



# Plasma electrolytic oxidation of 2024-T3 aluminum alloy and investigation on microstructure and wear behavior



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## ABSTRACT

In this study, plasma electrolytic oxidation has been used to improve wear resistance of 2024-T3 aluminum alloy. An electrolyte containing available and inexpensive constituents was used. A conventional DC source with low applied voltage was employed. It was found that with increase in oxidation treatment time the micro-hardness of the coating were decreased while the friction coefficient increased. It was seen that deposition at optimum treatment time of 10 min resulted in the highest micro-hardness and lowest friction coefficient and weight loss. The surface and cross-sectional morphology indicated that the coatings have a dense structure with low porosity and without any cracking. Also, the presence of wear scars on the worn surface morphology demonstrates that the three-body rolling was the main wear mechanism for coated specimen. The phase analysis of the coating indicated that the coating was formed mainly from  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>,  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, Al<sub>3.21</sub>Si<sub>0.47</sub> and small amounts of amorphous phases. The presence of glycerin in the electrolyte composition resulted in not only stabilizing the solution but also achieving of a dense and uniform coating without any cracking.

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## 1. Introduction

Plasma electrolytic oxidation (PEO) which also called micro arc oxidation (MAO) [1], anodic spark deposition (ASD) [2], or micro-arc discharge oxidation (MDO) [3] is a relatively new surface modification technique for light alloys such as aluminum, magnesium, titanium and etc. [4–7]. This method can enhance the corrosion and wear resistance properties of these alloys, or can offer anti-friction, thermal protection, optical and biomedical properties [8,9]. Also, this technique can provide load support for other layers [10] and much attention was mainly focused on wear resistance of PEO treated aluminum alloys [11]. Many researchers have indicated that the properties of PEO coating mainly depend on electrolytic concentration and composition [12], the alloying elements of substrate [13], the applied current density [14–16] and type of power source [8,17–20].

Regardless of the type of electrolyte or method of controlling the electrical parameters (constant current or constant voltage), the mechanism of PEO process is the same. Firstly, the natural, very thin and passive film of the substrate begins to dissolve. With increasing the applied voltage, gas bubbles are produced which result in a porous film with a columnar structure perpendicular

to the substrate. Plasma micro-discharge begins when the applied voltage exceeds the breakdown voltage of the oxide film [21,22].

Aluminum alloys are widely used in aerospace and automotive industry due to their excellent properties such as high strength, low density, non-magnetic properties and good formability [5,23]. Unfortunately, they show some poor tribological properties for mechanical applications, especially in sliding condition, which can be summarized as: low load bearing capacity, low abrasion resistance due to low hardness, high adhesion tendency due to relatively high ductility and reactivity [11,23]. Therefore, it is necessary to improve surface properties of these alloys by surface treatments.

In the present study, PEO treatment was performed on 2024-T3 aluminum alloy in an optimized electrolyte. A complex alkaline electrolyte was used in order to decrease the applied voltage during PEO. The electrolyte contained simple and inexpensive constituents and a conventional DC power source was used for applied voltage. The achievement of this study was the introducing of glycerin as a new constituent of PEO electrolyte.

## 2. Experimental

### 2.1. Materials

The electrode used in this study was 2024-T3 Al alloy. The alloy composition which was evaluated by the use of OES technique (optical emission spectrometer, foundry master quantometer) is shown in Table 1. Rectangular samples with dimension of

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**Table 1**

The bulk chemical composition of 2024-T3 aluminum alloy after surface treatment.

Element	Al	Cu	Mg	Mn	Fe	Zn	Si	Others
Average (wt%)	Matrix	4.45	1.57	0.56	0.17	0.16	0.06	0.04

20 × 20 × 2 mm were used as substrate. The surface of samples was ground to a roughness  $R_a \approx 0.5 \mu\text{m}$  with 400#, 800#, 1000# and 1200# SiC abrasive papers consecutively, cleaned with distilled water and acetone, and then dried by hot air flow for PEO treatment.

## 2.2. Preparation of the electrolyte and PEO process

The electrolyte was an aqueous solution of  $\text{Na}_2\text{SiO}_3$  (30 g/l),  $\text{Na}_3\text{PO}_4$  (25 g/l), KOH (15 g/l) and glycerin (10 g/l) in distilled water. DC power supply (15 kW) with approximate 650 V of the maximum output voltage was used for PEO treatment.

PEO treatment was performed under constant sparking voltage of 290 V at 30 °C. In this constant voltage, current density varied from 10 A/dm<sup>2</sup> to 3.2 A/dm<sup>2</sup>. A cylindrical stainless steel electrode with 15 cm diameter and 25 cm height was used as cathode. The 2024-T3 electrode was used as the anode (work-piece) which was located at the center of this cylinder. So that anode was immersed completely in the electrolyte and connected to the circuit. All circumferential areas of the specimens were masked with an adhesive and covered with Teflon tape to ensure that these areas did not involve in PEO treatment. The treatment time was recorded after discharges started. After coating, the samples were removed from the electrolyte, washed in distilled water and acetone and then dried with hot air flow. The coating process was performed in different treatment times of 10 min, 20 min, 30 min and 40 min in an identical procedure.

## 2.3. Microstructure and phase analysis

Microstructure, surface morphology and coating thickness were studied by scanning electron microscopy (Cambridge Stereo-scan S360). Some specimens were cross sectioned, mounted in acrylic resin and polished according to standard metallographic preparation technique for thickness measurement. The surface of PEO coatings was sputtered with a thin layer of gold in order to prevent surface charging prior to SEM inspection. The phase composition of the PEO coating was determined by X-ray diffraction (XRD) ( $\text{Cu-K}\alpha$  radiation) with D8-Advance, Bruker XRD instrument ( $\lambda = 0.15405 \text{ nm}$ ).

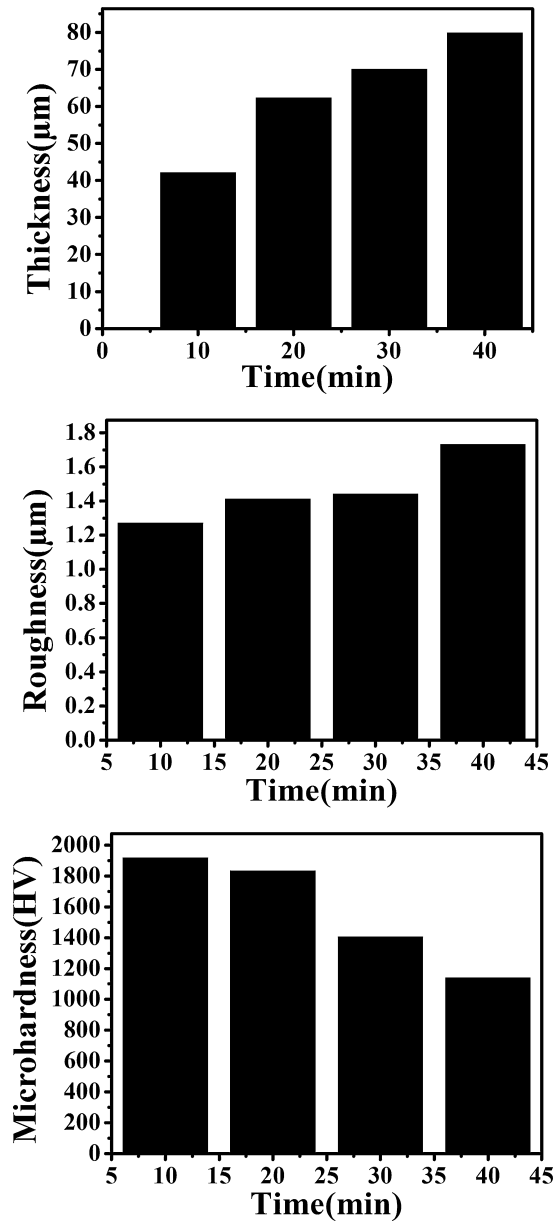
## 2.4. Wear and micro-hardness tests

Wear test for coated and uncoated specimens was carried out by pin-on-disc method under the dry sliding condition with 5 mm in diameter standard pin in length of 50 mm made of SAE 52100 steel. The measurement of friction coefficient was done under load of 2 N, the linear pin speed of 0.04 m/s, and the sliding distance of 100 m. The Vickers micro-hardness test was carried out by a load of 1 N and time of 15 s. Each hardness value was the average of five measurements.

## 3. Result and discussion

### 3.1. Time dependence of thickness, surface roughness and micro-hardness of the PEO coating

The variation of thickness, surface roughness and micro-hardness of the PEO coatings in different treatment times is shown in Fig. 1. The PEO treatment was performed in different time of



**Fig. 1.** The influence of PEO treatment time on thickness, roughness and micro-hardness of the coatings.

10 min, 20 min, 30 min and 40 min. It is clear that with increase in the treatment time, the coating is thickened; the surface roughness increased as also reported by other researchers [21,24–26]. Furthermore, decrease in the micro-hardness is seen which can be attributed to the change in the composition of coating and/or to the variation in roughness [21].

### 3.2. Wear test

The result of wear test for coated and uncoated specimens is represented as friction coefficient and weight loss of the specimens that are summarized below.

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