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Performance Study of Biocoating Material with Damar and Silica Extract from Rice Husk on Mild Steel in NaOH Solution

*Radius Bambang Saputra, N. Nuryoto, M. Pramudita**

Universitas Sultan Ageng Tirtayasa, Serang, Indonesia

*Correspondence: E-mail: marta_pramudita@untirta.ac.id.

ABSTRACT

Corrosion remains a critical challenge across various industries, necessitating the development of eco-friendly alternatives to conventional anti-corrosion methods. This study evaluates the performance of biocoating composed of rice husk silica and damar resin in inhibiting corrosion of mild steel in a 1M NaOH solution. The effects of drying temperature (27, 50, and 100°C) and duration (10, 30, 60 minutes) on corrosion resistance were systematically investigated. Optimal conditions were identified at 100°C for 10 minutes, achieving a corrosion rate of 0.041 mm/year and an inhibitor efficiency of 80%. Prolonged drying or higher temperatures resulted in reduced performance due to structural degradation. Comparative analysis revealed that these biocoating outperform untreated mild steel and are comparable to other natural inhibitors in terms of efficiency. The synergistic combination of rice husk silica and damar resin provides both physical and chemical protection, addressing the limitations of traditional methods. However, challenges in scaling up biocoating production, such as variability in material properties and integration into industrial processes, highlight the need for standardized protocols and further optimization. This study advances the understanding of biocoating mechanisms in alkaline environments, offering insights into their durability and effectiveness. The findings underscore the potential of rice husk silica and damar resin biocoating as sustainable, high-performance solutions for industrial corrosion protection.

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1. INTRODUCTION

Corrosion is a pervasive issue that significantly impacts industrial operations worldwide, leading to substantial economic losses due to equipment degradation, structural failures, and maintenance costs (Chen *et al*., 2021; Zhao, 2023). This deterioration of metal surfaces is driven by chemical interactions with the surrounding environment, often resulting in reduced functionality and shortened service life. Traditional approaches to mitigating corrosion, such as electrochemical protection, coatings, and chemical inhibitors, have proven effective but are frequently accompanied by environmental and health risks (Sheydaei, 2024). For instance, the use of heavy metals and toxic compounds in chemical inhibitors has been linked to ecological contamination and adverse health effects (Yang *et al*., 2020; Silviana, 2024). These challenges have necessitated the development of environmentally friendly alternatives that are both effective and sustainable.

In recent years, biocoating have emerged as a promising solution to address these challenges. Biocoating leverage natural materials, such as silica and organic resins, to provide corrosion resistance while minimizing environmental impact (Wang *et al*., 2023). Among these, silica derived from rice husks has garnered particular attention due to its abundance, cost-effectiveness, and high silica content (over 60%). Its strong adhesion properties make it an excellent candidate for forming protective layers on metal surfaces (Noviyanti, 2024). When combined with organic resins, such as damar resin, the synergistic effects enhance the biocoating's mechanical strength and corrosion resistance, offering an eco-friendly and effective alternative to traditional methods (Arief, 2023).

Damar resin, a natural polymer derived from tree sap, has been widely recognized for its adhesion and binding capabilities. With a melting point between 90°C and 130°C, damar resin demonstrates excellent thermal properties and compatibility with silica, enabling the formation of a cohesive biocoating. This compatibility allows the resin to act as a binder while silica serves as the primary corrosion-resistant component. Together, these materials create a robust protective layer that inhibits the diffusion of corrosive agents such as water vapor, ions, and oxygen to the metal surface.

Despite their potential, the performance of biocoating under alkaline conditions, which are common in industries such as chemical manufacturing and wastewater treatment, remains underexplored. Alkaline environments pose unique challenges due to their high pH, which can accelerate corrosion and degrade protective coatings. While previous studies have demonstrated the effectiveness of rice husk silica and damar resin in acidic or neutral environments, limited research has examined their combined performance in alkaline media like NaOH solutions (Pramudita *et al*., 2022; Mendili, 2024). This represents a critical gap in the current body of knowledge, underscoring the need for further investigation.

The objectives of this study are twofold: first, to optimize the drying conditions of biocoating formulated from rice husk silica and damar resin, and second, to evaluate their corrosion resistance in a 1M NaOH solution. Drying conditions, including temperature and duration, play a pivotal role in determining the final properties of biocoating, affecting parameters such as adhesion, porosity, and mechanical stability. Understanding these effects is essential for maximizing the coating's performance and durability in corrosive environments.

Previous research provides a foundation for this investigation. Studies have shown that drying conditions significantly influence the microstructural properties of coatings, impacting their corrosion resistance and inhibitor efficiency (Kian-Pour, 2023; Khan *et al*., 2018). For instance, high-temperature drying has been associated with improved coating performance

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due to enhanced adhesion and reduced porosity, although excessive drying can lead to pore formation and reduced effectiveness. By systematically varying drying temperatures and times, this study aims to identify optimal conditions that balance these factors, thereby enhancing the biocoating's protective capabilities.

This research builds on the findings of prior studies, including those by Luqmanulhakim, who investigated the effect of temperature on biocoating in acidic media, and Pramudita *et al*. (2022), who evaluated rice husk silica and damar resin biocoating in NaOH solutions. These studies demonstrated the potential of biocoating to achieve high inhibitor efficiencies under specific conditions, such as 98% efficiency in acidic media at 40°C. However, variations in drying conditions and their impact on performance in alkaline environments remain poorly understood. Addressing this gap will contribute to the broader application of biocoating in industrial settings.

In addition to addressing the technical aspects of biocoating optimization, this study emphasizes the broader implications for sustainable engineering practices. By utilizing natural materials like rice husk silica and damar resin, the proposed biocoating align with green chemistry principles, reducing reliance on toxic chemicals and promoting the use of renewable resources (Mendili, 2024). This approach not only mitigates the environmental impact of corrosion protection strategies but also offers cost-effective solutions for industries seeking to adopt sustainable practices.

In summary, this study investigates the performance of rice husk silica and damar resin biocoating under varying drying conditions in alkaline environments, with a focus on optimizing corrosion resistance and inhibitor efficiency. By bridging critical knowledge gaps and advancing sustainable corrosion protection strategies, this research aims to contribute to the development of eco-friendly solutions that align with industrial needs and environmental priorities.

2. METHODS

The materials used in this study included mild steel, which served as the substrate for the biocoating experiments. The steel samples were cut into rectangular dimensions of 29 mm × 21 mm × 4 mm and thoroughly cleaned to remove contaminants that could interfere with the coating process. Rice husk silica, extracted from rice husk ash, was selected as the primary inorganic component due to its high silica content and strong adhesion properties. Damar resin, a natural organic polymer, was utilized as the binder material for the biocoating formulation. Sodium hydroxide (1M NaOH) solution was used as the corrosive medium to simulate alkaline industrial environments. To achieve homogeneity, other materials, including hexane, were employed during the resin preparation process.

The biocoating material was prepared by combining damar resin and rice husk silica solutions. The damar resin solution was prepared by dissolving 75 grams of damar resin in 300 milliliters of hexane at a controlled temperature of 40°C, with continuous stirring to ensure a homogeneous latex solution. Simultaneously, the silica solution was prepared by dissolving 3 grams of silica powder in 1 liter of 1M NaOH at 200°C, producing a concentrated mother solution. This mother solution was diluted to achieve a working concentration of 1500 ppm. The final biocoating mixture was formed by combining 80 milliliters of the damar resin solution with 20 milliliters of the silica solution and stirring until a uniform product was obtained.

The mild steel samples were coated using the dip-coating technique, which ensures uniform application of the biocoating material. Cleaned and dried steel samples were immersed in the biocoating solution for 30 seconds to ensure complete surface coverage.

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After coating, the samples were subjected to different drying conditions to evaluate their effects on the biocoating's properties. Three drying conditions were tested: drying at room temperature (27°C) for 72 hours, drying at 50°C for 10, 30, or 60 minutes, and drying at 100°C for the same time intervals. These variations allowed the study to assess how temperature and drying duration influence the coating's adhesion, porosity, and overall performance.

To evaluate the performance of the coatings, corrosion tests were conducted by immersing the coated steel samples in 1M NaOH solution for varying durations of 7, 14, 21, 28, and 35 days. After immersion, the samples were removed from the solution, dried, and weighed to assess weight loss. This weight-loss method provided a quantitative measure of corrosion rates, as the difference between the initial and final weights of the samples indicated the amount of metal lost due to corrosion.

The corrosion rate (Cr) was calculated using the standard equation, which considers the steel sample's weight loss, density, surface area, and immersion duration. Inhibitor efficiency (IE%) was also determined to quantify the effectiveness of the biocoating in reducing corrosion. This was calculated by comparing the corrosion rates of coated and uncoated steel samples. These metrics were critical for evaluating the performance of the biocoating under various drying and immersion conditions.

Statistical analysis was conducted to ensure the reliability and significance of the results. Variations in corrosion rates and inhibitor efficiencies under different conditions were analyzed to determine the optimal drying parameters. Graphical representations of the data were created to visualize trends and relationships between drying conditions, immersion times, and biocoating performance.

This comprehensive methodology ensured that the study systematically explored the effects of drying conditions on the biocoating's properties and its ability to protect mild steel in alkaline environments.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Analysis Data

Figures 1, 2, and 3 are photograph images of samples. Figures include Sample Mild Steel, Dammar resin solution, and Mild steel sample coated with biocoating.

Figure 1. Sample Mild Steel.

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Figure 2. Dammar resin solution.

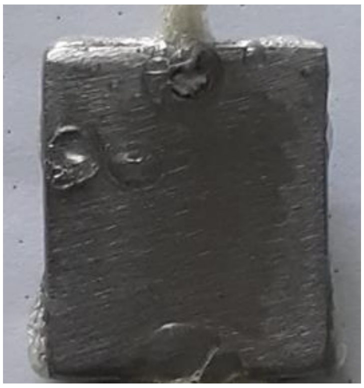

Figure 3**.** Mild steel sample coated with biocoating.

Several data were obtained. **Figures 4, 5, and 6** are the Corrosion rate and Inhibitor efficiency at 27, 50, and 100°C, respectively. **Tables 1, 2, and 3** are the results from drying at room temperature of 27, 50, and 100°C, respectively.

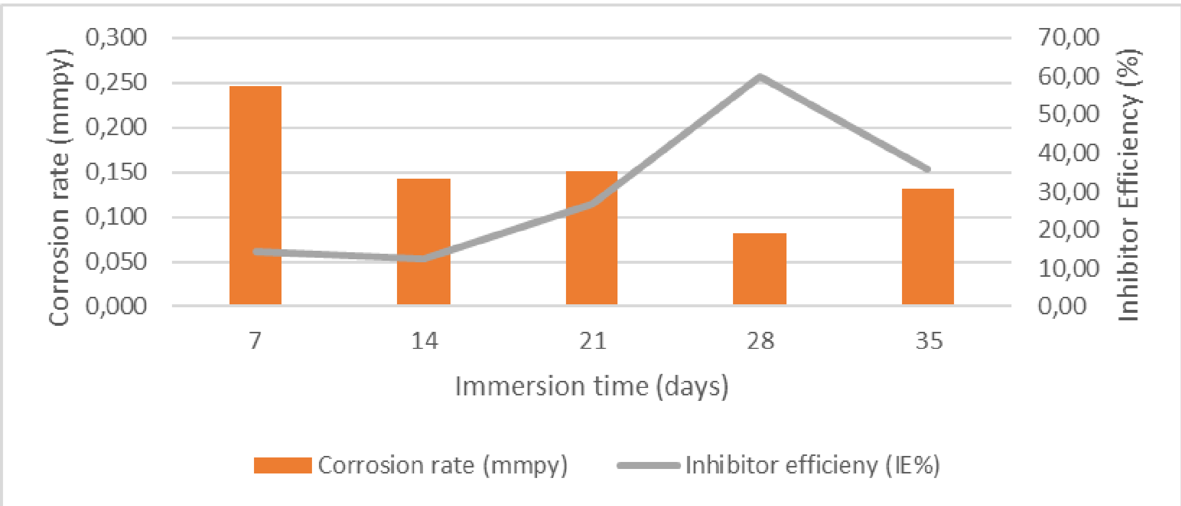

Figure 4. Corrosion rate & Inhibitor efficiency at 27°C.

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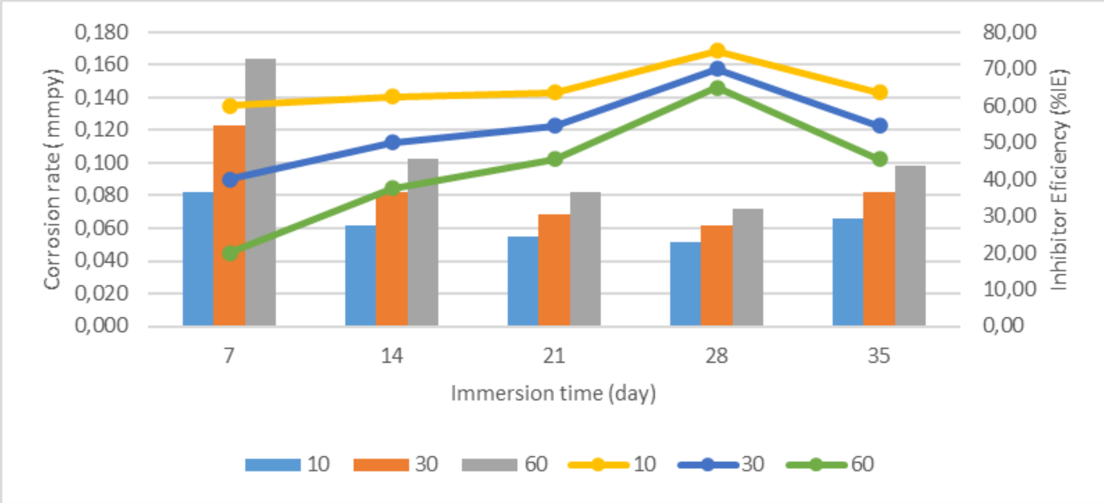

Figure 5. Corrosion rate & Inhibitor efficiency at 50°C.

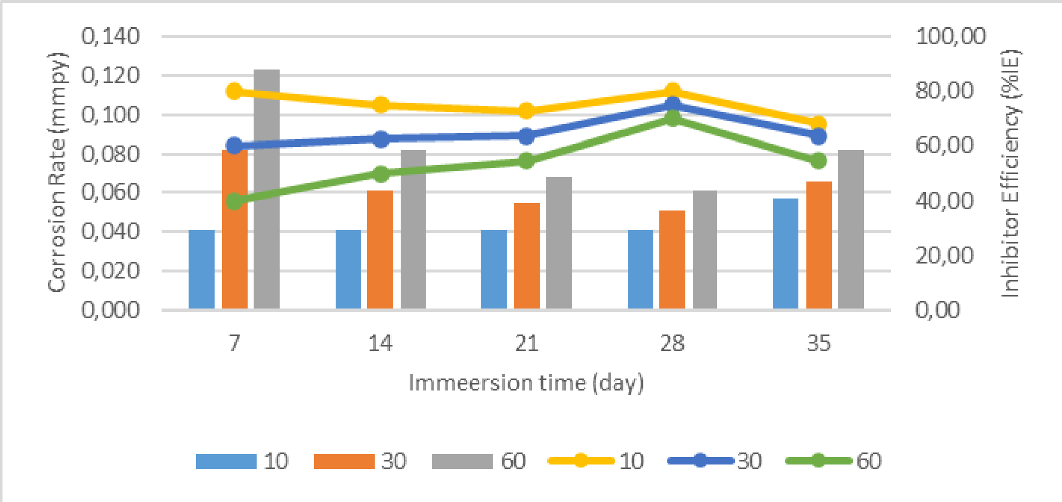

Figure 6. corrosion rate & Inhibitor efficiency at 100°C

Table 1. drying at room temperatur (27°C) 72 hrs.

Immersion Time (days)	Corrosion rate (mmpy)	Inhibitor efficiency (IE%)
7	0.246	14.29
14	0.144	12.50
21	0.150	26.67
28	0.082	60.00
35	0.131	36.00

Table 2. drying at temperature 50°C.

Immersion Time (days)	Corrosion rate (mmpy)			Inhibitor efficieny (IE%)		
	10 Minutes	30 Minutes	60 Minutes	10 Minutes	30 Minutes	60 Minutes
7	0.082	0.123	0.164	60.00	40.00	20.00
14	0.062	0.082	0.103	62.50	50.00	37.50
21	0.055	0.068	0.082	63.64	54.55	45.45
28	0.051	0.062	0.072	75.00	70.00	65.00
35	0.066	0.082	0.098	63.64	54.55	45.45

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Table 3. drying at temperature 100°C.

Immersion Time (days)	Corrosion rate (mmpy)			Inhibitor efficieny (IE%)		
	10 Minutes	30 Minutes	60 Minutes	10 Minutes	30 Minutes	60 Minutes
7	0.041	0.082	0.123	80.00	60.00	40.00
14	0.041	0.062	0.082	75.00	62.50	50.00
21	0.041	0.055	0.068	72.73	63.64	54.55
28	0.041	0.051	0.062	80.00	75.00	70.00
35	0.057	0.066	0.082	68.18	63.64	54.55

3.1.2. Effect of drying time and temperature on corrosion rate

The performance of biocoating on mild steel under various drying conditions was evaluated based on corrosion rate measurements in 1M NaOH solution. The results demonstrated a clear influence of drying temperature and duration on the coating's effectiveness. At room temperature (27°C) with a drying time of 72 hours, the corrosion rate decreased progressively over immersion durations, reaching a minimum value of 0.082 mm/year after 28 days. The corresponding inhibitor efficiency peaked at 60%, indicating moderate protection under these conditions. However, the corrosion rate increased to 0.131 mm/year after 35 days, highlighting potential limitations in long-term stability.

Drying at elevated temperatures yielded notable improvements. At 50°C, the corrosion rate decreased to 0.051 mm/year after 28 days for a drying duration of 10 minutes, with an inhibitor efficiency of 75%. Prolonging the drying time to 30 and 60 minutes slightly reduced the efficiency, likely due to increased porosity or cracking caused by extended heat exposure. At 100°C, the lowest corrosion rate of 0.041 mm/year was observed after 28 days for a 10-minute drying duration, corresponding to an inhibitor efficiency of 80%. These findings align with the literature indicating that optimal drying conditions enhance cross-linking of polymers, improving the coating's physical barrier properties (Pramudita *et al*., 2022). However, prolonged drying at high temperatures (30 or 60 minutes) led to a decline in performance, likely due to structural degradation (Krings, 2023).

3.1.3. Comparative performance of biocoating and untreated mild steel

Untreated mild steel exhibited significantly higher corrosion rates in 1M NaOH solution, exceeding 1 mm/year, consistent with previous studies (Ismail *et al*., 2021). In comparison, biocoated samples demonstrated a substantial reduction in corrosion rates across all drying conditions. This indicates the effectiveness of rice husk silica and damar resin as a natural anti-corrosion system, outperforming untreated samples by a factor of 10 to 20. These findings underscore the dual functionality of the biocoating materials, combining physical barrier properties with chemical interactions that enhance resistance to corrosive agents (Niyi *et al*., 2021).

3.1.4. Long-term stability of biocoating in NaOH solution

The stability of biocoating over prolonged immersion periods in NaOH solution was assessed to understand their durability in harsh environments. At room temperature, the biocoating showed a steady decline in inhibitor efficiency after 28 days, consistent with literature suggesting that alkaline exposure can degrade coating adhesion and structural integrity (Pramudita *et al*., 2022). Elevated drying temperatures (50°C and 100°C) provided greater stability, with coatings maintaining high efficiency for up to 35 days. However, samples dried for longer durations (60 minutes) exhibited signs of mechanical weakening,

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such as increased permeability and reduced efficiency, aligning with the known effects of excessive drying (Krings, 2023).

3.1.5. Microstructural effects of drying conditions

The drying process significantly influenced the microstructural integrity of the biocoating. Shorter drying times at elevated temperatures resulted in denser and more uniform coatings, as evidenced by the superior corrosion resistance observed. In contrast, prolonged drying at high temperatures introduced micro-cracks and increased porosity, reducing the coating's protective capabilities. These results are consistent with the hypothesis that optimal drying enhances cross-linking and adhesion, while excessive drying compromises structural cohesion (Pramudita *et al*., 2022).

3.1.6. Comparative analysis with other natural inhibitors

Rice husk silica and damar resin biocoating demonstrated comparable or superior performance to other eco-friendly inhibitors, such as natural gums and plant extracts. Natural gums, while cost-effective, may lack the dual functionality offered by rice husk silica and damar resin. Similarly, plant extracts provide corrosion resistance primarily through chemical interactions, whereas the biocoating studied here combine these interactions with robust physical barriers (Kamran *et al*., 2022; Niyi *et al*., 2021). These findings highlight the potential of rice husk silica and damar resin to serve as versatile and effective alternatives in sustainable corrosion protection strategies.

3.1.7. Summary of findings

The study confirmed that optimal drying conditions significantly enhance the performance of biocoating, with the best results achieved at 100°C for 10 minutes, yielding a corrosion rate of 0.041 mm/year and an inhibitor efficiency of 80%. The findings reinforce the importance of balancing drying temperature and duration to maximize the microstructural integrity and durability of biocoating in alkaline environments. These results contribute to the growing body of knowledge on natural anti-corrosion agents, providing practical insights for industrial applications.

3.2. Discussion

3.2.1. Performance of biocoating in alkaline environments

This study demonstrated that biocoating formulated from rice husk silica and damar resin exhibit significant potential as eco-friendly corrosion inhibitors in alkaline environments. The results showed that drying conditions play a pivotal role in determining the effectiveness and durability of the biocoating. At an optimal drying temperature of 100°C for 10 minutes, the biocoating achieved a corrosion rate of 0.041 mm/year and an inhibitor efficiency of 80%, outperforming untreated mild steel, which typically experiences corrosion rates exceeding 1 mm/year in similar conditions (Ismail *et al*., 2021). These findings corroborate existing literature, which highlights the dual functionality of rice husk silica and damar resin in providing both physical and chemical barriers to corrosion (Niyi *et al*., 2021).

However, prolonged drying times or excessively high temperatures led to diminished performance, likely due to the formation of micro-cracks and increased porosity in the coatings. This aligns with prior research, which suggests that excessive drying can compromise the structural integrity of coatings, reducing their effectiveness in harsh environments (Krings, 2023). The balance between drying temperature and time is therefore critical for achieving optimal performance and microstructural stability in biocoating.

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3.2.2. Comparison with other natural inhibitors

Rice husk silica and damar resin biocoating compare favorably to other natural corrosion inhibitors, such as natural gums and plant extracts, which rely predominantly on chemical interactions for protection. The biocoating in this study demonstrated superior mechanical properties, enhanced by the synergistic combination of silica and damar resin. The physical barrier provided by silica particles complements the adhesive and binding properties of damar resin, resulting in improved corrosion resistance compared to single-component inhibitors (Kamran *et al*., 2022; Vidal *et al*., 2023).

Alternative natural resins, such as Coumarone resin and bio-based epoxy resins, offer promising avenues for further enhancing biocoating performance. Coumarone resin's ability to improve thermal stability and mechanical strength could address some of the limitations observed in the current study, particularly under extended drying durations or higher temperatures (Feng, 2024). Similarly, bio-based epoxy resins derived from renewable resources could provide improved adhesion and chemical stability, further aligning with the goals of sustainability and environmental compatibility (Zhao *et al*., 2022). Future research could explore hybrid formulations incorporating these materials to enhance the robustness of biocoating in alkaline environments.

3.2.3. Mechanistic insights into biocoating behavior

The distinct behavior of biocoating in alkaline versus acidic environments underscores the importance of tailoring formulations to specific applications. In acidic environments, biocoating may benefit from enhanced adhesion and integration with the substrate, as the acidic medium facilitates interactions between coating components and the metal surface. Conversely, in alkaline environments, the high pH poses challenges, including the degradation of organic compounds and changes in mechanical properties. This study observed that prolonged exposure to 1M NaOH solution led to a gradual decline in inhibitor efficiency, particularly for coatings dried under suboptimal conditions. These findings are consistent with prior research indicating that alkaline conditions can compromise the stability of biocoating, emphasizing the need for optimized formulations and drying protocols (In-na *et al*., 2020).

3.2.4. Scalability and Industrial Applications

Scaling up the production of rice husk silica and damar resin biocoating presents both opportunities and challenges. While these materials are abundant and cost-effective, the variability in their properties requires stringent quality control measures to ensure consistent performance. Standardized production protocols, including controlled drying conditions and precise formulation processes, are essential for industrial-scale applications. Additionally, the unique characteristics of natural materials may necessitate modifications to existing manufacturing infrastructure, potentially increasing the complexity of scaling up (Feng, 2024).

The potential industrial applications of biocoating are diverse, encompassing sectors such as automotive, marine, and construction. In the automotive industry, biocoating can serve as lightweight, eco-friendly alternatives to traditional coatings, reducing corrosion and environmental impact. Marine applications could benefit from the biocoating' ability to protect vessels from both corrosion and biofouling, thereby extending their service life (Jin *et al*., 2021). In the construction industry, biocoating offer a sustainable solution for protecting steel structures and reinforcing materials, contributing to durability and sustainability goals (Martinsson *et al*., 2020). These applications highlight the versatility and broad applicability of biocoating in addressing corrosion challenges across industries.

3.2.5. Implications and Future Directions

This study provides critical insights into the optimization of biocoating performance in alkaline environments, paving the way for their broader adoption in industrial applications. Future research should focus on several key areas to build on these findings. First, the integration of alternative natural resins, such as Coumarone or bio-based epoxy resins, should be explored to enhance the mechanical and chemical stability of biocoating. Second, long-term durability studies in varying environmental conditions, including humidity and temperature fluctuations, are needed to evaluate the coatings' resilience under real-world conditions. Finally, life-cycle assessments of the biocoating could quantify their environmental benefits and further establish their value as sustainable alternatives to conventional corrosion protection methods.

In conclusion, rice husk silica and damar resin biocoating represent a promising solution to corrosion challenges, offering an effective and sustainable alternative to traditional methods. By addressing scalability and performance optimization, these biocoating have the potential to make significant contributions to industrial sustainability and corrosion management.

4. CONCLUSION

This study demonstrated the effectiveness of rice husk silica and damar resin biocoating as eco-friendly corrosion inhibitors for mild steel in alkaline environments. The optimal performance was achieved at a drying temperature of 100°C for 10 minutes, resulting in the lowest corrosion rate of 0.041 mm/year and the highest inhibitor efficiency of 80%. These findings highlight the critical role of drying conditions in enhancing the microstructural integrity and protective properties of the biocoating. Conversely, prolonged drying or excessive temperatures led to diminished performance due to increased porosity and structural degradation.

Compared to untreated mild steel and other natural inhibitors, the biocoating showed superior corrosion resistance, combining the physical barrier properties of silica with the adhesive qualities of damar resin. The study also identified scalability challenges in standardizing biocoating production due to the variability of natural materials and the need for specialized equipment.

This research contributes to the advancement of sustainable corrosion protection strategies, providing insights into the mechanisms and optimal conditions for biocoating performance in harsh environments. Future studies should explore hybrid formulations incorporating alternative resins, assess long-term durability under variable environmental conditions, and quantify the environmental benefits through life-cycle assessments. These directions will further establish the feasibility and industrial relevance of biocoating as a sustainable alternative to traditional anti-corrosion methods.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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