Engineering Chemistry
ISSN: 2813-6535, Vol. 9, pp 1-10
doi:10.4028/p-ryFR6C

Submitted: 2024-11-19
Accepted: 2024-12-02
Online: 2025-03-10

Promising Organic Inhibitor of Salak *(Salacca zalacca)* Peel Extract on AISI 1040

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Keywords: AISI, Corrosion, Green, Inhibitors, Peel

Abstract. This study investigates the corrosion inhibition properties of Salak (*Salacca zalacca*) peel extract as a green inhibitor on AISI 1040 steel in a 1M HCl acidic environment and focusing on secondary metabolites such as flavonoids and tannins. The qualitative phytochemical analysis showed antioxidant activity of the inhibitor extract was categorized as moderate with an IC50 value of 105.219 ppm. Functional group analysis using FTIR indicated that the flavonoids and tannins in the extract acted as antioxidants and inhibited corrosion growth. The weight loss test revealed the highest inhibition efficiency 11.13% was achieved at a concentration of 200 ppm after 20 days of immersion. In the potentiodynamic polarization test, the corrosion rate was 0.025 mm/year at the same concentration and immersion time. These results suggest that Salak (*Salacca zalacca*) peel extract can effectively inhibit corrosion at spesific concentrations but its efficiency diminishes at higher concentrations.

Introduction

Corrosion of metals is one of the matters with big losses in the world's industry [1], [2]. It can be seenthat the impact of corrosion on the domestic economy of various countries reaches 3% of GDP. When damage is major, expensive maintenance and replacement is required for safe and reliable construction use, and even if the serviceability of the structure is not compromised, deterioration in appearance results in a decrease in the value of the construction.[3] Corrosion is generally known as material degradation, which is an event of damage or decrease in the quality of a material, especially metal, due to environmental reactions that provide an atmosphere for oxidation-reduction reactions [4]. A corrosion inhibitor is a chemical compound that, when added, can be attached to the material's surface and will be a protector against cove environments [5].

There are several ways to protect against corrosion, namely cathodic protection [6], and coatings [7] one of the effective alternative ways to protect against corrosion on metal surfaces is inhibitors (inorganic and organic) [8], [9]. The selection of inhibitors is not only based on their ability to inhibitor corrosion rates with high efficiency. Several methods have been used to reduce the corrosion rate ofcarbon steel corroded by acid solutions. Still, an effective use is the use of organic inhibitors [10-17], but also in terms of their level of toxicity when applied to industry against environmental pollution. For this reason, the use of inorganic inhibitors is limited, like that encouraging the development of alternative organic inhibitors or green inhibitors that are economical, easily renewable, biodegradable, and environmentally friendly from extracts of natural ingredients. Substances from natural sources exhibit antioxidants. Antioxidant compounds can be found in plantssuch as meat, roots, skin, stems, and leaves [18][22].

Salak (*Salacca zalacca*) is a species of palm tree (family Aracaceae) native to Indonesia. Consumerslike snake fruit with thick flesh, a sweet taste, and small seeds [19]. However, the results of the phytochemical test showed that the bark of the Salak (*Salacca zalacca*) fruit contained flavonoids and tannins. The ethanol extract of Salak (*Salacca zalacca*) fruit peels has antioxidant activity with an IC50 value of 49,45 (µg/ml) [20] The presence of flavonoids and tannins from the bark extract of the zalacca fruit is the basis for supporting the utilization of the peel waste in this study. In addition to bark, many studies have used organic extracts on carbon steel with an HCl environmentamong sunflower seeds [21], peppers [23], jackfruit banana skin [24], and orange and mango peels [25].

In this study, the inhibitor was extracted from the bark of the Salak (*Salacca zalacca*) fruit cultivated at KM 21 Karang Joang. It was used as a corrosion inhibitor on AISI 1040 steel in a 1M HCl environment. The contentof AISI specimens were confirmed using OES. The 1,1- diphenyl-2-picrylhydrazyl (DPPH) test wasused to determine the antioxidant activity of salak fruit bark (*Salacca zalacca*). The Fourier Transform Infra-Red (FTIR) technique confirmed the extract's functional groups of antioxidant compounds. Furthermore, the effects of inhibitor concentration and immersion time on inhibitor performance were reviewed through weight loss corrosion testing methods and polarization measurements. In addition, surface observations of AISI 1040 steel macrostructures were analyzed using a Scanning Electron Microscope (SEM).

Research MethodologyInhibitors Preparation

Salak fruit skin (*Salacca zalacca*) obtained from KM 21 Karang Joang, North Balikpapan District, Balikpapan City, was dried by sunlight exposure for seven days. Inhibitor preparation was carried out by the maceration method by inserting 500 grams of dried zalacca skin and pulverizing it with a blender and 3000 mL of 96% ethanol into a 5000 mL container. Immersion was carried out for 3 x 24 hours. Then the extraction results are separated between the filtrate and residue. After that, the evaporator and oven are carried out [26]

Secondary Metabolite Identification Method

At this point testing was carried out to identify secondary metabolites, namely phytochemicals and DPPH. Phytochemical testing was done to determine the secondary metabolites contained in the skin extract of salak (*Salacca zalacca*), the compounds to be known were flavonoids and tannins.

After knowing the secondary metabolites of phytochemicals, then proceed with DPPH. Testing the antioxidant activity with 1,1- diphenyl-2-picrylhydrazyl (DPPH) aims to determine the antioxidant activity of salak (*Salacca zalacca*) bark extract.

Electrolyte Solution Preparation

1 M HCl is produced from 37% HCl which the molar is 10.32 M, then HCl is diluted in 1 liter of distilled water to obtain a 1 M HCl solution [27].

Weight loss Method

The sample used is AISI 1040 steel with a size of 2 cm x 2 cm x 0.3 cm as shown in Fig.1. This test was done with the aim of knowing the resulting weight loss in the sample when immersed in a corrosive medium, namely 1M HCl. This test was done with various inhibitor concentrations (0 ppm, 100 ppm, 200 ppm,300 ppm, 400 ppm, and 500 ppm) and Immersion time (10 days, 20 days, and 30 days) [27]. Corrosiontesting with the weight loss method with ASTM G31-21 standard was repeated three times [28].

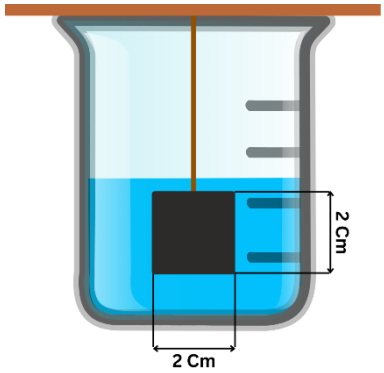

Fig. 1 Weight loss Method

Electrochemical Experimental

The polarization test was conducted using an autolab to gather corrosion rate data for AISI 1040 steel. This method employs a three-electrode setup which includes an Ag/AgCl reference electrode, a platinum auxiliary electrode, and AISI 1040 steel working electrode. This configuration allows precise measurement of the electrochemical behavior of the steel in the corrosive environtment and providing valuable insight into the effectiveness of the corrosion inhibitor based on concentration and soaking time as shown in Fig. 2.

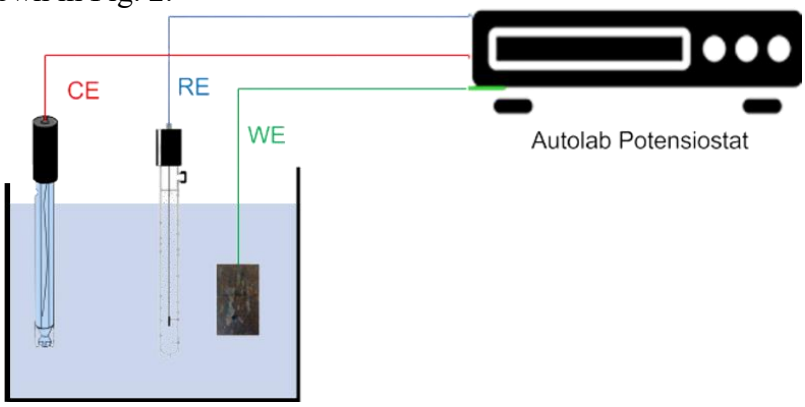

Fig. 2 Schematic of three electrodes Electrochemical

Characterization

Characterization testing was carried out to determine the functional groups content in Salak (*Salacca zalacca*) peel extract using Fourier Transform Infrared Spectroscopy (FTIR) to helped confirm the presence of key compounds such as flavonoids and tannins.ronScanning Electron Microscope with Energy Dispersive X-Ray (SEM-EDX) test was carried out to observe the surface morphology of steel samples and allowing for a comparison of the extent surface damage with and without the application of inhibitors.

Results and Discussion

Determination of Antioxidant Properties of Salak (*Salacca zalacca*) Peel Extract

The results of the linear regression equation for the antioxidant activity of Salak (*Salacca zalacca*) peel extract was determined to be y= 0.4935x – 1.9258 with a strong correlation coefficient of R2 = 0.91, indicating a good fit of the data. Then,using the IC50 value is substituted for the y value as a free radical inhibitor value of 50% so that the x value is obtained, which is the IC50 value. This provides a quantitative measure of the extract's antioxidant potential, helping to evaluate its effectiveness in reducing oxidative stress.

Table 1 Results of Measurement of Antioxidant Activity of 96% Ethanol Extract of Salak (*Salacca zalacca*) Peel with the DPPH method

Concentration (ppm)	Antioxidant Activity(%)	IC_{50} (ppm)	Antioxidant Potential
0	0	105,219	Medium
12,5	2,72		
25	3,63		
50	31,74		
100	44,82		

Qualitative Analysis of Secondary Metabolites of Salak (*Salacca zalacca*) Bark Extract

Table 2 Phytochemical Test Results

Secondary Metabolites	Reactor	Results
Flavonoid	NaOH 1% + HCl 1%	+
Tanin	Lead (II) acetate (CH3COO)2 Pb 1%	+
Saponin	Aquadest + HCl	-
Alkaloid	HCl + dragendorf	-

Information:
+ : detected
− : not detected

The phytochemical test results of the Salak *(Salacca zalacca)* bark extract revealed the presence of secondary metabolites specifically flavonoids and tannins which were detected through positive reactions in the assay. In contrast, the tests for alkaloids and saponins yielded negative results indicating their absence in the extract. These finding suggest that the corrosion inhibition properties of the extract may primarily be attributed to the flavonoid and tannins which are known for their antioxidant and metal-binding capabilities.

Analysis of Functional Groups in Salak (*Salacca zalacca*) Peel Extract

Secondary metabolites in Salak (*Salacca zalacca*) peel extract play crucial role in the inhibition mechanism making it essential to analyze the constituent compounds involved. In this study, we conducted FTIR characterization was performed to identify these key secondary metabolite.Based on the FTIR result confirmed the presence of tannins and flavonoids which both are known to contribute the corrosion inhibition process due to their antioxidant properties and ability to form protective layers on metal surfaces.

Flavonoids contain several functional groups, including C=O double bonds, C-O single bonds, C-H single bonds, and O-H single bonds which contribute to their chemical reactivity. These functional groups play a significant role in the interaction of flavonoids with metal surfaces aiding in formation of a protetctive barrier against corrosion. Based on the molecular structure of the flavonoids detected in this assay suggest their potential effectiveness in the corrosion inhibiton process through antioxidant activity and adsorption onto metal surface.

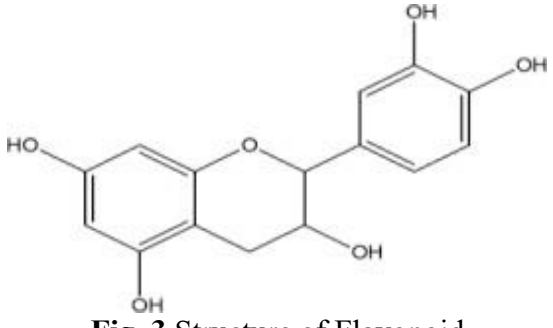

Fig. 3 Structure of Flavonoid

Secondary metabolite compounds, namely tannins, contain functional groups such as O-H and C-O single bonds which contribute to their chemical properties. FTIR analysis confirmed the presence of tannins in Salak (*Salacca zalacca*) peel extract indicating their role in the inhibition mechanism in Fig. 4**,** tannin is a detectable compound.

Table 3 FTIR result of Salak (*Salacca zalacca*) skin

Wavenummber (cm^{-1})	**Frequency Area (cm^{-1})**	**Chemical Bonds**	**Functional Group**
3340,23	3200-3600	O-H	Fenol
3010,54	3010-3100	C-H	Aromatic Ring
2923,99	2850-2970	C-H	Alkana
2853,93	2850-2970	C-H	Alkana
2171,87	2100-2260	C≡C	Alkuna
1718,54	1690-1760	C = O	Aldehid, Keton
1514,54	1500-1600	C = C	Aromatic Ring
1376,48	1300-1470	C – H	Alkana
1223,99	1180-1360	C – N	Amina, Amida
1155,99	1050-1300	C – O	Alkohol, Eter, Hydroxycarboxylic acid, Ester
921,09	675-995	C – H	Alkena
815,99	675-995	C – H	Alkena
770,66	675-995	C – H	Alkena
1718,54	1690-1760	C = O	Aldehid, Keton
1514,54	1500-1600	C = C	Aromatic Ring

Performance Analysis of Corrosion InhibitorsInhibition Efficiency

In Table 4, it can be seen that the inhibition efficiency from concentrations of 0 to 500 ppm by soaking for 20 days

Table 4 Inhibiton Efficiency

Inhibitor Concentration (ppm)	**Sample Number**	**Initial Weight (gr)**	**Final Weight (gr)**
0	1	10,225	8,591
	2	10,582	8,649
	3	10,449	8,584
100	1	10,240	8,602
	2	10,257	8,553
	3	10,498	8,791
200	1	10,130	8,659
	2	10,223	8,640
	3	10,180	8,414
300	1	10,393	8,667
	2	10,195	8,512
	3	10,534	8,236
400	1	10,847	8,921
	2	11,055	8,324
	3	10,894	8,750

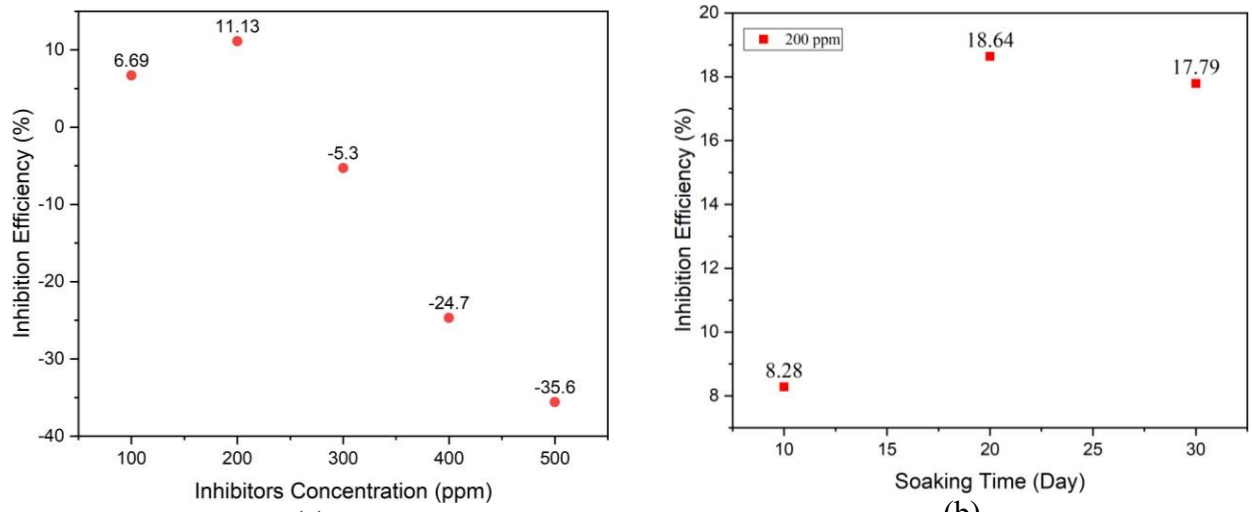

Fig. 4 Inhibition Efficiency of Salak (*Salacca zalacca*) peel Extract in 1M HCl Solution (a) Variation ofConcentration (b) Variation of Soaking Time

Based on data from the most optimum concentration variation, the highest inhibition efficiency was observed at a concentration of 200 ppm, which was 11.13% while the efficiency dropped drastically at 500 ppm to -35.6% the significant reduction in efficiency at higher concentrations can be attributed to the saturation of adsorption sites on the steel surface. Once these sites are saturated, excess inhibitor molecules may aggregate and disrupt the uniform protective layer causing the metal surface to be exposed of the corrosive medium. On the concentration of 200 ppm, the Fig. 5 above explains that the highest inhibition efficiency was obtained with variations in soaking time at the optimum concentration of 200 ppm at 20 days of immersion time of 18.6%.

Corrosion Rate

The corrosion rate in Fig. 5 decreased from 0.189 mm/year to less than 0.05 mm/year at concentrations of 100and 200 ppm; then, the corrosion rate increased to more than 0.2 mm/year at concentrations of 300, 400, and 500 ppm. There is a correlation between the corrosion rate and the corrosion current (i_{corr}) so that the decrease in the corrosion rate both without and with the addition of inhibitors at each concentration indicates that the presence of an inhibitor in Salak (*Salacca zalacca*) bark extract helps inhibit the corrosion rate.

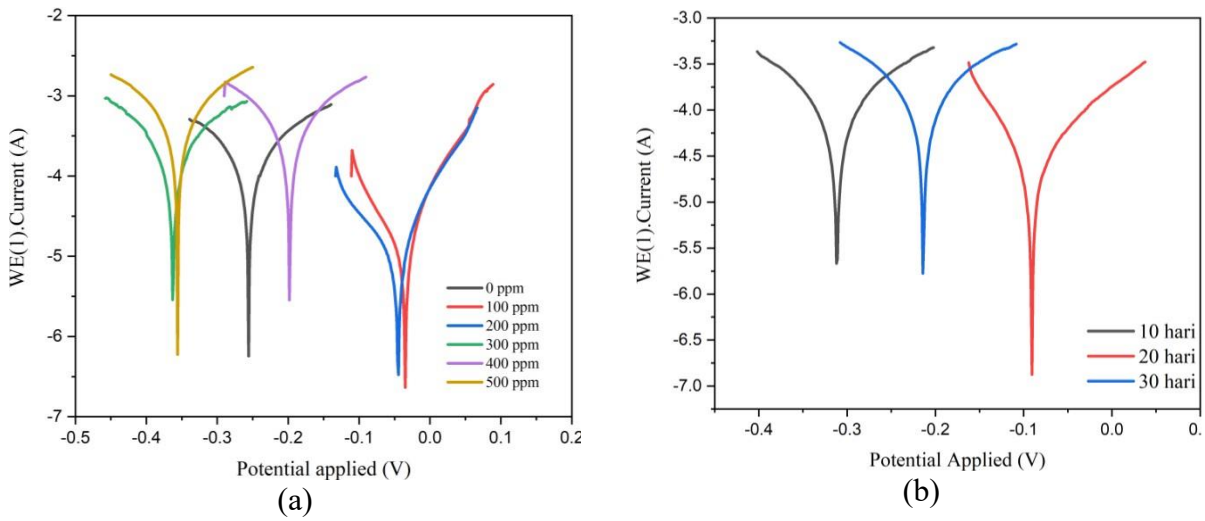

Fig. 5 Tafel Curve of Salak (*Salacca zalacca*) Peel Extract (a) Variation of Concentration(b) Variation of Soaking Time

The polarization test results mirrored those of the weight loss test, showing the lowest corrosion rate at the concentration rate of 0.025 mm/year at a concentration of 200 ppm. The polarization measurements were consistent with the weight loss test results. The lowest corrosion rate combined with the highest inhibition efficiency was observed at a concentration of 200 ppm and a 20-day immersion period.

Inhibition Mechanism

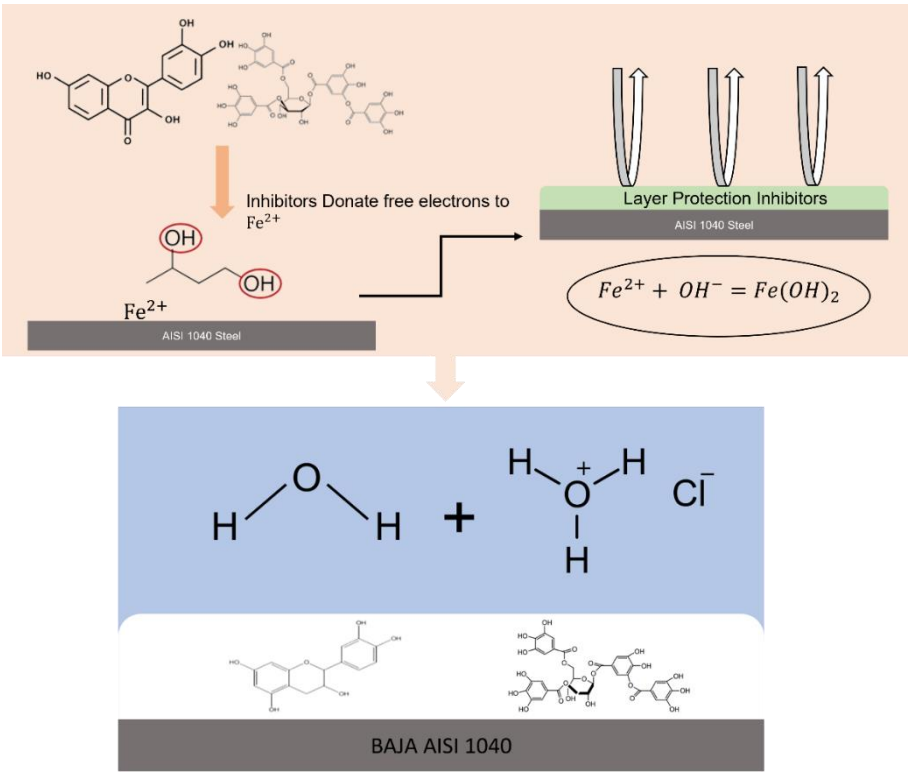

Fig. 6 Mechanism Inhibition

Salak (*Salacca zalacca*) peel extract is used to make corrosion inhibitors because Salak (*Salacca zalacca*) peel contains secondary metabolites that can stop corrosion growth. Flavonoids and tannins are secondary metabolites that play a role in this study.Flavonoids are plants that belong to the primary antioxidant class. They can end free radical reactionsby donating hydrogen or electrons to free radicals by turning them into a protective layer such as shown in Fig. **6**. Flavonoidswith part of the hydrocarbon chain can prevent the metal surface from directly contacting the electrolyte because they are hydrophobic. Based on the results of the FTIR test, where Alkene C = C has hydrophobic properties. In addition, the functional groups of phenol and alcohol hydrogen bonds(O – H) are hydrophilic functional groups. So that one end of the bond chain must be hydrophilic like OH so that this chain becomes a barrier for a corrosive environment for metals to come into direct contact. Then these functional groups undergo an adsorption process onto the metal surface to form aromatic groups so that the hydrophobic functional groups (C = C and C – H) will tend to reject water ions that react with the metal. Meanwhile, hydrophilic functional groups (O – H) will tend to capture unwanted ions so they do not react with metals.

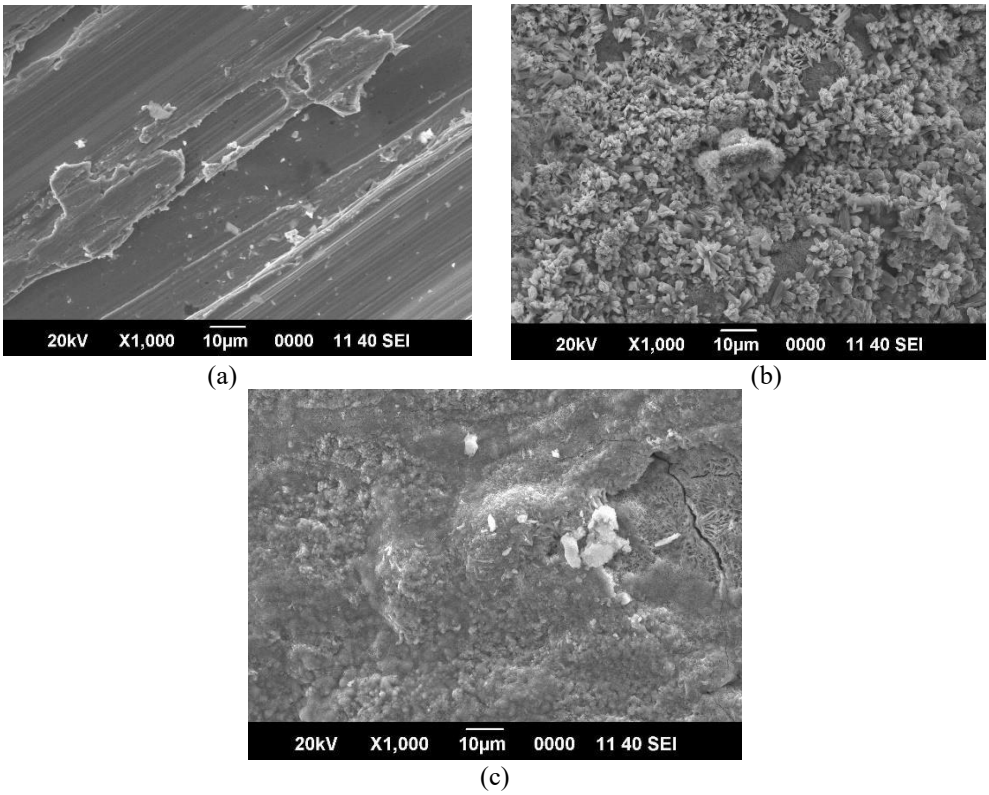

Fig. 7 Macrostructure Observation Results of AISI 1040 Steel (a) AISI 1040 Steel Without Treatment (b) AISI 1040 Steel with a Concentration of 0 ppm for 20 days of Soaking Time in 1M HCl (c) AISI 1040 Steel with a Concentration of 200 ppm at 20 Days of Soaking Time in HCl 1 M

Tannins have the potential as corrosion inhibitors because of their properties which have complex compounds and polyphenolic compounds with structures that form macromolecules and contain hydroxyl groups (-OH), so they are able to absorb transition metals (Fig. 7). Tannins the complex compoundcan directly become a barrier (barrier) that will coat the metal and protect it from coming into directcontact with the solution. From the morphological results with 1000x magnification on AISI 1040 steel samples with and without inhibitors and without treatment can be seen in the following figure.

Conclusion

The results of the corrosion test using the weight loss method obtained the results with the highest inhibition efficiency concentrations of 200 ppm at 11.13%. In the polarization test, the results with the lowest corrosion rate were obtained at a concentration of 200 ppm of 0.025 mm/year.The results in the corrosion test using the weight loss method obtained the highest inhibition efficiency with a 20-day immersion time of 18.6%. The Polarization test obtained the lowest corrosion rate at 20 days of immersion, which was 0.05 mm/year. The use of inhibitors of bark extract *(Salacca zalacca*) can reduce the corrosion rate of AISI 1040 steel in a 1M HCl environment due to the influence of secondary metabolites, namely flavonoids and tannins, which act as protectors to prevent metals from interacting with electrolyte environments.

Acknowledgments

Thank you for the facilities from Integrated Laboratory Kalimantan Institute of Technology and Research Center for Mining Technology, National Research and Innovation Agency (BRIN). Thank you for scientific suggestion and recommendation from Prof. Dr.rer.nat Fredy Kurniawan (Sepuluh November Institute of Technology) and Prof. Yusairie Mohd (Universiti Teknologi MARA, Shah Alam).

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