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CORROSION RATE OF ASTM A53 STEEL IN SEAWATER INFLUENCED BY VARIATION IN CONCENTRATION OF MANGIFERA INDICA L. PEEL EXTRACT

Selly Septianissa[1*], Ayu Zahra Chandrasari[2]
Department of Mechanical Engineering, Faculty of Engineering, Widyatama University, Bandung 40125, Indonesia[12]
selly.septianissa@widyatama.ac.id

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**Corresponding Author*

ABSTRACT
This study investigates the effectiveness of mango peel extract as a corrosion inhibitor for ASTM A53 steel, which is widely used in the oil and gas industry. The research aims to evaluate how different concentrations of mango peel extract can mitigate corrosion in seawater from Pangandaran, thereby extending the lifespan of steel components in marine environments. Corrosion tests were conducted through immersion experiments over durations of 1, 4, 9, 16, and 25 days with mango peel extract concentrations of 0 ppm, 20 ppm, 40 ppm, 60 ppm, and 80 ppm. Analytical methods including X-ray diffraction (XRD), Optical Microscopy (OM), energy dispersive spectroscopy (EDS), and scanning electron microscopy (SEM) were used to examine the steel's surface morphology and chemical composition. The results demonstrate that mango peel extract significantly reduces the corrosion rate of ASTM A53 steel, with the highest efficiency achieved at 40 ppm (58.15%) and a notable reduction at 60 ppm (56.4%). The inhibition is attributed to chemical absorption, which lowers the steel's corrosion potential. These findings suggest that mango peel extract is an effective, eco-friendly corrosion inhibitor, offering practical and theoretical benefits for corrosion management. This research supports the use of bio-based inhibitors and may inform future industrial corrosion protection strategies.
Keywords: *Inhibition, Corrosion, ASTM A53 Steel, Mango Peel, Mangifera Indica L. Peel Extract*

1. Introduction

Pipelines are integral components of various industries, including oil and gas, transportation, and infrastructure development, facilitating the efficient transport of fluids over long distances (Bukhari et al., 2022; Katysheva, 2023). Piping system technology plays a crucial role in this process, but during operation, pipes are susceptible to various forms of corrosion, which can significantly impact their performance and longevity (Lauzuardy et al., 2024; Titah & Pratikno, 2023).Among the materials commonly used for pipeline construction is ASTM A53 steel, which is valued for its strength, durability, and cost-effectiveness (Anandkumar et al., 2023; Shin et al., 2022). However, operating these pipelines in corrosive environments, such as seawater, presents a major challenge. Corrosion in such environments can severely compromise the structural integrity and lifespan of the pipelines (Alamri, 2020; Septianissa et al., 2022).

Corrosion is a pervasive issue in pipeline systems, driven by the aggressive nature of the fluids transported and the harsh environmental conditions to which the pipes are exposed (Amaya-Gómez et al., 2024; Bender et al., 2022; Septianissa et al., 2024; Shokri & Sanavi Fard, 2023). Traditional corrosion mitigation strategies typically involve the use of chemical inhibitors. These inhibitors work by slowing down the corrosion process, but they often pose environmental risks due to their chemical composition (Al-Amiery et al., 2024; P. Verma et al., 2021; Zehra et al., 2022). The increasing environmental awareness has led to the development of more sustainable alternatives, known as green inhibitors (Salleh et al., 2021; Zakeri et al., 2022), which offer less harmful impacts on the ecosystem (Al-Moubaraki & Obot, 2021; C. Verma et al., 2024).

Despite the advancements in corrosion prevention, existing green inhibitors often lack effectiveness or practical application in severe corrosive environments such as seawater (Aslam et al., 2022; Khan et al., 2022). This highlights a significant gap in current research: the need for effective, eco-friendly corrosion inhibitors that can withstand harsh environmental conditions and provide reliable protection for critical infrastructure. One promising candidate for a green corrosion inhibitor is the peel of Mangifera Indica L., commonly known as mango peel. Mango peel is rich in bioactive compounds, including polyphenols, flavonoids, and antioxidants, which have shown potential in mitigating corrosion in preliminary studies (Ituen et al., 2020; Sudiarti et al., 2020; Wongkaew et al., 2021). This research aims to evaluate the effectiveness of mango peel extract as a corrosion inhibitor for ASTM A53 pipelines exposed to seawater environments. By investigating the corrosion inhibition performance of this natural extract, this study seeks to contribute to the development of more sustainable and environmentally friendly corrosion protection strategies.

While there is considerable research on traditional and green corrosion inhibitors, there is a lack of comprehensive studies focusing on natural, sustainable solutions for severe corrosive conditions. The current literature often overlooks the potential of using fruit-derived extracts, such as mango peel, for this purpose (Albahri et al., 2021; Ramezanzadeh et al., 2019; Xuan Bach et al., 2023). This study addresses this gap by exploring the application of mango peel extract in corrosion prevention, thereby offering a novel and eco-friendly alternative to conventional chemical inhibitors.

Recent studies have highlighted the environmental impact of traditional chemical inhibitors and underscored the importance of developing green alternatives (Salim, 2020; C. Verma et al., 2024).However, many of these studies do not address the specific application of natural extracts in harsh environments. By critically analyzing recent literature and focusing on mango peel extract, this research will offer new insights into sustainable corrosion protection methods.

2. Research Methods

ASTM A53 grade A steel was cut into dimensions of 20x30 mm with a thickness of 1.25 mm using wire cutting and milling machines. The samples were then surface-smoothed using sanding machines and sandpaper with grit sizes of 60, 240, 600, and 1000 mesh to ensure a uniform surface finish. Initial measurements of specimen weight (W_0), width (l_0), thickness (t_0), and length (p_0) were recorded using a digital caliper and analytical balance for accuracy. These measurements were crucial for calculating corrosion rates and assessing the extent of material loss.

Metallographic testing was performed using a Nikon LV150 microscope to examine the microstructure of the steel samples. Chemical composition was analyzed using spectrophotometry, with results detailed in Table 1. Initial X-ray diffraction (XRD) testing was conducted to identify the elemental and oxide composition of the steel, which provided baseline data for comparison with post-exposure results.

Seawater from Pangandaran, Ciamis, West Java, was collected and analyzed using Atomic Absorption Spectrophotometry (AAS) to determine its chemical composition, as shown in Table 2. Mango peel extract was prepared using an evaporation method. Specifically, mango peels were first dried at 60°C for 48 hours, then ground into a fine powder. The powder was extracted with ethanol (1:10 w/v ratio) and evaporated at 45°C to obtain a concentrated extract. The concentration of the mango peel extract was adjusted to 10%, 20%, and 30% (w/v) for use in corrosion inhibition testing.

Table 1 - The chemical composition of ASTM A53 grade A steel based on astm standard handbook and spectrometry test results

Element	Spectrophotometric test results	ASTM A53 grade A standard
Fe	99%	*Balanced*
C	0.234%	0.25% max
Mn	0.338%	0.95% max
Si	0.216%	-
P	0.0049%	0.05% max
S	0.0500%	0.45% max
Cr	0.0153%	0.40% max
Mo	<0.0030%	0.15% max
Ni	<0.0050%	0.40% max

Al	<0.0020%	-
Co	0.0030%	0.40% max
Cu	0.0196%	-
V	<0.0010%	0.08% max
W	<0.0400%	-

Prior to immersion, the steel specimens underwent rinsing with distilled water, degreasing with acetone, and pickling in a 10% sulfuric acid solution for 30 minutes to remove surface contaminants. The specimens were then immersed in seawater with varying concentrations of mango peel extract (10%, 20%, and 30%) for different durations (1, 4, 9, 16, and 25 days) in separate beakers. A control group of ASTM A53 steel samples was also immersed in seawater without any inhibitors to serve as a baseline comparison.

Initial pH and potential measurements of the seawater were recorded using a pH meter and a potentiostat, respectively. Morphological changes on the surface of the specimens were observed using an optical microscope. Final XRD testing was performed to compare with initial results, assessing changes in the elemental composition. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) were conducted to characterize the surface morphology and elemental composition of the samples, following ASM Vol. 09 guidelines.

Table 2 - AAS Testing on Seawater

Element	Na	K	Cl	Ca	Mg
The results of AAS testing (ppm)	361.20	1264	10661	404.70	18918.3

Corrosion rates were determined by measuring the weight loss of the specimens before and after immersion using the following formula (Bahmani et al., 2020; Kadhim, 2021; Yang et al., 2018):

$$Corrosion\ Rate = \frac{Weight\ Loss}{Area\ x\ Exposure\ Time}$$

where weight loss was calculated by subtracting the final weight (W_f) from the initial weight (W_0) (Amaya-Gómez et al., 2024; Shokri & Sanavi Fard, 2023; Zehra et al., 2022). Statistical analysis of the corrosion rates and inhibitor effectiveness was performed using ANOVA and Tukey's test to determine significant differences between the control and treated groups (Al-Moubaraki & Obot, 2021; Lauzuardy et al., 2024). Data were analyzed using statistical software (e.g., SPSS or R) to assess the significance of the results. The mean corrosion rates and inhibition efficiencies were compared between the control and inhibitor-treated samples. Table 1 presents the chemical composition of ASTM A53 steel, which is critical for understanding its susceptibility to corrosion. Table 2 shows the chemical composition of the seawater used in the experiments, highlighting the corrosive elements present and their potential impact on the corrosion process.

3. Results and Discussions

3.1 Results

The spectrometry test results confirm that ASTM A53 steel used in this study is classified as low carbon steel with a carbon content of 0.234%. This low carbon content is typical for applications requiring good weldability and ductility but may limit overall strength. Alloying elements such as manganese (Mn) at 0.338% and silicon (Si) at 0.216% were also detected (Table 1). Manganese enhances the steel’s resistance to wear and impact, while silicon contributes to hardness and oxidative stability. However, excessive silicon can result in increased brittleness. The balance of these elements affects the steel's susceptibility to corrosion and its response to inhibitors.

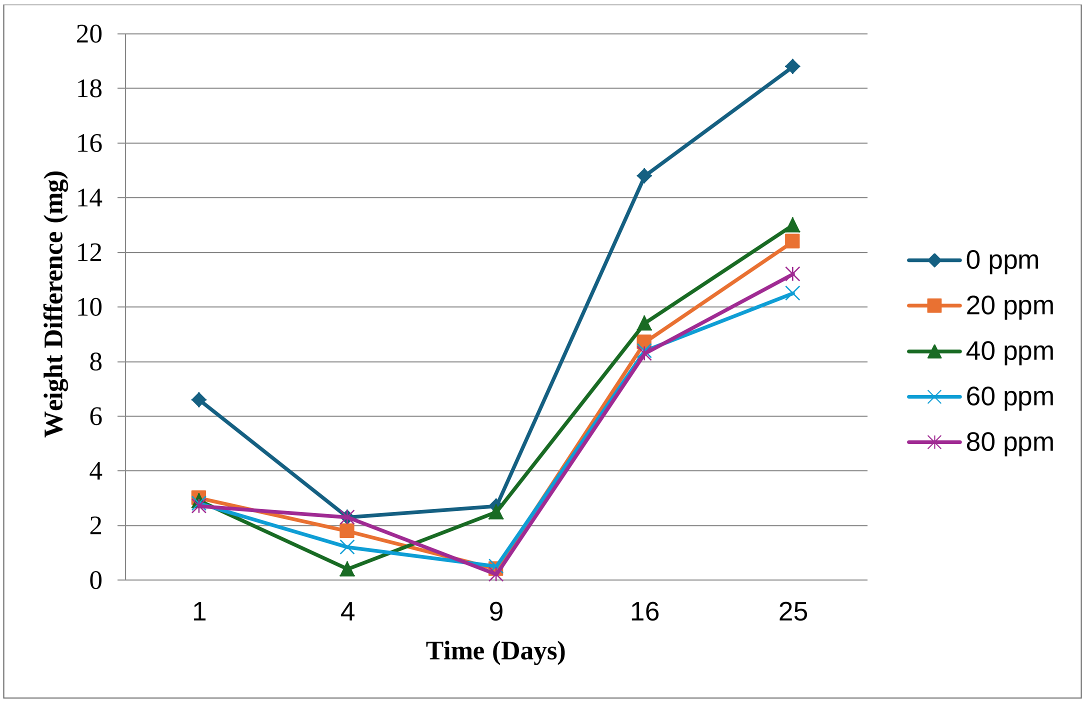

Fig. 1. Graph of Weight Change of ASTM A53 Steel with Variation in Immersion Time

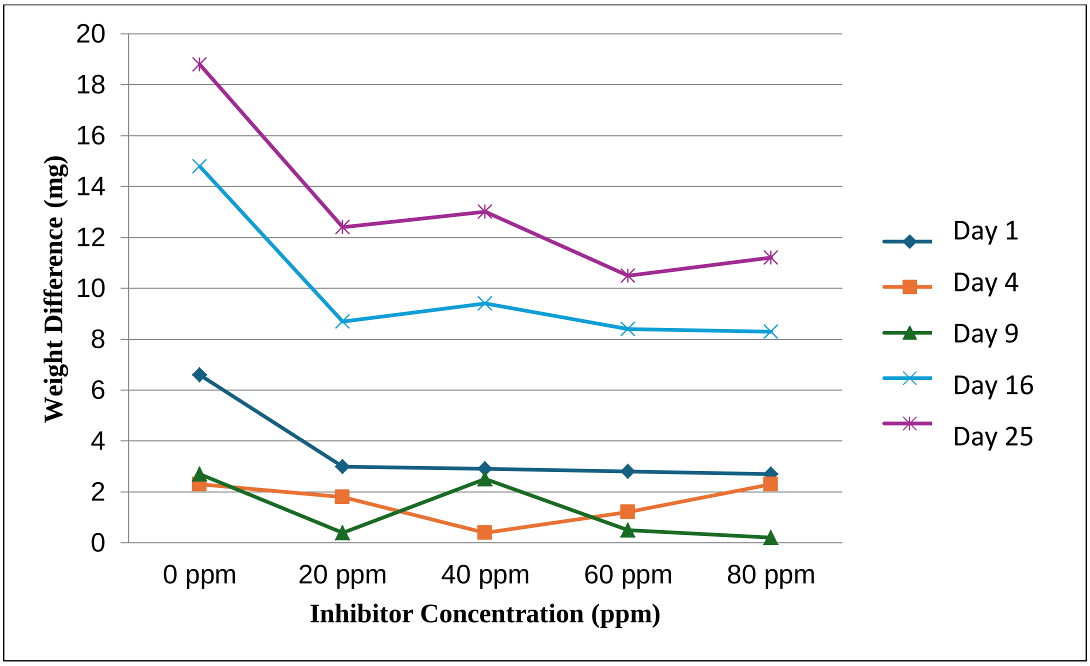

Fig. 2. Graph of Weight Change of ASTM A53 Steel with Variation in Inhibitor Concentration

Corrosion testing results, illustrated in Figure 1, demonstrate a direct correlation between immersion time and the thickness of corrosion products. Prolonged immersion in seawater leads to a proportional increase in oxide accumulation, reflecting the ongoing corrosive attack. Weight loss measurements over 25 days showed a clear increase, with specimens without inhibitors exhibiting significantly higher weight loss compared to those treated with mango peel extract. For instance, specimens immersed for 25 days without inhibitors experienced a weight loss of approximately 15.4 grams, while those with 20 ppm of mango peel extract showed a reduced weight loss of about 6.7 grams. These observations underscore the effectiveness of the mango peel extract in mitigating corrosion.For the corrosion rate, the weight loss method formula is used as follows (Chen & Su, 2021; Lun et al., 2021; Peng et al., 2021): $\frac{534W}{Pat}$

Figure 2 compares the weight loss of specimens with and without inhibitors, revealing that the control group, without any inhibitor, suffered the most severe weight loss, indicative of extensive corrosion. Conversely, specimens treated with mango peel extract displayed lower weight loss, suggesting reduced corrosion rates. This reduction aligns with the inhibitor's role in forming a protective layer on the steel surface, thus decreasing the rate of metal degradation.

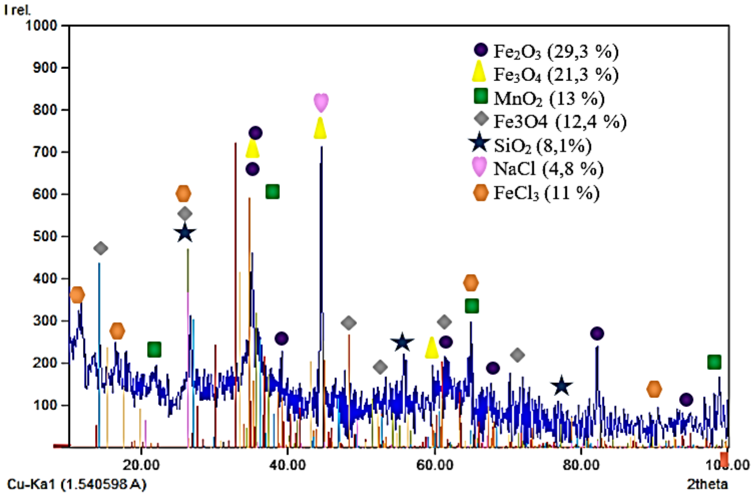

Fig. 3. XRD Testing on Day 1 with 0 ppm Concentration

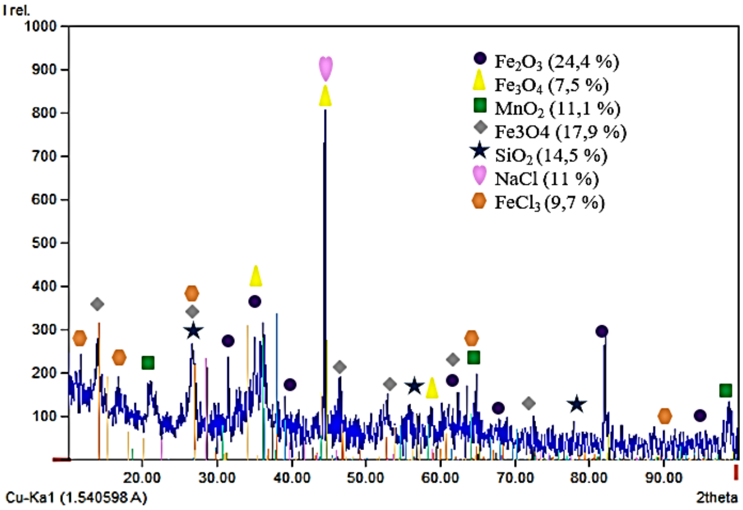

Fig. 4. XRD Testing on Day 25 with 0 ppm Concentration

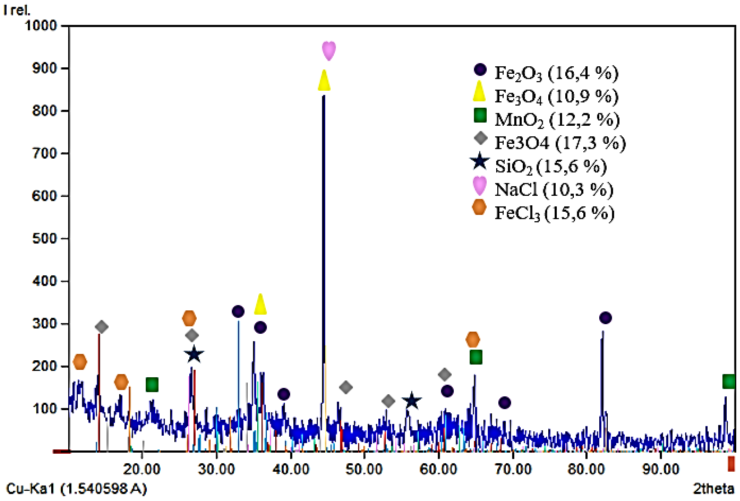

Fig. 5. XRD Testing on Day 25 with 20 ppm Concentration

X-ray diffraction (XRD) analysis further supports these findings. Figure 3 shows the presence of corrosion products such as Fe_2O_3, FeOOH, and Fe_3O_4 in specimens immersed for 1 day without inhibitors. By day 25, the corrosion products increased in peak intensity, reflecting higher corrosion levels (Figure 4). In contrast, specimens with 20 ppm mango peel extract exhibited lower peak intensities for these corrosion products (Figure 5), highlighting the inhibitor's effectiveness in reducing the formation of aggressive corrosion compounds.

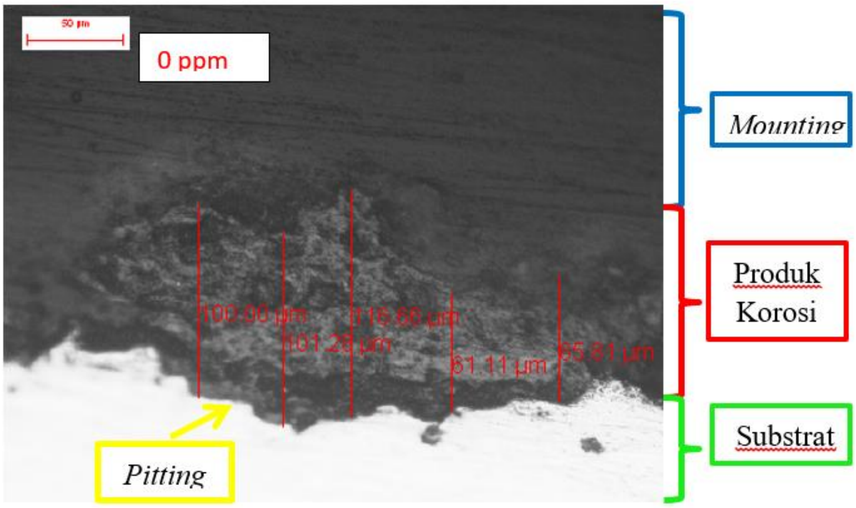

Fig. 6. The microstructure of the cross-section after 25 days of immersion with 0 ppm concentration

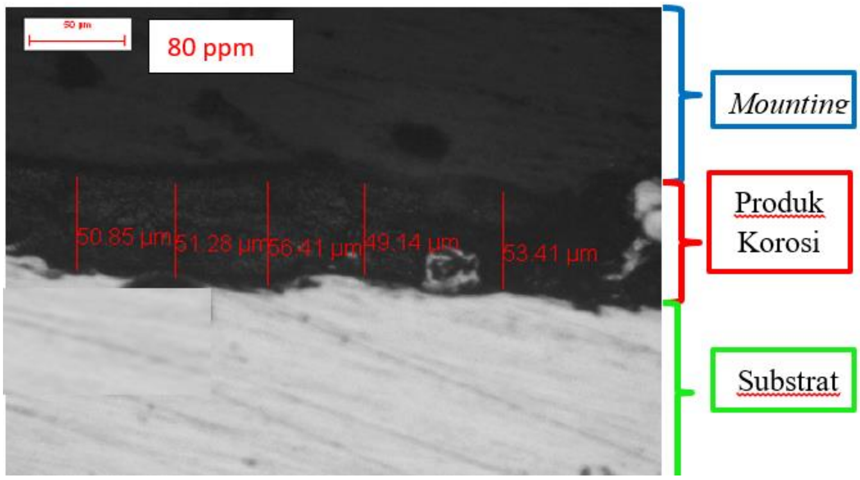

Fig. 7. The microstructure of the cross-section after 25 days of immersion with 80 ppm concentration

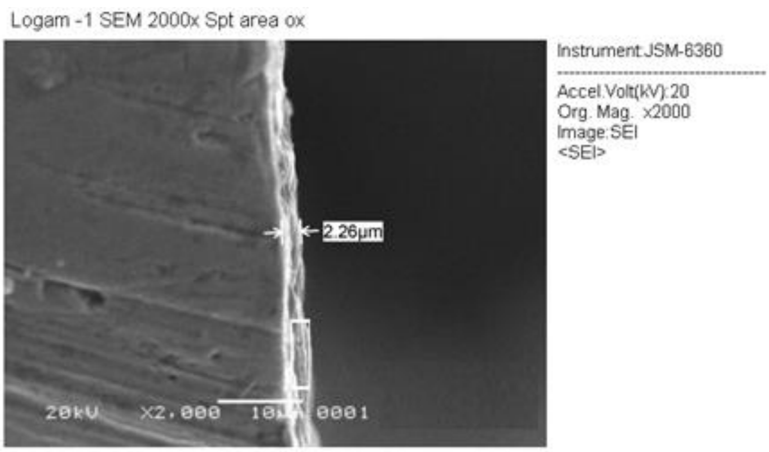

Fig. 8. SEM Test Result Photo on Cross-Section on Day 9 with 20 ppm Concentration

The SEM analysis, shown in Figure 8, reveals that specimens with 20 ppm of mango peel extract had a corrosion product layer thickness of 2.26 µm after 9 days. The EDS analysis (Figure 9) confirmed the presence of elements typical of corrosion products, including O, Fe, Mn, Al, Na, Cl, and Si. These results indicate that the mango peel extract not only reduces the extent of corrosion but also alters the composition of the corrosion layer, likely due to its antioxidant properties.

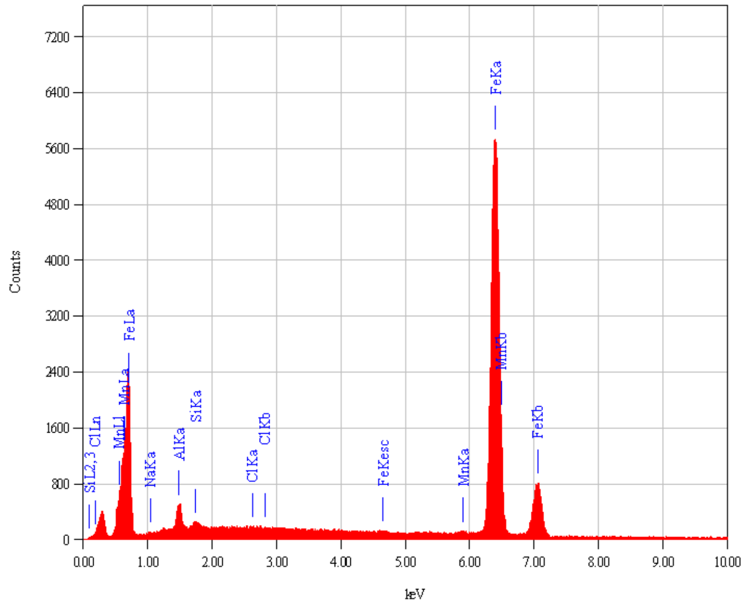

Fig. 9. Graph of EDS Test Results on Cross-Section on Day 9 with 20 ppm Concentration

3.1 Discussion

The primary objective of this study was to evaluate the effectiveness of Mangifera Indica L. peel extract as a green corrosion inhibitor for ASTM A53 steel in seawater environments. The results demonstrate that the mango peel extract significantly reduces corrosion rates and corrosion product thickness compared to untreated steel (Punia Bangar et al., 2021; Rojas et al., 2015).

Our findings are consistent with previous studies that have explored natural inhibitors. For example, Radin et al. (2023) reported that natural extracts can effectively inhibit corrosion by forming protective layers on metal surfaces. Similarly, recent work by Verma et al. (2024) highlighted the efficiency of green inhibitors in mitigating corrosion, corroborating our results with mango peel extract.

Compared to traditional corrosion inhibitors, which often involve hazardous chemicals (Gaidis, 2004; Punia Bangar et al., 2021; Zehra et al., 2022), the mango peel extract offers a more sustainable and environmentally friendly alternative (Punia Bangar et al., 2021; Rojas et al., 2015). This aligns with the growing emphasis on using green chemistry in corrosion protection (Bender et al., 2022; Chaubey et al., 2021; Shokri & Sanavi Fard, 2023). The reduction in corrosion product peaks and weight loss observed in our study supports the hypothesis that mango peel extract forms a protective film on the steel surface (Ituen et al., 2020; Punia Bangar et al., 2021; Wongkaew et al., 2021), thereby minimizing metal-environment interactions.

The XRD and SEM-EDS analyses provide detailed insights into the corrosion mechanisms (C. Verma et al., 2024; P. Verma et al., 2021; Zhang et al., 2022). The decrease in corrosion product peaks with mango peel extract suggests that the inhibitor effectively interferes with the formation of aggressive corrosion compounds (Anandkumar et al., 2023; Katysheva, 2023; Shin et al., 2022). SEM-EDS results further reveal a thinner and less aggressive corrosion layer in the presence of the extract, supporting the effectiveness of the mango peel extract in forming a protective barrier.

In conclusion, the use of Mangifera Indica L. peel extract as a corrosion inhibitor offers a promising, eco-friendly alternative to traditional methods. This study not only provides valuable insights into the effectiveness of natural inhibitors but also contributes to the broader field of sustainable materials science.

4. Conclusion

This study successfully demonstrated the effectiveness of Mangifera Indica L. peel extract as a green corrosion inhibitor for ASTM A53 low carbon steel in seawater environments. Through comprehensive analysis, including spectrometry, XRD, SEM, and EDS, we found that the steel, characterized by a carbon content of 0.234% and alloying elements like manganese and silicon, is highly susceptible to corrosion. The research highlighted that prolonged immersion in seawater significantly increases corrosion product thickness and weight loss. However, the application of mango peel extract markedly reduced these metrics by forming a protective film on the steel surface, which mitigates the corrosion process.

The XRD analysis revealed that without inhibitors, the corrosion products included aggressive compounds such as Fe_2O_3, FeOOH, and Fe_3O_4, along with NaCl from seawater. In contrast, specimens treated with mango peel extract showed reduced peaks for these corrosion products, indicating lower corrosion rates. SEM-EDS analysis further confirmed the presence of a less aggressive corrosion layer and the effectiveness of the mango peel extract in providing corrosion protection.

These findings underscore the practical benefits of using natural, environmentally friendly corrosion inhibitors like mango peel extract. The research not only provides an effective solution for reducing corrosion in steel exposed to harsh marine conditions but also aligns with the growing emphasis on sustainable and green technologies in materials science. By demonstrating the potential of mango peel extract as a cost-effective and eco-friendly alternative to traditional inhibitors, this study offers valuable insights for developing more sustainable corrosion protection strategies in industrial applications.

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