Journal listed in Halu Oleo University Journal System

International Journal of Acta Material

Int. J. Act. Mat.

homepage: https://ijacmat.uho.ac.id/index.php/journal

Research Article

Extraction of Tannin Compounds from *Samanea saman* (Jacq.) Merr Leaves and Their Application as Corrosion Inhibitor in ST 37 Steel

Syahruddin Kasim[a*], Siti Fauziah[a], Ratni Ananda[a], I Wayan Sutapa[b]

[a] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Hasanuddin University, Jalan. Perintis Kemerdekaan No.KM.10, Makassar, South Sulawesi, 90245, Indonesia*

[b] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kampus Hijau Bumi Tridharma, Anduonohu, Kendari, Sulawesi Tenggara 93232, Indonesia*

[*]*Corresponding Author: kasimsyahruddin1@gmail.com*

Article info

Received: June 2004
Received in revised: June 2004
Accepted: August 2024
Available online: August 2024

Abstract

Research has been conducted on extracting tannin compounds from *Samanea saman* (Jacq) Merr leaves and their potential application as corrosion inhibitors for ST 37 steel. The purpose of this study was to evaluate the impact of adding *Samanea saman* (Jacq) Merr leaf extract on the corrosion rate and inhibition efficiency of ST 37 steel when exposed to 25% acetic acid. The immersion process was carried out with different concentrations: 0%, 5%, 10%, 20%, and 30%, and with immersion time intervals of 2, 4, 6, and 8 days. The concentration and optimum immersion time results were then further tested at temperatures of 20ºC, 30ºC, and 40ºC. The test results indicate that corrosion occurs uniformly on the surface of the steel. The corrosion rate was determined using the weight loss method, and it was observed that the weight reduction of the steel without inhibitor was higher compared to that of the steel treated with *Samanea saman* (Jacq) Merr leaf extract inhibitor. Based on the study findings, the highest inhibition efficiency was achieved with a concentration of 20% and an immersion time of 6 days, resulting in an efficiency of 87.3464% and a corrosion rate of 1.9143 mpy. Regarding temperature variations, the highest inhibition efficiency was observed at 20ºC, with an efficiency of 66.6908% and a corrosion rate of 2.8435 mpy.

Keywords: Corrosion rate, inhibitors, inhibition efficiency, tannins, Samanea saman (Jacq) Merr Leaf Extract.

INTRODUCTION

Indonesia is a country that has experienced technological development and economic growth over the years. This development has led to an increased usage of various metals such as steel, iron, aluminum, and more (Revie & Uhlig, 2008; Trethewey & Chamberlain, 1992). One commonly used material is low carbon steel, which is preferred due to its ease of availability and fabrication (Aprilliani, Suka, & Suprihatin, 2017). Low carbon steel is an alloy consisting of 1.7% carbon (C), 1.65% manganese (Mn), 0.6% silicon (Si), 0.6% copper (Cu), 0.05% sulfur (S), and 0.04% phosphorus (P) (Kosasih, Priadi, & Suliyanti, 2023). Carbon steel is categorized into three types based on carbon content: low carbon steel, medium carbon steel, and high carbon steel (Jin et al., 2023). In construction, low carbon steel, such as ST 37 steel, is more commonly used than medium and high carbon steel. However, ST 37 steel has a weakness in terms of corrosion resistance, especially when exposed to corrosive environments (Bidi, Azadi, & Rassouli, 2021; Boudalia et al., 2019).

Corrosion is the process of metal material degradation due to chemical reactions with the environment. The environments that can cause corrosion include those with acids, salts, and aggressive ions such as Cl^- (Revie & Uhlig, 2008; Trethewey & Chamberlain, 1992).

DOI: 10.30598//ijcr.

Corrosion incidents cannot be prevented or removed, but they can be inhibited through coating, cathodic protection, anodic protection, and the use of inhibitors (Desiasni, Mardiana, & Hidayat, 2021; Vorobyova, Sikorsky, Skiba, & Vasyliev, 2023).

The use of corrosion inhibitors is an effective method to slow down the rate of corrosion. Inhibitors work by absorbing ions or molecules onto the metal surface. The performance of inhibitors is affected by factors such as pH, temperature, and concentration (Boudalia et al., 2019; Desiasni et al., 2021). Inhibitors can be divided into two types based on their source: inorganic and organic inhibitors.

Inorganic inhibitors typically involve the use of synthetic chemicals such as nitrites, chromates, phosphates, urea, imidazoline, and amine compounds. These chemicals are dangerous, relatively expensive, and not environmentally friendly. On the other hand, organic inhibitors are derived from natural ingredients containing tannins, alkaloids, flavonoids, and amino acids found in plants. Another characteristic of natural product extracts used as corrosion inhibitors is that they contain atoms such as N, O, P, S, which have a lone pair of electrons. These elements can act as ligands and form complex compounds with metals, thereby inhibiting the corrosion process. The advantages of using organic inhibitors are that they are easily obtainable, inexpensive, and environmentally friendly (Desiasni et al., 2021; Setiawan & Nasrulloh, 2020). The *Samanea saman*. (Jacq.) Merr tree is one plant that has the potential to be used as an organic inhibitor.

The *Samanea saman*. (Jacq.) Merr tree is a protective plant that provides shade and has many health benefits. The seeds of the *Samanea saman*. (Jacq.) Merr tree contain organic compounds such as lignin, calcium, phosphorus, carbohydrates, fats, and proteins (Sitanggang, Alexander, & Budijanto, 2020). The leaves of the *Samanea saman*. (Jacq.) Merr tree contain chemistry content such as flavonoids, saponins, steroids, alkaloids, cardiac glycosides, and tannins (Boudalia et al., 2019; Desiasni et al., 2021).

Tannins are complex organic substances that consist of phenolic compounds and have a molecular weight of 500-3000 g/mol. Tannins contain a lot of hydroxy groups (-OH), which are expected to have potential as corrosion inhibitors on metals. When Fe^{3+} ions react with OH^-, they form a complex compound called Fe (III)-tannins or tanat. Tanat attaches to the surface of iron and inhibits corrosion attack on the metal (Boudalia et al., 2019; Hussain, Verma, Aslam, Aslam, & Zehra, 2023; Li, Li, Zhang, & Zhou, 2019).

MATERIALS AND METHODS

The materials utilized in the current study include *Samanea saman* (Jacq.) Merr leaves, ST 37 steel, 400-grade sandpaper, seawater, a 25% CH_3COOH solution (Merck), 96% ethanol (Merck), 1% FeCl (Merck), gelatin, distilled water, acetone (Merck), a stick, godam thread, aluminum foil (Klin Pak), epoxy resin (Neckstone), hardener (Neckston), and Whatman filter paper number 42.

Production of the *Samanea saman* (Jacq) Merr. *Leaf Extract*

The *Samanea saman* (Jacq.) Merr. leaves are first washed to remove impurities and then dried in an open space for approximately 21 days. Once dried, the leaves are ground into a powder. A total of 300 g of *Samanea saman* (Jacq) Merr. leaf powder is then soaked in 96% ethanol in a closed container until fully submerged. The immersion is done at room temperature for 5 days, with 24 hours per day. The extract is filtered using strain paper to obtain the fiber. The solvent in the fiber is evaporated using a rotary evaporator. The extract is then tested for phytochemicals, analyzed by FTIR, and applied to steel as an inhibitor.

Preparation of carbon steel ST 37

The St 37 steel plate is cut into two sizes, measuring (1.5×1.5×0.3) cm³ and (1.0×1.0×0.3) cm³. The plates are then cleaned and sanded with 400-grade sandpaper. The steel plates with smooth surfaces are rinsed with distilled water and dipped in acetone, then dried. After drying, the steel plates are weighed to determine their initial mass.

Preparation of Inhibitor solutions

Amount of *Samanea saman* (Jacq.) Merr. leaf extract (0, 2.5, 5, 10, and 15 mL) then pipetted into five different 50 mL volumetric flasks, and dilute them with distilled water. Next, the inhibitor solutions for each concentration (5%, 10%, 20%, and 30%) are mixed with 3 mL of epoxy resin and 3 mL of hardener.

Immersion test of ST 37 steel in corrosive media

Cleaned and weighed St 37 steel plates are coated with the inhibitor solution mixed with epoxy resin and hardener, with concentrations varying from 5%, 10%, 20%, and 30%. Steel specimens for the 0% concentration are only coated with epoxy resin and hardener to serve as a control. The steel plates are then placed in a container filled with seawater, suspending them halfway in the seawater. The plates are left to soak for 2, 4, 6, and 8 days. After the immersion period, the corroded steel plates are washed with distilled water, dried, and re-weighed. The weight loss and inhibition efficiency of the inhibitors are calculated. This procedure is repeated by adding 25% acetic acid to the seawater. The steel plates are further characterized using the SEM-EDX instrument to determine the optimal concentration and immersion time. The obtained optimal concentration and immersion time are then used for testing at temperature variations of 20ºC, 30ºC, and 40ºC. This procedure is repeated on steel without inhibitors.

RESULTS AND DISCUSSION

Phytochemical compound tannins test on *Samanea saman* (Jacq) Merr. leaf ethanol extract

The process of obtaining the *Samanea saman* (Jacq) Merr. leaf ethanol extract involves dissolving the sample powder in 96% ethanol solvent, followed by maceration for 5 × 24 hours. The filtrate obtained from the maceration process is then filtered and concentrated through evaporation to obtain a concentrated extract of *Samanea saman*. (Jacq.) Merr leaves. This extract is then tested for the presence of tannin phytochemicals using 1% $FeCl_3$ and 2% gelatin. The results of this test can be found in Table 1.

Table 1. Phytochemicals compound tannins test results on leaf *Samanea saman*. (Jacq.) Merr

No	Reactor	Results	Tannin
1	$FeCl_3$ 1%	Green tanned	+
2	Gelatin 2%	Precipitate White	+

Corrosion rate calculation results

The corrosion rate calculation results for ST 37 steel, both with and without the addition of inhibitors, are shown in Figure 1. Based on Figure 1, it is evident that the highest corrosion rate occurs in steel without the addition of inhibitors, reaching 17.0187 mpy on the 8th day of immersion (purple diagram). The lowest corrosion rate of 9.6215 mpy is observed on the 2nd day of immersion (blue diagram). This indicates that the longer the immersion time, the higher the corrosion rate.

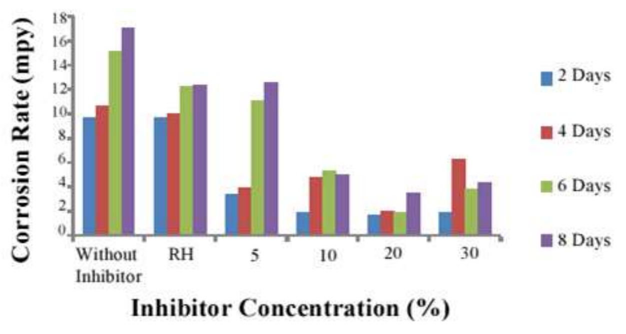

Figure 1. Graph the relationship between corrosion rate and inhibitor concentration and time of immersion in seawater media.

The corrosion rates for concentrations of 5%, 10%, 20%, and 30% also increase with the duration of immersion. However, the increase is not as significant as the corrosion rate without inhibitors. The highest corrosion rate for steel with the addition of inhibitors is obtained at a 5% concentration with an 8-day immersion time, measuring 12.5077 mpy. This suggests that a small amount of inhibitors is added and is quickly adsorbed onto the inner steel surface. Consequently, the relatively high corrosion rate is observed when a 5% concentration is used.

The lowest corrosion rate is achieved at a 20% concentration with a 6-day immersion time, measuring 1.9143 mpy. This is due to the formation of a passive layer on the steel surface, effectively preventing aggressive ions such as Cl- from attacking the metal. However, the corrosion rate increases again after 6 days of immersion as the inhibitor reaches its saturation point and the corrosion rate tends to rise. Increasing the inhibitor concentration can lower the corrosion rate. In this context, the *Samanea saman* (Jacq.) Merr. leaf inhibitor acts as an anodic inhibitor by suppressing the oxidation reaction of steel, thereby inhibiting electron transfer (Revie & Uhlig, 2008; Trethewey & Chamberlain, 1992).

This causes the corrosion rate to decrease. However, when an inhibitor with a concentration of 30% is added, it can be observed that the corrosion rate obtained is greater than that of a 20% concentration. This indicates that when the inhibitor reaches optimum concentration, its effectiveness decreases. The purpose of adding relative humidity (RH) in this study was to bond the inhibitor to the steel surface, as the performance of the inhibitor can be affected by the adhesion between the inhibitor and the steel surface (Sitanggang et al., 2020). It has been stated that the stronger the adhesive power of the inhibitor to the material, the stronger the layer formed by the inhibitor in inhibiting the corrosion rate.

In addition to that, the addition of RH is also intended for comparison purposes, comparing steel without the addition of RH and with the addition of inhibitors. The corrosion rate value obtained for the steel that is only added with RH is 12.2982 mpy. This corrosion rate value is lower when compared to the corrosion rate value without inhibitors. This indicates that RH closes the pores of steel, preventing aggressive ions from directly attacking the metal, although it is not optimal. Based on the research results, the optimum concentration was obtained at 20% addition with 6 days of soaking, which will be used for temperature variations.

Results of variation of corrosion rate with concentration and immersion time in 25% acetic acid media

The results of calculating the corrosion rate of ST 37 steel can be seen in Figure 2, both without inhibitor addition and with inhibitor addition. Based on Figure 2, the corrosion rate values obtained after 8 days of immersion time are as follows: 118.5138 mpy without inhibitors, 98.0764 mpy with 5% addition of inhibitors, 66.6979 mpy with 10% addition of inhibitor, 45.1565 mpy with 20% addition of inhibitors, 76.0617 mpy with 30% addition of inhibitors, and 73.5209 mpy for the coated sample at *Samanea saman* (Jacq.) Merr. When compared to the corrosion rate values in seawater media, there is a significant difference in the numbers. This indicates that the corrosive media has an effect on the corrosion rate of steel.

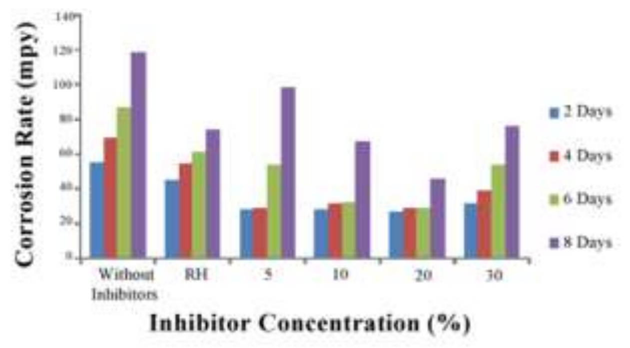

Figure 2. Graph of corrosion rate variation in relation to inhibitor concentration and time of immersion in sea water

Acetic acid, as a medium, affects the corrosion rate due to the rapid process of O_2 diffusion to the steel surface, which results in an enhanced concentration of H^+ and electron (e^-), as shown in the following Equation 1.

$$Fe \longrightarrow Fe^{3+} + 3^{e-} \qquad (1)$$

The H^+ ion in the CH_3COOH solution will be exchanged with the OH^- ion. This exchange increases the quantity of Fe^{3+} ions released to balance the excessive positive charge. Consequently, the cathodic limit increases, resulting in a higher rate of Fe dissolution. The acetate ion, which forms from the dissociation of acetate, can then combine with iron to form iron acetate, which is highly soluble in water. This process can be represented by the following Equation 2.

$$3\ CH_3COO^- + Fe^{3+} \longrightarrow Fe\ (CH_3COO)_3 \qquad (2)$$

The release of H^+ ions contributes to the diffusion of ions onto the steel surface, thereby increasing the rate of corrosion. However, the addition of inhibitors can decrease the corrosion rate by impeding the metal's ability to undergo reduction (Fahrizal & Sutjahjo, 2019).

Calculation results of corrosion rate with variation of immersion temperature in sea water media

The results of the corrosion rate calculation, both with and without the addition of the inhibitor, can be observed in Figure 3. Based on Figure 3, the corrosion rate increases with higher immersion temperatures. The lowest corrosion rate value was observed at an immersion temperature of 20ºC, with a value of 8.5367 mpy, while the highest corrosion rate value was observed at 40ºC, with a value of 43.4460 mpy. When inhibitors were added, the corrosion rate values at immersion temperatures of 20ºC, 30ºC, and 40ºC were reduced to 2.8435 mpy, 6.9359 mpy, and 29.8271 mpy, respectively. Similarly, for RH, the corrosion rate values obtained were 7.4088 mpy, 16.9202 mpy, and 41.5026 mpy, respectively.

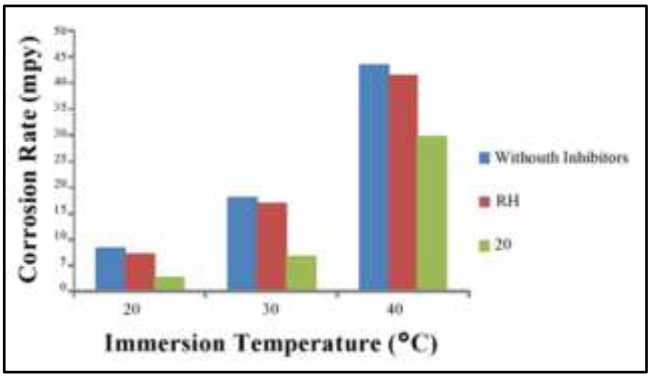

Figure 3. Graph illustrating the corrosion rate in relation to immersion temperature

The research results indicate that temperature has a significant impact on the corrosion rate. An increase in temperature leads to a higher corrosion rate (Boudalia et al., 2019). This can be attributed to the fact that higher temperatures result in an increase in the kinetic energy of the reacting particles, surpassing the activation energy and causing an increase in the corrosion rate (Kayadoe, Fadli, Hasim, & Tomasoa, 2015). According to Revie & Uhlig, (2008), the increased corrosion rate at higher temperatures is due to the enhanced oxygen diffusion process on the surface of steel.

Corrosion rate with variation of immersion temperature in 25% acetic acid medium

The calculation results of the corrosion rate of ST 37 steel with and without inhibitor addition can be seen in Figure 4. According to Khakeel (2018), an increase in temperature has a greater effect on the activation process of the reactants' diffusion rate. Immersion at higher temperatures accelerates the ionization of the acid solution and enhances the formation of pores on the metal surface. This condition facilitates the rapid diffusion of acids and oxygen onto the metal surface, leading to faster metal dissolution. As a result, the relative corrosion rate increases.

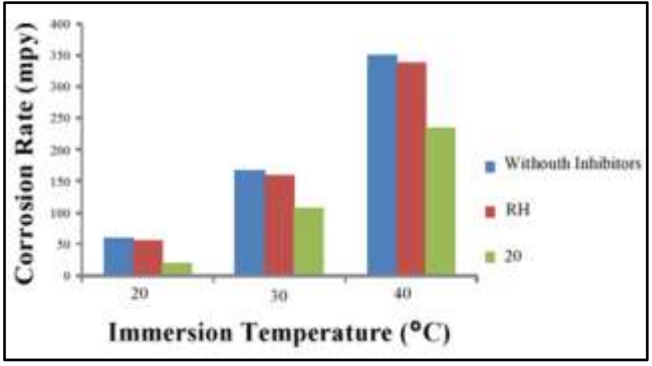

Figure 4. Corrosion rate versus temperature immersion graph

Concentration variation in inhibition efficiency and optimum immersion time

The effect of inhibitor concentration on inhibition efficiency value shows in Figure 5. Based on the conducted research, the highest efficiency is achieved at a concentration of 20%, with 87% immersion for a duration of 6 days. This is attributed to the formation of complex compounds between Fe and tannins, as well as an increase in the adsorption capacity of inhibitors on steel, resulting in complete coverage of the steel surface (Boudalia et al., 2019). However, the graph clearly demonstrates that the efficiency value decreases at a concentration of 30%, indicating that the absorption of the inhibitor has reached saturation point. The inhibition efficiency value is influenced by both inhibitor concentration and immersion time. A higher concentration of inhibitor and longer immersion time result in higher efficiency values. However, it is important to note that the ability of inhibitors to protect steel from corrosion diminishes over time, as the longer the immersion time, the more the inhibitor is attacked by the corrosive solution (Revie & Uhlig, 2008).

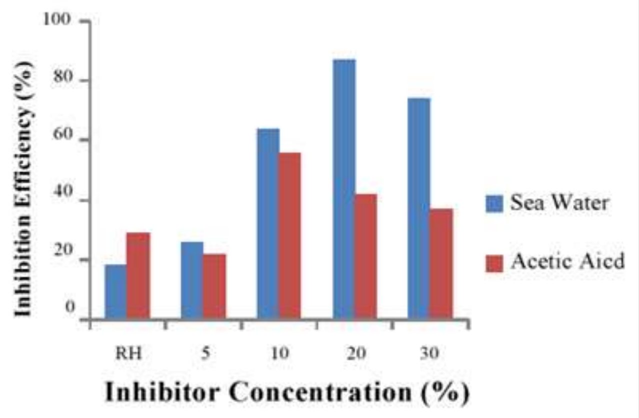

Figure 5. Inhibition efficiency graph

Inhibition efficiency of immersion temperature variation

The decrease in inhibition efficiency with increasing immersion temperature is depicted in Figure 6. The decline in inhibition efficiency indicates a decrease in the effectiveness of the *Samanea saman*. (Jacq.) Merr leaf extract inhibitor at elevated temperatures. Specifically, the inhibition efficiency values for a 20% concentration in seawater corrosive media at immersion temperatures of 20ºC, 30ºC, and 40ºC are 66.6908%, 61.4410%, and 31.3467% respectively.

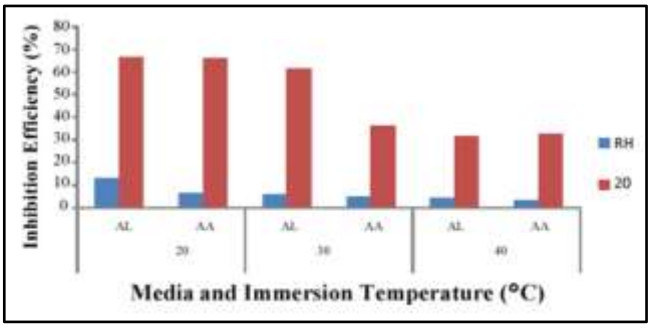

Figure 6. Graph of immersion temperature inhibition efficiency

The same phenomenon occurred in 25% sour acetate immersion, where the efficiency decreased as the temperature increased. The efficiency values obtained at different temperatures were as follows: 66.1399% at 20ºC, 36.0492% at 30ºC, and 32.7423% at 40ºC. This decline can be attributed to the presence of inhibitor molecules in the corrosive solution, which affect the metal surface. The inhibitors derived from *Samanea saman*. (Jacq.) Merr leaves are relatively large in size, resulting in slower diffusion at higher temperatures. Consequently, the metal surface becomes vulnerable to attack by aggressive ions present in the corrosive solution.

Macro analysis of steel surface

A macro analysis of the steel surface was conducted using the surface macro structure shown in Figure 7, which was obtained with a digital camera. This analysis aimed to compare the steel before and after immersion in seawater media and 25% acetic acid, both with and without the addition of inhibitors. The visuals of the steel surface before and after immersion in seawater and acetic acid without inhibitors can be observed in Figure 7.

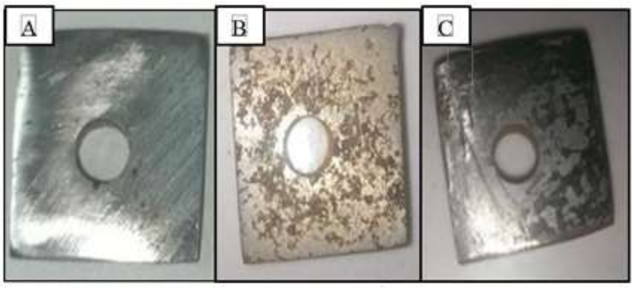

Figure 7. Pre- and Post-Immersion in various environments (a) pre-immersion: macro photo of ST 37 steel (b) post-immersion: macro photo of ST 37 steel in seawater(c) post-immersion: macro photo of ST 37 steel in 25% CH_3COOH solution

Figure 7 displays the morphological disparities between ST 37 steel prior to and following immersion in seawater and a 25% CH_3COOH solution. In Figure 7A, the steel surface remains flat, clean, and devoid of pores or holes due to the absence of corrosive substances and environmental factors such as air. Conversely, Figure 7B and 7C depict the formation of rust, resulting in structural damage to the steel and the emergence of pores. These effects arise from the oxidation of the steel in seawater and the 25% CH_3COOH solution, leading to rapid rusting. Corrosion attacks on the steel, manifesting as an increase in immersion time, are evident through macro analysis (Desiasni et al., 2021; Revie & Uhlig, 2008).

Figure 8 depicts the morphology of ST 37 steel following immersion with the addition of inhibitors. The presence of a passive layer of inhibitors on the surface of the specimen prevents the appearance of corrosion on the steel surface by effectively blocking aggressive ions from directly attacking the steel.

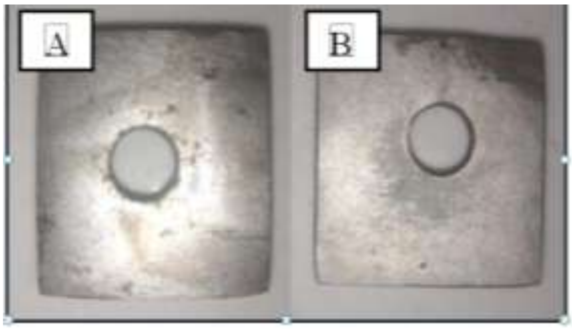

Figure 8. Surface morphology of steel after 6 days of immersion with 20% inhibitor (A) in seawater (B) and 25% CH_3COOH

FTIR analysis of Samanea saman. (Jacq.) Merr leaf extract

The spectrum of *Samanea saman*. (Jacq.) Merr leaf extract shown in Figure 9 demonstrates absorption in the 3412.08 cm^{-1} region, with strong intensity indicating the presence of -O-H groups bonded to aliphatic and aromatic components resulting from intramolecular hydrogen bond vibrations. The FTIR results of the *Samanea saman*. (Jacq.) Merr leaf extract also reveal functional groups such as alkane group (C-H) at the absorption peak of 2924.09 cm^{-1}, which is strengthened by the presence of absorption at 1456.26 cm^{-1}, corresponding to the methylene group (-CH$_2$). Additionally, a sharp absorption band with moderate intensity at 1712.79 cm^{-1} suggests the presence of a -C=O ester group, further supported by the presence of a wide absorption band with moderate intensity at 1068.56 cm^{-1}, indicating the presence of C-O-C ether groups. The presence of ester groups strengthens the suspicion of hydrolyzed tannins since they are formed by ester bonds between the hydroxy groups in glucose and the carboxyl groups of phenolic acids (Manito, 1981). The suspicion of tannin compounds is further reinforced by the strong intensity and wide absorption observed at 1625.99 cm^{-1} and 1514.12 cm^{-1}, indicating the presence of aromatic C=C bonds.

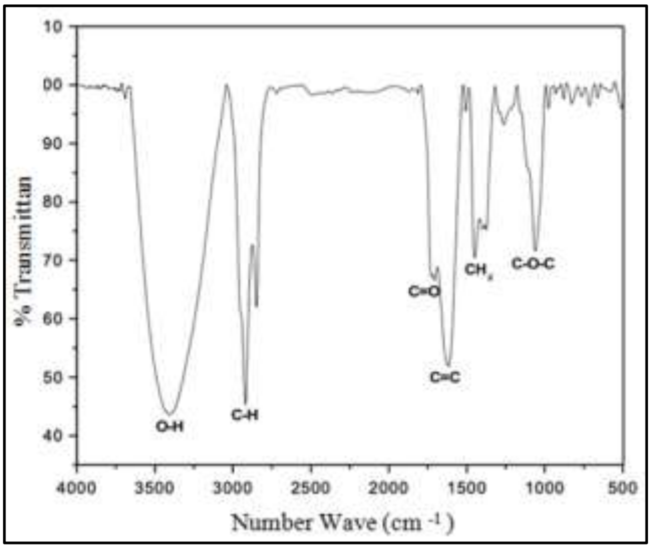

Figure 9. Spectrum of *Samanea saman*. (Jacq.) Merr leaf extract

The presence of OH groups, ester -C=O, -C=C, -CH, and -C-O-C- groups confirms the existence of tannins in the *Samanea saman*. (Jacq.) Merr leaf extract. This finding aligns with previous research conducted by (Desiasni et al., 2021), where the FTIR spectrum analysis revealed the presence of functional groups such as O-H, aliphatic -C-H, ester -C=O, aromatic -C=C, and ether -C-O-C-, indicating the presence of positive tannin compounds in the isolate.

SEM-EDX characterization

SEM-EDX analysis was conducted on steel specimens subjected to varying immersion times (specifically, 144 hours) and different concentrations of inhibitor (20%) within a seawater environment. The objective was to compare the impact of inhibitor addition on the microstructure of steel, particularly in terms of corrosion rates. The samples analyzed included steel with the lowest corrosion rate, untreated steel, and steel without inhibitor, each serving as points of reference for the observed differences.

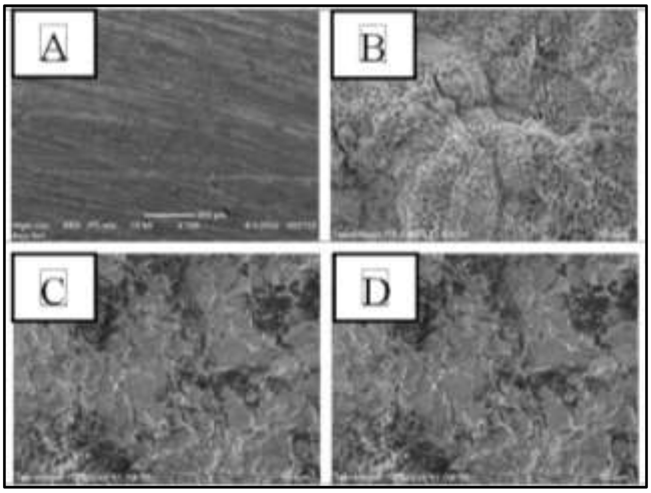

Figure 10. SEM test results A) Steel without treatment, (B) Steel without inhibitors, (C) Steel with 1000x magnification optimum inhibitor (D) Steel with 500x magnification inhibitors

Figure 10 illustrates the variations in steel morphology depicted in the three images. In Figure 10 (A), the untreated steel or steel not immersed in a corrosive media exhibits white smooth lines, which result from sanding during the steel preparation process. Additionally, no corrosion cells have formed on the steel surface. Figure 10 (B) showcases the steel immersed in a corrosive media without inhibitors, revealing cracks and small holes distributed evenly across the steel surface due to the absence of corrosion protection. Figures 10 (C) and (D) display cracks and small holes, although they are limited in number and size. This can be attributed to the presence of an inhibitor layer safeguarding the steel. Overall, the observed corrosion type can be classified as either pitting corrosion or uniform corrosion. Based on the micro-photo results, it can be concluded that *Samanea saman*. (Jacq.) Merr leaf extract has the capability to mitigate the formation of corrosion, provided it is used at a specific concentration and duration of exposure.

SEM-EDX analysis is utilized to ascertain the elemental distribution in metal alloys. The findings of the SEM-EDX examination conducted on ST 37 steel, both in the absence and presence of inhibitors, in a seawater environment, are presented in Table 2.

Table 2. Results of elemental content analysis in the sample

Inhibitors	**Rate Element (%)**			
	C	**O**	**Fe**	**Si**
Without Inhibitors	2.39	30.05	67,10	0.47
With Inhibitors	2,41	2.05	95.00	0.54

Table 2 presents the SEM-EDX test results, illustrating the elemental composition of ST 37 steel with and without the addition of inhibitors. In both cases, the predominant element is iron (Fe), accounting for 67.10% in steel without inhibitors and 95.00% in steel with inhibitors. This is expected, considering that Fe is the primary constituent of steel. Moreover, the presence of oxygen (O) in both samples indicates the occurrence of oxidation, which leads to corrosion. However, the concentration of elemental O in steel with inhibitors (2.05%) is notably lower than in steel without inhibitors, suggesting that *Samanea saman*. (Jacq.) Merr leaf extract effectively reduces the corrosion rate of the steel. Additionally, the presence of carbon (C) and silicon (Si) elements in both samples indicates their role as alloying elements within the ST 37 steel sample.

CONCLUSION

Based on the findings of the conducted research, it can be concluded that the extract derived from *Samanea saman*. (Jacq.) Merr leaves possesses the ability to reduce the corrosion rate of ST 37 steel. In seawater, the extract exhibited the lowest corrosion rate recorded at 1.9143 mpy, resulting in an inhibition efficiency of 87.3464%. Similarly, in a 25% CH_3COOH solution, the extract demonstrated the lowest corrosion rate of 26.5293 mpy at a concentration of 20%, with an inhibition efficiency of 51.8326%. Corrosion can significantly alter the morphological structure of the ST 37 steel surface, leading to erosion and roughness due to pitting corrosion. Notably, the corrosion rate of the steel is influenced by variations in concentration, time, and immersion temperature.

REFERENCES

Aprilliani, N., Suka, E. G., & Suprihatin, S. (2017). Efektivitas ekstrak daun belimbing wuluh (averrhoa bilimbi l.) sebagai inhibitor pada baja ST37 dalam medium korosif NaCl 3%. *JURNAL Teori Dan Aplikasi Fisika*, *5*(2), 161–172.

Bidi, M. A., Azadi, M., & Rassouli, M. (2021). An enhancement on corrosion resistance of low carbon steel by a novel bio-inhibitor (leech extract) in the H_2SO_4 solution. *Surfaces and Interfaces*, *24*, 101159. https://doi.org/10.1016/j.surfin.2021.101159

Boudalia, M., Fernández-Domene, R. M., Tabyaoui, M., Bellaouchou, A., Guenbour, A., & García-Antón, J. (2019). Green approach to corrosion inhibition of stainless steel in phosphoric acid of Artemesia herba albamedium using plant extract. *Journal of Materials Research and Technology*, *8*(6), 5763–5773. https://doi.org/10.1016/j.jmrt.2019.09.045

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

Fahrizal, Y., & Sutjahjo, D. H. (2019). Pengendalian korosi pada baja rendah karbon (mild steel) dengan inhibitor ekstrak tanin dari daun sirsak pada media air laut dan udara. *Jurnal Pendidikan Teknik Mesin*, *19*(1), 9–26.

Hussain, C. M., Verma, C., Aslam, J., Aslam, R., & Zehra, S. (2023). 1-Basics of corrosion and its impact. In C. M. Hussain, C. Verma, J. Aslam, R. Aslam, & S. Zehra (Eds.), *Handbook of Corrosion Engineering* (pp. 3–30). Elsevier. https://doi.org/10.1016/B978-0-323-95185-2.00001-0

Jin, J.-C., Cho, S., Kim, K., Sim, H., Park, B. G., & Lee, Y. K. (2023). Microstructures and intergranular corrosion resistances of hot-rolled austenitic stainless steel clad plates. *Journal of Materials Research and Technology*, *26*, 1–13. https://doi.org/10.1016/j.jmrt.2023.07.192

Kayadoe, V., Fadli, M., Hasim, R., & Tomasoa, M. (2015). Ekstrak daun pandan (Pandanus amaryllifous roxb) sebagai inhibitor korosi baja ST-304 dalam larutan H_2SO_4. *Molekul*, *10*(2), 88–96. https://doi.org/10.20884/1.jm.2015.10.2.9

Kosasih, R., Priadi, D., & Suliyanti, M. M. (2023). Coating material development by pulsed laser deposition for JIS SKD61 steel insert pins used in aluminum casting industry. *International Journal of Technology*, *14*(4), 833. https://doi.org/10.14716/ijtech.v14i4.6046

Li, J., Li, B., Zhang, J., & Zhou, X. (2019). Tannin resins for wood preservatives: A review. *Research and Application of Materials Science*, *1*(1), 48–53. https://doi.org/10.33142/msra.v1i1.667

Revie, R. W., & Uhlig, H. H. (2008). *Corrosion and corrosion control: An introduction to corrosion science and engineering* (1st ed.). USA: Wiley. https://doi.org/10.1002/9780470277270

Setiawan, S., & Nasrulloh, Y. (2020). Sintesis green inhibitor ekstrak daun trembesi (Samanea saman (Jacq.) Merr) sebagai pereduksi laju korosi logam baja karbon. *Khazanah: Jurnal Mahasiswa*, *12*(1), 83–87. https://doi.org/10.20885/khazanah.vol12.iss1.art9

Sitanggang, A. B., Alexander, R., & Budijanto, S. (2020). The utilization of bilimbi (Averrhoa bilimbi) and lime (Citrus aurantifolia) juices as natural acid coagulants for tofu production. *Journal of Food Science and Technology*, *57*(12), 4660–4670. https://doi.org/10.1007/s13197-020-04503-5

Trethewey, K. R., & Chamberlain, J. (1992). *Corrosion: For students of science and engineering* (1. publ., 3. impr). Harlow: Longman Scientific & Technical. France.

Vorobyova, V., Sikorsky, O., Skiba, M., & Vasyliev, G. (2023). Quebracho tannin as corrosion inhibitor in neutral media and novel rust conversion agent for enhanced corrosion protection. *South African Journal of Chemical Engineering*, *44*, 68–80. https://doi.org/10.1016/j.sajce.2023.01.003