Enhancing Durability and Adhesion of Moringa Oleifera as Green Corrosion Inhibitor on Mild Steel using Lignin -Based Polymer from Coconut Shell

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ORIGINAL RESEARCH

Abstract— This investigation explores the potential of a lignin-based polymer derived from coconut shells and Moringa oleifera extract as sustainable, natural corrosion inhibitors for mild steel. The study aims to develop novel, eco-friendly corrosion protection coatings by synergistically combining these two components. The mild steel used for this research are Thermo Mechanically Treated (TMT) bars having carbon content percentage range from 0.18 - 0.25%, procured from Abuja Steel Mill Limited, fresh moringa leaves and mature coconut shell from within Minna. A comprehensive characterization of the lignin-based polymer and Moringa oleifera extract was conducted to elucidate their chemical composition and properties. Coatings incorporating varying concentrations of these compounds were formulated to assess their corrosion inhibition efficacy. The developed coatings were subjected to rigorous adhesion testing and corrosion resistance evaluation. The results demonstrated an Inhibition Efficiency (IE%) of 91.79%, indicating the promising potential of Moringa oleifera and lignin-based polymer as sustainable alternatives. These findings suggest that the proposed approach holds significant promise for the development of durable and environmentally sustainable corrosion protection solutions for mild steel applications.

Keywords— Moringa Oleifera, Green Corrosion Inhibitor, Coconut Shell, Lignin-based Polymer, Sustainability.

1 INTRODUCTION

Corrosion represents a significant challenge across various industries, leading to substantial economic losses and safety hazards. Widely recognized as one of the most pressing contemporary societal issues, corrosion exerts a profound impact on the economy, human health, safety, technology, and culture. The corrosive environment compromises the structural integrity of materials, resulting in damage that necessitates costly replacement and repair efforts, as well as environmental degradation (Isaac et al., 2020; Al-Moubaraki and Obot, 2021; Ibrahimi, et., al., 2021). Various strategies have been employed to mitigate corrosion, including environmental control, the application of protective coatings, and the utilization of corrosion-resistant materials. However, conventional corrosion inhibitors derived from petroleum-based sources pose environmental concerns. The rapidly growing Moringa oleifera tree, native to Asia and Africa, has emerged as a promising sustainable alternative for corrosion inhibition. Mild steel, a widely used material that is prone to corrosion, necessitates the application of an inhibitor. Mild steel would corrode in any environment, but would corrode faster in acidic environment (Falowo, et., al. 2018; Desiasni, et., al. 2021; Isaac et al., 2020 & Marzorati, et., al. 2019).Organic molecules containing nitrogen, oxygen, and sulfur atoms can effectively regulate the corrosion of iron and steel in hydrochloric acid media.

However, the majority of conventional inhibitors are derived from or selected from organic compounds with heteroatoms in their molecular structures, which are often expensive and challenging to synthesize.

Researchers have explored the development of novel green corrosion inhibitors based on natural materials and environmentally friendly biopolymers. Plant extracts, characterized by their low cost, abundant availability, and high biodegradability, have emerged as promising candidates for the inhibition of mild steel corrosion (Jalajaa, et al., 2019; Hossain, et., al. 2021 & Popoola, 2019). The primary component of the inhibitor was Moringa oleifera leaves, which were dried for five days in the absence of sunlight to preserve their antioxidant properties. The leaves, typically measuring 4.5 cm in length, were subsequently ground and filtered to obtain a fine, microscopic powder to ensure optimal compatibility with seawater. Fourier-transform infrared spectroscopy (FTIR) analysis was conducted on the powdered Moringa oleifera leaves to verify the presence of essential elements, including oxygen, carbon, nitrogen, and sulfur, which are known to contribute to the corrosion inhibition process, (Atan et al., 2022).

Despite its promising potential, the application of Moringa oleifera extracts as corrosion inhibitors is subject to certain limitations. The solubility of Moringa oleifera compounds can influence their longevity and adhesion to metal surfaces. Additionally, the degradation of Moringa

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oleifera extract over time, particularly when exposed to high temperatures or ultraviolet radiation, can compromise its long-term effectiveness and lead to the instability of the inhibitor on the metal surface.

Research has demonstrated the significant potential of lignin-based polymers to enhance the durability, adhesion, and stability of Moringa oleifera-derived corrosion inhibitors. Lignin, second only to cellulose as the most abundant renewable biomass resource, is produced annually at a global scale of approximately 100 million tons. However, the majority of lignin is currently utilized as a low-value fuel for industrial heat generation, with only a small fraction (approximately 2%) being employed in the production of high-value products. Consequently, there has been a growing interest in transforming lignin into valuable materials. Due to its abundance of phenolic and alcoholic hydroxyl groups, lignin has been successfully incorporated as a polyol in the synthesis of polyurethane (PU) materials, including adhesives, foams, elastomers, coatings, and other applications. Given the finite nature of petroleum resources and the environmental concerns associated with petroleum-based products, lignin-based PU materials represent promising alternatives for future applications (Wu et al., 2022).

Steel remains the predominant material employed in contemporary shipbuilding. Among the most widely used low-carbon steels for ship hull construction is A36. Seawater corrosion constitutes a significant contributor to the degradation of hull plates. Corrosion, a consequence interaction of a metal with chemicals and the environment, leads to a deterioration of its properties. While complete elimination of metal corrosion is unattainable, effective management strategies can be implemented (Desiasni et al., 2021).

While Moringa oleifera extract has demonstrated potential as a green corrosion inhibitor for metals, its native form exhibits limitations in terms of durability and adhesion to metal surfaces, hindering its long-term efficacy and practical application. This investigation explores the potential of lignin, a readily available and renewable biopolymer, to augment the durability and adhesion properties of Moringa oleifera as a corrosion inhibitor. By leveraging the adhesive and film-forming characteristics of lignin, the study aims to enhance the durability, adhesion, and stability of Moringa oleifera on mild steel, thereby extending its corrosion protection capabilities and maintaining its green credentials.

This research seeks to improve the durability and adhesion of Moringa oleifera as a green corrosion inhibitor by employing a lignin-based polymer. Moringa oleifera extract and lignin were extracted from their respective sources, subsequently blended in specific proportions to enhance the adhesion of Moringa oleifera to the surface of mild steel as a green corrosion inhibitor. Through this approach, the study aims to develop a more resilient and long-lasting green corrosion inhibition solution utilizing lignin-based polymers and Moringa oleifera.

2 Materials and Methods

2.1 Materials

The materials used for this study includes the following: Mild steel rod, Coconut shell extract, Fresh Moringa Oleifera Leaf Extract, Distilled Water, Hydrochloric Acid (HCl), Sodium Hydroxide (NaOH), Sodium Chloride (NaCl), and Furnace.

2.1.1 Preparation of Mild Steel Rod

A commercially available grade of mild steel (Thermo Mechanically Treated (TMT) bars having carbon content percentage range from 0.18 - 0.25%) identified and obtain locally was used in this study. The mild steel rod was cut into pieces of equal length of 50mm and diameter of 20mm with the aid of a saw blade, Vernier caliper for measurement and a clamp to hold the material in place. The specimen was descaled by wire brush and was degreased using sand paper. They were thoroughly cleaned, rinsed and dried for further weight loss tests.

2.1.2 Extraction of Moringa Oleifera Extracts

Fresh moringa oleifera leaves were obtained from Bosso, Minna Niger state, Nigeria. The leaves were thoroughly washed under running water to remove impurities, then the leaves were granulated, distilled water was added to the grinded moringa and the mixture was allowed to settled down in a beaker for 48 hours and afterward the mixture was filtered with a Buchner funnel and filter paper at the end of the extraction period, then moringa extract was kept in a clean container for further analysis (Atan et al., 2022).

2.1.3 Extraction of Lignin from Coconut Shell

Mature Coconut shells, dried and defibered were obtained from Kure Market, Bosso local government area, Minna Niger State, Nigeria. The shells were thoroughly washed under running water to get rid of impurities. The coconut shell was sun dried to remove moisture, then the shell was pulverized and grinded to a fine powder by a milling machine. The grinded coconut shell was separated into coarse and fine fractions by a means of a 0.78mm sieve, 50g of sodium hydroxide NaOH was measured and dissolved in 500ml of distilled water, then 20g of coconut shell powder was measured and dissolved in 240ml of aqueous NaOH and was stirred continuously for 45 minutes at 120°C, then the mixture was allowed to cool down at room temperature.

The mixture was filtered using filter paper and Buchner funnel to separate the liquid containing the lignin from the solid residue. The filtrate was diluted with 2M of dilute HCl to precipitate the lignin.

2.1.4 Preparation of Corrosion Test Media

100ml of moringa oleifera extract was measured into four different beakers. Different amount of lignin extract 67ml, 133ml, 200ml was measured, the lignin extract was added to 100ml of moringa oleifera
extract. 100ml of moringa extract was left in a beaker without add the lignin extract. This served as the control experiment (Zakaria et al., 2017).

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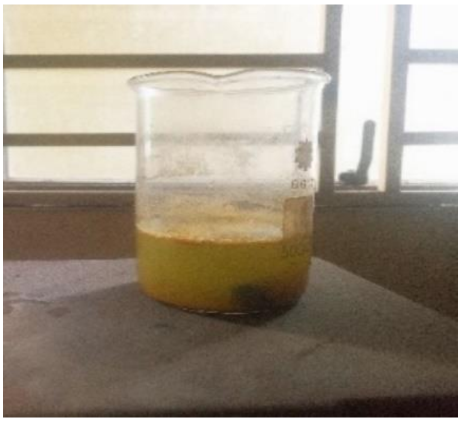
Figure 1a: Cut Pieces of Mild Steel Rod

1b. Lignin extract from coconut shell

Figure 2a: Moringa Oleifera Leaves



2b. Moringa Oleifera Leaves Extract

Figure 3a: Coconut Shell

3b. Pulverized Coconut Shell

2.1.5 WEIGHT LOSS EXPERIMENT

After the initial weighing, the specimen (mild steel rod) was immersed into 100ml of moringa oleifera containing different concentration of lignin for one week (168 hours). After every 24 hours each specimen was removed, washed, dried completely and their final weights were noted. From the initial and final weights of mild steel rod, the weight loss, corrosion rate (CR) ($gcm^{-2}hr^{-1}$), inhibition efficiency (IE) (%), were determined.

$$CR = \frac{\Delta W}{At} (gcm^{-2}hr^{-1}) \quad (1)$$

$$\Delta W = w_1 - w_2 \quad (2)$$

$$IE (\%) = \left(\frac{w1 - w2}{w1}\right) \times 100 \quad (3)$$

$$\text{Surface coverage } (\Theta) = \frac{IE(\%)}{100} \quad (4)$$

Where W is the change in weight of mild steel after time t, A is the area of the mild steel, t (hours) is the time of immersion, w_1 and w_2 are the weight of the mild steel before and after every 24 hours of immersion.

The anodic dissolution of iron in acidic media and the corresponding cathodic reaction has been reported as follows.

$$Fe\ (s) = Fe2 + (aq) \quad + 2e- \quad (5)$$

$$2H\ (aq) + \quad 2e - = H_2\ (g)$$

2.1.6 Durability and Adhesion Test

Durability is the ability of a product to withstand wear and tear over time. It is about how well it holds up to its intended use.

2.1.7 Preparation of Test Medium

100ml of distil water was measured equally into two

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different beakers, and 10g and 20g of sodium chloride (NaCl) were measured and dissolved in the distil water respectively.

The inhibitor coating was applied on the mild steel rod and the weights were measured and recorded. Then the mild steel was immersed in the 10g salt solution and was kept in the furnace at a temperature of 120°C for six hours. Afterwards the mild steel was allowed to cool down, the weight of the steel was measured and recorded, and the surface texture was observed. Then the same procedure was repeated for 20g of salt solution, the weight of the mild steel was measured and recorded.

3.0 RESULTS AND DISCUSSION

3.1 Result and Tables

From the experiment carried out, the weight loss, corrosion rate, inhibition efficiency and durability test for mild steel rod, in 100ml of moringa oleifera extract solution at 0ml, 67ml, 133ml, and 200ml of lignin extract from coconut shell were determined. The anodic dissolution of iron in acidic media and the corresponding cathodic reaction has been reported in equation (4) and (5) respectively. As a result of these reactions, including the high solubility of the corrosion products, the metal loses weight in the solution as stated in equation (1) and (2) respectively.

$$A = 2\pi (r + h) \quad (6)$$

Where r is the radius of the rod and h is the height (length) of the rod.

$A = 2\pi \times 1(1 + 5)$

Surface area (A) = 18.85 cm^2

$$\text{Inhibition efficiency (IE\%)} = \Delta w / CR \quad (7)$$

$$\text{Surface coverage } (\Theta) = IE/100 \quad (8)$$

The mild steel rod was immersed in the inhibitor for a week (168 hours) and the weight of the steel was noted after every 24 hours, the results are tabulated below.

Table 1: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 24 hours

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverag (Θ)
1	Metal 1	0 ml of lignin	68.8	68.6	0.2	0.04485	0.146069	0.00291
2	Metal 2	67 ml of lignin	68.7	68.6	0.1	0.02242	0.147560	0.00146
3	Metal 3	133 ml of lignin	68.8	68.7	0.1	0.02242	0.149348	0.00145
4	Metal 4	200 ml of lignin	68.8	68.5	0.3	0.06727	0.154360	0.00436

Table 2: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 48 hours.

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverag (Θ)
1	Metal 1	0 ml of lignin	68.6	68.3	0.3	0.03364	0.17373	0.00437
2	Metal 2	67 ml of lignin	68.6	68.4	0.2	0.02243	0.17692	0.00292
3	Metal 3	133 ml of lignin	68.7	68.5	0.2	0.02243	0.17991	0.00291
4	Metal 4	200 ml of lignin	68.5	68.4	0.1	0.01121	0.18459	0.00146

Table 3: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 72 hours

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverage (Θ)
1	Metal 1	0 ml of lignin	68.3	68.2	0.1	0.00748	0.19464	0.00146
2	Metal 2	67 ml of lignin	68.4	68.3	0.1	0.00748	0.19946	0.00146
3	Metal 3	133 ml of lignin	68.5	68.4	0.1	0.00748	0.20460	0.00146
4	Metal 4	200 ml of lignin	68.4	68.3	0.1	0.00748	0.21462	0.00146

Table 4: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 96 hours.

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverage (Θ)
1	Metal 1	0 ml of lignin	68.2	68.0	0.2	0.01121	0.22325	0.00293
2	Metal 2	67 ml of lignin	68.3	68.1	0.2	0.01121	0.22983	0.00293
3	Metal 3	133 ml of lignin	68.4	68.2	0.2	0.01121	0.23424	0.00292
4	Metal 4	200 ml of lignin	68.3	68.2	0.1	0.00561	0.24641	0.00146

Table 5: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 120 hours.

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverage (Θ)
1	Metal 1	0 ml of lignin	68.0	67.8	0.2	0.00897	0.24411	0.00294
2	Metal 2	67 ml of lignin	68.1	67.9	0.2	0.00897	0.24937	0.00294
3	Metal 3	133 ml of lignin	68.2	68	0.2	0.00897	0.25326	0.00293
4	Metal 4	200 ml of lignin	68.2	68.1	0.1	0.00449	0.26227	0.00147

Table 6: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 144 hours

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Covera (Θ)
1	Metal 1	0 ml of lignin	67.8	67.6	0.2	0.00747	0.26149	0.00295
2	Metal 2	67 ml of lignin	67.9	67.7	0.2	0.00748	0.26946	0.00295
3	Metal 3	133 ml of lignin	68.0	67.9	0.1	0.00374	0.27631	0.00147
4	Metal 4	200 ml of lignin	68.1	68	0.1	0.00374	0.28315	0.00149

Table 7: Corrosion of mild steel rod in ml of lignin / 100ml of Moringa extract after 168 hours.

S/N	Specimen	Concentration of ml of lignin / 100ml of moringa extract	W_1(g)	W_2(g)	ΔW(g)	Corrosion Rate (CR) ($gcm^{-2}hr^{-1}$)	Inhibition Efficiency (IE%)	Surface Coverag (Θ)
1	Metal 1	0 ml of lignin	67.6	67.4	0.2	0.00641	0.29586	0.00296
2	Metal 2	67 ml of lignin	67.7	67.6	0.1	0.00320	0.29915	0.00148
3	Metal 3	133 ml of lignin	67.9	67.8	0.1	0.00320	0.32728	0.00147
4	Metal 4	200 ml of lignin	68.0	67.9	0.1	0.00320	0.34515	0.00147

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3.2 Discussion of Results

3.2.1 Variation of Corrosion rate and inhibitor efficiency with time

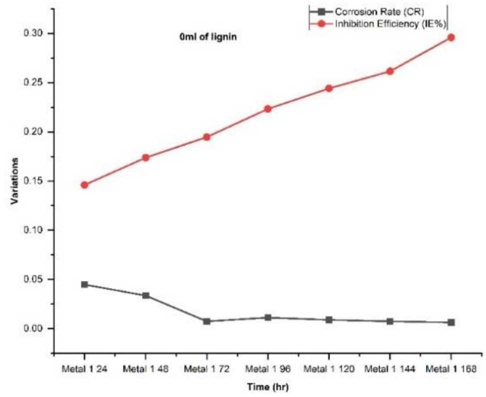

Figure 4: Variation of corrosion rate with time in 0ml of lignin / 100ml of moringa extract for 168 hours, the result show that corrosion rate decreases with increase in time of immersion in 0ml of lignin / 100ml of moringa extract for 168 hours and the efficiency increases in the same time frame.

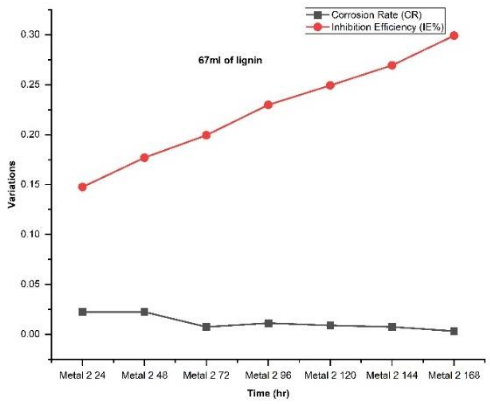

Figure 5: Variation of corrosion rate with time in 67ml of lignin / 100ml of moringa extract for 168 hours, the result show that corrosion rate decreases with increase in time of immersion in 0ml of lignin / 100ml of moringa extract for 168 hours and the efficiency increases in the same time frame.

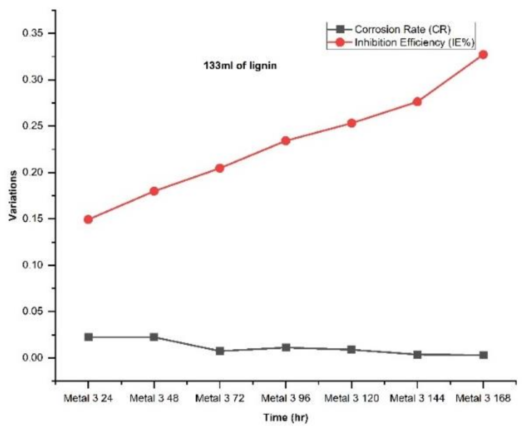

Figure 6: Variation of corrosion rate with time in 133ml of lignin / 100ml of moringa extract for 168 hours, the result show that corrosion rate decreases with increase in time of immersion in 0ml of lignin / 100ml of moringa extract for 168 hours and the efficiency increases in the same time frame.

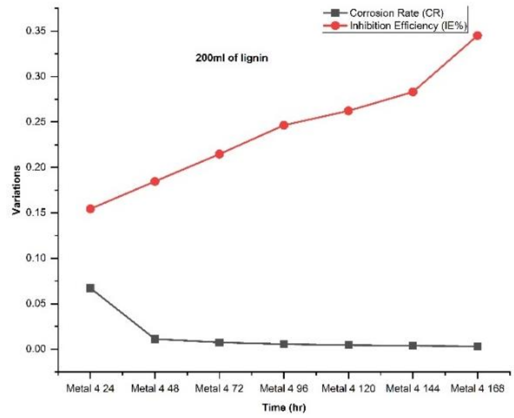

Figure 7: Variation of corrosion rate with time in 0ml of lignin / 100ml of moringa extract for 168 hours, the result show that corrosion rate decreases with increase in time of immersion in 0ml of lignin / 100ml of moringa extract for 168 hours and the efficiency increases in the same time frame. Therefore, it can be deduced that the addition of higher concentration of lignin has increased the inhibition efficiency of Moringa Oleifera extract. These results were supported by similar finding by (Jane & Nakara 2019; Rosidah, et. al., 2021; Saifullahi & Muhammad 2022)

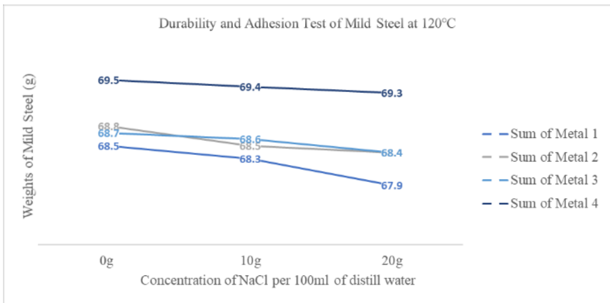

Figure 8: Variation of the weights of mild steel in sodium chloride at 120℃

The result shows that metal 1 has the least durability and adhesion, Metal 4 shows the highest durability and adhesion, while metal 2 & 3 shows closely related durability and adhesion.

From physical observation, metal 1, metal 2, metal 3 had some cracks on them, but metal 4 retained it smooth surface provided by the inhibitor coatings.

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Figure 9: Final Mixture of Lignin and Moringa Blends

Figure 10: Mild Steel after Corrosion testing

4. Conclusion

This investigation underscores the potential of a lignin-based polymer derived from coconut shells and Moringa oleifera extract as sustainable, natural corrosion inhibitors for mild steel. Our research demonstrates the synergistic interaction between these components, resulting in significantly enhanced adhesion and durability of the resulting coatings. By providing a protective barrier on the metal surface, these coatings effectively mitigate corrosion processes, thereby exhibiting exceptional corrosion protection. The utilization of natural, renewable resources aligns with the growing emphasis on environmental sustainability, reducing reliance on hazardous synthetic chemicals. The findings of this research offer promising avenues for the development of innovative, eco-friendly corrosion protection technologies applicable to a wide range of industrial applications. The results demonstrated an Inhibition Efficiency (IE%) of 91.79%, indicating the promising potential of Moringa oleifera and lignin-based polymer as sustainable alternatives. These findings suggest that the proposed approach holds significant promise for the development of durable and environmentally sustainable corrosion protection solutions for mild steel applications.

4.1 Recommendation for Further Studies

This study suggests that Spectro analysis should be conducted on the mild steel after corrosion testing, so as to determine the effects/Impact of the corrosion on the sample. From our physical observation of cracks on the three samples, the Spectro analysis would have determine the extent of the damage done to the mild steel which resulted in cracks, whether there is possible alteration in the chemical structure of the mild steel due to corrosion and also, determine the mechanical properties of the mild steel like yield strength, tensile strength and elongation after corrosion testing.

References

Al-Moubaraki, A. H., & Obot, I. B. (2021). Top of the line corrosion: causes, mechanisms, and mitigation using corrosion inhibitors, In Arabian Journal of Chemistry 14(5): 103-116. https://doi.org/10.1016/j.arabjc.2021.103116

Atan, F., Rosliza, R., & Wan Syahidah, W., M. (2022). The efficiency of moringa leaf (Moringa Oleifera) as green material carbon steel corrosion inhibitor for different concentration of sea water. Journal of Physics: Conference Series, 2266(1): 1-10, https://doi.org/10.1088/1742-6596/2266/1/012009

Desiasni, R., Mardiana, M., & Hidayat, S. (2021). Corrosion inhibition efficiency of moringa leaf extract (Moringa oleifera) against A36 steel. Jurnal Pijar Mipa, 16(5): 600–607. https://doi.org/10.29303/jpm.v16i5.2969

Falowo, A. B., Mukumbo, F. E., Idamokoro, E. M., Lorenzo, J. M., Afolayan, A. J., & Muchenje, V. (2018). Multi-functional application of Moringa oleifera Lam. in nutrition and animal food products: A review. Food Research International, 106(2): 317–334. https://doi.org/10.1016/J.FOODRES.2017.12.079

Hossain, N., Asaduzzaman, Chowdhury, M., & Kchaou, M. (2021). An overview of green corrosion inhibitors for sustainable and environment friendly industrial development. In Journal of Adhesion Science and Technology, 35(7): 673–690, https://doi.org/10.1080/01694243.2020.1816793

Ibrahimi, B. El., Nardeli, J. V., & Guo, L. (2021). An Overview of Corrosion. In ACS Symposium Series, American Chemical Society, 14(3): 1–19, https://doi.org/10.1021/bk-2021-1403.ch001

Isaac, K. I., Oparadike, O. E., & Luke, F. E. (2020). Study of Corrosion Inhibitive Behaviour of Moringa Oleifera Leaf Extract on Mild Steel, In *Journal of Newviews in Engineering and Technology (JNET)* 2(2): 21-28.

Jalajaa, D., Jyothi, S., Muruganantham, V. R., & Mallika, J. (2019). Moringa oleifera gum exudate as corrosion inhibitor on mild steel in acidic medium. *Rasayan Journal of Chemistry*, *12*(2), 545–548. https://doi.org/10.31788/RJC.2019.1224096

Jane, N., M. and Nakara, M. T. (2019). Determination of the Corrosion Inhibition Effect of Terminalia Ivorensis Leave Extract on Galvanized and Mild Steel in Sulphuric Acid Media. American Journal of Physical Chemistry. 8(1): 11-16

Marzorati, S., Verotta, L., & Trasatti, S. P. (2019). Green corrosion inhibitors from natural sources and biomass wastes. Molecules, 24(1). https://doi.org/10.3390/molecules24010048

Popoola, L. T. (2019). Organic green corrosion inhibitors (OGCIs): A critical review. In Corrosion Reviews. De Gruyter, 37(2)71–102 https://doi.org/10.1515/corrrev-2018-0058

Rosidah, A., S, Vuri, S., Suheni, & Rijayanto, R. (2021). The effect of time variation on the steels corrosion rate in 0.5 M H2SO4 solution. Journal of Mechanical Engineering, Science, and Innovation. 1(2): 49-55. https://doi.org/10.31284/j.jmesi.2021.v1i2.2183

Saifullahi L. M. & Muhammad B. I. (2022). Corrosion Inhibition of Zinc In 0.5 M Hno3 Using Azadirachta Indica Extract: Experimental and Computational Study, Special Conference Edition, Bayero Journal of Pure and Applied Sciences, 13(1): 149 – 162, http://dx.doi.org/10.4314/bajopas.v13i1.26S

Wu, T., Li, X., Ma, X., Ye, J., Shen, L., & Tan, W. (2022). Modification of lignin by hexamethylene diisocyanate to synthesize lignin-based polyurethane as an organic polymer for marine polyurethane anticorrosive coatings. Materials Research Express, 9(10): 1-11. https://doi.org/10.1088/2053-1591/ac95fc