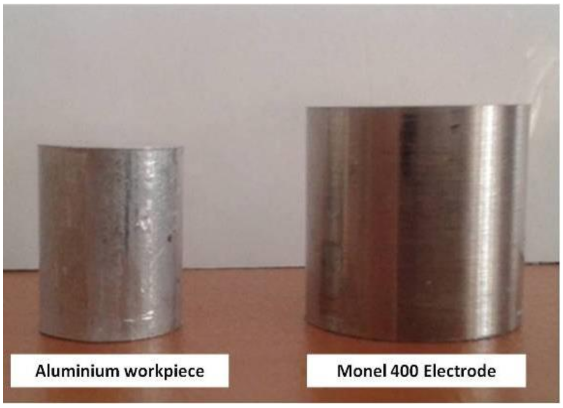


Fig. 1. Monel Electrode and work piece

Fig. 2 indicates the setting of electrodes before starting EDA, and Table 3 provides the input parameters and test conditions. To obtain the wear resistance, the dry ball-on-disc method was used. Also, to calculate the weight loss of the samples before and after the wear test, firstly the samples were washed with acetone and then weighed using a digital balance (CP224S-Surtorius) with a resolution of 0.1 mgr. The machined specimens were sectioned transversely and prepared under a standard procedure for metallographic observation by utilizing Cam Scan MV2300 scanning electron microscopy (SEM). Also, optical microscope Olympus PMG3 was used to provide microscopic images. Table 4 shows the conditions for the wear test and Fig. 3 shows the wear test setting.

Fig. 2. Setting the electrode to electrical discharge process

Table 3. Experimental test conditions

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

Table 4. Wear test conditions

Disc diameter (cm)	Sliding distance(m)	Force (Kgf)	Linear velocity (cm/s)	Time (min)
14	500	4	10	84

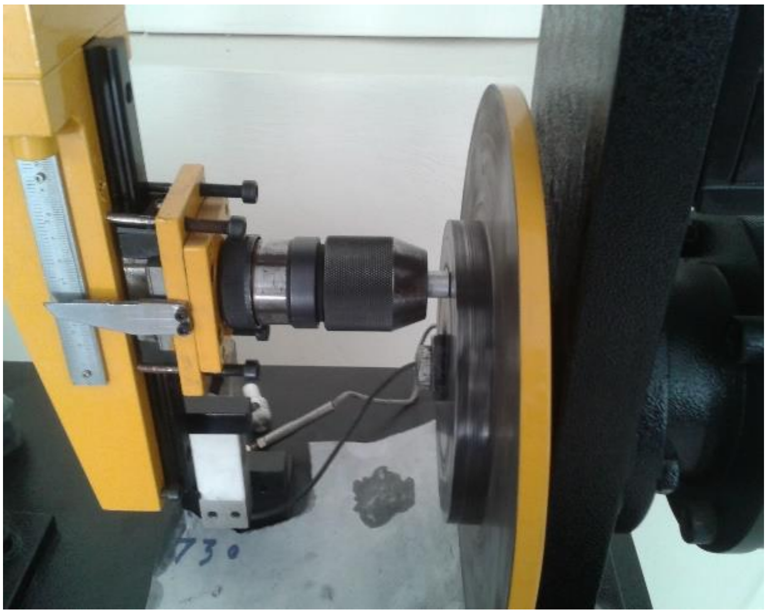


Fig. 3. Setting the dry ball-on-disc wear test

3- Results and discussion

Fig. 4 shows the effect of surface alloying by electrical discharge on the surface wear resistance of aluminum specimens. As can be seen, by performing the improvement of surface properties through EDA, the weight loss of the aluminum sample compared to the base metal has been decreased. Fig. 5 shows the result of the XRD analysis of the alloyed layer. As a result of the electrical discharge, the Monel 400 was decomposed and the copper and nickel elements diffusion to aluminum surface and causes the formation of Al_3Ni_2 and AlCu compounds. Also, the carbon from Kerosene oil decomposition has formed an Al_4C_3 layer on the aluminum surface. The presence of hard particles and intermetallic compounds (Al_3Ni_2 and AlCu) in surface of material can be a barrier to the formation of surface scratches (Fig. 6).

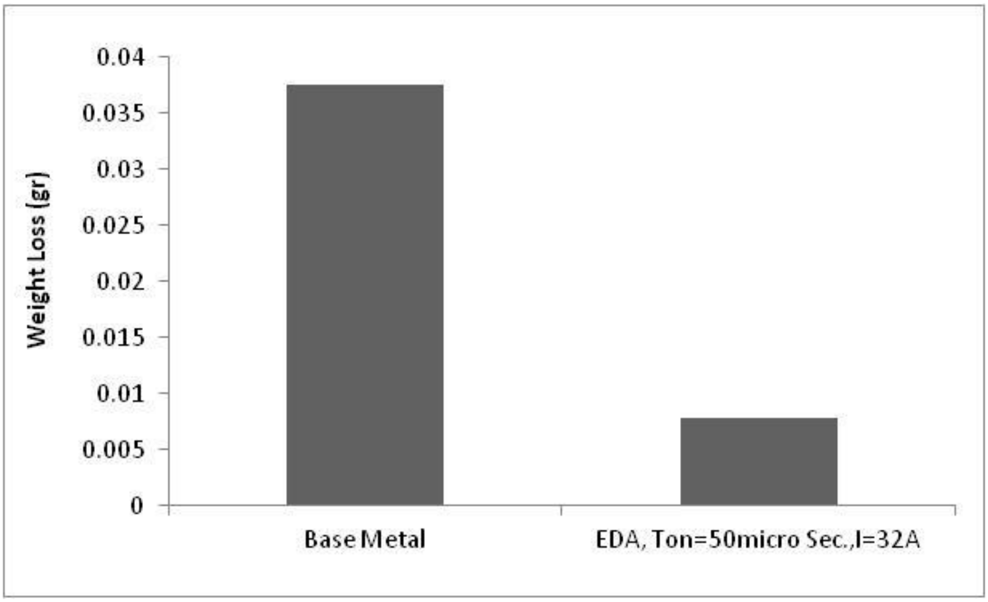


Fig. 4. Comparison of wear resistance of EDAed aluminum and the base metal

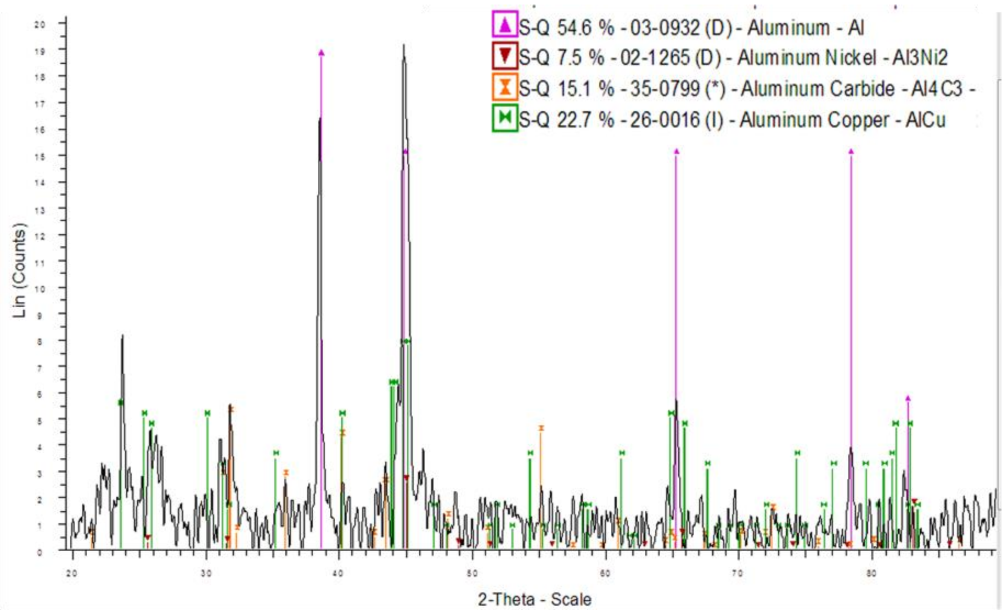


Fig. 5. XRD pattern of the alloyed layer after electrical discharge alloying

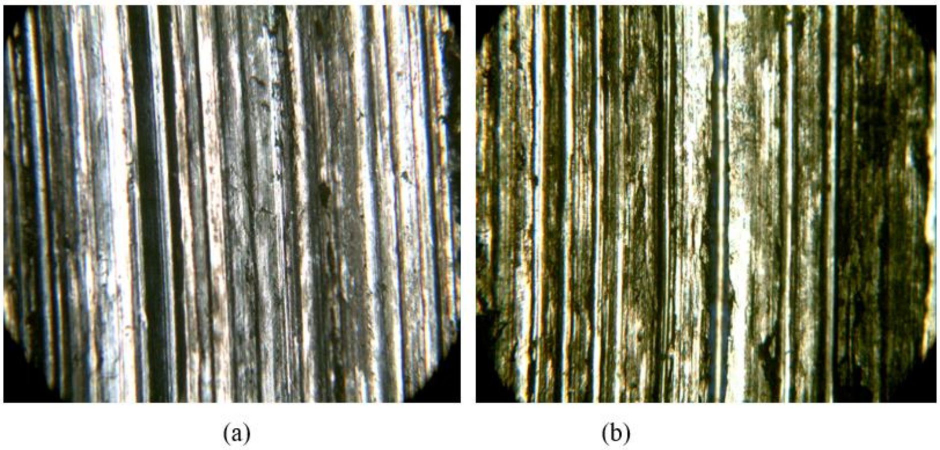


Fig. 6. Base metal and EDAed surface after wear test (100 X)
a) Pure aluminum, b) EDAed specimen (Ton=50μs,I=32A)

3-1-The effect of pulse on time on the surface wear resistance

Fig. 7 shows the effect of the pulse on time on the wear resistance of aluminum parts after surface improving by EDA method and figure 8 shows the effect of pulse on time on the thickness of surface layer. As can be seen, through increasing pulse on time surface layer thickness increases and thus wear resistance increases. This could be justified by the fact that the energy of each spark according to its electrical concept is a function of discharge current (I), pulse on time (Ton) and discharge voltage (U) [16]. This relationship is shown in Equation 1:

$$\int_0^{T_{on}} U(I_i)I(T_i)dT_i \qquad (1)$$

Pulse on time is one of the main parameters affecting the energy of sparks. As the pulse on time increases, the sparks energy increases. Increasing the sparks energy increases the thickness of the melted layer and, as a result, the depth of the alloyed layer increases. Increasing the thickness of the alloyed layer at the surface increases the wear resistance of the aluminum [17, 18]. 3-2- Friction coefficient

Fig. 9 and Fig. 10 show the friction coefficient diagram according to the sliding distance during the wear test. As can be seen, the average friction coefficient of aluminum without surface alloying is 0.078 and the average friction coefficient for the alloyed surface is 0.084. The friction coefficient does not change much and the small increase in the average friction coefficient is due to the carbide particles and AL_3Ni_2, AlCu particles in the surface composition of the alloyed layer. The slight variation of the friction coefficient can be due to the fact that the aluminum surface roughness has increased with electrical discharge alloying method. Increasing surface roughness through reduces tangential force reduces the friction coefficient [19].

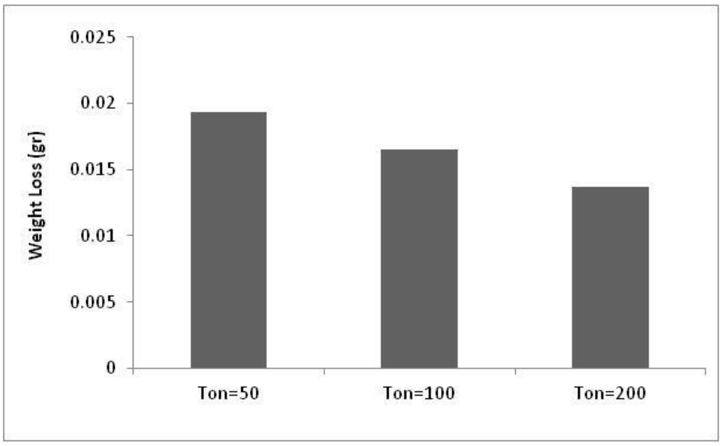
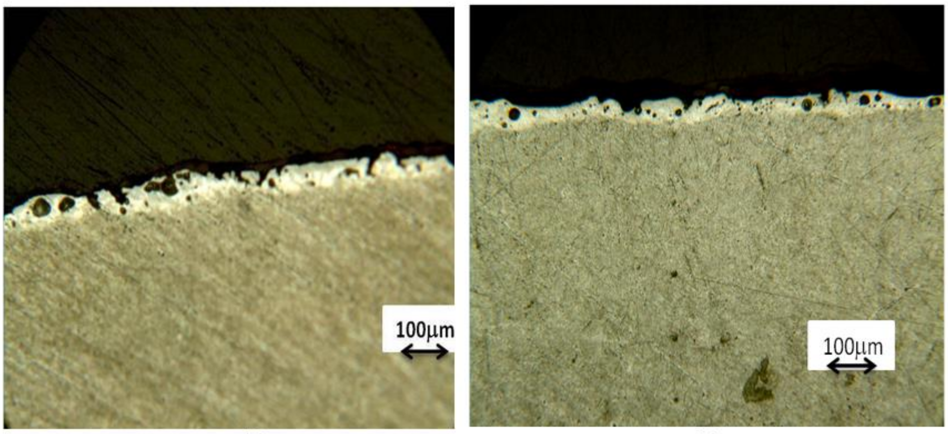


Fig. 7. Effect of pulse on time on wear resistance



(a) (b)

Fig. 8. Aluminum surface after EDAed process (200 X)
a) Ton=400µs,I=16A b) Ton=100µs,I=16A

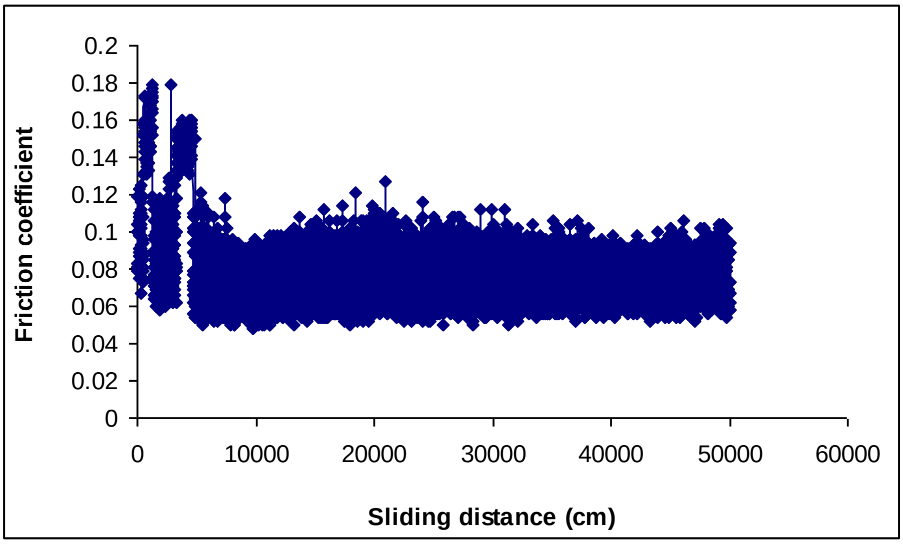


Fig. 9. Friction coefficient diagram (base metal)

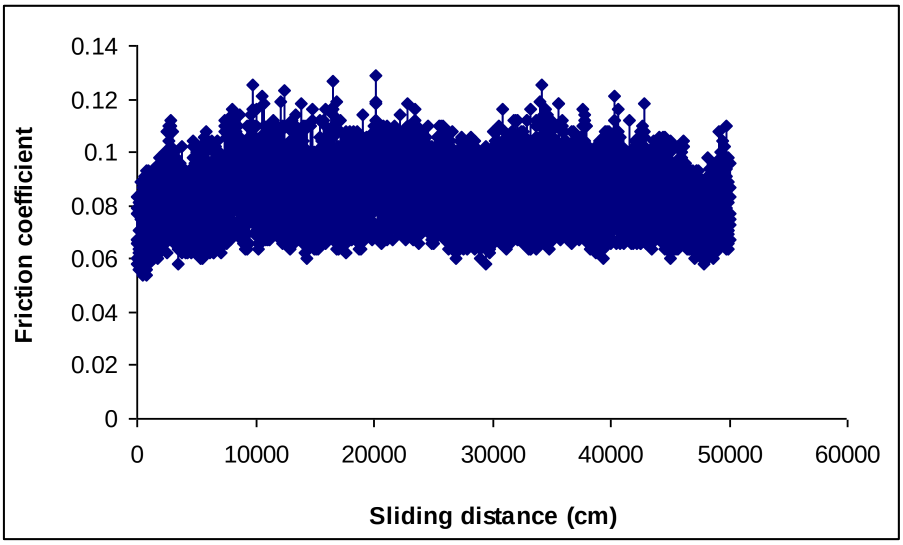


Fig. 10. Friction coefficient diagram after EDAed process (T_{on}=200µs,I=12A)

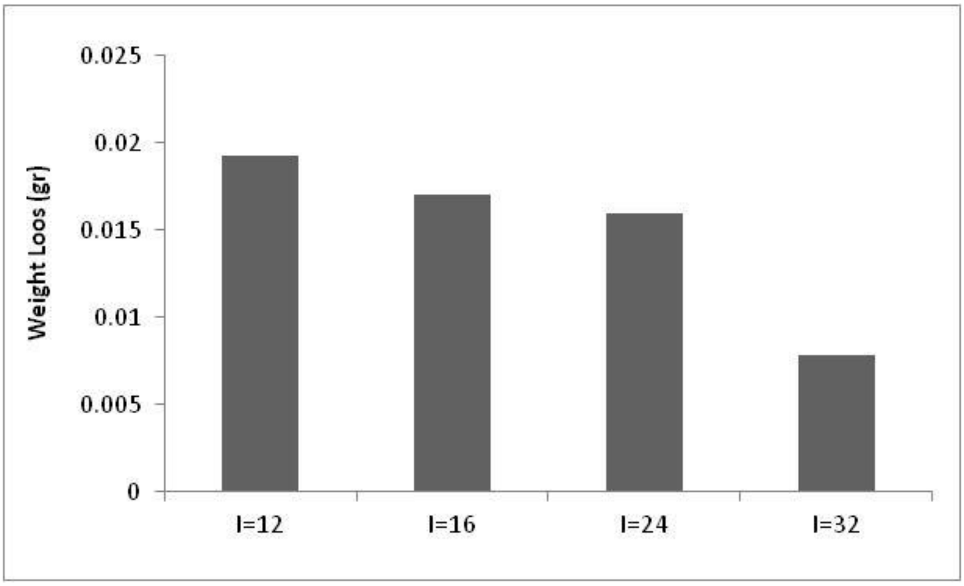
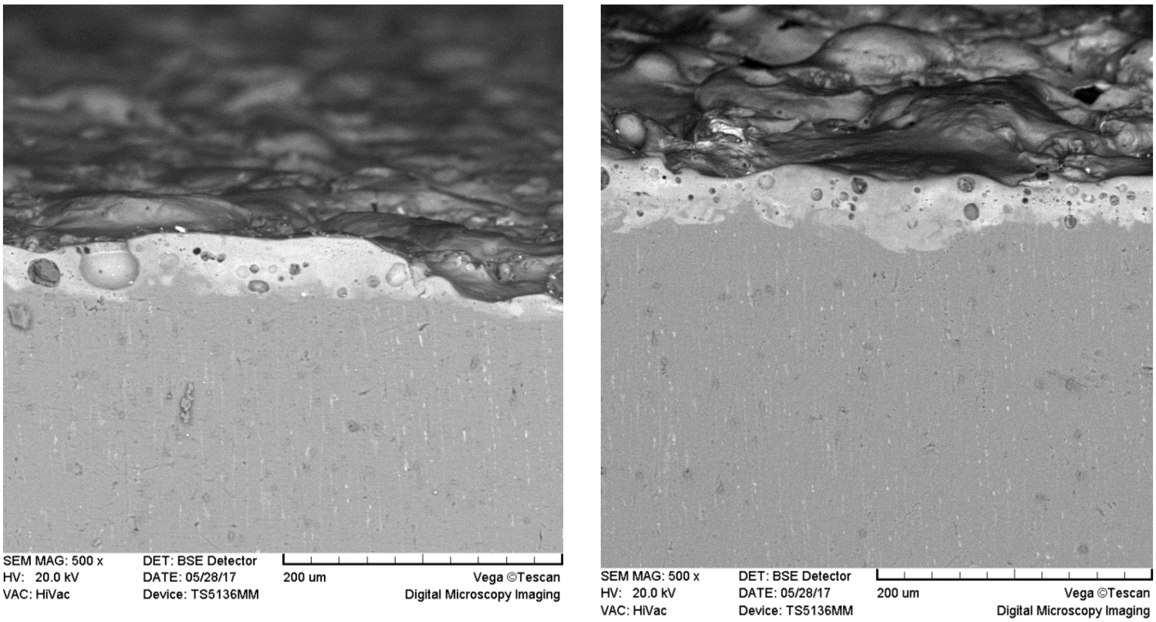


Fig. 11. Effect of Pulse current on wear resistance



(a) (b)

Fig. 12. Aluminum surface after EDAed process (500 X)
a) Ton=100µs,I=16A b) Ton=100µs,I=24A

3-3- The effect of pulse current on the wear resistance

Fig. 11 shows the weight loss diagram of the aluminum specimens and Fig. 12 shows the effect of pulse current on the thickness of surface layer after the electrical discharge alloying. As can be seen, with the increase in the pulse current, the weight loss of the alloyed parts is reduced and their wear resistance is improved. Another important parameter on the sparks energy is the pulse current (Equation 1). Increasing the pulse current increases the heat generated at the work piece surface. As the surface temperature increases, the depth of the alloyed layer increases which improves the surface wear resistance.

4 – Conclusion

In this paper, the increase of surface wear resistance of pure aluminum with EDA process was studied. Increasing the wear resistance by EDA method is a successful method and this process can increase mechanical property of metals surface. The leading conclusions are as follows:

1- The XRD analysis demonstrated that Al_3Ni_2 and AlCu intermetallic compound was formed on the alloyed surface.
2- Increasing the input parameters increases the thickness of the alloyed layer.
3- The friction coefficient measuring after EDA process shows that the average friction coefficient does not change much.
4- With increasing pulse current and pulse on time the surface wear resistance increases.

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