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Investigating the hydrophobic properties and corrosion resistance of copper surfaces via octadecanoic acid chemical deposition technique

ABSTRACT

This study investigates the enhancement of copper's hydrophobicity and corrosion resistance through the chemical deposition of octadecanoic acid. Structural and chemical modifications of the treated copper surfaces were analyzed using X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Energy-Dispersive X-ray Spectroscopy (EDS). SEM images revealed significant alterations in surface topography, promoting water repellency, while EDS confirmed the uniform coating of octadecanoic acid. XRD analysis showed that the crystalline structure of copper was preserved. Hydrophobicity was quantitatively assessed through contact angle measurements, which increased from 75° for bare copper to 121.5° for the octadecanoic acid-coated copper, confirming the transition to a hydrophobic surface. Water jetting and water bouncing tests demonstrated superior water repellency and self-cleaning efficiency of the coated surfaces. The contact angle measurement for the coated surface reached approximately 160° during the bouncing tests, indicating highly hydrophobic behaviour. Corrosion resistance was evaluated using dynamic potential polarization and electrochemical impedance spectroscopy (EIS). The dynamic polarization curve indicated a corrosion potential (Ecorr) of -0.0700 V for the coated copper, compared to -0.2036 V for the uncoated copper. The corrosion current density (Icorr) for the coated copper was 3.577×10^{-6} A/cm², significantly lower than the bare copper's value of 2.214×10^{-5} A/cm². The corrosion rate of the coated copper was reduced to 1.388×10^{-1} mm/a from 3.226×10^{-1} mm/a for the uncoated copper, resulting in an efficiency of 83.8%. These findings demonstrate that octadecanoic acid is an effective and cost-efficient protective coating for enhancing copper's durability and functionality, especially in moisture-prone environments.

Keywords: *Copper, Corrosion Resistance, Hydrophobicity, Octadecanoic Acid, Self-Cleaning, Surface Modification*

1. INTRODUCTION

Copper, renowned for its exceptional electrical and thermal conductivities, stands as a cornerstone in the advancement of modern technology and infrastructure [1,2]. Its significance in the global market is projected to escalate, with forecasts indicating a surge in demand comparable to that of gold. The global copper market insight for 2024 anticipates a robust expansion from $199.67 billion in 2023 to $252.33 billion by 2031, driven by a compound annual growth rate (CAGR) of 3.98% [3].

Figure 1 illustrates the significance of copper in diverse sectors.

Exhibiting a distinct pinkish-orange hue when freshly exposed, copper is extensively utilized in heat and electricity conduction, as well as a fundamental building material in the form of wires, rods, and pipes [4, 5]. Despite its widespread use, copper's Achilles' heel is its susceptibility to corrosion, particularly in humid environments. This limitation has spurred research into enhancing copper's corrosion resistance, with hydrophobic films emerging as a promising solution[6]. These films significantly increase the water contact angle on surfaces, thereby reducing the interaction between corrosive agents and the metal,

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preserving the metal's inherent mechanical properties.

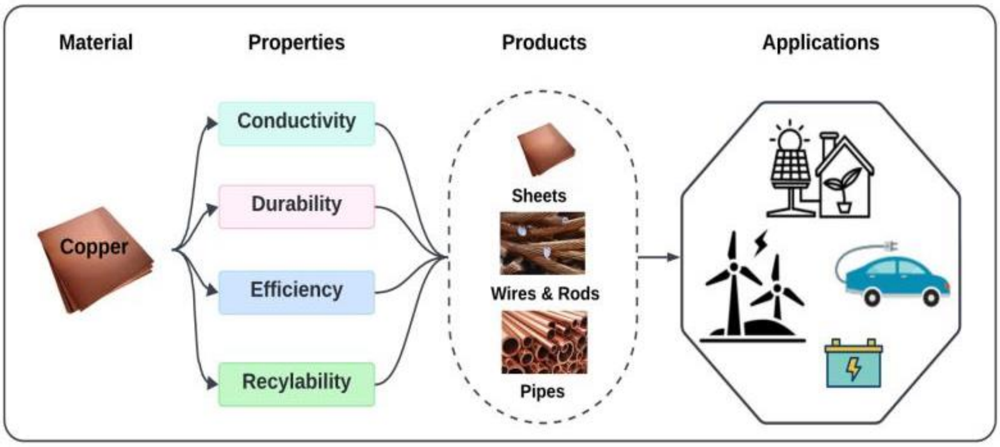


Figure 1. Significance of copper in different sectors

The quest for hydrophobic surfaces on copper has led to various methods, including etching[7], sol-gel techniques[8], and chemical vapor deposition[9]. Yet, the practical deployment of these surfaces is often hampered by their mechanical and chemical stability, as well as cost considerations. Hydrophobic coatings have demonstrated utility across diverse applications, from consumer electronics to marine and automotive components, offering enhanced durability and performance [10, 11]. Improving copper's hydrophobicity through coatings could yield substantial benefits, enhancing its water repellence, corrosion resistance, wear resistance, friction resistance, self-cleanability, and antimicrobial properties.

In the realm of hydrophobic coating technology, octadecanoic acid has emerged as a pivotal component due to its unique properties. Octadecanoic acid (OA) chemical deposition has proven to be a promising method for developing hydrophobic surfaces on many materials, offering improved corrosion resistance in aggressive environments [6]. OA prevents the diffusion of corrosive ions, such as chloride, and reduces the accumulation of moisture, a key factor in electrochemical corrosion processes. OA-treated metal surfaces exhibit reduced corrosion rates, as water and contaminants are kept from reaching the metal substrate The preparation and corrosion resistance of superhydrophobic coating on Cu plate via two-step electrodeposition[12, 13]. The key benefits of octadecanoic acid include its biodegradability, surface compatibility, cost-effectiveness, enhanced protection, longevity, versatility, and ease of application. These attributes make it highly suitable for the extensive variety of applications in hydrophobic coatings[14].

Recent studies have highlighted the potential of octadecanoic acid in various applications. Kim et al.[15] inspected the enhancement of hydrophobicity in zeolite composites coated with octadecanoic acid, finding a significant increase in impact strength compared to uncoated zeolites. Similarly, Jeong et al.[16] observed improvements in the flowability and floodability of $CaCO_3$ powder when coated with octadecanoic acid, with the coated powder outperforming uncoated calcium carbonate.Ng et al. [17] synthesized organic coatings on magnesium through hydrothermal treatment followed by immersion in octadecanoic acid, resulting in superior corrosion resistance, although they noted that long-term immersion led to coating degradation. Gupta et al. [18] compared the corrosion resistance of magnesium coated with phytic acid followed by immersion in octadecanoic acid, concluding that the latter provided better protection than both phytic acid-coated and uncoated magnesium.In another study, Nguyen et al.[19] explored the effect of octadecanoic acid over the dispersion of inorganic fillers, finding that treated fillers exhibited enhanced dispersion without affecting the melting temperature. Additionally, the mechanical properties of films treated with octadecanoic acid were superior to those of untreated films, suggesting significant improvements in material performance.Advanced applications have also been explored, such as Liu et al.[20] developing a novel superhydrophobic coating for magnesium ions through a hybrid approach integrating electro-deposition with immersion techniques. Their study revealed that the resultant coatings exhibited enhanced super hydrophobicity, chemical stability, and anti-corrosioncharacteristics. Concurrently, Hu et al.[21]

synthesized a stearic acid-TiO_2/zinc composite superhydrophobic coating on carbon steel employing electrochemical deposition and surface modification processes. The fabricated coating demonstrated superior mechanical and chemical toughness, self-cleaning functionality, and improved corrosion resistance.Rongjun Ma et al. [22] investigated the superhydrophobic properties of copper mesh substrates using octadecanethiol. The resulting surfaces exhibited superhydrophobic and superoleophilic characteristics, which enhanced the self-cleaning, wettability, durability, and anticorrosive properties of the samples.

Building on this background, the present research study evaluated the hydrophobic performance of copper by applying an octadecanoic acid-based coating. The hydrophobic properties of copper surfaces are influenced primarily by surface roughness and chemical composition. OA deposition forms a self-assembled monolayer (SAM) that reduces surface energy, resulting in a water-repellent layer. This interaction between the carboxyl group of OA and the copper surface creates a stable hydrophobic layer. Surface roughening enhances this effect, leading to a Cassie-Baxter wetting state, where water droplets maintain minimal contact with the surface. The behaviour of the coated copper was documented and assessed to determine its effectiveness, further emphasizing the potential of octadecanoic acid in enhancing material properties across various applications.

2. METHODS AND MATERIALS

2.1 Preparation of the Samples

The preparation process involved modifying copper surfaces using high-purity chemicals sourced from Otto ChemiePvt. Ltd and Avra Synthesis Pvt. Ltd in India, as well as Sigma Aldrich in the USA. Two distinct sets of copper plate samples, each measuring 1 × 1 × 1 cm, were prepared. One set underwent a comprehensive cleaning and coating process, while the second set remained uncoated, serving as a control sample to evaluate the efficacy of the treatment (Figure 2).

The cleaning process began by immersing the copper plates in an ammonium persulfate solution, prepared by dissolving 0.1 g of ammonium persulfate salt in 50 ml of distilled water (Figure 3a). The plates were immersed in this solution at 60 °C for one hour to ensure the removal of any surface contaminants and to enhance surface reactivity. This step is crucial for preparing the copper surface for subsequent coating, thereby improving the adhesion of the coating material.

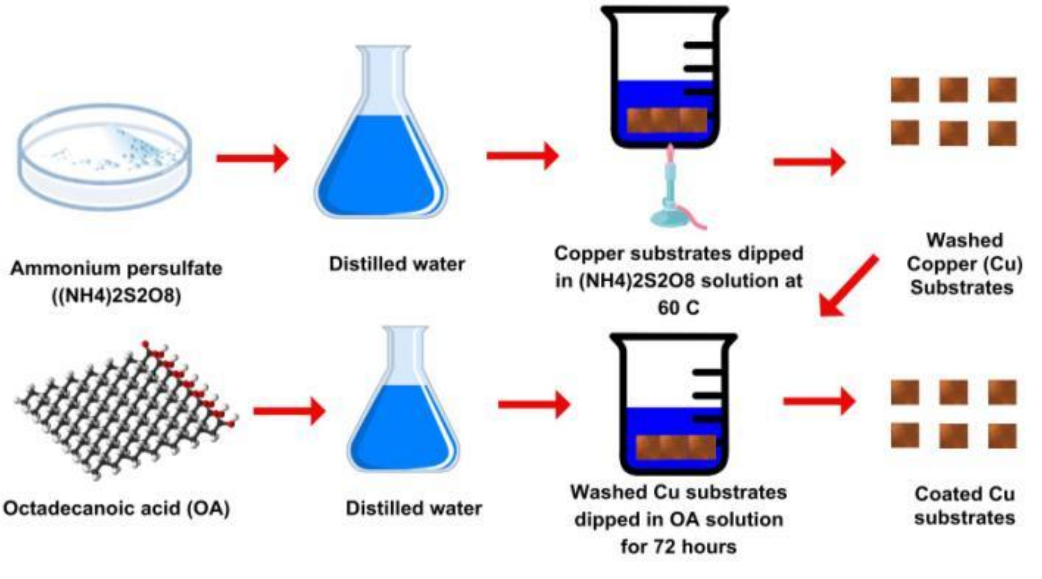


Figure 2. Illustration of Copper Washed and Copper Coated Substrates

The coating process involved immersing cleaned copper plates in a solution of octadecanoic acid (OA), prepared by dissolving 1 g of OA in 50 ml of ethanol (Figure 3b). The copper plates were submerged in this ethanol-OA solution for 72 hours at ambient temperature, ensuring the formation of a uniform and adherent coating on the surface. After the treatment, the coated plates were removed from the solution and air-dried using heated air for 30 minutes to eliminate any residual solvent. The treated surfaces were then systematically documented through both schematic and photographic representations. The effects of the surface treatment are illustrated in Figures 3(a) and 3(b), highlighting the physical transformations of the copper plates before and after coating.

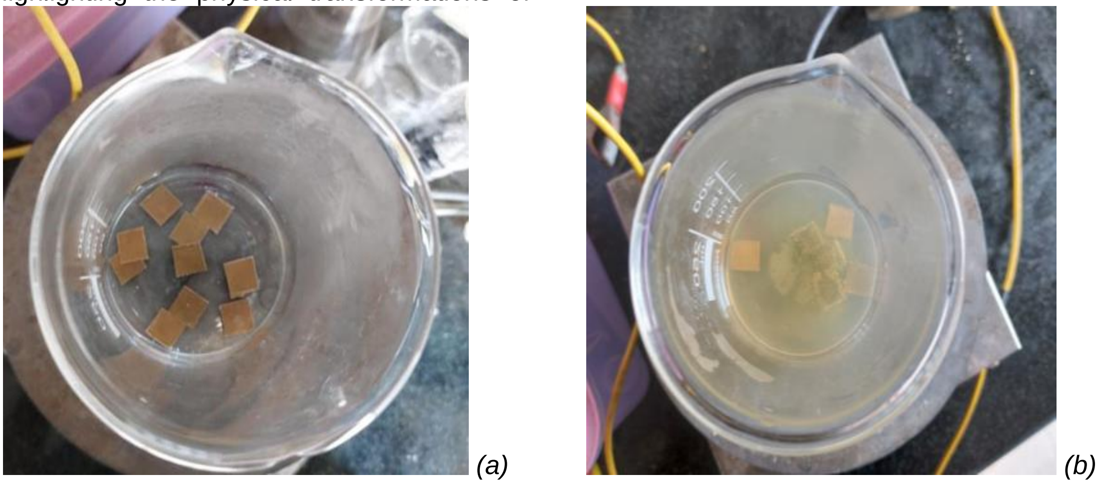

(a) (b)

Figure 3. (a) Cleaning, and (b) Coating of the Copper plates

3. RESULT AND DISCUSSION

3.1. X-Ray Diffraction (XRD) Analysis

The structural and surface composition of the octadecanoic acid-coated copper plate were determined using X-ray diffraction (XRD) analysis with an ECO Brukerdiffractometer equipped with a copper anode (Cu-Kα radiation source, λ = 1.54060 Å). The analysis spanned a 2θ range of 10° to 80° to capture potential diffraction peaks from both the octadecanoic acid coating and the underlying copper substrate. Diffractometer settings, including voltage, current, and scan rate, were optimized to ensure high-resolution data. Special attention was given to sample preparation to maintain uniform coating and reduce surface irregularities, ensuring accurate and reproducible results.

Observed diffraction peaks of the octadecanoic acid-coated copper were compared with those of uncoated copper to validate the successful deposition of octadecanoic acid and assess the interaction between the coating and the substrate. The degree of crystallinity of the copper samples was calculated using Equation 1:The occurrence of crystalline elements can be identified through the diffractograms illustrate sharp peaks and broad patterns [23].

$$Percent\ Crystallinity(\%) = \frac{\sum I_{crystalline\ peaks}}{\sum I_{crystalline\ peaks} + \sum I_{amorphous\ background}} * 100 \qquad (1)$$

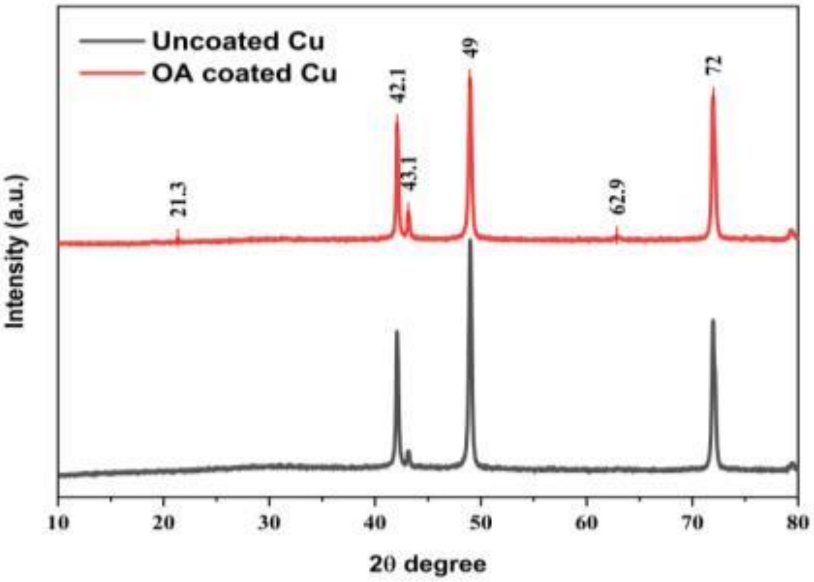


Figure 4. XRD Analysis of Uncoated and Octadecanoic Acid-Coated Copper (Cu) Samples

XRD analysis revealed significant structural modifications, confirming the successful deposition of the octadecanoic acid coating (Figure 4). New peaks at 21.3° (d-value = 4.16042 Å)and 62.8° (d-value = 1.47739 Å), with net intensities of 497 and 112, respectively, were observed in the coated sample but were absent in the uncoated sample. Additionally, the intensity of key copper peaks decreased in the coated samples, such as at 42.1° (d-value = 2.14517 Å) and 48.9° (d-value = 1.85745 Å), with net intensities dropping from 3634 to 2884 and 6244 to 4275, respectively (Table 2). These changes suggest that the octadecanoic acid coating alters the copper's crystal structure.

Figure 4 showcases the XRD diffraction patterns of both samples, highlighting new peaks exclusive to the coated copper, indicating structural changes and increased crystallinity. The emergence of new peaks at 21.3° and 62.8° signifies the presence of crystalline elements unique to the coating, further confirming successful deposition of octadecanoic acid.

Table 2. Comparative Analysis of XRD Spectrograms for Uncoated and Octadecanoic Acid-Coated Copper (Cu) Samples

Peaks	Angle	d-Value	Net-Intensity		Gross-Intensity		New Peaks
	2θ	(A)	Uncoated	Coated	Uncoated	Coated	
1	21.3	4.16042	-	126	-	497	Yes
2	42.1	2.14517	3634	2884	4233	3375	No
3	43.1	2.0952	433	642	1022	1130	No
4	48.9	1.85745	6244	4275	6822	4769	No
5	62.8	1.47739	-	112	-	556	Yes
6	71.9	1.31079	4076	3901	4602	4389	No
7	79.3	1.20441	122	215	615	687	No

These structural modifications and increased crystallinity improve the copper's water-repellent properties, enhancing its hydrophobicity and corrosion resistance. These findings align with studies by Chen et al. [24] and Ma et al. [22], who observed similar structural changes and enhanced hydrophobicity following surface modifications.

3.2. Scanning Electron Microscopy (SEM) Analysis

The surface morphology of uncoated and octadecanoic acid-coated copper (Cu) samples was examined using scanning electron microscopy (SEM). This analysis aimed to compare the surface features of the uncoated and coated samples and evaluate the uniformity and coverage of the octadecanoic acid coating. Observations were conducted at magnifications of 100x, 500x, 1000x, and 5000x to provide a comprehensive view of the surface textures and the distribution of the coating material.

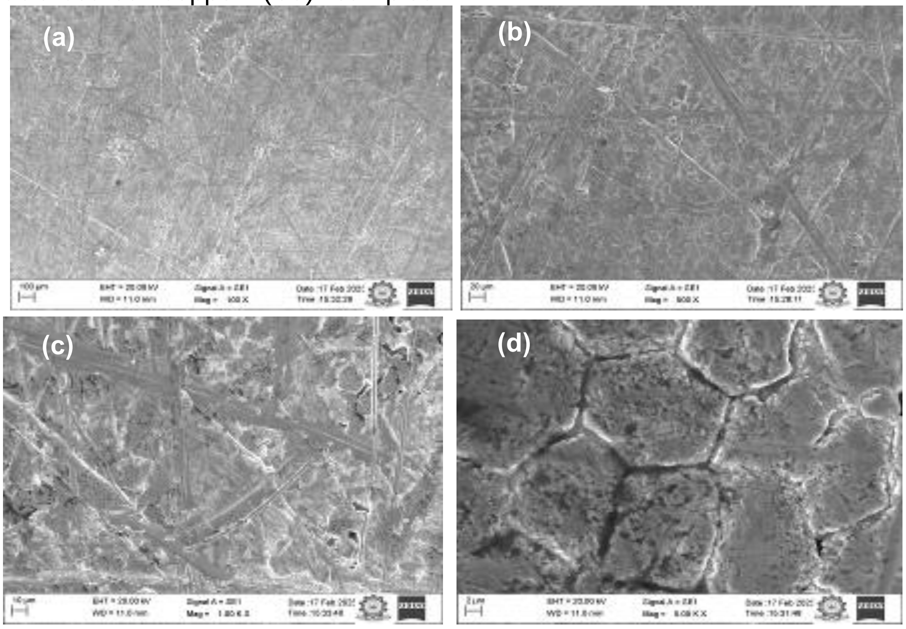


Figure 5. SEM Analysis of Uncoated Cu

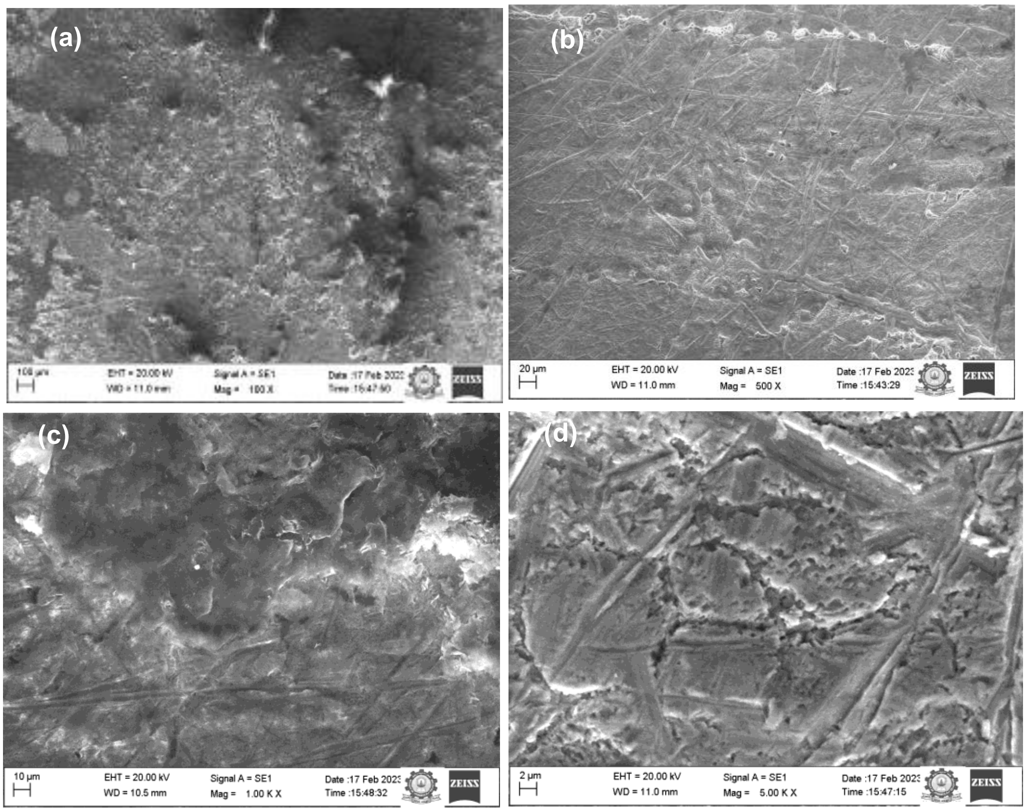


Figure 6. SEM Analysis of Octadecanoic Acid-Coated Cu

The uncoated Cu surface, as depicted in Figure 5, exhibited numerous micro-cracks, which increase susceptibility to corrosion and water absorption. In contrast, the octadecanoic acid-coated Cu surface, shown in Figure 6, appeared smoother and more uniform, suggesting that the coating contributes to surface smoothening and may enhance hydrophobicity. SEM analysis confirmed the formation of a self-assembled monolayer (SAM) of long-chain fatty acids on the copper surface.

The result illustrates strong bonding between the copper and the octadecanoic acid, contributing to the smoother surface and enhanced protection. Additionally, the coated Cu surface exhibited reduced accumulation of dust and other foreign materials, which is crucial for improving corrosion resistance. This finding suggests that the octadecanoic acid coating improves a degree of self-cleaning effect, further enhancing the long-term performance of the copper surface.

3.3 Energy-Dispersive X-ray (EDX) Spectroscopy

The elemental composition of the uncoated and octadecanoic acid-coated copper (Cu) samples was analysed using energy-dispersive X-ray (EDX) spectroscopy. This technique was employed to identify and quantify the elements present on the sample surfaces, providing crucial information about the chemical composition of the coating.

Table 3. Estimated elemental compositions from the samples

Element	Uncoated Cu			Coated Cu		
	Weight %	Atomic %	Error %	Weight %	Atomic %	Error %
C K	4.8	19.5	15.8	45.1	74.4	9.1
O K	3.2	9.9	11.7	9	11.1	10.9
Cu K	58	44.9	2.6	27.9	8.7	3.1
Zn K	34	25.6	3.3	17.1	5.2	3.9

P K	-	-	-	0.9	0.6	12.1

EDX measurements were conducted in conjunction with scanning electron microscopy (SEM) to accurately localize the areas under analysis. The spectroscopic data were acquired by directing an electron beam onto the sample surface, inducing characteristic X-ray emissions that were subsequently detected and analysed.

From the EDX compositional investigations, spectrograms were obtained and are presented in Figure 7. Table 3 quantifies these variations, demonstrating a significant increase in carbon and oxygen content and a decrease in copper and zinc content after coating.From Figure 7, it may be noted that the uncoated Cu displayed predominant copper (58 wt%) and zinc (34 wt%), with minor carbon (C) and oxygen (O) content, indicating surface oxidation. In contrast, the coated Cu revealed a significant increase in carbon (45.1 wt%) and oxygen (9%), and a reduction in copper (27.9 wt%) and zinc, confirming the deposition of octadecanoic acid.

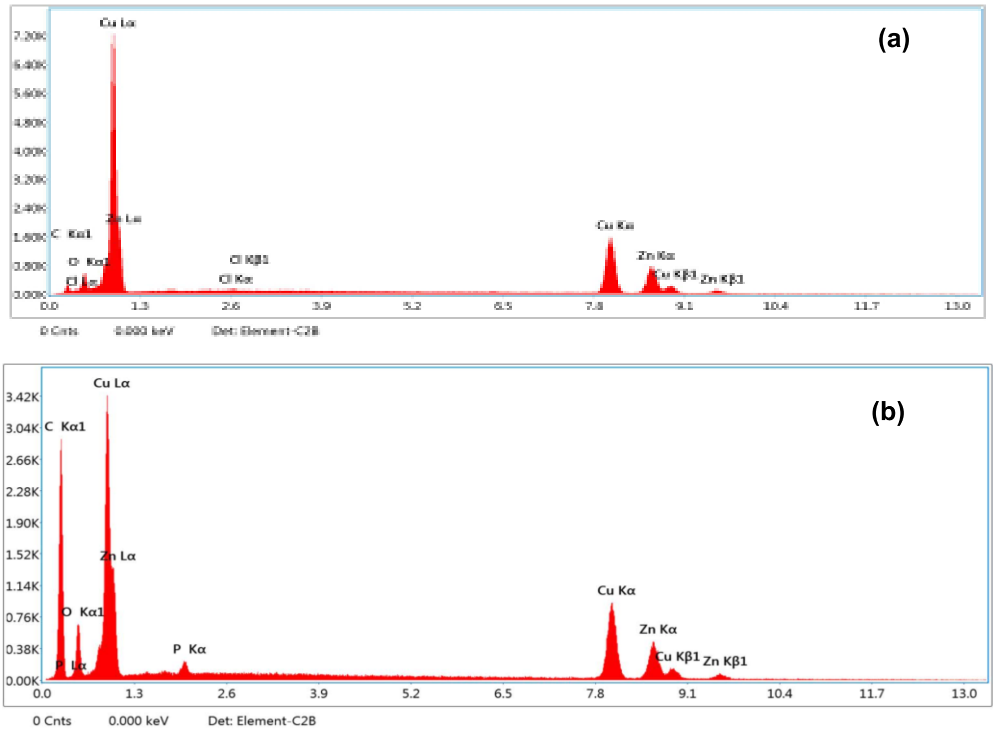


Figure 7. EDX compositional investigations of (a) bare Cu, (b) OA coated Cu

3.4 Contact Angle Measurements

To quantify the hydrophobic nature of the octadecanoic acid-coated copper (Cu) samples, contact angle measurements were performed using a goniometer equipped with a high-resolution camera. A controlled volume of deionized water (5 μL) was deposited onto the sample surface, and the contact angle formed between the water droplet and the surface was recorded. Measurements were taken at multiple locations to ensure surface uniformity and coating consistency. Uncoated copper samples were tested under identical conditions for comparison. The results, compared to standard hydrophobicity benchmarks, confirmed a significant increase in water repellency due to the octadecanoic acid coating, validating the hydrophobic properties observed in the material characterization studies.

The contact angle measurements, as illustrated in Figure 8, quantified the hydrophobic nature of the octadecanoic acid-coated copper (Cu) samples. The uncoated Cu surface exhibited a contact angle of 98.3°, indicating its less hydrophobic nature, whereas the coated Cu sample achieved a contact angle of 121.5°, indicating a transition to hydrophobic behaviour. This enhancement is attributed to the deposition of octadecanoic acid, which forms a continuous air gap between water droplets and the copper surface, characteristic of the Cassie-Baxter phenomenon[25]. According to Table 4, surfaces with contact angles exceeding 90° are classified as hydrophobic. The results affirm the efficacy of the immersion method for creating hydrophobic surfaces, highlighting its potential for applications requiring anti-wetting and corrosion resistance.

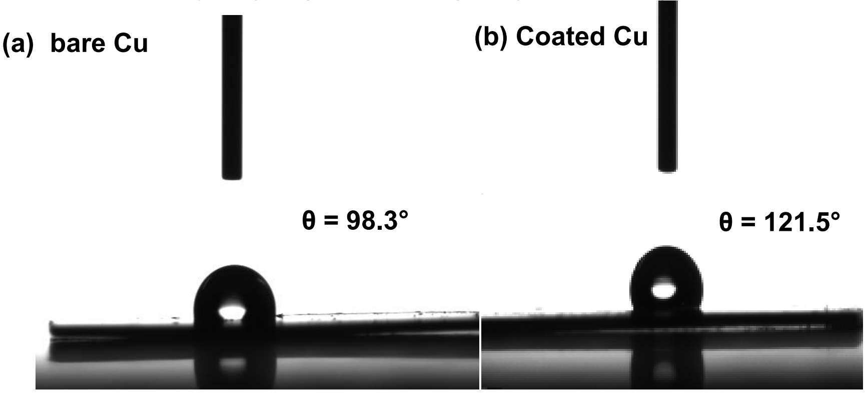


Figure 8. Contact angle measurements of (a) Bare Cu, (b) Coated Cu

Table 4. Wettability Nature of Metal Surface[26]

Contact Angle Measurement	Wettability Nature
0-90	Hydrophilic Nature
Above 90	Hydrophobic Nature

3.5. Water Jetting Investigations

The hydrophobic behaviour of octadecanoic acid-coated copper (Cu) samples was further evaluated through water jetting investigations. A fine stream of water droplets was directed at both uncoated and coated samples using a controlled nozzle setup. The water droplets were retained on the uncoated copper surface, indicating its hydrophilic nature. In contrast, the octadecanoic acid-coated samples exhibited pronounced water repellency, with droplets being repelled upon contact. This behaviour is attributed to the low-surface-energy layer formed by the octadecanoic acid coating, which minimizes interaction between the water droplets and the substrate. The water droplet dynamics during the jetting process were recorded and analyzed, providing a qualitative comparison between the coated and uncoated samples. These results validated the enhanced hydrophobicity of the coated copper, confirming the effectiveness of the octadecanoic acid treatment.

During the water jetting investigations, a significant contrast was observed between the uncoated and octadecanoic acid-coated copper (Cu) samples, illustrating the influence of the coating on the surface properties. The uncoated Cu samples retained water droplets, indicative of their lower hydrophobic nature, where high surface energy promotes water adhesion[27]. On the other hand, the octadecanoic acid-coated Cu samples exhibited strong water repulsion, demonstrating hydrophobicity. This behaviour is attributed to the formation of a low-surface-energy layer from the octadecanoic acid, which minimizes the interaction between water and the surface. The hydrophobicity follows the Cassie-Baxter model, where air pockets are trapped beneath water droplets, reducing the contact area. Figure 9 shows these observations, with panel (a) illustrating water retention on the uncoated surface and panel (b) showing the repulsion on the coated surface.

(a) Uncoated Cu *(b) Coated Cu*

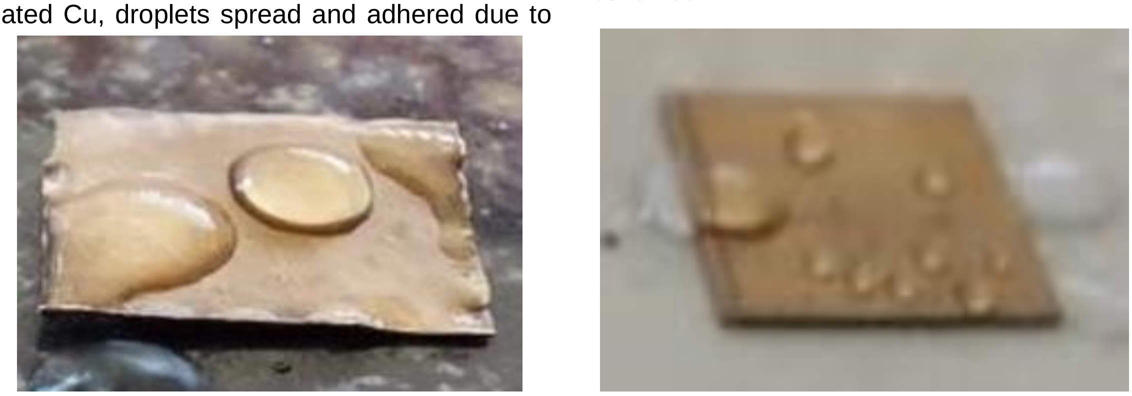
Figure 9. Water Jetting Investigations

3.6. Water Bouncing Investigations

The hydrophobic nature of octadecanoic acid-coated copper (Cu) samples was further confirmed through water bouncing investigations. In this test, 5 µL water droplets were dispensed from a height of 5 cm onto both uncoated and coated Cu surfaces. The uncoated samples showed adhesion, with droplets spreading and remaining stationary. In contrast, the coated samples exhibited a bouncing effect, with droplets rebounding off the surface. This behaviour is attributed to the low-surface-energy layer formed by the octadecanoic acid coating, reducing adhesive forces and enhancing water repellency, consistent with findings from water jetting and contact angle measurements.

Figure 10 compares water bouncing on (a) an uncoated Cu and (b) a coated Cu sample. In uncoated Cu, droplets spread and adhered due to high surface energy. In coated Cu, droplets rebounded completely, demonstrating super hydrophobicity. This confirms the coating's effectiveness in reducing surface energy and enhancing water repellency. The observed behaviour in the coated sample supports the conclusion that the surface treatment significantly improves droplet mobility [28]. The contrast between the two surfaces visually highlights the impact of the octadecanoic acid coating on surface properties.

The study demonstrated that the coated Cu surface exhibited a superhydrophobic nature with a contact angle of approximately 160°. The coated surface enabled complete droplet rebound, indicating minimal adhesion and high mobility, while the uncoated surface showed no bounce behaviour.

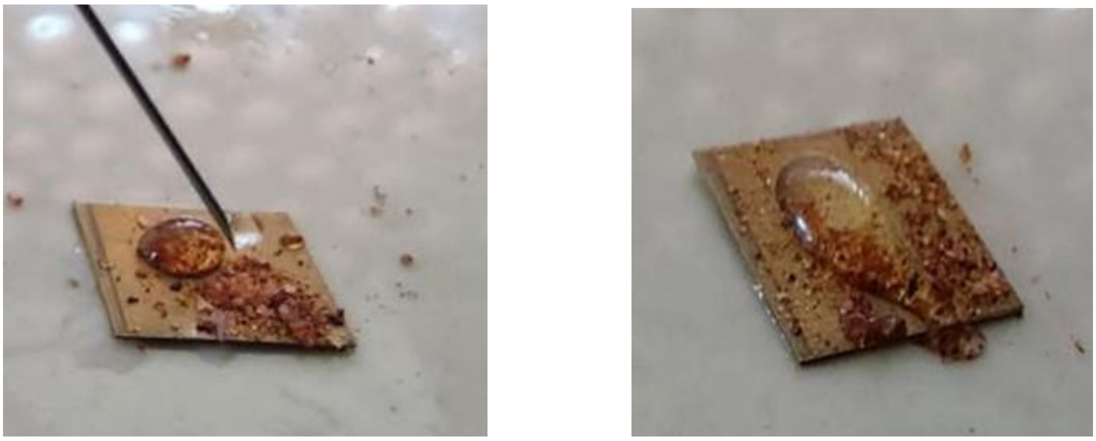


(a) Bare Cu *(b) Coated Cu*

Figure 10. Water Jetting Investigation

3.7. Self-Cleaning Investigations

The self-cleaning properties of octadecanoic acid-coated copper (Cu) samples were evaluated by observing the removal of soil particles under water application. Soil particles were uniformly sprinkled onto both uncoated and coated Cu surfaces, followed by the application of water droplets. The uncoated Cu samples showed water adhesion, failing to dislodge the particles, indicating the absence of self-cleaning properties. In contrast, the coated Cu samples demonstrated a self-cleaning effect, with water droplets rolling off and carrying the soil particles with them. This behaviour is attributed to the enhanced hydrophobicity and low-surface-energy characteristics of the octadecanoic acid coating.



(a) Bare Cu (b) Coated Cu

Figure 11: Self-Cleaning Investigations

Figure 11(a) shows the uncoated Cu sample with soil particles adhering to the surface due to its high surface energy, preventing the removal of dirt by water droplets. Figure 11(b) illustrates the coated Cu sample, where soil particles are efficiently washed away by the water droplets, demonstrating the surface's self-cleaning ability.

3.8. Corrosion Resistance Analysis

Corrosion resistance analysis is crucial for assessing the durability of copper surfaces in aggressive environments. Superhydrophobic coatings have been widely recognized for their effectiveness in mitigating corrosion by reducing metal exposure to corrosive media. Among these, octadecanoic acid (OA) chemical deposition has been established as a reliable method to enhance corrosion resistance due to the hydrophobic properties of fatty acids. To further investigate the effectiveness of this approach, this study evaluates the corrosion resistance of uncoated and OA-coated copper (Cu) samples using electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization techniques [29].

In this analysis, the experimental setup consisted of a three-electrode electrochemical cell, where the copper sample served as the working electrode, a saturated calomel electrode (SCE) acted as the reference electrode, and a platinum wire functioned as the counter electrode. A 3.5 wt% NaCl solution was used as the electrolyte to simulate seawater conditions, ensuring a realistic assessment of the corrosion behaviour. Prior to testing, copper samples underwent ultrasonic cleaning in acetone, ethanol, and deionized water, followed by air drying. OA-coated samples were prepared for uniform surface properties. Initial weights were recorded, and surface conditions were analysed. Post-corrosion weight loss measurements assessed material degradation. To evaluate the corrosion resistance, EIS measurements were performed by immersing the sample in NaCl solution. Impedance analysis was conducted over a frequency range of 100 kHz to 0.01 Hz with a 10 mV AC perturbation, and the resulting Nyquist plots were used to determine the charge transfer resistance (R_{ct}), a key indicator of corrosion resistance [30].

Additionally, Tafel slopes were extracted using the Tafel extrapolation method, where the linear regions of the anodic and cathodic branches of the potentiodynamic polarization curves were fitted to determine the anodic (β_a) and cathodic (β_c) slopes. These slopes were used to derive the corrosion current density (I_{corr}) and corrosion potential (E_{corr}) for both bare and OA-coated Cu samples. The polarization scans were performed in the range of -250 mV to +250 mV relative to OCP, at a scan rate of 1 mV/s, following 30 minutes of stabilization at OCP. This enabled a comparative evaluation of the corrosion rates between uncoated and OA-coated samples. To ensure data reliability, all experiments were repeated three times for reproducibility. The results, as presented in Table 5, indicate that OA-coated Cu exhibited a significantly lower corrosion rate, confirming the enhanced protective effect of the OA coating. These findings demonstrate the effectiveness of OA-based superhydrophobic coatings in improving the corrosion resistance of copper in aggressive environments.

To quantify the corrosion resistance, the corrosion rate (Y_1) was calculated using Equation (2), the efficiency of corrosion resistance (η) was determined using Equation (3) and (4) provides the tafel equation:

$$Y_1 = \frac{87600*(w_a - w_b)}{\rho * A_s * t} \qquad (2)$$

$$Efficiency, \eta = \frac{I_{corr(Cu)} - I_{corr(coated\ Cu)}}{I_{corr(Cu)}} \qquad (3)$$

$$Overpotential\ \vartheta = \beta\ \log i + constant \qquad (4)$$

where w_a (g) represents the sample's weight before the corrosion test, w_b (g) is the sample's weight after the test, A_s (cm^2) is the sample's surface area, ρ (g/cm^3) is the sample's density, t (h) is the duration of the test, β is the Tafel slope, and i is the current density.

Table 5 shows the dynamic potential polarization curve results, illustrating the corrosion resistance performance of uncoated and OA coated copper samples in a 3.5 wt.%NaCl solution.

The results reveal that uncoated Cu substrates exhibit a corrosion potential (Ecorr) of −0.2036 V and a corrosion current density (Icorr) of 2.214×10^{-5} A/cm², leading to a corrosion rate of 3.226×10^{-1} mm/a. In contrast, OA-coated Cu samples demonstrate significantly enhanced corrosion resistance, with an Ecorr of −0.0700 V, an Icorr of 3.577×10^{-6} A/cm², and a notably reduced corrosion rate of 1.388×10^{-1} mm/a. The efficiency of corrosion resistance for the OA coating is calculated to be 83.8%, as summarized in Table 5.

Table 5. Results on dynamic potential polarization curves

Name of the sample	**E_{corr} (VSCE-Subscript Font for SCE)**	**I_{corr} (A/cm^2)**	**Corrosion rate, (mm/a)**	**Efficiency (*η* %)**
Bare Cu	-0.2036	2.214×10^{-5}	3.226×10^{-1}	-
Coated Cu	-0.0700	3.577×10^{-6}	1.388×10^{-1}	83.8

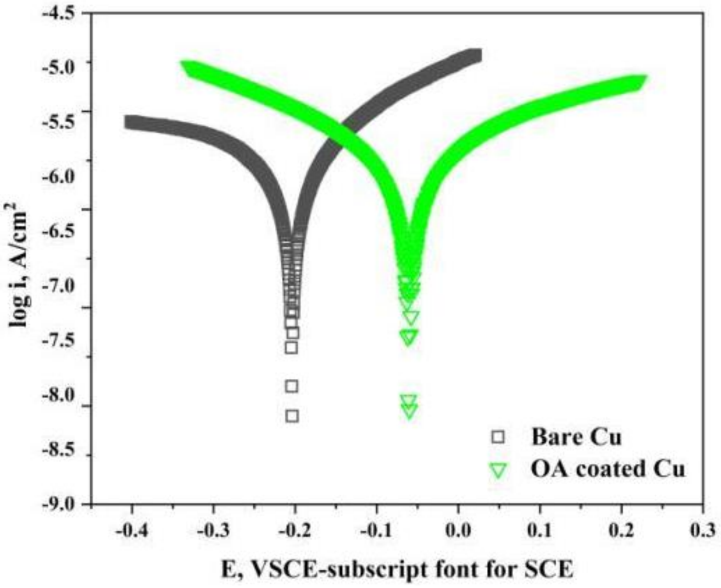


Figure 12. Tafel Polarization curve of bare and coated Cu substrate

In addition, as illustrated in figure 12, the Tafel polarization curves indicate that bare copper samples exhibit a higher corrosion current density (Log I, A/cm²), with their corresponding curve positioned higher on the log I axis compared to coated Cu. This positioning signifies an increased corrosion rate in uncoated samples. Additionally, the corrosion potential (E, VSCE) for bare Cu was more negative, suggesting a greater susceptibility to corrosion compared to OA-coated Cu. These findings further validate the effectiveness of the octadecanoic acid coating in enhancing the corrosion resistance of copper surfaces, making it a viable protective solution for mitigating degradation in aggressive environments.

Electrochemical impedance spectroscopy (EIS) data presented in Table 6 further substantiate the corrosion resistance improvement in OA-coated Cu.

Table 6. EISData Equivalent Circuit Fitting Outcomes

Material	R_s (Ωcm^2)	R_{ct} (Ωcm^2)	R_f (Ωcm^2)	CPEdl ($\mu F\ cm^{-2}$)
Bare Cu	18	878.7	340.42	5.48×10^{-4}
Coated Cu	14.7	3.52×10^3	1180.3	2.36×10^{-6}

The solution resistance (R_s) values for both uncoated and coated Cu samples are comparable, with bare Cu at 18 Ω·cm² and coated Cu at 14.7 Ω·cm², indicating that the OA coating does not significantly influence the electrolyte's resistance. However, a notable increase in charge transfer resistance (R_{ct}) was observed for the coated sample, with bare Cu exhibiting 878.7 $\Omega\cdot cm^2$ and OA-coated Cu reaching 3.52×10^3 $\Omega\cdot cm^2$. This substantial increase highlights the OA coating's ability to impede charge flow, thereby enhancing corrosion resistance.

Additionally, the coating resistance (Rf) is significantly higher for OA-coated Cu (1180.3 $\Omega\cdot cm^2$) compared to bare Cu (340.42 $\Omega\cdot cm^2$), further confirming the protective nature of the OA layer. The capacitance of the double layer (CPEdl) is notably lower for the coated sample (2.36×10^{-6} $\mu F\cdot cm^2$ vs. 5.48×10^{-4} $\mu F\cdot cm^2$ for bare Cu), indicating reduced electrochemical activity at the copper surface due to the OA coating. These findings are further validated by the Nyquist plots (Figure 13), where the larger semicircular arc for OA-coated Cu reflects its superior corrosion resistance.

The EIS data were not fitted due to challenges in selecting an appropriate equivalent circuit model that accurately represents the corrosion behaviour of OA-coated Cu. Instead, charge transfer resistance (R_{ct}) was directly extracted from the Nyquist plots, which provided a reliable comparative measure of corrosion resistance between uncoated and coated samples. This approach ensured that the analysis remained focused on evaluating the protective effectiveness of the OA coating without introducing potential errors from arbitrary circuit fitting. However, future studies could explore refined circuit modelling to further enhance electrochemical characterization.

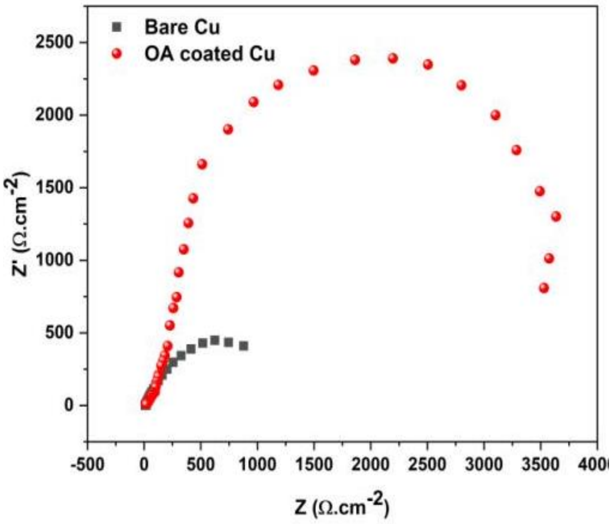


Figure 13. NyqusitImage of OA Coated and Uncoated Cu Substrates in 3.5 wt.%NaCl

The significant improvement in corrosion resistance observed in this study is primarily attributed to the superhydrophobic nature of the OA coating, which minimizes direct contact between the substrate and the corrosive medium. This effect aligns with findings from Jia et al. [29], who demonstrated that chemically treated copper surfaces exhibited enhanced corrosion resistance due to their hydrophobic properties. Similar to previous studies on electrodeposited superhydrophobic coatings, the OA coating effectively reduces ion transport at the metal-electrolyte interface, leading to lower corrosion current densities and improved corrosion resistance efficiency.The higher charge transfer resistance (R_{ct}) and impedance values observed for OA-coated Cu confirm its superior corrosion resistance compared to bare Cu. These results demonstrate that OA-based superhydrophobic coatings significantly reduce electrochemical activity and enhance surface protection, making them a promising solution for corrosion mitigation in aggressive environments.

4. CONCLUSIONS

This study demonstrates that octadecanoic acid (OA) coating significantly enhances the corrosion resistance and hydrophobicity of copper surfaces, making it a highly promising protective solution for industrial applications. Structural analysis using XRD, SEM, and EDS confirmed the uniformity of the coating, which preserved the copper's crystalline integrity while improving surface roughness, leading to superior water repellency. The contact angle increased from 75° (bare copper) to 121.5° (OA-coated copper), with water jetting and droplet rebound tests indicating enhanced self-cleaning properties, achieving a maximum contact angle of 160°.Electrochemical evaluations further validated the effectiveness of the OA coating. The corrosion potential of coated copper improved from -0.2036 V (bare Cu) to -0.0700 V, while the corrosion current density decreased from 2.214×10^{-5} A/cm^2 to 3.577×10^{-6} A/cm^2. This resulted in a substantially lower corrosion rate of 1.388×10^{-1} mm/a and an impressive corrosion resistance efficiency of 83.8%. Electrochemical impedance spectroscopy (EIS) measurements revealed a significantly higher charge transfer resistance (3.52×10^3 $\Omega.cm^2$) for OA-coated copper, underscoring its superior barrier properties.

To further optimize the industrial viability of OA coatings, future work should focus on enhancing corrosion resistance through multi-layer coatings or synergistic integration high performing nanoparticles with other protective compounds. Fine-tuning coating thickness and chemical composition could elevate hydrophobicity beyond 150°, making it even more effective for marine and pipeline applications. In summary, OA coatings offer a robust, cost-effective, and environmentally friendly solution for mitigating copper corrosion in aggressive environments.

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Competing Interests

The authors found no conflicting interests in the research work.

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IZVOD

ISTRAŽIVANJE HIDROFOBNIH SVOJSTAVA I OTPORNOSTI BAKRA NA KOROZIJU TEHNIKOM HEMIJSKOG TALOŽENJA OKTADEKANSKOM KISELINOM

Ova studija istražuje poboljšanje hidrofobnosti i otpornosti bakra na koroziju hemijskim taloženjem oktadekanske kiseline. Strukturne i hemijske modifikacije tretiranih bakarnih površina analizirane su pomoću rendgenske difrakcije (XRD), skenirajuće elektronske mikroskopije (SEM) i energetski disperzivne rendgenske spektroskopije (EDS). SEM slike su otkrile značajne promene u topografiji površine, što je doprinelo vodoodbojnosti, dok je EDS potvrdio ujednačen premaz oktadekanskom kiselinom. XRD analiza je pokazala da je kristalna struktura bakra očuvana. Hidrofobnost je kvantitativno procenjena merenjem kontaktnog ugla, koji se povećao sa 75° za goli bakar na 121,5° za bakar obložen oktadekanskom kiselinom, potvrđujući prelazak na hidrofobnu površinu. Testovi mlaznog pranja vode i odbijanja vode pokazali su superiornu vodoodbojnost i efikasnost samočišćenja obloženih površina. Merenje kontaktnog ugla za obloženu površinu dostiglo je približno 160° tokom testova odbijanja, što ukazuje na visoko hidrofobno ponašanje. Otpornost na koroziju je procenjena korišćenjem dinamičke polarizacije potencijala i elektrohemijske impedansne spektroskopije (EIS). Kriva dinamičke polarizacije je pokazala potencijal korozije (Ecorr) od -0,0700 V za obloženi bakar, u poređenju sa -0,2036 V za neobloženi bakar. Gustina struje korozije (Icorr) za obloženi bakar bila je 3,577 × 10^{-6} A/cm^2, što je značajno niže od vrednosti za goli bakar od 2,214 × 10^{-5} A/cm^2. Brzina korozije obloženog bakra je smanjena na 1,388 × 10^{-1} mm/a sa 3,226 × 10^{-1} mm/a za neobloženi bakar, što je rezultiralo efikasnošću od 83,8%. Ovi nalazi pokazuju da je oktadekanska kiselina efikasan i isplativ zaštitni premaz za poboljšanje izdržljivosti i funkcionalnosti bakra, posebno u okruženjima sklonim vlazi.

Ključne reči: *Bakar, otpornost na koroziju, hidrofobnost, oktadekanska kiselina, samočišćenje, modifikacija površine*

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