ELECTRODEPOSITION PROCESSES FOR ENHANCED SILVER AND GOLD COATINGS

Milica Vlahović[1] Nenad Vušović[2] Darja Žarković[3] Jovanka Pejić[1]

Abstract: This study explores the optimization of pulse-reverse current (PRC) regimes for silver and gold electrodeposition, aiming to enhance coating quality, energy efficiency, and environmental sustainability. The research highlights the significant benefits of PRC, including the production of high-quality coatings with improved surface characteristics such as uniformity and reflectivity, achieved without hazardous additives. The optimized PRC parameters led to substantial energy savings, demonstrating the potential of these techniques in sustainable metal finishing processes. Through systematic adjustments of PRC parameters, the study achieved superior coatings, showcasing the technique's versatility and effectiveness. These findings underscore the value of PRC in advancing eco-friendly and cost-effective electrochemical deposition practices.

Key words: silver electrodeposition, gold electrodeposition, pulse-reverse current, coating quality, energy efficiency

1. INTRODUCTION

Electrochemical deposition is an essential process in various industrial applications, particularly for creating high-quality metal coatings used in electronics, automotive, and jewelry sectors. The traditional constant current (DC) methods, although effective, often require hazardous additives to achieve desirable properties such as gloss, adhesion, and uniformity. These chemicals pose significant environmental and safety risks.

To address these concerns, alternative techniques such as pulse-reverse current (PRC) methods have been developed [1,2]. PRC techniques involve alternating cathodic and anodic pulses, which provide enhanced control over the deposition process. This control allows for the reduction or elimination of harmful additives, while still achieving superior coating properties. The key advantage of PRC methods is their ability to produce coatings with improved surface characteristics, such as higher reflectivity, smoother finishes, and better uniformity, without the associated environmental risks.

The theoretical foundation of PRC methods is based on the principle of using periodic current reversals to mitigate common issues in DC deposition, such as dendritic growth and uneven layer formation. By alternating the current, PRC methods promote the formation of compact and uniform metal layers, even on complex geometries. This approach not only enhances the aesthetic qualities of the coatings but also improves their mechanical properties and durability [3,4].

The importance of optimizing PRC parameters, including current density, pulse duration, and frequency, cannot be overstated. Fine-tuning these parameters allows for the customization of the deposition process to meet specific application requirements, enhancing both performance and efficiency [5,6]. Moreover, PRC techniques contribute to sustainability by reducing energy consumption and material waste [7].

The focus of this study is on the electrodeposition of silver and gold, two precious metals widely used in high-value applications. The primary objective is to explore how PRC methods can be optimized to achieve high-quality coatings that are both economically and environmentally sustainable. By systematically varying the key parameters of the PRC process, this research aims to

[1]Dr Milica Vlahović, Research Professor, University of Belgrade, Institute of Chemistry, Technology and Metallurgy-National Institute of the Republic of Serbia, Njegoševa 12, Belgrade, Serbia, email: m.vlahovic@ihtm.bg.ac.rs; mvlahovic@tmf.bg.ac.rs
[2]Dr Nenad Vušović, Professor, University of Belgrade, Technical Faculty in Bor, Vojske Jugoslavije 12, Bor, Serbia, email: nvusovic@tfbor.bg.ac.rs
[3]Darja Žarković, Professor of Vocational Studies, The Academy of Applied Technical Studies Belgrade, Katarine Ambrozić 3, Belgrade, Serbia, email: dzarkovic@atssb.edu.rs
[1]MSc Jovanka Pejić, Research Assistant, University of Belgrade, Institute of Chemistry, Technology and Metallurgy-National Institute of the Republic of Serbia, Njegoševa 12, Belgrade, Serbia, email: jovanka.kovacina@ihtm.bg.ac.rs

provide insights into the best practices for silver and gold electrodeposition, paving the way for broader adoption of these techniques in industrial settings.

2. EXPERIMENTAL METHODS

2.1. Pulse-Reverse Current (PRC) Regime

The PRC regime involves alternating cathodic and anodic pulses, which helps in achieving uniform deposition and minimizing defects. Key parameters include cathodic current density (j_c), anodic current density (j_a), pulse duration (t_c), and anodic pulse duration (t_a). These parameters were systematically varied to identify optimal conditions for silver and gold electrodeposition.

- **Silver Electrodeposition:** A commercially available silver electrolyte with a concentration of 30 g/L was used. Parameters such as j_c, j_a, t_c, and t_a were adjusted to optimize the coating process.
- **Gold Electrodeposition:** For gold, an electrolyte with a concentration of 10 g/L was employed. The PRC parameters were similarly optimized to ensure high-quality deposition.

2.2. Measurement Techniques

To evaluate the effectiveness of the PRC regime, several measurement techniques were employed:

- **Reflectivity:** Surface brightness was assessed using semiconductor lasers at wavelengths of 445 nm, 520 nm, and 635 nm.
- **Thickness:** Coating thickness was measured using X-ray fluorescence (XRF) technology, with standard deviations calculated to assess uniformity.
- **Energy Efficiency:** Energy consumption was monitored and compared across different power regimes, with energy savings quantified relative to the DC regime.

3. RESULTS AND DISCUSSION

3.1. Silver Coatings

Micrographs of silver coatings revealed that PRC regimes produce smoother and more uniform surfaces compared to DC methods. The use of PRC significantly reduced dendritic growth, leading to coatings with higher reflectivity and improved surface quality. Energy savings were also noted, with PRC regimes demonstrating superior efficiency.

Figure 1 shows the microstructure of the silver coating obtained under the PRC regime, demonstrating significant improvements in uniformity and surface smoothness.

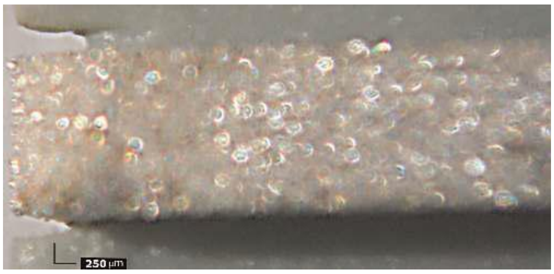

Figure 1 -Micrograph of Silver Coating under PRC Regime

The observed improvements in coating quality are attributed to the precise control over the deposition process afforded by PRC. The alternating current pulses help in mitigating issues such as dendritic growth and uneven deposition, which are common in DC methods. This results in a more consistent and visually appealing coating.

3.2. Gold Coatings

Similar benefits were observed for gold coatings. PRC regimes resulted in brighter, more uniform coatings with excellent edge coverage. The elimination of hazardous additives further underscored the environmental advantages of PRC techniques.

Figure 2 shows the microstructure of the gold coating obtained under the PRC regime, demonstrating high reflectivity and surface uniformity.

Figure 2 -Micrograph of Gold Coating under PRC Regime

The enhanced quality of gold coatings, as evidenced by increased reflectivity and uniformity, is a significant advancement. The ability to achieve these results without hazardous chemicals not only reduces environmental risks but also lowers production costs by eliminating the need for expensive additives.

3.3. Energy Efficiency

The study quantified energy savings achieved through the use of PRC regimes. Both silver and gold electrodeposition processes demonstrated significant improvements in energy efficiency, highlighting the economic and environmental benefits of optimized PRC parameters.

Figure 3 shows the comparison of energy consumption between the DC and PRC regimes for silver and gold, where the PRC regime demonstrates significant energy savings.

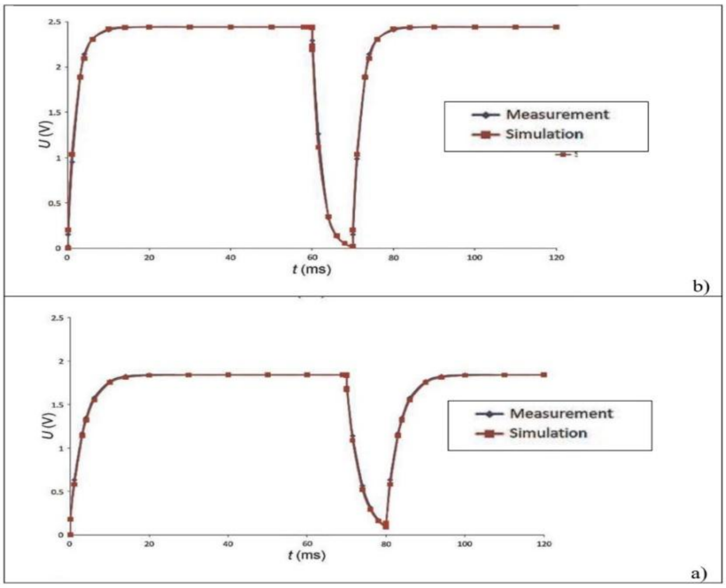

Figure 3 -Comparison of Energy Consumption between DC and PRC Regimes: a) silver, b) gold

The energy savings observed in PRC regimes are particularly noteworthy. By optimizing the pulse parameters, the process achieves higher efficiency, reducing overall energy consumption. This makes PRC a more sustainable choice for industrial applications, aligning with global efforts to reduce energy usage and carbon emissions.

4. CONCLUSION

This research confirms that pulse-reverse regimes significantly enhance the quality of silver and gold coatings. Optimized PRC parameters resulted in superior coating performance, increased energy efficiency, and reduced environmental impact. The findings highlight the potential of PRC techniques to replace traditional methods, offering a safer and more cost-effective alternative.

Future work will focus on further refining PRC techniques and exploring their application in other electrochemical processes. This includes extending the study to other metals and alloys, as well as investigating the long-term durability of PRC coatings under various environmental conditions. The ongoing development of PRC methods promises to contribute significantly to the advancement of sustainable manufacturing practices.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Bicelli L.P., Bozzini B., Mele C., D'Urzo L.: *A Review of Nanostructural Aspects of Metal Electrodeposition*, International Journal of Electrochemical Science 3(4): 356-408, 2008.

[2] Kanani, N.: *Electroplating: basic principles, processes and practice*, Elsevier, Oxford, United Kingdom, 2006.

[3] Mariani E., Giurlani W., Bonechi M., Vincenzo Dell'Aquila V., Innocenti M.: *A systematic study of pulse and pulse reverse plating on acid copper bath for decorative and functional applications*, Scientific Reports 12: 18175, 2022. https://doi.org/10.1038/s41598-022-22650-x.

[4] Subramaniyam C., Pushpavanam M.: *Pulse and pulse reverse plating- Conceptual, advantages and applications*, Electrochimica Acta 53: 3313-3322, 2008. 10.1016/j.electacta.2007.11.054.

[5] Liu Z., West A.C.: *Modeling of galvanostatic pulse and pulsed reverse electroplating of gold*, Electrochimica Acta 56 (9): 3328, 2011. 10.1016/j.electacta.2011.01.020.

[6] Joseph A., Kirubasankar B., Mathew A.M., Narayanasamy M., Yan C., Angaiah S.: *Influence of pulse reverse current parameters on electrodeposition of copper-graphene nanocomposite coating*, Applied Surface Science Advances 5(1): 100116, 2021. https://doi.org/10.1016/j.apsadv.2021.100116.

[7] Jennings Taylor E.: *Perspective–Opportunities for Industrial Applications of Pulse Electrolytic Processes Beyond Plating and Surface Finishing*, Journal of Electrochemical Society 171(8): 083503, 2024. 10.1149/1945-7111/ad680c.