Surface Roughness and Hardness Characteristic of 2024 Aluminum Alloy by Electroplating Ni-Cr

Akhyar1*, R I Yaqin2, A Farhan3 and Z Jalil4

1Department of Mechanical Engineering, Universitas Syiah Kuala, Jl. Syech Abdurrauf No. 7, Darussalam, Banda Aceh 23111, Indonesia
2Program Studi Permesinan Kapal, Politeknik Kelautan dan Perikanan Dumai, Indonesia
3Department of Physic Education, FKIP Universitas Syiah Kuala, Darussalam, Banda Aceh-23111, Indonesia
4Physics Department, Universitas Syiah Kuala, Darussalam, Banda Aceh, Indonesia

*Corresponding author: akhyar@unsyiah.ac.id

Abstract. Aluminum alloy 2024 is widely applied to aircraft because it has excellent mechanical properties. However, the application requires better properties on the surface. However, in its application, sometimes better properties are needed on the surface. This experiment aimed to evaluate the effect of electroplating time duration (nickel solution: 15 and 20 minutes, and chromium solution: 10, 15, and 20 minutes) on surface roughness. Investigate surface hardness due to variations in electroplating time: 10, 15, 20, 20, 25, 30, and 35 minutes. The results show that the time duration can affect the surface roughness after electroplating coating compared to untreated samples. On the other hand, electroplating on 2024 alloy with time variations, initially the surface hardness value increases with increasing time duration and reaches the highest at 25 minutes (electroplating time), then the hardness value decreases with increasing treatment time duration.

1. Introduction

The 2024 aluminum alloy is widely used in manufacturing industries such as aircraft such as airplane skin wings, automotive products, and some elements on ships because aluminum is a light metal and has good mechanical properties. However, material degradation during operation is caused by several things such as surface defects [1,2], friction, corrosive environment, and surface roughness. These problems can be solved by electroplating and shot peening [3-5].

Parameters that affect the coating are solution concentration, current density, temperature, and coating time. Studies on the effect of solution concentration on the electroplating process have been evaluated for several materials and processes. Zirconium alloys coated with Cr were evaluated for their microstructure evolution by the electroplating process. The chemical reaction between nickel and zirconium indicates the thermal formation of structures: NiZr, Ni$_3$Zr$_2$, Ni$_5$Zr, Ni$_{10}$Zr$_7$, NiZr, and NiZr$_2$ (multilayer by metallurgical bonding) [6]. The results show that changes in the concentration of zinc solution can affect several important things, including morphology, elemental properties, the structural film deposited. In addition, the electrical resistivity behavior is also seen to be different [7]. Electrodeposition conditions can affect the composition, microstructure, and corrosion resistance.
during coating Zn-Ni alloys [8]. Coating parameters on PET fabrics can affect the properties of conductive fabrics on Cu-Ni-P alloys when electroplated [9].

The bath composition and deposition time were evaluated on rhenium–nickel, and the bath solution consisted of ammonium perrhenate, citric acid, and nickel sulfamate. The result shows, Faradaic efficiency and rhenium content in the coating can be improved by emphasizing the route [10]. The electroplating process of Ni-Cr nanocomposite alloys was reported under ultrasonic waves and titanium nanofluids with continuous flow. The coating was carried out onto a porous substrate [11]. The concentration of metal ions in the electrodeposited CuZnSn film was studied to apply sterile Cu2ZnSnS4 solar cells [12]. Electrodeposition treatment by rubbing was investigated on aluminum alloys (metallization) [13].

The important role of current density and solid electrolyte interphase layer in controlling plating morphology was observed through real-time nucleation, growth, and dissolution of Ca, formation of dead Ca [14]. The upper and lower limits of current use for solution electrodialysis were analyzed instead of rinse water from the zinc acid plating process [15]. The effect of current density on the transformation of crystal texture and corrosion behavior was observed due to electroplating of multilayer Ni/Co-pumice nanocomposite coatings [16]. Electrodeposition analysis through modeling and simulation, the effect of current density-conductivity of the electrolyte on the thickness of the electroplating [17]. Electroplating effects agitation, current density, and cyanide concentration in Cu-Zn alloys [18]. Electroplating Cu on TSV - low alpha solder bumpsing can be affected by current density and coating time [19]. Ionic liquids for electroplating against high current densities were investigated during electrodeposition of cationic organic copper [20]. The purpose of this experiment was to examine the effect of the surface roughness of the 2024 alloy from two variations of the duration of electroplating time in nickel solution and followed by three differences in the duration of electroplating time in chromium solution. Two differences in electroplating time in nickel solution were 15 and 20 minutes, and three electroplating time durations in chromium solution were 10, 15, and 20 minutes. Hardness characteristics were also evaluated due to the duration of electroplating time in nickel solution: 10, 15, 20, 25, 30, and 35 minutes.

2. Experimental Procedure

The 2024 alloy is machined for surface treatment samples by electroplating in a round flat shape with a diameter of 25 and a thickness of 5 mm. The 2024 sample was prepared for surface roughness and micro-hardness testing after being treated with Ni-Cr electroplating. Chemical composition testing in this experiment was carried out using a metal analyzer, namely the Metalscan analyzer 2500 series. Microstructure observations were carried out using an Optical Microscope. A Surface roughness test was carried out on the sample surface with a contact stylus profilometer (Surfcom 120A, Advanced metrology system, UK). Surface hardness tests were observed with Micro-Vickers indentation using Buchler Micromet according to ATSM E-384 and surface roughness with Surfcom 120A [21].

2.1. Surface Roughness

All samples were ground with SiC #400 and #800 paper, then polished with metal polish. The electroplating process on the 2024 alloy sample was carried out in several steps, such as a nickel (Ni) solution was put into a plating bath with a solution temperature of 26 °C. First, the sample was tied with a 3 mm copper wire, which served as a holder, then the sample was washed using acetone to remove dirt, dust, and oil (degreasing) before the nickel plating process was carried out. The clean sample is then put into an immersion bath containing a nickel solution. The nickel plating process begins by turning on and flowing an electric current from a DC power supply with a voltage of 2 V and a current of 0.03 A by connecting the positive pole on the nickel plate (anode) and the negative pole connected to the sample (cathode). The distance between the anode and cathode in the nickel
The plating process is 4 cm. Nickel plating time was varied, namely 15 and 20 minutes. Finally, the nickel-coated samples were flushed with clean water (rinsing) for further chromium (Cr) plating.

The procedure for chrome plating in this experiment is as follows, specifically filling the chrome solution into a plating bath with a solution temperature of 40-45 °C. The nickel-coated samples were washed using acetone to remove dirt, dust, and oil before the chrome plating process was carried out. Then turn on the DC power supply and set the voltage to 4.5 V and current to 0.3 A. The cleaned sample was tied with 3 mm copper wire and then put into an immersion bath containing a chromium solution. Next, they connected the positive pole on the lead plate (anode) and the negative pole connected to the sample (cathode). The distance between the anode and cathode in the chrome plating process is 15 cm. The chrome plating process on samples with variations in time for 10, 15, and 20 minutes; after completion, the samples were taken, rinsed with water, and dried, then placed in an airtight container.

2.2. Surface Hardness

The electroplating process is carried out on 2024 aluminum alloy by dipping the sample into the plating bath. First, the sample was tied with a 3 mm copper wire to function as a holder, and then the sample was washed using acetone to remove dirt, dust, and oil (degreasing) before the nickel plating process was carried out. The clean sample is then put into an immersion bath containing a nickel solution. The nickel plating process begins by turning on and flowing an electric current from a DC power supply with a voltage of 2 V and a current of 0.03 A by connecting the positive pole on the nickel plate (anode) and the negative pole connected to the sample (cathode). The distance between the anode and cathode in the nickel plating process is 4 cm and the duration of nickel plating time is varied from 10, 15, 20, 25, 30, and 35 minutes. After completion of the sample is taken, flushed with water, and dried, then put in an airtight container.

3. Result and Discussion

The chemical composition of 2024 aluminum alloy can be seen in Table 1. The chemical composition shows that the metal alloy contains the highest element of Copper (Cu) after Aluminum (Al).

|   | Cu    | Mg    | Si    | Fe    | Mn    | Cr    | Ni    | Zn    | Ti    | Al    |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|   | 5.9311| 1.9359| 0.1597| 0.2531| 0.7332| 0.0118| 0.0122| 0.1835| 0.0143| Bal   |

The microstructure of the 2024 aluminum alloy is shown in Figure 1. Observation of the microstructure of the 2024 alloy showed that the microstructure was partially equiaxed grain. The distribution of Al looks dominant with a light gray color, while the dark color is eutectic at grain
boundaries. There are also some discontinuous grain boundaries; this is estimated to come from the formation of imperfect dendritic arms or the formation of new grains that are not completed when the metal solidifies.

3.1. Surface Roughness

The electroplating process was carried out on 2024 samples with variations in duration times of nickel plating, which were 15 and 20 minutes. Furthermore, the nickel-coated samples were subjected to a chrome plating process with time variations of 10, 15, and 20 minutes.

![Figure 2](image1.png)

**Figure 2** Surface roughness with time variation for chrome electroplating (15 minutes of Ni plating).

Figure 2 shows the surface roughness characteristics after grinding with #400 and #800 SiC paper. The surface roughness in the 2024 alloy sample with non-treatment (NT) was given a nickel solution for 15 minutes and continued with a chrome plating and a variation of 10, 15, 20 minutes. The surface roughness of the electroplating time duration effect in chromium solution, after grinding with SiC #400 paper, fluctuated. The maximum value of 0.32 μm is presented at the time duration of 10 minutes and 20 minutes. At the same time, the minimum surface roughness of 0.22 μm appears in the sample before being treated.

The duration of time on the coating in chromium solution was seen in the sample ground with SiC #800 paper. Surface roughness before treatment was 0.26 μm, then the roughness number decreased to 0.18 μm and was stable even though the duration of chromium plating was increased.

![Figure 3](image2.png)

**Figure 3** Surface roughness with time variation for chrome electroplating (20 minutes of Ni plating).
Figure 3 shows the results of surface roughness testing on aluminum alloy 2024 by coating the surface in nickel solution for 20 minutes, then continued with plating in chrome solution with varying durations (10, 15, and 20 minutes). Then the samples were ground with #400 and #800 SiC paper. The result shows that the maximum surface roughness is 0.38 \( \mu m \) at a time duration of 10 minutes, and the minimum value is 0.22 \( \mu m \) at a time duration of 15 minutes after grinding with SiC #400 paper. The maximum surface roughness was 0.28 \( \mu m \) after surface coating was ground with SiC #800 paper, and the minimum value was 0.20 \( \mu m \) at the time duration of 10 and 20 minutes.

The effect of surface coating in nickel solution and chromium solution by varying the duration of the plating time shows an impact on surface roughness. The number of surface roughness seems to fluctuate for several experimental conditions. This is because the use of #400 and #800 SiC paper is too rough, so the surface coating is not thick enough. However, from the surface roughness data, there is an effect of variations in the duration of time when the 2024 aluminum metal surface is coated in a nickel solution and a chrome solution. The Cr layer is combined with the Ni layer in a lattice-matching mode so that no visible defects can be found at the interface between each layer [6]. Electrolyte concentration conditions and current density can affect the coating properties of electrodeposited metal alloys [22]. Low temperature and optimum current density will cause the coating to be rough and dull, but the coating result will be uneven if the temperature is high with optimum current density. Coating time will affect the quantity of the coating that occurs on the surface of the coated product. An increase in temperature will cause an increase in the conductivity and diffusivity of the electrolyte solution, meaning that the electrolyte resistance will decrease so that the potential needed to reduce metal ions decreases.

3.2. Surface Hardness

The nickel plating process on samples with time variations: 10, 15, 20, 20, 25, 30, and 35 minutes is shown in Figure 4. The hardness values are taken randomly as many as five points with the distance adjusted on the sample's surface with a diameter of 25 mm.

![Figure 4](image)

**Figure 4** Hardness value vs. electroplating duration.

The maximum hardness is 444 kgf/mm\(^2\) with an electroplating time of 25 minutes, while the minimum hardness is 361 kgf/mm\(^2\) with the longest electroplating time of 35 minutes. The results show that the duration of electroplating time in Ni solution affects the hardness of the 2024 aluminum alloy. The hardness number initially increases with increasing duration of electroplating time and reaches a peak at 25 minutes, and then the hardness decreases with increasing duration of electroplating time. Thus, the hardness number can be affected by the time duration of electroplating.
On the other hand, the concentration of electrolyte solutions (saccharin and cobalt) can affect the microhardness of nanocrystalline Ni-Co alloys [23].

4. Conclusions
The effect of two durations of electroplating time in nickel solution and followed by three different durations of electroplating time in chromium solution on the surface roughness of alloy 2024 has been discussed in this paper. The results obtained were the effect of time duration variations on the surface roughness during the electroplating process of 2024 alloy. The maximum surface roughness value is 0.38 μm at 20 minutes of electroplating time in nickel solution and 10 minutes in chrome solution. The minimum value of surface roughness is 0.18 μm, indicated on samples with a duration of 15 minutes for nickel plating and 10 minutes for chrome plating.

Hardness characteristic due to the effect of the duration of electroplating in nickel solution, the maximum saw is 444 kgf/mm² with 25 minutes. At the same time, the minimum hardness value is 361 kgf/mm² with a nickel plating time of 35 minutes. Thus, the initial hardness number increases with increasing the electroplating time. However, the hardness value further decreased after 25 minutes of electroplating duration.

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