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REGULAR ARTICLE

Electrodeposition and Corrosion Behavior of Lanthanum Coatings on Tinplate in Chloride Medium

Farida Boucetta[1,2,*] ✉, Mohammed-Amin Boumehraz[3], Saaid Naouel[2]

[1] *Physics Laboratory of Thin Layers and Applications, University Mohamed Khider Biskra, 07000, Algeria*
[2] *Department of Chemistry, Faculty of Exact Sciences and Computer Science, University of Mohammed Seddik Benyahia, 18000 Jijel, Algeria*
[3] *Laboratory of Research in Civil Engineering, Mohammed Khider University of Biskra, 07000, Algeria*

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This study investigates the electrodeposition of lanthanum-based coatings on tinplate and the effect of additives (H_3BO_3, H_2O_2, and NH_4Cl) on their morphology and corrosion resistance in a 3.5 wt. % NaCl solution. The coatings were characterized by optical microscopy and potentiodynamic polarization measurements. The results show that the nature of the additive significantly influences the microstructure of the deposits. H_3BO_3 leads to relatively uniform and well-defined coatings, H_2O_2 promotes more compact structures, while NH_4Cl results in heterogeneous and rough morphologies. Electrochemical measurements indicate a positive shift in corrosion potential and a significant decrease in corrosion current density after lanthanum deposition. The polarization resistance increases markedly, confirming the improved protective behavior of the coatings. A maximum protection efficiency of 96.45 % was obtained for the lanthanum-coated tinplate. The enhanced corrosion resistance is attributed to the formation of a protective layer acting as a barrier against electrolyte penetration, reducing oxygen diffusion and blocking active corrosion sites. These findings demonstrate that additives play a key role in controlling the deposition process and optimizing the protective performance of lanthanum-based coatings.

Keywords: Electrodeposition, Lanthanum-based coatings, Tinplate, Corrosion, Polarization resistance.

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1. INTRODUCTION

Corrosion of metallic materials represents a major challenge in many industrial sectors, particularly in environments containing aggressive ions such as chlorides [1]. Tinplate materials are widely used in packaging, food industry containers, and various industrial applications due to their good mechanical properties and formability [2]. However, despite their advantages, tinplate surfaces remain susceptible to corrosion when exposed to saline environments [3]. Therefore, improving the corrosion resistance of such materials is a critical issue in materials engineering [4].

Traditional corrosion protection methods often rely on chromate-based coatings because of their high efficiency. Nevertheless, the use of hexavalent chromium compounds has been increasingly restricted due to their toxicity and environmental impact [5, 6]. As a result, the development of environmentally friendly alternatives has become an important research topic in recent years.

Rare earth elements have emerged as promising candidates for corrosion protection applications due to their unique chemical properties and their ability to form stable oxide layers on metallic [7, 8]. among which lanthanum has attracted considerable attention because of its strong tendency to form insoluble oxide and hydroxide compounds that act as effective corrosion barriers [9, 10], exhibiting significant corrosion inhibition in various metallic systems through the formation of compact protective layers that limit the penetration of aggressive species, reduce electrochemical reactions responsible for metal degradation, and promote surface passivation by precipitating at cathodic sites [11, 12].

Electrodeposition represents an effective and versatile technique for producing protective coatings on metallic substrates [13, 14]. This method allows precise control over the thickness, morphology, and composition of the deposited layers by adjusting electrochemical parameters such as potential, current density, electrolyte composition, and deposition time [15, 16]. In recent years, numerous studies have highlighted the beneficial effects of rare earth coatings on improving the corrosion resistance of metals and alloys, including tinplate [17]. However, the electrodeposition behavior of lanthanum, as well as the influence of electrolyte composition and additives on the formation and properties of these coatings, remains insufficiently understood and requires further investigation. The aim of the present work is to investigate the electrodeposition of lanthanum coatings on tinplate substrates and to evaluate their corrosion resistance in a chloride medium. Particular attention is given to the influence of additives on the electrochemical behavior of lanthanum coatings and their protective efficiency in a 3.5 % NaCl solution. The obtained results

* Correspondence e-mail: farida.boucetta@univ-jijel.dz

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provide valuable insight into the corrosion protection mechanism of lanthanum-based coatings and their potential application as environmentally friendly alternatives for surface protection technologies.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Tinplate samples were used as substrates for the electrodeposition experiments. Prior to deposition, the samples were mechanically polished, degreased in acetone, rinsed with distilled water, and dried. Lanthanum nitrate solution was used as the source of lanthanum ions in the electrolyte.

2.2 Electrodeposition Process

Lanthanum coatings were deposited using a traditional two-electrode electrochemical cell consisting of:

- working electrode: tinplate substrate
- counter electrode: platinum electrode

The electrodeposition was carried out in an aqueous electrolyte containing lanthanum ions with different additives. The deposition parameters such as potential and deposition time were carefully controlled.

2.3 Electrochemical Measurements

Electrochemical measurements were carried out using a potentiostat/galvanostat (SOLATRON, Electrochemical Interface SI 1287). The experiments were performed in a double-walled cylindrical Pyrex glass cell with a capacity of 100 mL. The electrochemical system consisted of a three-electrode configuration: a tinplate working electrode with an exposed surface area of 1 cm^2, a saturated calomel electrode (SCE, +0.224 V vs. SHE at 25 °C) as the reference electrode, and a platinum counter electrode.

All electrochemical data were acquired and processed using a computer equipped with CorrView software, enabling real-time monitoring of the potential evolution and the plotting of polarization curves (E vs. log$I$).

2.4 Surface Characterization

Optical Microscopy (OM): The surface morphology and microstructure of the samples were examined using optical microscopy. Observations were conducted at the Materials Laboratory (Department of Physics) using an OPTIKA B-350 microscope.

3. RESULTS AND DISCUSSION

3.1 Electrodeposition Behavior of Lanthanum

The present experimental study focuses on the fabrication of rare earth-based coatings on tinplate substrates and the subsequent evaluation of their electrochemical behavior in corrosive media. Thin films were electrodeposited onto tinplate using a galvanostatic mode from a 0.01 M nitrate-based electrolyte. The deposition process was conducted at room temperature under continuous magnetic stirring for 10 minutes, applying a constant current density of 1 $mA \cdot cm^{-2}$, previously optimized and selected based on earlier studies [18]. After deposition, all samples were thoroughly rinsed with acetone to remove any residual impurities and subsequently stored in a desiccator at 22 °C ± 2 °C until further characterization.

In general, cathodic electrolytic deposition involves electrochemically induced base generation reactions at the electrode surface [17, 19]:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (1)$$

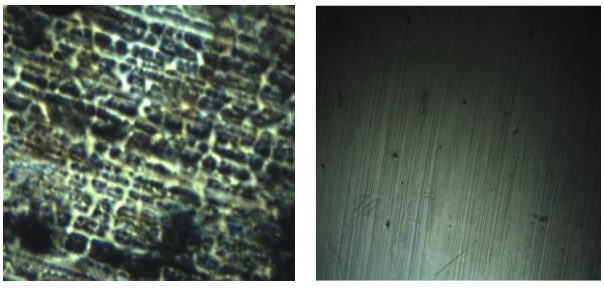
$$NO_3^- + H_2O + 2e^- \rightarrow NO_2^- + 2OH^- \quad (2)$$

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (3)$$

These reactions consume water and generate hydroxide ions (OH^-), resulting in a localized increase in interfacial pH near the cathode surface. This pH rise plays a key role in the deposition mechanism, as it promotes the hydrolysis of metal ions and their complexes. Consequently, insoluble species such as metal hydroxides, oxides, or peroxides are formed and progressively deposited onto the cathodic sites of the substrate.

In the case of lanthanum-based systems, the electrogenerated OH^- ions favor the precipitation of lanthanum hydroxide species, mainly $La(OH)_3$ and/or partially hydrolyzed complexes such as $La(OH)_2^+$. The deposition process is therefore governed by a coupled mechanism involving mass transport of ionic species, interfacial pH increase, and nucleation and growth phenomena. Initially, nucleation occurs at active sites on the substrate surface, followed by lateral growth and coalescence of nuclei, leading to the formation of a continuous and adherent film.

Furthermore, the structure and morphology of the resulting coating strongly depend on parameters such as current density, electrolyte composition, and hydrodynamic conditions. These factors influence the rate of OH^- generation and, consequently, the supersaturation level at the interface, which controls nucleation density and crystal growth. From an electrochemical standpoint, the formed lanthanum-based layer acts as a protective barrier, limiting charge transfer processes and enhancing corrosion resistance, as typically evidenced by an increase in charge transfer resistance and the modification of capacitive behavior in impedance spectra.



a b

Fig. 1 – Optical micrographs (X800) of tinplate surfaces: (a) with lanthanum deposition; (b) bare substrate without deposition

Microscopic observations of the lanthanum coatings obtained by electrodeposition reveal significant morphological differences depending on the presence of the deposit. Fig. 1 (a) shows a granular and relatively uniform coating, indicating the formation of a continuous

protective layer on the substrate. Well-defined grains suggest controlled crystalline growth and good surface coverage, which is favorable for corrosion protection. In contrast, Fig. 1 (b), corresponding to the bare substrate, exhibits a smooth surface with polishing-related scratches and no granular structure, confirming that the features observed in Fig. 1 (a) result from the lanthanum deposition.

3.2 Electrochemical Behavior of Electrodeposited Coatings

Free Potential Monitoring

Once the deposits were formed, we performed corrosion tests by monitoring the evolution of the open-circuit potential (corrosion potential) over time for samples maintained at room temperature. While simple to measure, the evolution of this potential is quite difficult to interpret because the interface is generally not the site of a single electrochemical process: there is a coupling between at least two elementary mechanisms, anodic and cathodic, and any variation in the corrosion potential implies a modification of each of them as well as their compensation. Fig. 2 shows the shape of the OCP curves over 30 minutes for lanthanum films produced at a current density of 1 mA/cm² during an electrodeposition time of 10 minutes.

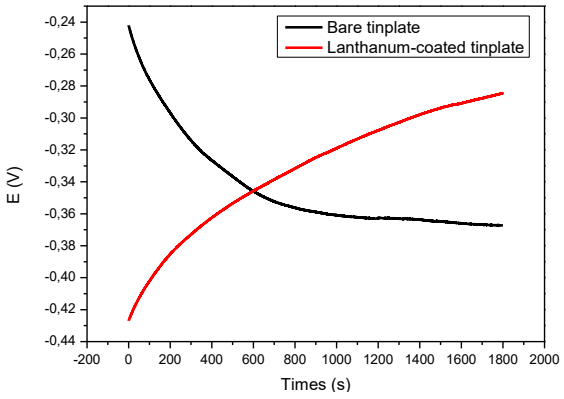


Fig. 2 – Evolution of the open-circuit potential obtained in a NaCl (3.5 %) solution

These curves show that the potential becomes more pronounced in the presence of a lanthanum film. We also observe that, in the presence of lanthanum deposition, there is a progressive increase in potential, linked to the formation of the protective film.

Polarization Curves

Before any measurement, the working electrodes were systematically maintained in a 3.5 % NaCl solution at the corrosion potential. Fig. 3 shows the cathodic and anodic polarization curves, obtained at a voltage sweep rate of 1 mV/s, of the tin-plated electrode in the absence and presence of lanthanum coatings, generated at a current density of 1 mA/cm² and after 10 minutes of immersion. They are represented on a semi-logarithmic scale (Tafel plot). The corresponding corrosion parameters are presented in Table 1.

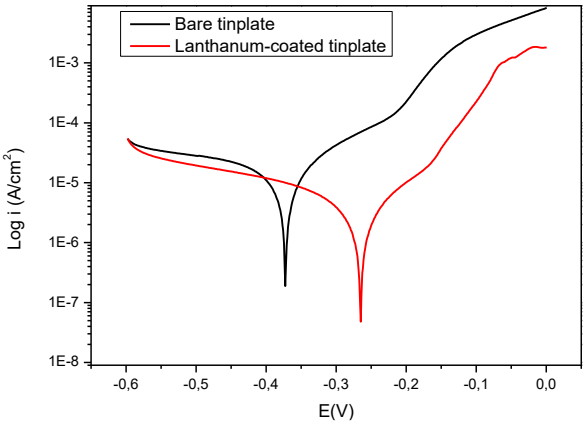


Fig. 3 – Polarization curves, obtained in a NaCl (3.5 %) solution, for Tinplate without and with deposits

Table 1- Electrochemical quantities of cerium deposition, for tinplate without and with deposits

	E_{corr} (V/ECS)	i_{corr} (µA/cm²)	R_p (Ω/cm²)	E (%)
Tinplate without deposits	– 0.35982	89.7040	2908.1	/
Tinplate with deposits	– 0.26539	3.1807	8201.6	96,45

Furthermore, a comparative examination of these different results leads to the following observations.

The corrosion potential shifts towards more anodic values, and the current density decreases when the electrode is coated with the rare earth layer. In addition, a useful parameter that can often be extracted from potentiodynamic polarization curves is the polarization resistance (RP). According to the data in Table 1, the polarization resistance of the coatings exhibits reversible behavior with respect to current density, where it is noted that the higher RP resistance value (8201.6 Ω/cm²) is observed in the case of lanthanum deposits.

Table 1 also gives the percentage protection efficiency (E %) of the deposits, expressed as follows [20]:

$$E\ \% = \frac{i_{corr} - i'_{corr}}{i_{corr}} \times 100$$

Where i_{corr} and i'_{corr} are the corrosion current densities without and with lanthanum deposition, respectively, determined by extrapolation of the cathodic Tafel lines to the corrosion potential (E_{corr}).

The improvement in corrosion resistance can be attributed to differences in coating morphology, particularly grain size and porosity. In non-oxidizing solutions, metal corrosion generally proceeds via uniform anodic dissolution [21]:

$$Sn \rightarrow Sn^{2+} + 2e^- \quad (4)$$

While the dominant cathodic reaction is oxygen reduction:

$$2H_2O + O_2 + 4e^- \rightarrow 4OH \quad (5)$$

For the corrosion of tinplate, the reduction of dissolved oxygen is the dominant cathodic reaction. Of

course, the structure and properties of the tin coating layer can greatly affect the oxygen diffusion and reduction process. Therefore, the difference in E_{corr} of tinplate after Lanthane electrodeposition is also related to the formation of a protective layer blocking the active sites of tinplate [4].

3.3 Effect of Additives

In order to investigate the influence of additives introduced into the rare earth bath on the electrochemical behavior, morphology, and thickness of the films, different additives were separately added to the cerium and lanthanum baths, as follows:

- H_3BO_3 solution (0.01 g/L), acting as a buffer or complexing agent [22];
- H_2O_2 solution (0.01 M), used as an oxidizing agent [18];
- NH_4Cl solution (0.01 g/L), used as a supporting electrolyte to enhance ionic conductivity [23].

Before studying the corrosion behavior of the substrates in different media, it is important to monitor the evolution of the open circuit potential (OCP) as a function of time. These variations are presented in Fig. 4 for an immersion time of 30 minutes in an aerated 3.5 % NaCl solution at room temperature.

Open Circuit Potential Evolution of Lanthanum Coatings with Additives

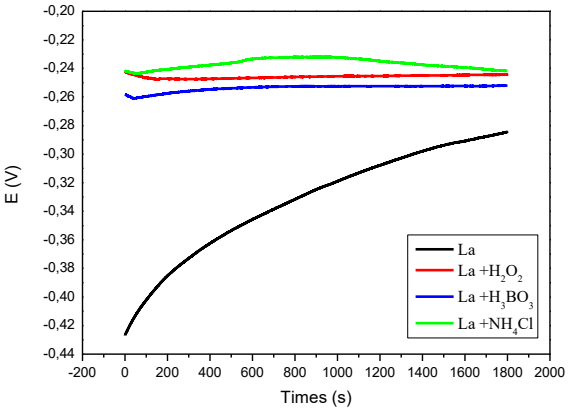


Fig. 4 – Open circuit potential (OCP) of lanthanum deposits on tinplate in a 3.5 % NaCl solution, prepared in the presence of different additives

All measured potentials fall within a narrow range, between − 0.30 and − 0.24 V vs. SCE. The incorporation of additives in the lanthanum bath significantly affects the corrosion potential of the samples. The OCP evolution in the presence of additives indicates the formation of a protective layer on the metallic surface, as evidenced by a shift toward more noble potentials.

Polarization Curves

In the potentiostatic method, the electrode potential was stabilized for 30 min before recording the $I = f(E)$ curves. The polarization curves of lanthanum deposits, with and without additives, at room temperature are shown in Fig. 5.

The overall shape of the *I-E* curves is relatively similar for all coatings. However, both cathodic and anodic currents are higher in the presence of additives compared to the additive-free condition.

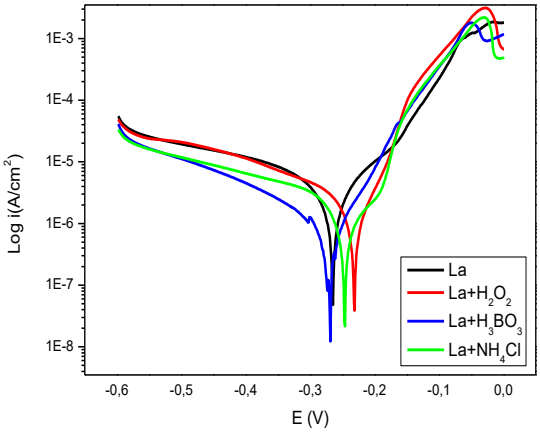


Fig. 5 – Polarization curves of lanthanum coatings

The Tafel plots (Fig. 5) allowed the determination of key electrochemical parameters, namely the corrosion current density i_{corr} (μA·cm^{-2}), corrosion potential E_{corr} (mV), and polarization resistance R_p (Ω·cm²), using CorrView software. The obtained results are summarized in Table 2.

Table 2 – Electrochemical parameters of lanthanum deposits on tinplate prepared in the presence of different additives

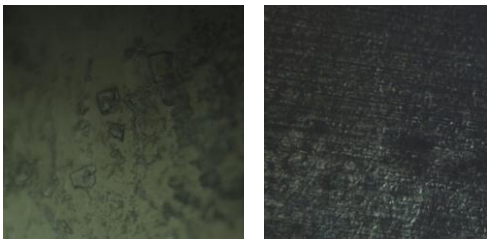
	E_{corr} (V/ECS)	i_{corr} (μA/cm²)	R_p (Ω/cm²)
La coating without additives	– 0.26539	3.1807	8201.6
La + H_2O_2	– 023214	1.136	11237
La + H_3BO_3	– 0.26985	0.6549	24474
La + NH_4Cl	– 0.24661	1.0659	15930

From these results, it can be observed that:

- Regardless of the coating, the current density values remain low, indicating good corrosion resistance and confirming the effectiveness of electrodeposited coatings.
- The best corrosion performance is achieved with the addition of H_3BO_3 and NH_4Cl, which exhibit lower current densities and higher polarization resistance values.

These findings are further supported by optical microscopy observations of the sample surfaces (Fig. 6). The images clearly show that the surface morphology varies with the type of additive used.

The micrographs reveal that the nature of the additive significantly affects the morphology of lanthanum deposits.



a b

c

Fig. 6 – Microscopic images of coatings obtained from a 0.01 M $La(NO_3)_3$ solution with the addition of: (a) H_3BO_3, (b) H_2O_2, and (c) NH_4Cl, deposited for 10 min at room temperature

In the presence of H_3BO_3 (a), the coating appears relatively uniform with well-defined structures, indicating controlled growth. The addition of H_2O_2 (b) results in a more compact but less structured surface, suggesting rapid nucleation and grain coalescence. In contrast, with NH_4Cl (c), the deposit exhibits a more heterogeneous and rough morphology with noticeable agglomerates, reflecting non-uniform growth.

These results confirm that additives influence the nucleation and growth mechanisms, thereby affecting the homogeneity and quality of the obtained coatings.

4. CONCLUSION

The present work demonstrates that lanthanum electrodeposition is an effective method for improving the corrosion resistance of tinplate in chloride media. The obtained coatings exhibit a relatively homogeneous and compact morphology, which depends on the electrolyte composition and additives. Electrochemical results confirm a significant reduction in corrosion current density and an increase in polarization resistance, reflecting enhanced surface protection. The high protection efficiency highlights the strong inhibitive effect of the lanthanum layer. This improvement is mainly attributed to the formation of a protective barrier that limits both anodic dissolution and cathodic oxygen reduction. Overall, lanthanum-based coatings represent a promising and environmentally friendly alternative for corrosion protection of metallic substrates.

REFERENCES

1. H. Aljibori, A. Alamiery, A. Kadhum, *Int. J. Corros. Scale Inhib.* **12** No 4, 1476 (2023) http://dx.doi.org/10.17675/2305-6894-2023-12-4-6.
2. G.K. Deshwal, N.R. Panjagari, *J. Food Sci. Technol.* **57** No 7, 2377 (2020) https://doi.org/10.1007/s13197-019-04172-z.
3. K.-H. Chang, et al., *Corrosion* **78** No 2, 127 (2022) https://doi.org/10.5006/3963.
4. Y.-X. Jiang, *Trans. Nonfer. Met. Soc. China* **22** No 3, 717 (2012) https://doi.org/10.1016/S1003-6326(11)61236-3
5. P. Kesari, *Advanced Coating and Cladding Technologies* (CRC Press: 2026).
6. X. Huang, N. Li, *J. Alloy. Compd.* **465** No 1-2, 317 (2008) https://doi.org/10.1016/j.jallcom.2007.10.093.
7. T. Zehra, M. Kaseem, *ACS Sustain. Chem. Eng.* **11** No 18, 6776 (2023) https://doi.org/10.1021/acssuschemeng.3c00763.
8. X. Huang, et al., *Thin Solid Films* **516** No 6, 1037 (2008) https://doi.org/10.1016/j.tsf.2007.08.044.
9. R. Amini, P. Kardar, *J. Rare Earths* **43** No 5, 859 (2025) https://doi.org/10.1016/j.jre.2024.07.002.
10. J.A.C. Mendez, Y.M. Vong, J.d.J.P. Bueno, *Prot. Met. Phys. Chem. Surf.* **58** No 4, 801 (2022) https://doi.org/10.1134/S2070205122040141.
11. O.J. Lawal, *Rare Earth Element (REE) SS-Diketone Complexes as Novel Corrosion Inhibitors for Mild Steel and Stainless Steels in a Corrosive Chloride Media* (University of the Witwatersrand, Johannesburg (South Africa): 2022).
12. M. Cao, et al., *J. Mater. Sci.* **60** No 8, 3663 (2025) https://doi.org/10.1007/s10853-025-10705-z.
13. M.B. Kale, et al., *Adv. Funct. Mater.* **31** No 25, 2101313 (2021) https://doi.org/10.1002/adfm.202101313.
14. F.C. Walsh, S. Wang, N. Zhou, *Curr. Opin. Electrochem.* **20**, 8 (2020) https://doi.org/10.1016/j.coelec.2020.01.011.
15. S.M. Dezfuli, M. Sabzi, *Ceram. Int.* **45** No 17, 21835 (2019) https://doi.org/10.1016/j.ceramint.2019.07.190.
16. B. Pandit, E.S. Goda, S.F. Shaikh, *Simple Chemical Methods for Thin Film Deposition: Synthesis and Applications* 245 (2023) https://doi.org/10.1007/978-981-99-0961-2_6.
17. M. Nahian, R. Reddy, *J. Electrochem. Soc.* **172** No 2, 022503 (2025) https://doi.org/10.1149/1945-7111/adb07d.
18. T. Yousefi, A.N. Golikand, M.H. Mashhadizadeh, *Mater. Sci. Semicond. Proc.* **16** No 6, 1943 (2013) https://doi.org/10.1016/j.mssp.2013.07.017.
19. T. Zhou, *Adv. Ceram. Proc.* 85 (2015) https://dx.doi.org/10.5772/61056.
20. L. Bammou, et al., *Int. J. Electrochem. Sci.* **6** No 5, 1454 (2011) https://doi.org/10.1016/S1452-3981(23)15085-1.
21. L. Shen, et al., *Int. J. Electrochem. Sci.* **16** No 6, 210650 (2021) https://doi.org/10.20964/2021.06.18.
22. R. Srinivasan, G. Ramesh Bapu, *Trans. IMF* **91** No 1, 52 (2013) https://doi.org/10.1179/0020296712Z.00000000062.
23. X. Huang, et al., *Mater. Lett.* **62** No 3, 466 (2008) https://doi.org/10.1016/j.matlet.2007.05.071.

Електроосадження та корозійна поведінка лантанових покриттів на жерсті в хлоридному середовищі

Farida Boucetta[1,2] ✉, Mohammed-Amin Boumehraz[3], Saaid Naouel[2]

[1] *Physics Laboratory of Thin Layers and Applications, University Mohamed Khider Biskra, 07000, Algeria*
[2] *Department of Chemistry, Faculty of Exact Sciences and Computer Science, University of Mohammed Seddik Benyahia, 18000 Jijel, Algeria*
[3] *Laboratory of Research in Civil Engineering, Mohammed Khider University of Biskra, 07000, Algeria*

У роботі досліджується електроосадження покриттів на основі лантану на жерсть та вплив добавок (H_3BO_3, H_2O_2 та NH_4Cl) на їхню морфологію та корозійну стійкість у розчині NaCl з концентрацією 3,5 мас. %. Покриття були охарактеризовані за допомогою оптичної мікроскопії та потенціодинамічних поляризаційних вимірювань. Результати показують, що природа добавки суттєво впливає на мікроструктуру осадів. H_3BO_3 призводить до відносно однорідних та чітко визначених покриттів, H_2O_2 сприяє утворенню більш компактних структур, тоді як NH_4Cl призводить до неоднорідної та шорсткої морфології. Електрохімічні вимірювання вказують на позитивний зсув потенціалу корозії та значне зниження щільності струму корозії після осадження лантану. Поляризаційний опір значно зростає, що підтверджує покращену захисну поведінку покриттів. Максимальна ефективність захисту 96,45 % була отримана для жерсті з покриттям лантаном. Підвищена корозійна стійкість пояснюється утворенням захисного шару, який діє як бар'єр проти проникнення електроліту, зменшує дифузію кисню та блокує активні центри корозії. Ці результати демонструють, що добавки відіграють ключову роль у контролі процесу осадження та оптимізації захисних властивостей покриттів на основі лантану.

Ключові слова: Електроосадження, Покриття на основі лантану, Жерсть, Корозія, Поляризаційна стійкість.