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Electrochemical nickel coatings deposition on copper

Stanko Spasojević¹ | Milena Milovanović² | Danijela Jovičić¹ | Stana Stanišić¹ | Zorica Ristić¹ | Marija Mitrović² |
Nebojša Vasiljević^{2,3} | Milorad Tomić^{2,4}

¹“Orao” a.d. Bijeljina, Šabačkih đaka
bb, 76300 Bijeljina, Republic of Srpska,
Bosnia and Herzegovina

²University of East Sarajevo, Faculty of
Technology Zvornik, Karakaj 34A,
75400 Zvornik, Republic of Srpska,
Bosnia and Herzegovina

³University of Novi Sad, Faculty of
Technology Novi Sad, Cara Lazara 1,
21000 Novi Sad, Serbia

⁴Engineering Academy of Serbia,
Department of Technology and
Metallurgy, Kneza Miloša 9/IV, 11000
Belgrade, Serbia

Correspondence

Milena Milovanović

Email:

mimamilovanovic51@gmail.com

Abstract

This paper investigates the electrodeposition of a nickel coating on a copper substrate with dimensions ($5 \times 5 \times 0.1$) mm, focusing on the influence of parameters such as current density, electrolyte temperature and deposition time. Copper samples were treated in nickel-based electrolytes under different deposition times and current densities, while the temperature was maintained constant. In the electrochemical deposition process, copper plates were used as cathodes, while high-purity electrolytic nickel (99.999%) was used as the anode. Electrochemical nickel coatings were applied for 10, 15 and 20 minutes at current densities of 1.0, 1.5 and 2 A/dm², at a bath temperature of 42 °C. The results show that deposition parameters significantly affect the morphology and physical-mechanical properties of the formed layers. With an increase in the current density, there is an increase in the thickness of the metal coating deposited on the copper surface, as well as with an increase in the time of the electrochemical process. Based on the obtained data, the work provides useful guidelines for the optimization of the process of electrochemical deposition of nickel on copper for industrial applications.

Keywords: copper, nickel coating, electrochemical deposition, roughness, current efficiency, coating thickness

1. INTRODUCTION

Electrochemical coating deposition is a process in which a metallic coating is deposited onto the surface of a conductive material using an electrochemical process. This method is essential in industries that require improved material properties, such as corrosion resistance, wear resistance, or enhanced electrical and thermal properties. Copper is one of the most commonly used materials in electrochemical coating due to its excellent electrical conductivity. However, copper itself is not corrosion-resistant, which limits its application in aggressive environments. For this reason, copper is often coated with metals that enhance its properties (Priyadarshini, Bhat, Bindu, Nagaraj, & Rekha 2025; Sivasubramanian, Upadhyay, Mallik, & Basu 2025; Tazhibayeva, Bayeshova, Bayeshov, & Osińska 2025).

Requirements that every metallic coating must meet include good adhesion to the substrate (except in electroforming), fine-grained structure, homogeneity, strength,

and uniform thickness. Depending on the application, other common requirements include corrosion resistance, hardness, ductility, brightness, and soldering and welding compatibility (Dorđević 1970; Molina, Cano, & Ramírez-Barat 2023; Zhang et al. 2024).

One of the most commonly used coatings is nickel, known for its high resistance to corrosion, wear, and elevated temperatures. Electrochemical deposition is one of the most widely used methods for producing nickel coatings on copper. This technique enables control over alloy properties, phase composition, and morphology by adjusting electrochemical deposition parameters, such as current density (Baskaran, Sankara Narayanan, & Stephen 2006; Pellicer et al. 2011; Roy, Matlosz, & Landolt 1994), deposition potential, type of bath (H₃BO₃-based electrolytes or citrate-containing solutions), and electrolyte pH (An et al. 2024; Calleja et al. 2012; Ren et al. 2025).

Ni-Cu alloys can be deposited over a wide pH range, from 2 to 9. The concentration of Cu²⁺ in the electrolyte

and pH value significantly affect the surface characteristics and morphology. The copper content in the alloy increases with agitation, higher pH values, and increased Cu^{2+} concentration in the electrolyte (Ghosh, Grover, Dey, & Totlani 2000). Moreover, surface roughness increases when the electrolyte pH decreases and copper content rises (Hacıismailoglu & Alper 2011). The applied potential strongly influences the composition, microstructure, and morphology of the Ni–Cu alloy surface. At lower deposition potentials, the alloys become richer in nickel, the surface morphology shifts from dendritic to cauliflower-like, and surface roughness decreases (Sarac, Öksüzoglu, & Baykul 2012).

Electrochemical nickel coating on copper enables the formation of highly resistant surfaces, which is of great importance in industries such as electronics, automotive, and electrical device manufacturing. This process offers numerous advantages over other coating methods, including controlled coating thickness, application precision, and energy efficiency (Ma et al. 2022; Reis et al. 2022; Tomić, Pavlović, Pavlović, & Rakočević 2003).

The aim of this study is to investigate the electrochemical deposition of nickel coatings on copper, with the goal of optimizing the process and improving the quality of the deposited layers. Understanding the parameters that affect coating quality can contribute to the development of new, more efficient methods for industrial applications.

2. MATERIALS AND METHODS

The electrochemical deposition of nickel coatings was carried out at the Joint Stock Company for Production and Overhaul “ORAO” a.d. Bijeljina. Copper samples (5×5 cm) of tested chemical composition were used as cathodes. The chemical composition of the copper plates was determined using the XRF method (X-ray fluorescence spectrometry) on the X-MET 8000 device. For the electrochemical deposition, industrial electrolytes used by the company were applied, based primarily on the Watts electrolyte with certain additives for brightness. The composition of the baths and the working conditions for the electrochemical deposition of nickel coatings are presented in Table 1.

Prior to electrochemical treatment, the samples were mechanically prepared, followed by pickling and the deposition of a nickel layer. To achieve optimal conditions for the start of deposition, the cathodes were placed in a heated electrolyte solution for preheating for two minutes, aiming to reach an optimal temperature for current flow through the electrolyte. A 99.999% nickel anode was used, and the holders for the cathodes were reinforced with copper wire to ensure better conductivity.

Nickel coatings were deposited from three baths in an electrochemical reactor with a volume of 64 dm^3 . The nickel electrochemical coatings were deposited for 10, 15, and 20 minutes at current densities of 1, 1.5, and 2 A/dm^2 , respectively, at a bath temperature of 42°C . After deposition, the samples were rinsed with running water and subjected to dehydrogenation. The dehydrogenation process involved heating the samples in a furnace for 60 minutes at a temperature of $200 \pm 10^\circ\text{C}$ to remove hydrogen trapped within the coating during electrolytic deposition.

Subsequently, all samples were weighed again, and based on the mass gain, i.e., the difference between the mass before and after coating deposition, the cathodic current efficiency and coating thickness for each sample were calculated. The roughness of the coatings was measured using a Mitutoyo device, and hardness was determined by the Vickers method. The adhesion of nickel coatings was tested by the bending method.

3. RESULTS AND DISCUSSION

Tables 2, 3, and 4 show the results of electrochemically deposited nickel coatings from the three baths.

Figure 1 shows the dependence of the average cathodic current efficiency on the change of current density for the used baths 1, 2, and 3.

From Figure 1, it can be concluded that the average cathodic current efficiency increases with the rise in current density for all three baths. The highest cathodic efficiency was observed for Bath 1 (the bath without gloss additives), indicating that gloss additives slightly reduce current efficiency but positively affect the appearance and quality of the coating.

When comparing baths 2 and 3, both containing gloss additives, Bath 3, which uses sulfosalicylic acid as the brightener, exhibits higher current efficiency compared to Bath 2, which contains the commercial high-gloss additive 301.

The trend shown in Figure 1 is presented in more detail in Figure 2(a–c) for each bath and current density individually. The graphical representations clearly show that the highest current efficiency was achieved with treatment in Bath 1 at a current density of 2 A/dm^2 and a deposition time of 20 minutes.

Dependence of coating thickness on deposition time is shown in Figure 3.

The thickest coatings were obtained after 20 minutes of deposition for all baths, with the maximum measured thickness of $8.05 \mu\text{m}$ achieved in Bath 1, at a current density of 2 A/dm^2 and a deposition time of 20 minutes. Thicker coatings were obtained from Bath 1 (without gloss additives) compared to baths 2 and 3 (with gloss

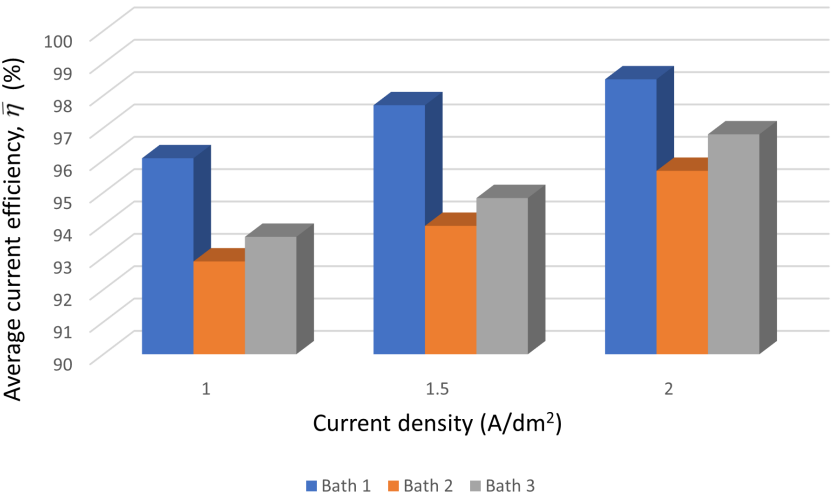


Figure 1. Dependence of average cathodic current efficiency on the change in current density for baths 1, 2, and 3.

Table 1. Bath Composition and Operating Conditions

	Bath 1	Bath 2	Bath 3
Based on Watts electrolyte with the same concentration in all three baths			
NiCl ₂ · 6H ₂ O 30–50 g/dm ³			
H ₃ BO ₃ + 15–30 g/dm ³			
NiSO ₄ · 7H ₂ O 200–250 g/dm ³			
Composition	Basic additive 302 (5 cm ³ /dm ³) Wetting additive 304 (8 cm ³ /dm ³) Ductility additive 305 (12 cm ³ /dm ³) (all from “Protekta”, Belgrade)	Basic additive 302 (5 cm ³ /dm ³) Wetting additive 304 (8 cm ³ /dm ³) Ductility additive 305 (12 cm ³ /dm ³) High-gloss additive 301 (0.5 cm ³ /dm ³) (all from “Protekta”, Belgrade)	Basic additive 302 (5 cm ³ /dm ³) Wetting additive 304 (8 cm ³ /dm ³) Ductility additive 305 (12 cm ³ /dm ³) Sulfosalicylic acid (0.5 cm ³ /dm ³)
Reactor volume (dm ³)	64		
pH	4.5–5.5		
Operating conditions	Current density: 1, 1.5, and 2 A/dm ² Deposition time: 10, 15, 20 minutes Temperature: 42°C		

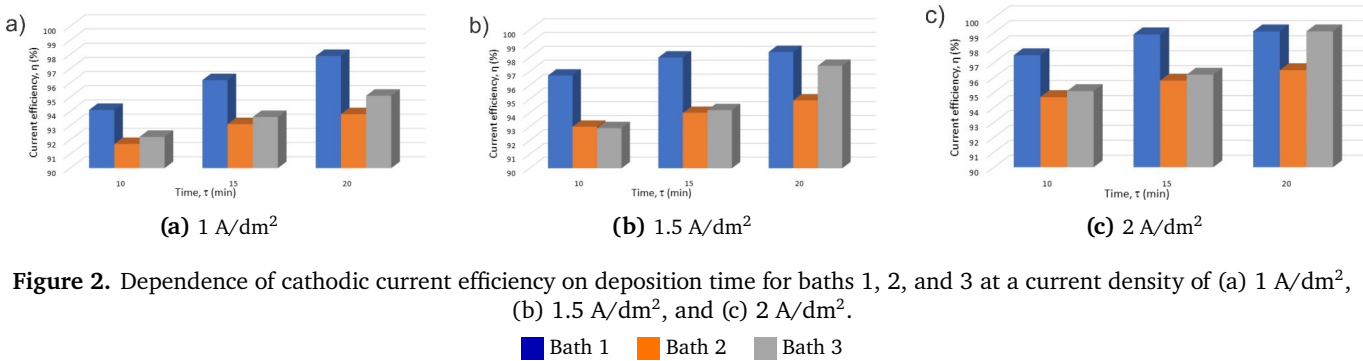


Figure 2. Dependence of cathodic current efficiency on deposition time for baths 1, 2, and 3 at a current density of (a) 1 A/dm², (b) 1.5 A/dm², and (c) 2 A/dm².

Table 2. Results of electrochemical nickel coatings deposited from Bath 1

Bath 1: Watts electrolyte + basic additive 302 (5 cm³/dm³), wetting additive 304 (8 cm³/dm³), and ductility additive 305 (12 cm³/dm³)

Current density j (A/dm ²)	Temp. T (°C)	Time t (min)	Current efficiency η (%)	Avg. current efficiency $\bar{\eta}$ (%)	Coating thickness d (μm)	$v = d/t$ (μm/min)	$\bar{v}$ (μm/min)
1	42	10	94.1	96.06	1.93	0.193	0.196
		15	96.2		2.96	0.197	
		20	97.9		3.97	0.198	
1.5	42	10	96.7	97.70	2.98	0.298	0.298
		15	98.0		4.52	0.301	
		20	98.4		5.97	0.295	
2	42	10	97.5	98.50	4.01	0.401	0.402
		15	98.9		6.08	0.405	
		20	99.1		8.05	0.402	

Table 3. Results of electrochemical nickel coatings deposited from Bath 2

Bath 2: Watts electrolyte + basic additive 302 (5 cm³/dm³), wetting additive 304 (8 cm³/dm³), ductility additive 305 (12 cm³/dm³), and high gloss additive 301 (0.5 cm³/dm³)

Current density j (A/dm ²)	Temp. T (°C)	Time t (min)	Current efficiency η (%)	Avg. current efficiency $\bar{\eta}$ (%)	Coating thickness d (μm)	$v = d/t$ (μm/min)	$\bar{v}$ (μm/min)
1	42	10	91.7	92.87	1.88	0.188	0.190
		15	93.1		2.86	0.190	
		20	93.8		3.81	0.191	
1.5	42	10	93.0	93.97	2.86	0.286	0.288
		15	94.0		4.34	0.289	
		20	94.9		5.78	0.289	
2	42	10	94.7	95.67	3.89	0.389	0.394
		15	95.8		5.89	0.392	
		20	96.5		7.83	0.393	

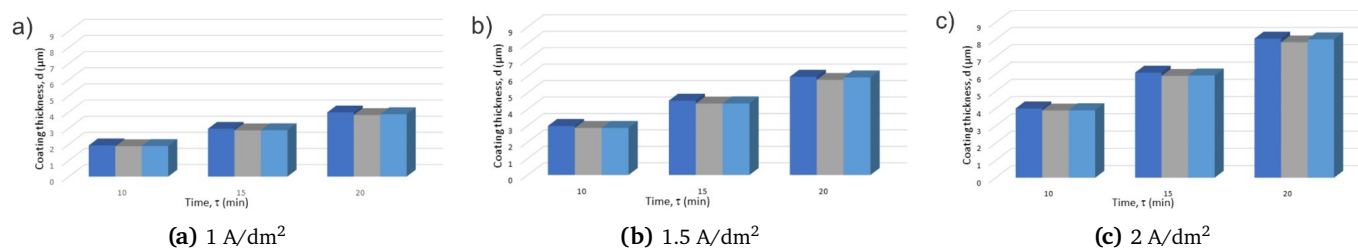


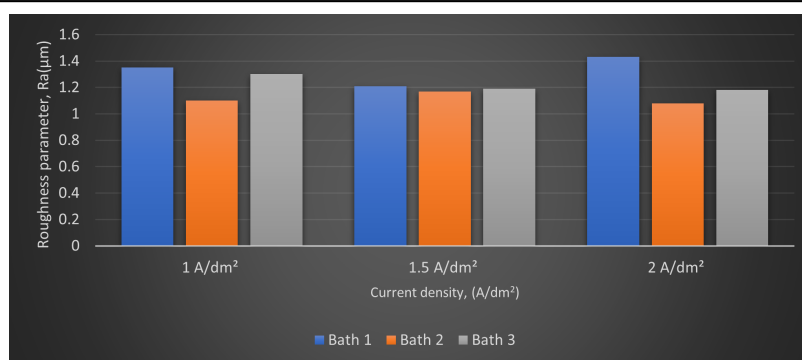
Figure 3. Dependence of coating thickness on deposition time for baths 1, 2, and 3 at a current density of (a) 1 A/dm², (b) 1.5 A/dm², and (c) 2 A/dm².

■ Bath 1 ■ Bath 2 ■ Bath 3

Table 4. Results of electrochemical nickel coatings deposited from Bath 3

Bath 3: Watts electrolyte + basic additive 302 (5 cm³/dm³), wetting additive 304 (8 cm³/dm³), ductility additive 305 (12 cm³/dm³), and sulfosalicylic acid (0.5 cm³/dm³)

Current density j (A/dm ²)	Temp. T (°C)	Time t (min)	Current efficiency η (%)	Avg. current efficiency $\bar{\eta}$ (%)	Coating thickness d (μm)	$v = d/t$ (μm/min)	$\bar{v}$ (μm/min)
1	42	10	92.2	93.63	1.89	0.189	0.191
		15	93.6		2.87	0.191	
		20	95.1		3.86	0.193	
1.5	42	10	92.9	94.83	2.86	0.286	0.291
		15	94.2		4.35	0.290	
		20	97.4		5.93	0.296	
2	42	10	95.1	96.80	3.91	0.391	0.395
		15	96.2		5.92	0.394	
		20	99.1		8.01	0.400	

**Figure 4.** Average arithmetic surface roughness (R_a) as a function of current density.

additives). Between baths 2 and 3, Bath 3, which included sulfosalicylic acid, resulted in thicker coatings.

Surface roughness was measured using a Mitutoyo device, which provided the R_a parameter (average surface profile deviation and maximum roughness height, in μm). The measurement path length for roughness determination was 0.8 mm. As shown in Figure 4, the device detected the lowest surface roughness in the coatings from Bath 2, indicating that the gloss additive has a favorable effect on reducing surface roughness.

A key condition for the adhesion of a metallic coating is that the coating must not separate from the base metal. The samples were bent using a bending tool, and it was observed whether any cracking or delamination of the coating from the base metal occurred. Table 5 shows the appearance of the coated plates after the bending test, aimed at evaluating the adhesion of the nickel coating to the copper surface. All samples exhibited satisfactory and acceptable adhesion of the nickel coating to the copper substrate.

Surfaces of the electrodeposited nickel coatings observed under a microscope at 100× magnification are pre-

sented in Table 6. From Table 6, it can be observed that the nickel coatings obtained from all three baths exhibit similar structure and morphology. The copper substrate surface is uniformly and completely covered. However, it is noticeable that the coatings from Bath 1 are slightly coarser-grained compared to those from baths 2 and 3, and they exhibit lower gloss. This is further supported by the measured surface roughness values, which indicate that the coarser-grained coatings from Bath 1 have higher roughness.

The nickel coatings obtained at all deposition times and current densities are homogeneous and compact. The coatings from baths 2 and 3 are finer-grained, less rough, and have a more attractive and glossy appearance, indicating that the gloss additives positively affect surface smoothness.

Table 5. Photographic view of nickel-coated plates after bending, deposited in baths 1–3 at current densities of 1, 1.5, and 2 A/dm² for 10, 15, and 20 minutes.

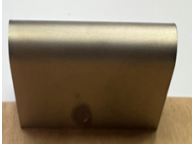
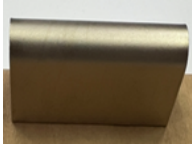
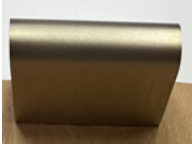
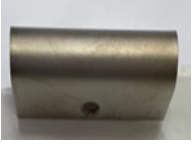
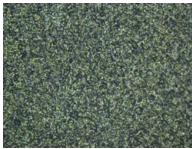
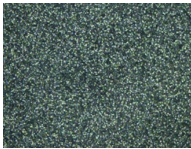
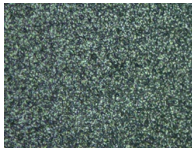
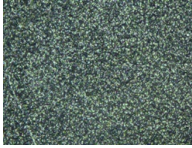
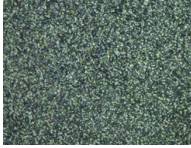
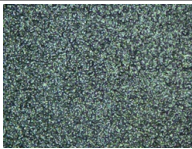
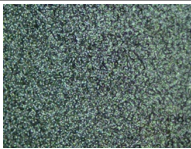
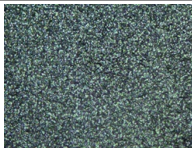
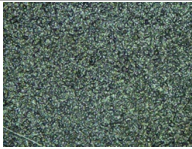
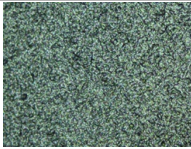
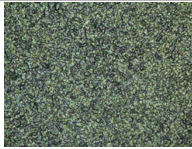
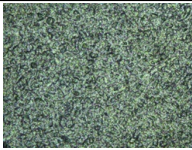
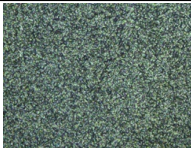
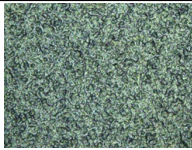
Bath 1				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			
Bath 2				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			
Bath 3				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			

Table 6. Nickel coatings obtained from baths 1–3 after deposition times of 10, 15, and 20 minutes, at current densities of 1, 1.5, and 2 A/dm² (100× magnification).

Bath 1				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			
Bath 2				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			
Bath 3				
		Time		
		10 min	15 min	20 min
Current density	1 A/dm ²			
	1.5 A/dm ²			
	2 A/dm ²			

4. CONCLUSION

Based on the obtained results, it can be concluded that the cathodic current efficiency increases with increasing current density for all three baths. The highest current efficiency was achieved in Bath 1 (without gloss additives). This indicates that gloss additives slightly reduce current efficiency, but they have a positive effect on the appearance and quality of the coating, which are very important properties. Comparing baths 2 and 3, both of which contained gloss additives, higher current efficiency was observed in Bath 3, where sulfosalicylic acid was used, compared to Bath 2, where a commercial high-gloss additive 301 was used. An increase in current density also led to an increase in coating thickness, with the thickest coatings obtained at the highest current densities for all baths. Higher current efficiency and thicker coatings were obtained from Bath 1, which did not include gloss additives. Also, gloss additives slightly reduce current efficiency and coating thickness, but significantly improve the appearance and overall quality of the coating. The lowest measured surface roughness was observed in coatings from Bath 2. All coatings showed satisfactory and acceptable adhesion to the base metal. The research has shown that the proper selection of deposition parameters for nickel coatings on copper is crucial in achieving coatings with the desired properties.

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