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The Role of Sengon (*Albizia falcataria*) Leaf Extract in the Zinc Electrodeposition Process on Iron Substrate

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Abstract. The development of natural additives in metal electrodeposition processes has emerged as a promising alternative. This study evaluates the role of aqueous extract of sengon leaves (Albizia falcataria) as an additive in the zinc electrodeposition process on iron plates. The plating was carried out in a zinc chloride electrolyte solution with variations in current density and deposition time. Observed parameters included surface morphology, coating mass, and thickness. The results showed that the addition of sengon leaf aqueous extract improved the coating quality by producing a smoother and more uniform surface. The active compounds in the extract are presumed to act as wetting agents, aiding the growth of zinc crystals. This study indicates that sengon leaf aqueous extract has potential as an alternative additive in the zinc electrodeposition process.

Introduction

Indonesia possesses a wide variety of metals commonly used in industry and household equipment. One such material is iron. Iron is a strong and durable metal, widely used in daily life due to its good electrical conductivity, availability, and relatively low cost. However, iron has a significant drawback—it is highly susceptible to oxidation, commonly known as corrosion (Utomo., 2015). Therefore, it is necessary to develop solutions to repair iron surfaces that have undergone corrosion and to implement measures that can slow down the progression of further corrosion.

Corrosion prevention efforts can be carried out through various methods, including painting, applying oil or grease, and coating the surface using the electrodeposition method. Electrodeposition or electroplating can be performed using solutions containing chromium, copper, zinc, or nickel. This process aims to create a protective layer that reduces the direct contact between the metal and its environment (Haqiqi *et al.*, 2021).

In the electrodeposition process, the resulting coating is often rough and non-uniform. Therefore, the addition of additives is necessary. Additives play an important role in influencing the quality and characteristics of the deposited layer. Additives such as brighteners, levelers, and inhibitors can enhance gloss, improve surface uniformity, reduce surface tension, and control the rate of crystal growth.

Therefore, the use of additives has become an effective strategy to produce smoother and denser coatings. These additives can be either synthetic or derived from natural plant extracts. Commonly used synthetic additives include NP16 (polyoxyethylene nonyl phenyl ether), OCBA (o-chloro benzyl aldehyde), and S40 (polyoxyethylene lauryl amine) (Hsieh *et al.*, 2009). CTAB (Cetyl trimethyl ammonium bromide) (Nayana and Venkatesha., 2011). Natural additives include plant-based extracts such as pineapple fruit extract (Loto., 2012), pomegranate extract (Loto *et al.*, 2020), and shallot extract (Rajendran *et al.*, 2009).

The addition of additives has been proven to enhance the quality of zinc electrodeposition. However, the effectiveness of additives is significantly influenced by several factors, including current density, temperature, immersion time, and concentration. The development of this research concept is also based on previous studies that utilized natural plant-based additives. Most of these plants contain amino acids and a high content of saponins. One such plant with a notable saponin content is stinging nettle (*Urtica dioica* L.). Phytochemical analysis of nettle

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leaf extract has shown the presence of saponins, indicated by the formation of stable foam, which remains intact even after the addition of one drop of 1% HCl (Laksono *et al*., 2022; Rahman *et al*., 2021).

Nettle leaf extract can be used as an additive due to its function as a natural surfactant, which allows it to modify the characteristics of the electrodeposited layer. Prior to the addition of nettle leaf extract, the electrodeposited surface appeared rough and uneven; however, after its addition, the morphology became smoother, as observed through Scanning Electron Microscope (SEM) analysis. In addition to nettle, another plant known to contain saponins is the sengon leaf (*Albizia falcataria*).

Sengon leaves contain a saponin level of 15.04% (Susanti and Marhaeniyanto., 2014). The saponin content in sengon leaves plays an important role as an effective wetting agent. This compound functions by reducing the surface tension of the solution, allowing the liquid to spread more evenly across the substrate surface. As a natural surfactant, saponin also helps maintain the stability of the electrodeposition solution, preventing the formation of clumps or precipitates that may interfere with the electrodeposition process (Putri *et al*., 2023).

Previous studies have investigated various natural extracts, such as pineapple, garlic, pomegranate, and ginger extracts, as additives in zinc electrodeposition systems due to their ability to improve coating quality and modify crystal growth behavior. However, studies regarding the utilization of aqueous sengon leaf extract (Albizia falcataria) as a natural additive in zinc electrodeposition are still very limited. Sengon leaves contain phytochemical compounds, particularly saponins, which are predicted to function as natural surfactants capable of influencing zinc deposition behavior and improving coating morphology. Therefore, this study aims to investigate the effect of aqueous sengon leaf extract on zinc electrodeposition in comparison with deposition without additives, particularly in terms of deposited mass, coating thickness, and surface morphology under different current densities and deposition times.

Experimental

Material and Methods

The equipment used in this study includes an electrochemical cell, mortar and pestle, direct current (DC) power supply, 100 mL and 250 mL beakers, 100 mL and 250 mL volumetric flasks, Erlenmeyer flasks, glass funnels, measuring pipettes, suction bulbs, a hot plate, magnetic stirrer, analytical balance, hair dryer, sandpaper, and instruments such as a digital microscope and a micrometer screw gauge.

The materials used in this study include zinc chloride ($ZnCl_2$) electrolyte solution, potassium chloride (KCl), boric acid (H_3BO_3), hydrochloric acid 35% (HCl 35%), hydrochloric acid 5% (HCl 5%), aqueous extract of sengon leaves, iron plates (2 × 5 × 0.2 cm) as substrates, distilled water (aqua DM), filter paper, and sandpaper.

Procedures

Preparation of Iron Plate Substrate

The substrate used in this study was iron (Fe), cut into dimensions of 5 × 2 cm with a thickness of 0.2 cm. After cutting, the surface was polished using sandpaper. The polished iron was then cleaned of rust and impurities by washing under running water and with soap. Subsequently, it was dried at room temperature or using tissue paper.

Preparation of Aqueous Extract of Sengon Leaves (Albizia falcataria)

Fresh sengon leaves were washed, air-dried, and blended to obtain fine particles. A total of 200 g of blended leaves was mixed with 200 mL distilled water (solid-to-liquid ratio 1:1 w/v). The extraction process was conducted at 70°C under magnetic stirring for 30 min. The mixture was then cooled to room temperature and filtered using Whatman No.40 filter paper. The obtained aqueous extract was dark green-brown in color and directly used as an additive without further purification. Based on the extraction volume, the crude extract concentration was approximately 1 g/mL fresh leaf equivalent.

Preparation of Zinc Electrolyte Solution

The electrolyte solution was prepared by mixing 71 g of $ZnCl_2$, 207 g of KCl, and 35 g of H_3BO_3 in a 1000 mL beaker. Distilled water (aqua DM) was added up to the mark, and the solution was stirred using a magnetic stirrer for 60 minutes at room temperature (Loto *et al*. 2020).

Thickness Measurement of Zinc Deposits on Iron Substrates

Measurement of the zinc coating thickness was carried out using a micrometer screw gauge at nine points across the corners of the iron plate. The measurement stages included readings taken after pickling, and after the electrodeposition process. Measurements were conducted after the samples were dried. The average thickness was calculated based on all measurement points.

Mass Measurement

The mass of the zinc coating was calculated based on the difference in the weight of the iron plate measured using an analytical balance after pickling and after the electrodeposition process, following drying.

Observation of Zinc Coating Morphology on Iron Plate

The surface morphology of the substrate was observed using a digital microscope after zinc electrodeposition, with drying performed using a hair dryer.

Zinc Electrodeposition Process

The zinc electrodeposition process was carried out by preparing 250 mL of $ZnCl_2$ solution in a 250 mL beaker. The iron substrate with dimensions of 5 × 2 × 0.2 cm was sanded and then measured for its initial mass, thickness, and surface morphology. The substrate was immersed in 35% HCl for 5 minutes to remove rust, rinsed with distilled water for 1 minute, and then immersed in 5% HCl for 2 minutes to open the pores. Electrodeposition was performed using direct current (DC) with current variations of 0.1 A, 0.3 A, and 0.5 A, and deposition times of 5, 10, and 15 minutes. The iron plate functioned as the cathode while the zinc plate served as the anode in the electrochemical cell. Two types of treatments were applied, one using aqueous sengon leaf extract as an additive and the other without any additive. After the electrodeposition process, the substrates were dried using a hair dryer and subsequently analyzed for mass, thickness, and surface morphology. Each treatment was repeated three times. The measured mass and thickness were analyzed using three-way ANOVA to determine the effects of additive type, current density, and deposition time on the mass and thickness of the zinc coating.

Result and Discussion

Electrodeposition Zinc

The cathode used was an iron plate with dimensions of 2 × 5 × 0.2 cm, while the anode consisted of zinc metal placed on the left and right sides of the substrate. At the anode, an oxidation reaction occurs where zinc releases Zn^{2+} ions into the electrolyte solution and two electrons ($2e^-$) flow through the electric current to the cathode. At the cathode, a reduction reaction takes place where Zn^{2+} ions in the electrolyte react with $2e^-$ at the cathode surface to form a layer of metallic zinc. This process occurs continuously, resulting in the gradual formation of a zinc coating.

The mechanism of zinc deposition formation is illustrated in Figure 1a, and the electrochemical cell used in the process is shown in Figure 1b. In this electrodeposition process, electrical current was supplied by a DC (Direct Current) power supply. The use of DC (Direct Current) current in metal deposition allows metal ions to move constantly from the anode to the cathode, resulting in stable and continuous deposition of the metal. In contrast, AC (Alternating Current) changes direction periodically, which can cause the already deposited metal to potentially dissolve back into the electrolyte, making it difficult to maintain a stable layer of metal. A study on Zn electrodeposition on mild steel showed that coatings produced using direct current (DC) exhibited thicknesses ranging from 10–28 μm and provided good corrosion protection, although slightly lower compared to those obtained using pulse current methods. (Upadhyay *et al*., 2023). In the electrodeposition of Zn-Mn alloys, direct current (DC) was able to produce coatings with specific morphological characteristics; however, the resulting layers tended to form porous corrosion products, leading to lower corrosion resistance compared to coatings deposited using pulse current techniques (Deo *et al*., 2021).

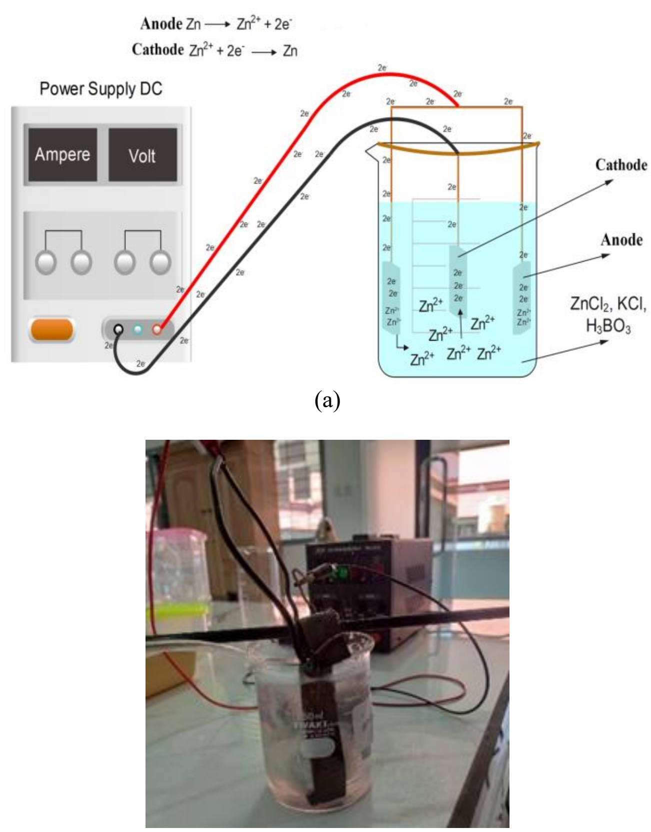

Figure 1. Zinc electrodeposition process (a) process illustration, (b) zinc electrodeposition setup.

Surface Morphology Observation

In the zinc electrodeposition process without the addition of additives, the surface morphology after electrodeposition can be observed in Figure 2.

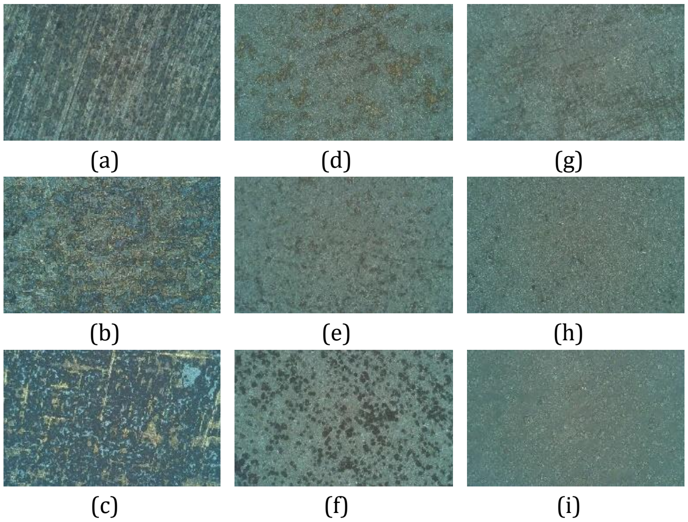

Figure 2. Surface morphology observation using a digital microscope in zinc electrodeposition without additive addition (a) 0,1 A 5 min, (b) 0,1 A 10 min, (c) 0,1 A 15 min, (d) 0,3 A 5 min, (e) 0,3 A 10 min, (f) 0,3 A 15 min, (g) 0,5 A 5 min, (h) 0,5 A 10 min, (i) 0,5 A 15 min.

Figure 2 shows the zinc deposition results observed using a digital microscope. The surface morphology in Figure 2a, at 0.1 A for 5 minutes, shows uneven deposition. Similar results are also observed in Figures 2b to 2f. However, as the current and deposition time increase, the coating becomes more uniform (Tribbia *et al*., 2023). A noticeable improvement can be seen in Figures 2g, 2h, and 2i, where the zinc deposition appears relatively uniform, although it does not completely cover the iron substrate. Observations were also carried out visually and documented using a camera, as shown in Figure 3.

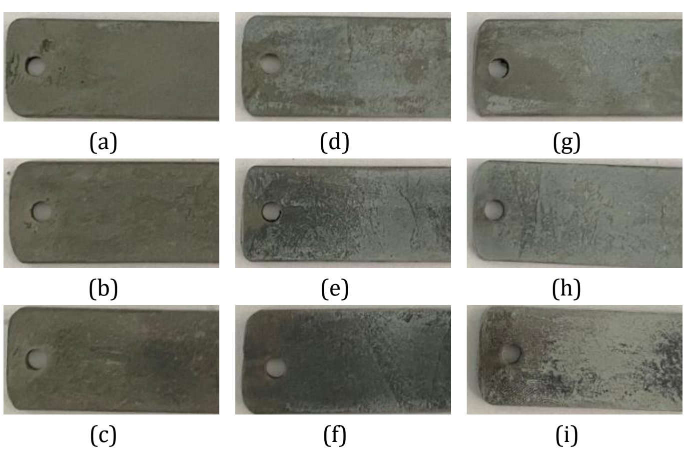

Figure 3. Visual morphology observation using a camera (a) 0,1 A 5 min, (b) 0,1 A 10 min, (c) 0,1 A 15 min, (d) 0,3 A 5 min, (e) 0,3 A 10 min, (f) 0,3 A 15 min, (g) 0,5 A 5 min, (h) 0,5 A 10 min, (i) 0,5 A 15 min.

Figures 3a to Fig. 3i show the morphology observed using a camera. The deposition appears unstable and uneven across the entire surface of the iron substrate. This indicates that the zinc deposition process without the addition of additives resulted in suboptimal coating quality. The results of this study are consistent with findings reported in the literature, which state that zinc electroplating without the addition of additives produces relatively rough and non-uniform surfaces due to uncontrolled crystal growth (Jeon *et al*., 2023). Zinc electrodeposition with the addition of sengon leaf aqueous extract as carried out using volume variations of 5 mL, 10 mL, and 20 mL. Comparative observations of the deposition results were conducted at 0.5 A for 15 minutes.

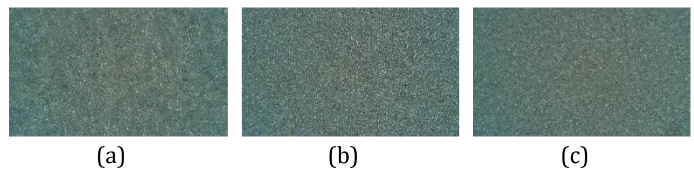

Figure 4. Comparison of deposition results at different extract volume variations (a) 5 mL sengon leaf aqueous extract, (b) 10 mL sengon leaf aqueous extract, (c) 20 mL sengon leaf aqueous extract.

The addition of 5 mL, 10 mL, and 20 mL of sengon leaf aqueous extract resulted in good deposition, indicating that the extract enhances the quality of the zinc electrodeposition. However, the three extract volume variations did not show significant differences in deposition. All three variations exhibited good deposition quality when observed using a digital microscope. Observations were also conducted using a camera, as shown in Figure 5.

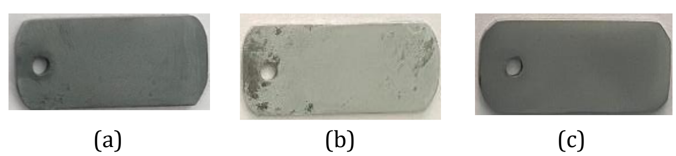

Figure 5. Comparative observation of deposition results with extract addition using a camera (a) 5 mL sengon leaf aqueous extract, (b) 10 mL sengon leaf aqueous extract, (c) 20 mL sengon leaf aqueous extract.

From the camera observations, it can be seen that the deposition in Figure 5c, with the addition of 20 mL sengon leaf aqueous extract, produced the best result, covering the entire substrate uniformly and effectively. The higher the extract volume added, the better the deposition quality observed. The results of this study indicate that increasing the volume of sengon leaf extract added to the electrodeposition solution tends to improve the quality of the resulting zinc deposit. This phenomenon is consistent with previous findings reporting that the addition of organic additives to zinc electrodeposition baths significantly enhances deposit morphology and efficiency compared to additive-free conditions. The presence of organic additives promotes more controlled crystal growth, leading to smoother and more uniform coatings (Sorour *et al*., 2017).

Sengon leaves contain a high level of saponins, which act predominantly as wetting agents. Saponins are natural surfactants with an amphiphilic structure, consisting of both polar and non-polar regions. It is predicted that, the hydrophobic part consists of a non-polar carbon chain, while the hydrophilic part is water-soluble and polar (Meshram *et al*., 2021). When saponins are added to a solution, their molecules occupy the surface, with the hydrophobic region oriented away from water and the hydrophilic region interacting with it. This arrangement creates a physical barrier at the surface, reducing the strong intermolecular interactions between water molecules (hydrogen bonding). As a result, the surface tension decreases (Lin., 2025). The hydrophobic part is typically an aglycone or sapogenin, while the hydrophilic part consists of glycosides or sugar chains (Marliana *et al*., 2005). The chemical compounds presented in the sengon leaves are predicted to exhibit similar properties to the saponins which function as wetting agents during the electrodeposition process.

Sengon leaves contain several phytochemical compounds such as saponins, flavonoids, tannins, and polyphenols (Susanti & Marhaeniyanto, 2014; Marliana *et al*., 2005). Among these compounds, saponins are predicted to play the dominant role as natural wetting and leveling agents during zinc electrodeposition due to their amphiphilic molecular structure (Meshram *et al*., 2021; Timilsena *et al*., 2023). The hydrophilic glycoside groups interact with the aqueous electrolyte, while the hydrophobic sapogenin groups reduce surface tension and improve the spreading of electrolyte on the cathode surface (Lin, 2025). Furthermore, adsorption of saponin molecules on active cathodic sites may suppress uncontrolled Zn crystal growth, resulting in finer and more uniform deposits (Sorour *et al*., 2017; Nayana & Venkatesha, 2011).

Organic additives are known to modify nucleation behavior, crystal growth kinetics, and ion transport at the cathode/electrolyte interface through adsorption-mediated mechanisms (Lin *et al*., 2024). Saponins possess amphiphilic molecular structures consisting of hydrophilic glycoside groups and hydrophobic sapogenin moieties. Due to this amphiphilic nature, saponin molecules tend to migrate toward the cathode/electrolyte interface and adsorb on the cathode surface during electrodeposition. The hydrophilic functional groups, particularly hydroxyl (–OH) and glycoside groups, are predicted to interact with Zn^{2+} ions and the cathode surface through electrostatic interactions and physical adsorption, while the hydrophobic groups form a thin organic adsorption layer on the electrode surface. This adsorption behavior alters the local interfacial energy and affects zinc nucleation and crystal growth processes (Shen *et al*., 2023). In the absence of additives, zinc deposition generally occurs preferentially at highly active cathodic sites with high local current density. Under these conditions, rapid reduction of Zn^{2+} ions promote anisotropic crystal growth and the formation of coarse grains, nodular structures, and non-uniform surface morphology. In addition, localized electric field enhancement at protruding regions accelerates zinc deposition at specific sites, leading to rough and irregular coatings (Lin *et al*., 2024). After the addition of Sengon leaf extract, the adsorbed organic molecules partially block high-energy growth sites on the cathode surface. The adsorption layer suppresses excessive localized zinc deposition and reduces uncontrolled crystal growth. Consequently, the growth rate of existing crystals decreases, while the formation of new nucleation sites becomes more favorable. This phenomenon increases nucleation density and promotes grain refinement, resulting in finer and more homogeneous zinc crystals. Similar adsorption-controlled nucleation mechanisms have been widely reported in electro-crystallization systems containing surfactant or polymer additives (Lin *et al*., 2024). Furthermore, the surfactant characteristics of saponins contribute to lowering the surface tension of the electrolyte solution and improving wetting behavior on the iron substrate. Better wetting promotes a more uniform distribution of electrolyte and Zn^{2+} ions across the cathode surface, resulting in more homogeneous current distribution during deposition. This effect suppresses preferential deposition and dendritic growth while enhancing coating compactness and surface smoothness (Shen *et al*., 2023).

The adsorption layer formed by phytochemical compounds is also predicted to modify the diffusion layer near the cathode surface. Adsorbed organic species increase resistance to ion transfer and slightly slow the reduction kinetics of Zn^{2+} ions into metallic zinc. As a consequence, the deposition process becomes slower and more controlled, which explains the decrease in coating mass and thickness observed at higher extract concentrations. However, despite the lower deposition rate, the resulting zinc layer exhibits smoother morphology, finer grain structure, and improved coating uniformity due to the suppression of excessive crystal growth (Luo *et al*., 2023).

Mass and Thickness

Mass measurement was performed using an analytical balance by weighing the substrate after pickling and after deposition. The thickness of the deposited layer was measured using a micrometer screw gauge. The experimental results were then compared with theoretical values calculated based on Faraday's Law. The mass and thickness of the deposition without additive addition can be observed in Fig. 6

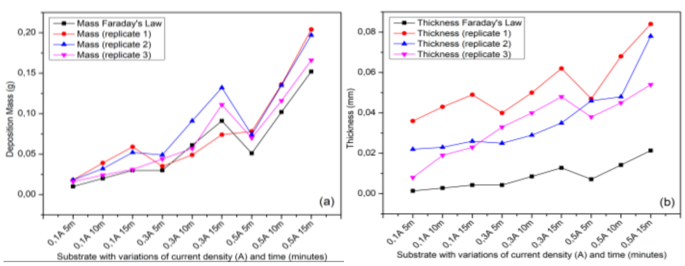

Figure 6. Zinc deposition results without additive addition in three replications (a) zinc deposition mass, (b) zinc deposition thickness.

The measurement results in Fig. 6a and Fig. 6b show an increase in both mass and thickness along with the increase in current and deposition time (Draz *et al*., 2025). The measured mass is consistent with the theoretical mass calculated using Faraday's Law. The highest deposition mass was observed in P9, with a mass of 0.189 grams. The maximum thickness was also found in P9, with a thickness of 0.072 mm. Subsequently, the measurement results of zinc deposition mass and thickness with the addition of sengon leaf aqueous extract can be observed in Figure 7.

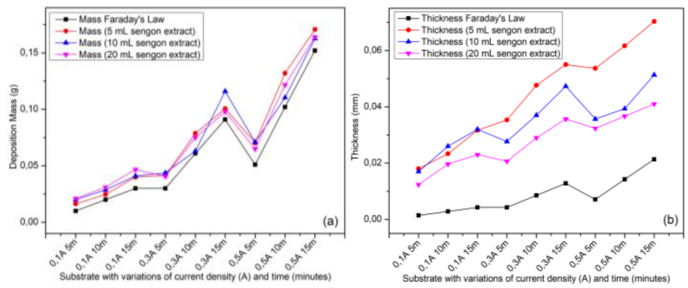

Figure 7. Deposition results with the addition of sengon leaf aqueous extract (a) deposition mass, (b) deposition thickness.

The measurement results in Fig. 7a and Fig. 7b show that as the current and deposition time increase, both the mass and thickness of the deposit also increase. However, with the addition of higher volumes of extract, the deposition mass and thickness tend to decrease. As reported in zinc electroplating studies, organic surfactants adsorbed on the electrode surface can inhibit the reduction of Zn^{2+} ions into metallic zinc due to the formation of an adsorption layer that blocks ion transfer. As a result, the deposition kinetics become slower compared to conditions without surfactant (Kazimierzak *et al*., 2019).

Data Analysis

The measured values of deposition mass and thickness, both without additives and with sengon leaf aqueous extract, were analyzed using SPSS to determine the effects of additive type, current, and deposition time on the mass and thickness of the zinc deposit. The results of the three-way ANOVA test for deposition mass can be observed in Table 1.

Table 1. Three-way ANOVA results for zinc deposition mass (Test of Between-Subjects Effects: Dependent Variable = Mass).

Source	Type III Sum of Squares	df	Mean Square	F	Sig	Partial Eta Squared
Corrected Model	0.243[a]	35	0.007	54.860	<0,001	0.964
Intercept	0.606	1	0.606	4785.484	<0,001	0.985
Additive	0.000	3	0.000	1.085	0.361	0.043
Current (A)	0.150	2	0.075	591.989	<0,001	0.943
Time (minutes)	0.072	2	0.036	283.979	<0,001	0.887
Additive x Current (A)	0.001	6	0.000	1.684	0.137	0.123
Additive x Time (minutes)	0.001	6	0.000	1.252	0.291	0.094
Current (A) x Time (minutes)	0.018	4	0.004	34.865	<0,001	0.660
Additive x Current (A) x Time (minutes)	0.001	12	8.253E-5	0.652	0.791	0.098
Error	0.009	72	0.000			
Total	0.858	108				
Corrected Total	0.252	107				

Based on the three-way ANOVA results shown in Table 1, current density and immersion time significantly affected the zinc deposition mass ($p < 0.001$), with partial eta squared values of 0.943 and 0.887, respectively, indicating strong effect sizes. The interaction between current density and immersion time was also significant ($p < 0.001$), indicating that the effect of current density on deposition mass depends on the duration of electrodeposition. Higher current density accelerates electron transfer at the cathode surface, resulting in faster reduction of Zn^{2+} ions and greater zinc deposition mass. In addition, longer immersion time allows more zinc ions to continuously deposit on the substrate surface. In contrast, additive type did not significantly affect deposition mass ($p = 0.361$), suggesting that the additives used had limited influence on the zinc deposition rate under the applied conditions. The R^2 value of 0.964 indicates that the model explains 96.4% of the variation in zinc deposition mass (Shen *et al*., 2024).

Table 2. Three-way ANOVA results for deposition thickness (Test of Between-Subjects Effects: Dependent Variable = Thickness).

Source	Type III Sum of Squares	df	Mean Square	F	Sig	Partial Eta Squared
Corrected Model	0.022[a]	35	0.001	7.558	<0,001	0.786
Intercept	0.148	1	0.148	1751.066	<0,001	0.961
Additive	0.004	3	0.001	16.665	<0,001	0.410
Current (A)	0.012	2	0.006	69.497	<0,001	0.659
Time (minutes)	0.005	2	0.002	26.739	<0,001	0.426
Additive x Current (A)	0.001	6	0.000	2.639	0.023	0.180
Additive x Time (minutes)	0.000	6	2.087E-5	0.246	0.959	0.020
Current (A) x Time (minutes)	0.000	4	3.683E-5	0.435	0,783	0.024
Additive x Current (A) x Time (minutes)	0.000	12	2.128E-5	0.251	0.994	0.040
Error	0.006	72	8.473E-5			
Total	0.177	108				
Corrected Total	0.029	107				

The results of the three-way ANOVA analysis (Table 2) show that the additive type, current density, and immersion time significantly affected the thickness of the zinc coating ($p < 0.001$). Current density showed the greatest influence on coating thickness, with a partial eta squared value of 0.659, followed by immersion time (0.270) and additive type (0.245). This indicates that increasing current density accelerates the reduction of Zn^{2+} ions, leading to faster formation of a thicker zinc layer. Longer immersion time also increases coating thickness because the deposition process occurs for a longer duration on the substrate surface. Additive type also affected coating thickness, which may be related to its influence on nucleation and crystal growth during electrodeposition (Tamurejo-Alonso *et al*., 2023). The interaction between additive type and current density was significant ($p = 0.023$), indicating that the effectiveness of the additive varied under different current density conditions (Li *et al*., 2014). Meanwhile, other interactions, including the three-way interaction among additive type, current density, and immersion time, were not statistically significant ($p > 0.05$). The R^2 value of 0.786 indicates that the model explains 78.6% of the variation in zinc coating thickness.

The smoother morphology obtained after the addition of sengon leaf extract was associated with lower deposition mass and thickness because the adsorbed organic molecules reduced the deposition rate of Zn^{2+} ions. The adsorption layer formed by saponin molecules limited rapid crystal growth and reduced the number of active cathodic sites. As a result, zinc deposition proceeded more slowly and uniformly, producing finer grains and smoother coatings despite lower total deposited mass.

Conclusion

Zinc electrodeposition without additives resulted in uneven coatings, especially at low current and short immersion time. Increasing both parameters improved mass and thickness, but the surface remained rough. The addition of Sengon leaf extract improved surface quality, producing smoother and more uniform layers, though with slightly lower mass and thickness. Among extract volumes tested, 20 mL gave the best surface morphology. Based on the statistical analysis using three-way ANOVA, it was found that current and immersion time had a significant effect on the mass, while the thickness was influenced by the type of additive, current, and immersion time. Among these factors, current had the greatest impact on the thickness of the zinc layer. Therefore, the addition of sengon leaf extract was proven to enhance the morphological quality of the zinc coating.

Conflict of Interest

The authors declare that there is no conflict of interest.

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