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Bamboo Leaves Extract as Corrosion Inhibitor for Mild Steel

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Abstract

Mild steel is a type of low-carbon steel that is easy to shape and weld, commonly used in construction and manufacturing due to its ductility and malleability. However, corrosion significantly impacts the durability and safety of metals like mild steel. It weakens the material's strength and ductility, leading to costly repairs. To prevent corrosion, organic inhibitors are used as they not only prevent rust but are also safer for the environment. Bamboo leaves extract (BLE) is an organic and eco-friendly corrosion inhibitor, contains compounds like flavonoids that act as antioxidants and can form a protective layer on metal surfaces, which is can reducing corrosion by inhibiting electrochemical reactions. The objectives of this study are to analyse the effect of bamboo leaves extract (BLE) in preventing corrosion. It begins with immersion tests conducted with four different ratios of NaCL and BLE (100% NaCl, 90 NaCl: 10% BLE, 70 NaCl: 30% BLE and 50% NaCl: 50% BLE). The analysis methods used for chemical property analysis including FTIR, SEM-EDX, and EIS. FTIR analysis was performed to identify functional groups in the bamboo leaves extract, such as hydroxyl groups (O-H), alkanes (C-H), and phenols (C-O). After seven days of immersion, SEM-EDX analysis was conducted on both pre- and post-immersion samples. The pre-immersion analysis showed a clear and smooth mild steel surface, while the post-immersion analysis revealed oxidation and different rate of corrosion on all samples. EIS analysis shows the inhibitors effect of BLE, with Tafel and Nyquist plots showing increased charge transfer resistance (Rct) and reduced double-layer capacitance (Cdl) in BLE-treated samples. The 50% BLE concentration provided the strongest protective layer, resulting in the lowest corrosion rate observed in the Tafel plots. The final results highlight that the solution with 50% NaCl: 50% BLE showed the best performance with the lowest corrosion rate compared to the other ratios.

1. Introduction

Corrosion is the natural process where metals degrade into more stable forms when exposed to gases or liquids. This occurs due to oxidation reactions between the metal and its environment, leading to significant economic losses and safety risks. Examples include the collapse of structures, pipeline fractures, and sewer system failures.[1] In engineering sector, mild steel is very well-known steel type for its low carbon content, ductility, toughness, machinability, weldability, affordability, and availability where it lead to highly susceptible to corrosion. This susceptibility affects its durability and functionality, posing challenges in controlling corrosion rates in various environments. Corrosion occurs as metals lose electrons and undergo oxidation. [2] Developing eco-friendly corrosion inhibitors is essential to protect infrastructure and the environment, representing a key advancement in materials science and corrosion engineering. [3]

Mild steel is widely used but doesn't resist corrosion well, especially in acidic environments. This is a big problem for industries that use acidic solutions, like pickling, acid cleaning, descaling, and drilling in oil and gas. As a result, iron and steel equipment in these industries often corrodes.[4] Inorganic inhibitors that usually containing phosphate, chromate and heavy metals have been used to prevent this corrosion. However, these substances are toxic and harmful to the environment, leading to stricter regulations and bans. [5]

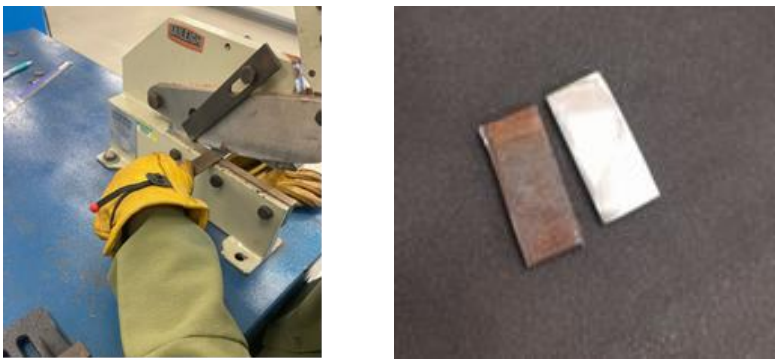
Corrosion leads to high costs for maintenance and replacement. There are many organic inhibitors that can prevent corrosion, and bamboo leaf extract (BLE) is one of them. Bamboo is easy to grow and abundant, and it contains flavonoids that act as antioxidants, offering a sustainable way to stop corrosion. [6] BLE is also an eco-friendly and effective corrosion inhibitor for mild steel in acidic environments. [7] It forms a protective layer on metal surfaces, preventing corrosion in hydrochloric, sulfuric, citric, and trichloroacetic acid solutions, making it a good option for corrosion protection. [8]. This study aims to study the effectiveness of organic corrosion inhibitor for the mild steel surface in the salty environment. Surface characterization and corrosion rate study for the corrosion product were study using several analytical methods including SEM-EDX, FTIR and EIS.

2. Materials and Method

There are five (5) steps to conduct this corrosion inhibitor test which is start with preparing mild steel samples and bamboo leaves extract (BLE). A series of 1.0M sodium chloride (NaCl) solutions with varying concentrations of bamboo leaf extract (BLE) as a corrosion inhibitor were prepared for the immersion test. The prepared solutions included: (1) 100% NaCl (control), (2) 90% NaCl with 10% BLE, (3) 70% NaCl with 30% BLE, and (4) 50% NaCl with 50% BLE. The functional groups and chemical properties of the BLE samples then are analysed using Fourier Transform Infrared (FTIR). Next, Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy (SEM-EDX) is used to investigate the samples' morphology and elemental composition of mild steel pre and post immersion. Finally, the corrosion rate is analysed using Electrochemical Impedance Spectroscopy (EIS) by analysing Tafel and Nyquist plot of each sample that allows determination of how effectively the BLE shields the mild steel from corrosion.

2.1 Sample Preparation (Mild Steel)

Preparing a mild steel sample for corrosion testing involves cutting it into identical dimension of area, 1 cm x 1 cm pieces. The sample surface was cleaned using sandpaper and a polishing compound, followed by degreasing with acetone. It was then handled with clean gloves and stored in silica gel to absorb moisture and prevent oxidation before testing. This preparation ensured accurate corrosion test results. Figure 1 shows two main steps in preparing mild steel samples which is Fig. 1 (a) shows the precise cutting of mild steel using a steel cutter while Fig. 1 (b) shows the comparison of mild steel samples before and after polishing using sandpaper of highlighting the transition from a rough, imperfect surface to a smooth, reflective one.



(a) (b)

Fig. 1 The metal preparation process including, a) Process of cutting mild steel using steel cutter, b) Mild steel before and after polished

2.2 Sample Preparation of Bamboo Leaves Extract (BLE)

Preparation of BLE is one of the most crucial parts of this work. The first stage was involved with collecting the leaves and drying them in an oven at 50°C for 24 hours. This is followed by grinding the dried leaves and sieving the resulting powder. Finally, the powder undergoes extraction using a rotary evaporator. Fig. 2 (a) shows the sieving of bamboo leaf powder through a 250-micron sieve. In this process, dried bamboo leaves are ground into a powder and sieved, allowing particles smaller than 250 microns to pass through. This ensures uniform particle size, which is crucial for the effectiveness of the subsequent extraction process while Part (b) shows the filtering of a bamboo solution mixed with 60% of ethanol. This process able to removes solid contaminants to ensure the solution's clarity and purity before final extraction using rotary evaporator for more accurate analysis. Ethanol helps dissolve the components from bamboo leaf powder while keeping the solution effective during filtration.

(a) (b)

Fig. 2 a) Process of sieving bamboo leaves powder using 250 micron sieve, b) Filtration process of diluted bamboo solution of 60 % ethanol

2.3 Immersion Test

Mild steel samples were immersed in four different compositions of NaCl and BLE. Firstly, a concentrated 1M of NaCl solution was prepared. The cleaned steel samples were then immersed in four different solutions: 100% NaCl, 90% NaCl + 10% BLE, 70% NaCl + 30% BLE, and 50% NaCl + 50% BLE, as shown in Fig. 3. Each sample was left in the solutions for 7 days to allow corrosion to take place. This method enabled a thorough comparison of how varying concentrations of NaCl and BLE influenced the corrosion of mild steel.

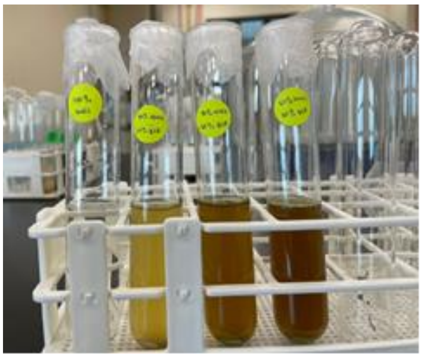


Fig. 3 Immersion test of mild steel with different concentration of NaCl and BLE

3. Results and Discussion

3.1 Chemical properties (functional groups) of bamboo leaves extract using Fourier Transformation Infrared (FTIR) analysis.

The superimpose of FTIR analysis of bamboo leaf extract (BLE) as shown in Fig. 4 revealed several functional groups. FTIR peak at 3349.98 cm represent hydroxyl (O-H) groups, showing strong hydrogen bonding interactions. Peaks around 2900 cm^{-1} suggested the presence of alkanes, while those around 1600 cm^{-1} and 1500 cm^{-1} indicated C=C bending originated form. The 1400 cm^{-1} peak likely corresponds to C-H bending of alkanes, and the peaks between 1200-1000 cm^{-1} suggested C-O stretching, indicating phenols. These functional groups, particularly hydroxyl groups likely contribute to the extract's effectiveness as a corrosion inhibitor for mild steel. The OH group is important because it forms strong bonds that help the bamboo leaf extract stick to the metal surface, protecting it from corrosion. While other groups like C=C and C-H also help, the OH group is key because it creates a strong protective layer on the metal.

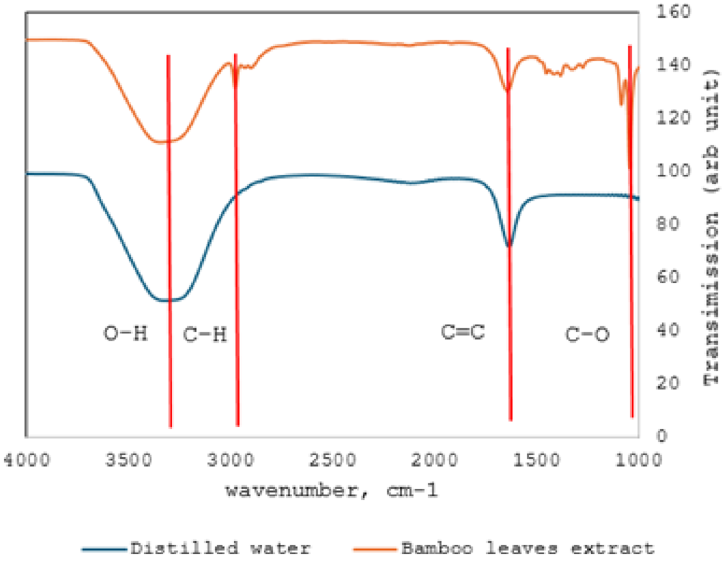


Fig. 4 FTIR analysis from bamboo leaves extract (BLE) extract

The functional group of the bamboo leaves extract was determined using Fourier Transform Infrared (FTIR) spectroscopy, mainly consists of functional groups and chemical bonds such as alkynes and saturated aromatic rings. The FTIR spectra showed significant shifts after diluting the bamboo leaf powder with ethanol and distilled water, indicating changes in the chemical structure.

3.2 Elemental composition and morphology analysis of mild steel for pre and post immersion in BLE inhibitor using Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM-EDX).

Fig. 5 show the SEM-EDX analysis of raw mild steel reveals its surface morphology structure. The SEM provides high-resolution images of the mild steel's microstructure, showing grain pattern and surface roughness before the immersion of BLE. It shows smooth and flat surface without any damage and corrosion.

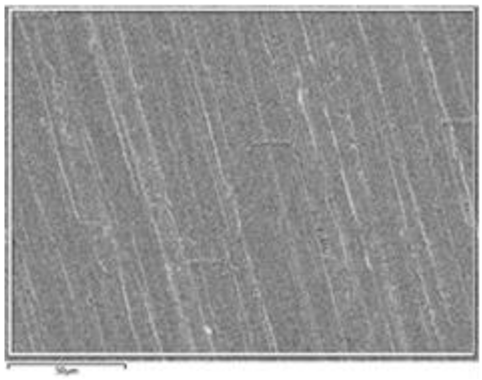
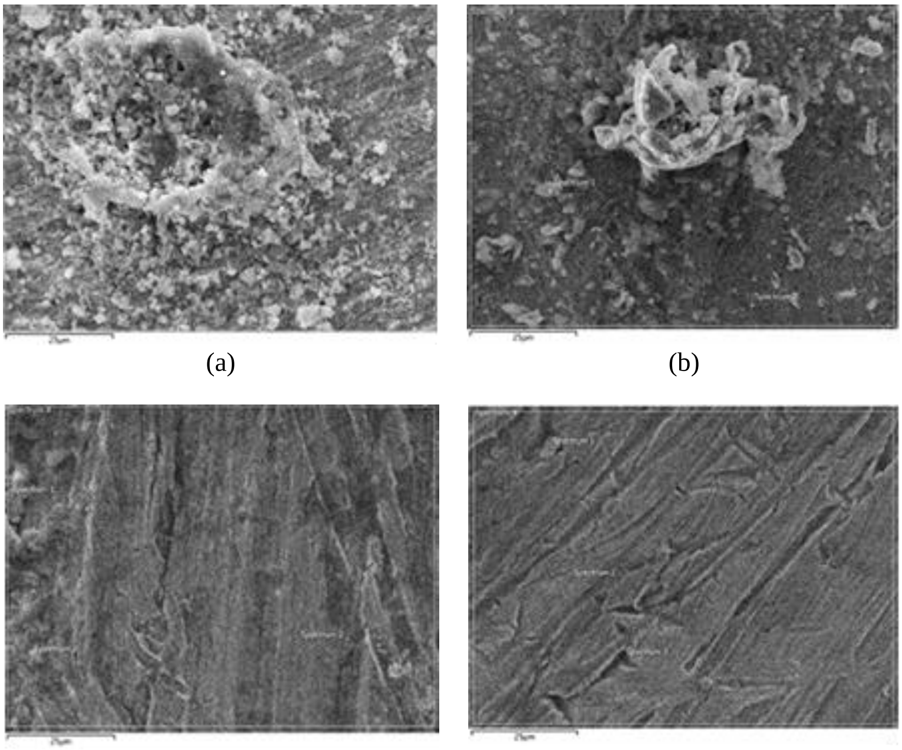


Fig. 5 Raw sample of mild steel

Fig. 6(a) shows the sample in 100% NaCl, exhibiting a thick, volcanic-like structure with a rough and uneven surface and crystalline surface due to the present of sodium while Fig. 6(b) displays the sample in 90% NaCl and 10% BLE, showing fewer and smaller crystals for a more refined texture. Next, in Fig. 6(c), the sample in 70% NaCl and 30% BLE has a smoother, more even surface with fewer crystals and Fig. 6(d) shows the sample in a

50% NaCl and 50% BLE solution, with a flat, smooth surface and minimal crystalline structures, making it the most consistent surface sample among other samples. From the morphology it shows that the d is the best results. It is because of not much surface degradation occurred for Fig. 6(d) and may suggest that this surface could coated very well with inhibitor layer.



(a) (b) (c) (d)

Fig. 6 (a) 100% NaCl immersion, (b) 90% NaCl with 10% BLE extract immersion, (c) 70% NaCl with 30% BLE extract immersion and (d) 50% NaCl with 50% BLE extract immersion

Table 1 support the finding by the elemental composition of Fe, C and O as tabulated in Table 1. From comparison between raw sample and all sample composition, it is clear seen that not much Fe composition reduce for the mixture of 50% NaCl an 50% BLE extract. The Fe composition is slightly reduced from 88.27% to 78.93% and this suggest that not much Fe is being oxidised in this condition. This is also supported by less amount of oxygen for this mixture condition compared to other mixture ratio.

Table 1 Elemental composition from EDX of raw sample and immersed mild steel

Samples	Elements (%)			
	Fe	C	O	Total
Raw mild steel sample	88.27	4.42	7.31	100
100 % NaCl	20.58	19.38	60.04	100
90% NaCl 10% Extract	55.74	9.06	35.20	100
70% NaCl 30% Extract	70.87	11.07	18.06	100
50% NaCl 50% Extract	78.93	5.17	15.90	100

3.3 Corrosion rate analysis for without non inhibitor and inhibitor mild steel surface using Electrochemical Impedance Spectroscopy (EIS).

EIS data shows that as the concentration of BLE increases, the corrosion potential shifts positively, and the current densities for both the cathodic and anodic reactions decrease as shown in Fig. 7. This indicates that BLE acts as an effective corrosion inhibitor for mild steel in NaCl solutions, with higher concentrations providing better corrosion protection.

Tafel plot in the Fig. 7 shows the electrochemical corrosion behaviour of mild steel in different NaCl solutions with varying concentrations of Bamboo Leaf Extract (BLE) as a corrosion inhibitor. The black curve represents the corrosion behaviour in a 100% NaCl solution without any inhibitor. The cathodic part exhibits typical Tafel behaviour, indicating the reduction of hydrogen ions and oxygen, while the anodic part indicates Tafel behaviour for the oxidation of mild steel. The corrosion potential for 100% NaCl is the most positive among all the samples, signifying the highest corrosion rate in the absence of BLE.

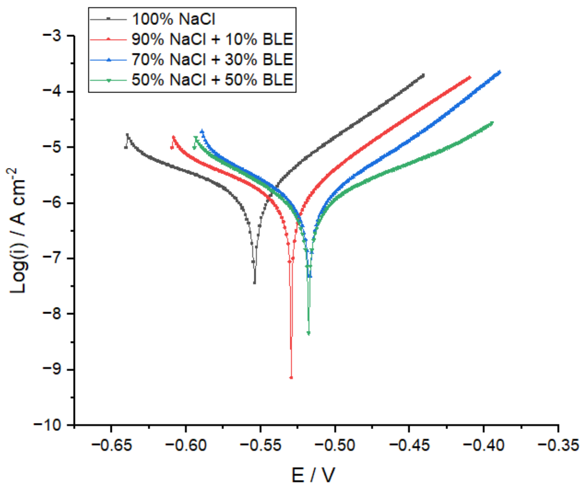


Fig. 7 A superimposed plot of Tafel plot for all different concentrations of NaCl and BLE

The Nyquist plot shows in Fig. 8 indicates that the addition of bamboo leaves extract (BLE) to the NaCl solution improves the corrosion resistance of mild steel. The corrosion inhibition efficiency increases with the concentration of BLE, as evidenced by the larger semicircles in the resistance plot. The 50% NaCl + 50% BLE mixture shows the highest resistance, suggesting the best protection against corrosion. This suggests that BLE is an effective corrosion inhibitor for mild steel in NaCl environments.

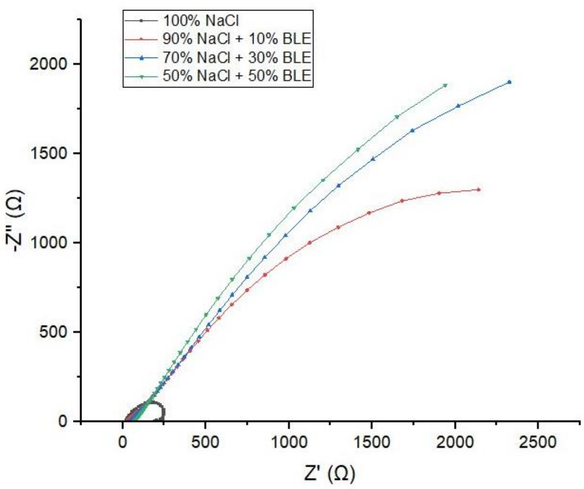


Fig. 8 Nyquist plot comparison for all different concentrations of NaCl and BLE

From both Tafel and Nyquist plot, it can suggest that highest concentration of BLE (50%) exhibited the most substantial increase in charge transfer resistance, correlating with the lowest corrosion rate observed in the Tafel plots. These results, alongside the data from FTIR and SEM-EDX, collectively demonstrate that BLE is highly effective in reducing the electrochemical activity responsible for the corrosion of mild steel in NaCl solutions.

4. Conclusion

This study show that bamboo leaves extract (BLE) can reduce the rate of corrosion in mild steel after being immersed in sodium chloride (NaCl). Fourier Transform Infrared (FTIR) analysis successfully identifies the functional groups of hydroxyl compound, alkanes and phenols in BLE, providing insights into its corrosion inhibition mechanisms. Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM-EDX) reveals significant changes in the surface morphology and elemental composition of mild steel during pre- and post-immersion testing. These changes show that when the ratio of BLE increase, the corrosion occur on the mild steel surface mild steel against sodium chloride (NaCl) will decrease. Electrochemical Impedance Spectroscopy (EIS) quantifies corrosion rates by analysing the Tafel and Nyquist plot that show the corrosion potential for 50% NaCl + 50% BLE solution as the most positive among others and the increasing of resistance from the mentioned solution respectively. The results indicate that a concentration of 50% NaCl with 50% BLE shows the best ratio among other ration in order to prevent corrosion of mild steel samples.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of results, draft manuscript preparation:*** *Nur Farzana Edyanto, Zaidi Embong, Khawarizmi Jefry, Maisarah Abd Rahim and Mohamad Sidiq Mohd Basir. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Sajadi, G. S., Naghizade, R., Zeidabadinejad, L., Golshani, Z., Amiri, M., & Hosseini, S. M. A. (2022). Experimental and theoretical investigation of mild steel corrosion control in acidic solution by Ranunculus arvensis and Glycine max extracts as novel green inhibitors. Heliyon, 8(10), e10983.

[2] Chuka, C. E., Odio, B. O., Chukwuneke, J. L., & Sinebe, J. E. (2014). Investigation of the effect of corrosion on mild steel in five different environments. International Journal of Scientific and Technology Research, 3(7), 306–310.

[3] Ribeiro, D. V., & Abrantes, J. C. C. (2016). Application of electrochemical impedance spectroscopy (EIS) to monitor the corrosion of reinforced concrete: A new approach. Construction and Building Materials, 111, 98–104.

[4] Chigondo, M., & Chigondo, F. (2016). Recent Natural Corrosion Inhibitors for Mild Steel: An Overview. Journal of Chemistry, 2016, 1–7.

[5] Verma, C., Ebenso, E. E., Quraishi, M. A., & Hussain, C. M. (2021). Recent developments in sustainable corrosion inhibitors: design, performance and industrial scale applications. Materials Advances, 2(12), 3806–3850.

[6] He, S., Xue, S., Xu, H., Li, B., & Li, J. (2013). Hairy bamboo leaf extract as an eco-friendly corrosion inhibitor for L245N steel in CO 2 -saturated oilfield produced water. Corrosion Reviews, 41(5), 575–591.

[7] Li, X., Deng, S., & Fu, H. (2014). Inhibition of the corrosion of steel in HCl, H2SO4 solutions by bamboo leaf extract. Corrosion Science, 62, 163–175.

[8] Odoroaba, V., Akcakayiran, D., Grigoriev, D. O., & Shchukin, D. G. (2014). Characterization of micro- and nanocapsules for self-healing anti-corrosion coatings by high-resolution SEM with coupled transmission mode and EDX. The Analyst, 139(8), 2004.

[9] Van Der Heijden, O., Park, S., Vos, R. E., Eggebeen, J. J. J., & Koper, M. T. M. (2024). Tafel slope plot as a tool to analyze electrocatalytic reactions. ACS Energy Letters, 9(4), 1871–1879.

[10] Laschuk, N. O., Easton, E. B., & Zenkina, O. V. (2021). Reducing the resistance for the use of electrochemical impedance spectroscopy analysis in materials chemistry. RSC Advances, 11(45), 27925–27936.