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Effect of jackfruit seed extract (Artocarpus heterophyllus) concentration on corrosion inhibition of galvanized steel in seawater

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Abstract

Corrosion is the gradual degradation of materials, particularly metals, caused by chemical or electrochemical reactions with their environment. Corrosion control using natural resources has gained attention, with plant extracts serving as effective inhibitors. Compounds such as flavonoids and tannins in these extracts form protective layers on metals surface, and reducing corrosion. Jackfruit seeds (Artocarpus heterophyllus) show great potential as corrosion inhibitors due to flavonoids and tannins, which help reduce electrochemical reactions on metal surfaces. The objective of this research is to evaluate the efficacy of jackfruit seed extract in curtailing corrosion rate and to identify the nature of corrosion that occurs in the presence of inhibitor concentrations of 0%, 2%, 4%, and 6%. Additionally, the study seeks to ascertain the impact of variations in immersion time, specifically, 10, 20, and 30 days on the corrosion rate. This research employed the maceration method to extract jackfruit seeds and used the weight loss method to determine the corrosion rate of the samples. A macro microscope was utilized to identify the type of corrosion occurring in galvanized steel pipes. The results showed that the highest corrosion rates were observed during immersion periods of 10, 20, and 30 days without the use of an inhibitor (0%), with corrosion rate values of 0.3826 µpy, 0.4243 µpy, and 0.4395 µpy, respectively. Conversely, the lowest corrosion rates were recorded with the use of a 6% inhibitor concentration during the same immersion periods, with values of 0.2386 µpy, 0.0735 µpy, and 0.0192 µpy, respectively. The study also revealed that the uniform corrosion on the surface of galvanized steel was reduced by the extract of jackfruit seeds. The highest inhibition efficiency was at 95.62% in 6% inhibitor concentration immersed at 30 days. This finding indicates that increased immersion time leads to higher inhibition efficiency.

Keywords:
Inhibitor, Corrosion Rate, Weight Loss, Microscope

1 Introduction

Corrosion is a natural reaction between metal and its environment, that reduces the quality and durability of metal over time. While it cannot be entirely prevented, using natural inhibitors offers an effective way to mitigate corrosion by forming protective layers on metal surfaces. This is particularly important in applications like pipelines, where metals are commonly used as base materials. A method for reducing metal corrosion involves the use of natural inhibitors, which function as corrosion inhibitors by forming a protective layer on the metal surface. [1,2].

Pipeline galvanized steel is widely used because it offers two protective properties. As a protective coating, galvanization provides a tough, metallurgically bonded zinc layer that fully covers the steel surface and shields it from corrosive environmental attacks. Additionally, the sacrificial anode effect of zinc protects the steel, minimizing damage or discontinuities. The performance of the galvanized coating has been proven in various environmental conditions. The corrosion resistance of the zinc layer is primarily determined by its thickness but also varies depending on the level of environmental corrosivity [3].

The corrosion resistance of a zinc layer is largely determined by its thickness, but environmental factors also play a significant role. Material degradation, such as corrosion, reduces metal quality and can be influenced by the concentration of the corrosive medium. In marine environments, chloride ions are a primary contributor to corrosion. Higher chloride ion concentrations accelerate the corrosion process, posing significant challenges to materials, particularly those exposed to seawater. Thus, understanding both the material properties, like zinc layer thickness, and environmental factors, such as chloride concentration, is crucial for improving corrosion resistance in harsh environments. [4].

One way to inhibit corrosion on metals is by protecting the metal surface with an inhibitor, preventing direct contact between the metal and the corrosive medium [6]. Inhibitors are chemical compounds that can be used to inhibit the corrosion reaction of steel with its environment. The use of organic inhibitors or natural materials can be more effective as corrosion inhibitors. In addition to being easily obtained, natural materials are also more economical and environmentally friendly. The inhibitor used in this study is derived from jackfruit seed extract [7].

Plant extracts have emerged as effective corrosion inhibitors due to their low cost, high biodegradability, abundant availability, renewable source material, ecological acceptability, and non-toxic properties [8]. Plant extracts contain natural compounds that can reduce the corrosion rate of metals, such as tannins, organic acids, amino acids, alkaloids, and pigment [9]. Tannin compounds on the steel surface inhibit the corrosion reaction of steel by forming complex compounds with corrosive ions that will attack the steel surface [9]. Almost all plants contain tannin compounds, such as vegetables and fruits. When tannins are formed in sufficient amounts in plants, they are typically found in the leaves, fruits, bark, and stems [10].

The use of tannins as an organic inhibitor is considered effective in helping to reduce the corrosion rate of metals [11]. Tannins adsorb onto the metal surface due to their polar functional groups, such as hydroxyl (-OH) and carboxyl (-COOH) groups. This adsorption creates a physical and chemical barrier, reducing direct contact between the metal and the corrosive environment. The hydroxyl and carboxyl groups in tannins can chelate iron ions (Fe^{2+} or Fe^{3+}) produced during the initial stages of corrosion. This reaction results in the formation of a stable Fe-tannate complex on the metal surface by reaction: Fe2+/Fe3+ +Tannins + Fe-tannate complex

The Fe-tannate complex forms an insoluble, adherent layer on the metal surface. This layer acts as a barrier that slows down the diffusion of oxygen, water, and corrosive ions, such as chlorides, to the metal surface. By blocking the active sites on the metal surface, the Fe-tannate layer reduces the anodic (metal dissolution) and cathodic (oxygen reduction) reactions that drive corrosion processes.

On the other hand, the use of natural inhibitors is expected to help preserve the environment because they are biodegradable and non-harmful to the environment. One plant that contains tannins is the jackfruit seed; however, not all parts of the plant are used as a source of tannins, only the seeds, as jackfruit seeds, are often discarded in many households and trash bins in Indonesia, thus often regarded as waste.

From this, the idea arose to turn the jackfruit seeds, initially considered waste, into something useful as a corrosion inhibitor for metals.

Inhibition efficiency is a measure that indicates how effective a method or material is in inhibiting or reducing the corrosion rate of a material. It is usually expressed as a percentage and describes the extent to which corrosion can be reduced compared to an unprotected condition [12].

Based on this, this study aims to utilize jackfruit seed extract as an organic inhibitor that can inhibit the corrosion rate on galvanized steel pipe material, using the weight loss method to analyze the reduction in corrosion rate that occurs on the steel pipe after the addition of the inhibitor from jackfruit seed extract.

2 Methods

The tools used in this research process are a blender, spatula, analytical balance, beaker, volumetric flask, caliper, metal cutting tool, sandpaper, tissue, aluminum foil, and bottles.

The materials used in this study are galvanized steel pipes, seawater solution, ethanol, aquades (distilled water), and jackfruit seeds.

2.1 Research variables

This research was conducted using inhibitor concentrations of 0%, 2%, 4%, and 6%. Additionally, immersion variations were executed for 10, 20, and 30 days. The analysis method entailed the calculation of the sample weight, the determination of the corrosion rate, and the observation of the surface morphology of the sample.

2.2 Research procedure

The research procedure is divided into two stages. The first stage is the preparation of jackfruit seed extract, followed by conducting the experimental procedure to observe the corrosion rate on the prepared steel.

2.3 Steel preparation

The sample preparation involves cutting the galvanized pipe into flat plates measuring 30 x 30 x 3 mm, with 4 samples for each concentration variation. The steel surface is cleaned using sandpaper with grit numbers 400, 600, and 800 to remove dirt and scratches resulting from the steel-cutting process. The steel is then dipped in acetone to clean any attached impurities. The steel is weighed first to obtain the initial weight of the steel before corrosion.

2.4 Process of Making Organic Inhibitor Solution

Dry 200 grams of jackfruit seeds at room temperature for 2 days to remove water from the jackfruit seeds. Puree the dried jackfruit seeds using a blender to facilitate and maximize the extraction process. Extract the jackfruit seeds using the maceration method. Put 90 grams of mashed jackfruit seeds into a container/bottle that has been filled with 96% ethanol and immersed for 2x24 hours. After soaking, then filter the maceration results using filter paper to get the filtrate. Evaporate the filtrate from the maceration using a hot plate at 60°C until the ethanol evaporates, leaving a thick extract. Prepare various concentrations of jackfruit seed extract inhibitors with variations of 0%, 2%, 4%, and 6%. Variation of jackfruit seed extract inhibitor volume can be seen in Table 1.

Table 1 Variation of jackfruit seed extract inhibitor volume

No.	Inhibitor solution volume (%)	Corrosive solution volume (ml)	Inhibitor solution volume (ml)
1	0	250	0
2	2	250	5
3	4	250	10
4	6	250	15

2.5 Calculation of corrosion rate and inhibition efficiency

To calculate the corrosion rate using the weight loss method, the research is conducted through the immersion of steel specimens in a prepared corrosive solution. The surface area of the steel pipe is measured, weighed, and recorded prior to immersion.

The specimens are then soaked in a corrosive solution medium containing an inhibitor solution, with the mass of the inhibitor and immersion time varied according to the experimental parameters. After the designated immersion period, the steel specimens are washed with acetone to remove any adhered corrosion products, rinsed with distilled water, and dried using tissue paper. Finally, the cleaned specimens are weighed again, and the weight change is recorded to determine the corrosion rate.

The specimens were initially weighed at the commencement of the study and subsequently at 10-day intervals over 30 days, using concentration levels of 0%, 2%, 4%, and 6%. After each weighing, the specimens were cleaned by rinsing in a 1000 mL solution of distilled water applied to the galvanized steel pipe. Following the immersion period, any debris or contaminants on the metal surface were removed by gentle scrubbing with a small brush, followed by wiping with tissue paper. The specimens were then reweighed to determine and record the weight loss.

A weight analysis is conducted based on the results of two weightings: the initial measurement performed before the corrosion test and the final measurement conducted after the test. This analysis evaluates changes in the specimen's weight to determine whether it has decreased, remained constant, or increased.

The corrosion rate is defined as the rate at which external particles are removed from the entire surface area of spring steel, as formulated in Eq. (1).

$$CR\ (mpy) = \frac{K \times W}{A \times t \times D} \tag{1}$$

When CR is the corrosion rate by mills per year, W is weight loss in grams, A surface area in cm2, D is the density of the material and K refers to the Constant value at 34,5x106.

Corrosion inhibition efficiency is assessed by calculating the difference in the corrosion reaction rates with and without the inhibitor as in Eq. (2).

$$EI = \frac{\text{Pcor} - \text{Pcorr}}{\text{Pcorr}} \times 100\% \tag{2}$$

When Pcor referred to the Weight loss of steel without inhibitor in grams and Pcorr referred to the Weight loss of steel with inhibitor.

3 Results and discussion

This study investigated the effect of a natural inhibitor derived from jackfruit seed extract on the corrosion rate of galvanized steel pipes immersed in seawater with a pH of 8.7. The research includes weight loss analysis of the steel to determine the difference in weight before and after corrosion. Corrosion rate analysis is conducted to calculate the annual corrosion rate of the material. Additionally, the inhibition efficiency of the jackfruit seed extract inhibitor is evaluated to assess its effectiveness in reducing the corrosion process on the metal.

3.1 Weight loss analysis

The corrosion rate can be determined using the weight loss method. This method calculates the corrosion rate by measuring the weight loss resulting from the corrosive impact on the metal. The duration of the study is used to quantify the extent of corrosion-related weight loss over time.

Comparison of weight loss during immersion over 10, 20, and 30 days, variates in the concentration of jackfruit seed extract inhibitor (Fig. 1). The data demonstrate that the addition of the inhibitor reduces the weight loss of the material when immersed in a corrosive seawater medium. It can be concluded from Fig. 1 that immersion with the inhibitor results in less mass loss compared to immersion without the inhibitor. This effect is attributed to the inhibitor's role in slowing the corrosion rate. Specifically, as the duration of immersion with the inhibitor increases, the weight loss in the sample decreases, whereas longer immersion without the inhibitor leads to greater weight loss in the galvanized steel sample. [13].

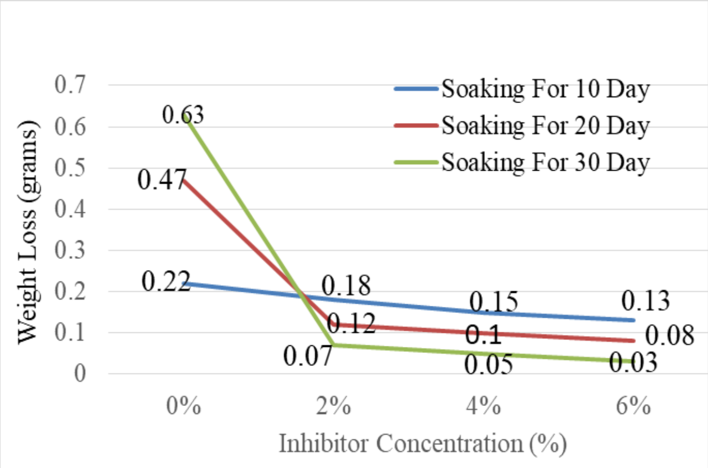

Fig. 1. Weight loss comparison during immersion for 10, 20, and 30 days with concentrations of 0%, 2%, 4%, and 6%

The compound most responsible for inhibiting the corrosion rate is the *Fe-tannate* compound, which forms a protective layer (passive film) on the metal surface. This layer effectively prevents direct contact between the metal and the seawater. [14].

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3.2 Corrosion rate analysis

The magnitude of the corrosion rate significantly influences the reactions involved in the corrosion process. The Corrosion Rate of the whole experiment is presented in Fig. 2.

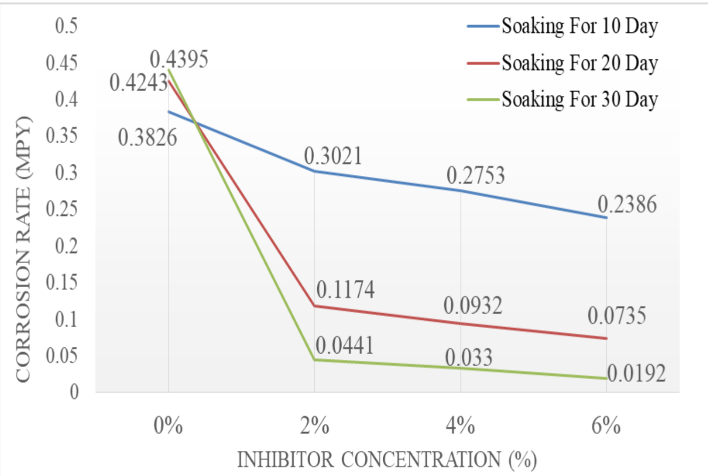

Fig. 2. Effect of Inhibitor concentration vs Corrosion Rate immersed for 10, 20, and 30 days.

Fig. 2 shows that with the increase in inhibitor concentration added, the corrosion rate tends to decrease. This is due to the fact that the extract jackfruit seed extract contains antioxidant compounds that function to slow down the oxidation reaction in corrosion. It can be concluded that with the increase in antioxidant compounds in the corrosive medium, Corrosive ion attacks on steel surfaces can be reduced due to the passive layer formed by *Fe-tannate* on the surface of galvanized steel.

As shown in Fig. 2, the corrosion rate of galvanized steel pipes immersed in a corrosive medium such as seawater increases with prolonged immersion time in the absence of an inhibitor. This indicates that a higher corrosion rate accelerates the corrosion of the steel, primarily due to the release of electrons. However, the corrosion rate decreases significantly with the addition of the inhibitor, especially as the concentration of jackfruit seed extract increases. This reduction is attributed to the faster formation of a passive protective layer at higher concentrations of the extract. Jackfruit seed extract as inhibitor functions by covering the steel surface and forming protective layers, which are composed of Fe-tannate complex compounds. These complexes act to protect the steel surface from corrosion. [15].

3.3 Inhibition Efficiency Analysis

Inhibition efficiency refers to the ability of an inhibitor to reduce the corrosion rate of a metal. Also known as inhibitor efficiency, it is expressed as a percentage that indicates the reduction in the corrosion rate. This is determined by comparing the corrosion rate with and without the inhibitor, calculating the difference, and then dividing this difference by the corrosion rate without the inhibitor, followed by multiplying the result by 100%. [17]. The inhibition efficiency values for immersion durations of 10, 20, and 30 days are shown in Fig. 3.

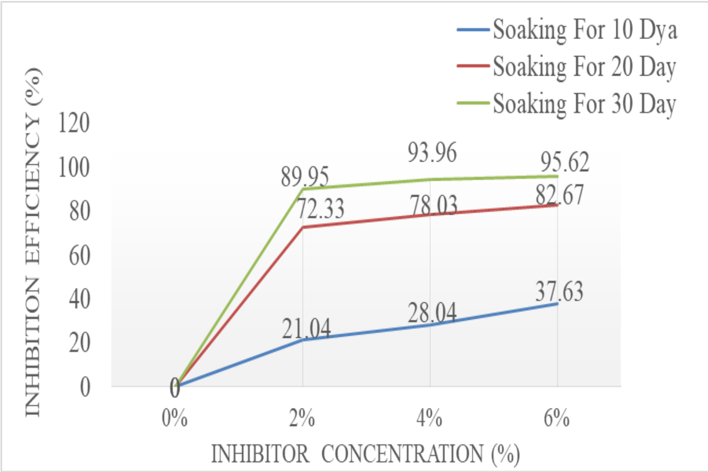

Fig. 3. Inhibitor Concentration vs Inhibition Efficiency for 10, 20, and 30 Days of Immersion

As shown in Fig. 3, there is a direct proportional relationship between immersion time and inhibition efficiency, indicating that as the immersion time increases, the inhibition efficiency also rises. This is attributed to the inhibitor's effective action and its adherence to the metal surface. During this process, tannin compounds form a *Fe-tannate* complex on the galvanized steel surface, which thickens over time, thereby creating a protective layer. This layer reduces the corrosion rate and enhances the inhibition efficiency [19]. Furthermore, Fig. 3 illustrates that both the concentration of the jackfruit seed extract inhibitor and the immersion time contribute to increased inhibition efficiency. As immersion time lengthens, the inhibition efficiency improves, resulting in a reduction in the galvanized steel's corrosion rate [16].

3.4 Macro structure analysis

Macrostructural observations were performed to analyze the changes that occurred in the specimen following the testing process.

Fig. 4 shows the surface of galvanized steel pipes immersed in a seawater solution as a corrosive medium, with inhibitor concentrations of 0%, 2%, 4%, and 6%. In the absence of an inhibitor, pitting corrosion, characterized by small holes on the metal surface was observed. At 2% inhibitor concentration, corrosion manifests as surface degradation accompanied by pitting corrosion. At a 4% concentration, pitting corrosion is still present but less severe than at 2%. Finally, at a 6% concentration, pitting corrosion is further reduced compared to the other concentrations. Pitting corrosion is a localized form of corrosion that creates small pits or holes on the metal surface. [12]. Corrosion on the metal surface is the result of a chemical reaction between the seawater solution and the metal, leading to a gradual thinning of the surface. This phenomenon can be correlated with the mitigation of corrosion through the application of inhibitors. As the concentration of the inhibitor increases, the extent of corrosion on the specimen decreases. Conversely, lower concentrations of the inhibitor result in higher levels of corrosion on the galvanized steel pipe. [20].

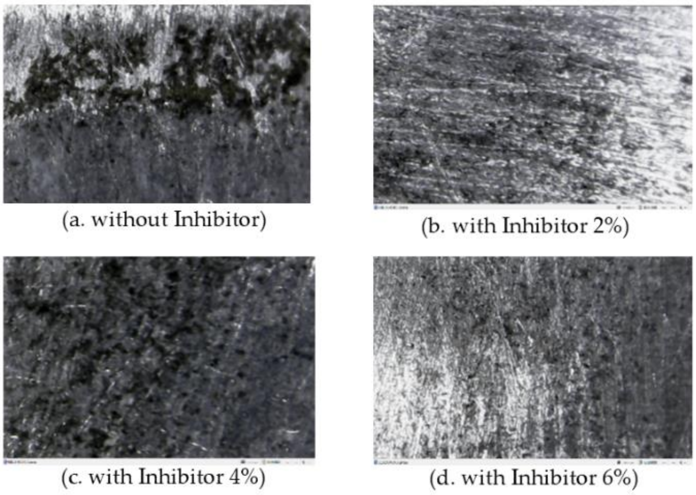

Fig. 4. Surface morphology of Galvanized Steel Pipe with Inhibitor Concentrations at (a).0%, (b).2%, (c).4%, and (d).6% after 10 days of Immersion

Fig. 5 reveals a notable difference in the specimens after a 10-day immersion period. Microstructural observations indicate the presence of holes with accumulated black deposits, signifying the formation of corrosion products on the specimen. In the samples immersed in a solution with a 0% inhibitor concentration, a substantial amount of corrosion products is observed on both the 10th and 20th days. However, the addition of inhibitors significantly reduces the presence of these corrosion products.

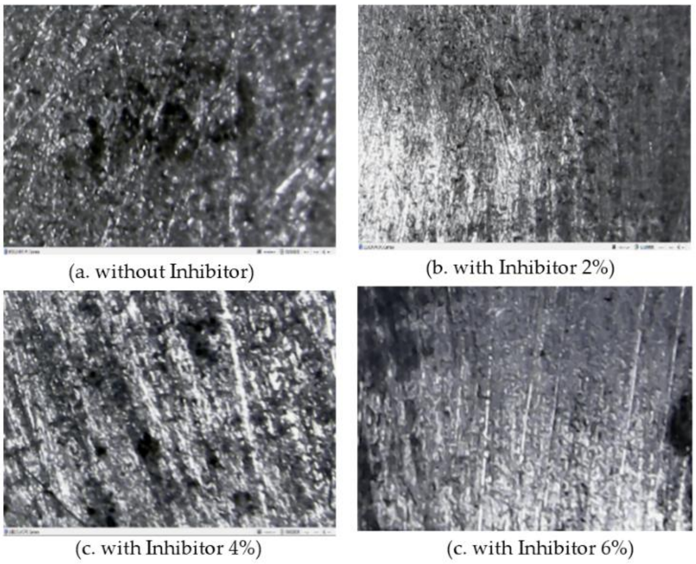

Fig. 5. Surface morphology Galvanized Steel Pipe with Inhibitor Concentrations at (a).0%, (b). 2%, (c).4%, and (d).6% after 20 days of immersion

This is evident in the immersion with a 6% inhibitor concentration, where significantly less corrosion is observed on the steel pipe. In contrast, the corrosion occurring on the steel pipe at a 0% inhibitor concentration is attributed to the absence of any protective inhibitor. Based on the observations, it can be concluded that the concentration of the inhibitor has a direct influence on the corrosion rate of the material. Specifically, higher inhibitor concentrations are associated with a lower corrosion rate

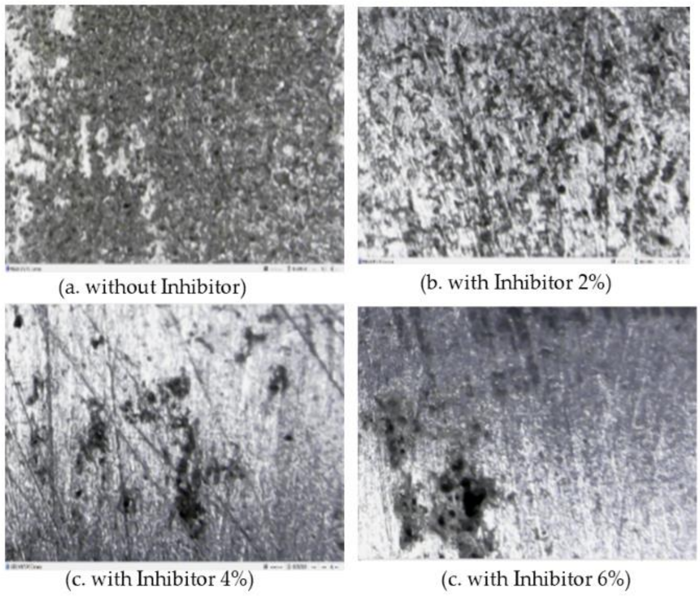

Fig. 6. Surface morphology Galvanized Steel Pipe with Inhibitor Concentrations at (a).0%,(b). 2%, (c).4%, and (d).6% after 30 days of immersion.

Fig. 6 shows the surface of the test plate, after immersion in seawater solutions with inhibitor concentrations of 0%, 2%, 4%, and 6%, exhibits black spots and a dull appearance. The corrosion observed in Figs 4 and 5 is less severe than that in Fig. 6, which is attributed to the formation of the *Fe-Tannate* complex compound. This compound results from a chemical reaction and functions to inhibit the corrosion rate. The corrosion depicted in Fig. 6 is identified as pitting corrosion, characterized by small holes resembling pits on the steel plate's surface [18]. This type of corrosion is caused by a chemical reaction between the seawater and the steel, leading to thinning of the metal surface [16].

4 Conclusion

This study confirms that immersion time and inhibitor concentration significantly affect the corrosion rate of galvanized steel in seawater. Without an inhibitor (0% concentration), the corrosion rate progressively increases, reaching a maximum of 0.4395 µpy after 30 days. In contrast, the addition of jackfruit seed extract effectively reduces corrosion, with the lowest rates observed at 0.0441 µpy (2%), 0.0330 µpy (4%), and 0.0192 µpy (6%) after 30 days. These results highlight the high efficiency of jackfruit seed extract as a natural corrosion inhibitor, demonstrating that higher concentrations and longer immersion times enhance corrosion protection. This study suggests that jackfruit seed extract is a viable, eco-friendly alternative to synthetic inhibitors, offering a sustainable solution for corrosion prevention in marine environments. Further research on long-term stability and large-scale applications is recommended to optimize its industrial implementation.

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