Poll Res. 44 (3–4) : 237-245 (2025)

ISSN 0257–8050

DOI No.: http://doi.org/10.53550/PR.2025.v44i03-04.014
Journal Home Page: www.envirobiotechjournals.com

ANTI-CORROSIVE PROFICIENCY OF ZINC METAL IN SEA WATER USING AMINO BENZOIC ACID AS AN INHIBITOR

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(Received 12 February, 2025; Accepted 10 April, 2025)

ABSTRACT

The study investigates the effectiveness of an amino benzoic acid as an inhibitor in reducing the corrosion rate of zinc metal exposed to seawater. Using a variety of analytical techniques, including mass loss measurements, electrochemical studies, and AC impedance spectroscopy, the researchers examined the inhibitor's impact on corrosion. To further assess surface morphology changes, by employed atomic force microscopy (AFM), infrared (IR) spectroscopy, scanning electron microscopy (SEM), and energy-dispersive X-ray analysis (EDAX). Findings from the mass loss approach reveal that the presence of 250 parts per million (ppm) of the amino benzoic acid compound achieves an inhibition efficiency (IE) of 83.78% in protecting zinc from seawater-induced corrosion. Polarization studies suggest that the inhibitor operates predominantly through cathodic inhibition mechanisms, effectively impeding corrosion at the cathode of the electrochemical cell. AC impedance spectra indicate the formation of a protective layer on the zinc surface, which reduces corrosion. This protective film, containing a complex of Zn²z ions and amino benzoic acid, is confirmed through SEM, EDAX, and AFM analyses.

KEY WORDS : Inhibitor, Seawater, zinc metal, SEM, EDAX, AFM

INTRODUCTION

Zinc metals are primarily utilized in nonferrous alloys and are highly prevalent in various industries due to their exposure to chloride ions, which are commonly encountered in industrial and environmental conditions. Chloride ions have been shown to react aggressively with zinc, leading to significant corrosion issues. Research has highlighted various plant-based heterocyclic compounds with corrosion-inhibiting properties, which have proven effective in reducing the degradation of zinc metal in chloride-rich seawater environments (Habeeb *et al.*, 2018; Rahimi *et al.*, 2022; Aslam *et al.*, 2022; Jassim *et al.*, 2022). For instance, studies on thiocarbonyl-containing organic-inorganic materials have demonstrated their corrosion defense potential. Similarly, (Ramezanzadeh *et al.*, 2019) reported a synergistic corrosion inhibition effect involving *Mangifera indica* leaf extract and zinc ions on mild steel in simulated seawater (Sheit *et al*., 2022). Another study by Sheit *et al.* (2022) investigated the anticorrosive efficiency of mild steel in sodium chloride solutions, using a compound known as 5-acetyl-3-phenyl-2,6-dipyridin-2-yltetrahydropyrimidin-4(1H)-1 as an inhibitor. In a related study, (Keleº *et al*., 2021) examined the inhibition behavior of 2-((4-(dimethylamino) benzylidene) amino) benzenethiol for carbon steel in hydrochloric acid, revealing valuable insights into inhibitor performance. Karthikeyan *et al.* (2019) explored corrosion characteristics of zinc-coated steel in seawater, focusing on the synergistic effects of metal cations and organic compound mixtures, which were further studied by Umoren, S.A. for various marine applications (Ravichandran *et al.*, 2019). Additionally, investigated the electrochemical behavior of brass in artificial seawater, assessing the role of organic inhibitors (Abd El-Lateef *et al.*, 2023). The current research aims to identify the multifaceted properties of amino benzoic acid compounds as corrosion inhibitors. Using mass loss measurements, electrochemical analysis, and AC impedance spectroscopy, the efficacy of a specific amino benzoic acid complex in mitigating zinc corrosion in seawater was evaluated. Surface analysis methods, including infrared (IR) spectroscopy, scanning electron microscopy (SEM), energy-dispersive X-ray analysis (EDAX), and atomic force microscopy (AFM), were employed to further investigate the surface morphology and composition of the protective film formed on the zinc metal surface, providing insights into the inhibitory action of amino benzoic acid in corrosive marine environments.

Preparation of zinc metal specimens

Zinc metal specimens were prepared using a sheet of metal with a specific composition: lead (0.03%), cadmium (0.04%), iron (0.001%), with the remainder being pure zinc. The metal sheet was cut into specimens measuring 4 cm × 2 cm × 0.08 cm, which were subsequently polished to a mirror finish ([Medupin *et al.*, 2023; Mhiri, *et al.*, 2013).

Characterization Techniques

The surface morphology and topography of the prepared mild steel samples were examined using a Zeiss Sigma model FEI Quanta 250 scanning electron microscope (SEM). This SEM enabled high-resolution imaging, providing detailed insights into the surface features and morphological changes induced by corrosion and inhibition processes. Topographical images captured with this instrument highlighted the effects of the anticorrosion treatment on the mild steel's surface. To identify and confirm the functional groups present on the mild steel surface, Fourier-transform infrared (FTIR) spectroscopy was conducted using a Spectrum One model spectrometer from Perkin Elmer. The FTIR analysis helped to identify specific chemical bonds and molecular structures, offering a deeper understanding of the inhibitor's interaction with the steel surface. Elemental composition analysis was performed using the attached Energy Dispersive X-ray Analyzer (EDX), which identified and quantified the elements present on the mild steel surface.

RESULTS AND DISCUSSION

Analysis of the Mass loss and Corrosion rate

The mass loss technique was performed in accordance with protocol (Dehghani *et al.*, 2019; Prasanna *et al.*, 2019). One day of mass loss protocols entailed dipping specimens of zinc metal in seawater and diverse concentrations of amino benzoic acid (50 ppm -250 ppm). After being captured for 24 hours, the tester is completely exposed, soaked in sequence with water, shriveled, and placed on a scale. The effectiveness of the inhibition is then intended using the equation below:

$$\text{IE } (\%) = \frac{W_0 - W_1}{W_0} \text{X100}$$

Where W1 and Wo be there the mass defeat values in gram by the survival and scarcity of inhibitors, consistently. The rot paces of zinc metal immersed in sea water regardless of consumption inhibitors were acquired by mass decrease and are displayed in Table 1. Around 250 ppm of inhibitor exposed 83.78% consumption control. As the inhibitor focus expanded, the rot restraint effectiveness likewise expanded. The electron-giving capacity of the N and O molecules adjoining the delocalized pi electrons likewise adds to the development of better inhibitors.

Table 1. Corrosion rates (CR) and inhibition efficiency (IE %) data obtained from mass loss measurements for zinc metal is immersed in seawater without and with various concentration of amino benzoic acid.

Blank	Amino benzoic acid (ppm)	CR (mdd)	IE (%)
Sea water	-	59.67	–
	50	51.21	38.52
	100	40.65	47.28
	150	32.54	58.03
	200	22.32	69.68
	250	13.21	83.78

Analysis of the consequences of potentio dynamic polarity study

The polarization analyse was ensured on 3-terminal cells. The by walking terminal has been fabricated as of a light metallic substantial, with one look of the cathode revealed in a normal 1 cm^2 locale and the left district covered with red finish. A soaked calomel cathode was utilized, and a quadrangular platinum foil was changed as locus terminal. The counter terminal's environmental factors transformed into an enormous cathode looking like a running terminal. The activity terminal and platinum cathode had been drenched in ocean water and were without any trace of inhibitor. A brackish extension associated a soaked calomel cathode to the trial reply. The worth of E is plotted against I (log current), from this plot, consumption potential (E_{corr}) and Tafel slants ba and bc are found (Merimi, *et al.*, 2023; Krid *et al.*, 2018; Chung *et al.*, 2019).

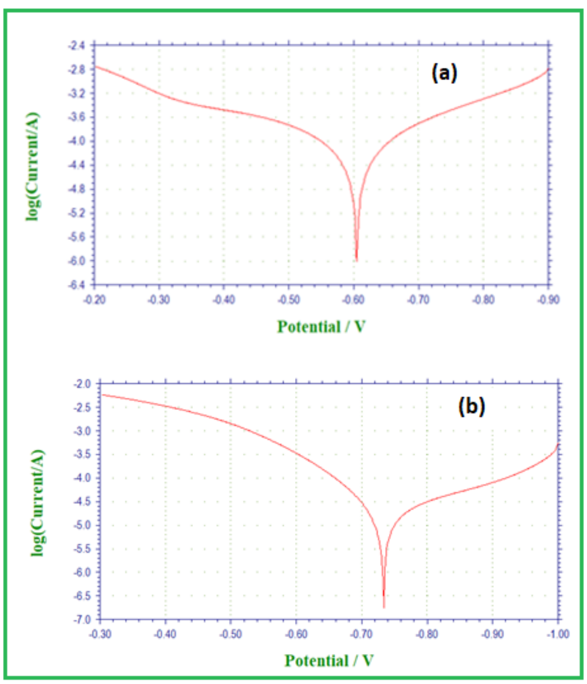

Fig. 1. Polarization curves (a) zinc metal immersed in test Solutions Sea water (blank) (b) Sea Water + 250 ppm of amino benzoic acid

A polarization concentrate on has been utilized to affirm the development of a defensive riffle on the zinc metal superficial during the erosion restraint process. On the off chance that a defensive film is shaped on the zinc metal surface, the straight polarity opposition esteem (LPR) increments and the consumption current worth (Icorr) diminishes (Boukazoula *et al.*, 2022; Rajamohan *et al.*, 2022; Deyab *et al.*, 2022). The potentiodynamic polarity bends of zinc metal submerged in seawater, as well as the restraint efficiencies (IE) in nonappearance and existence of an inhibitor, are displayed in Figure V.1(a, b). The erosion boundaries are given in Table 2. At the point when zinc metal was submerged in seawater, the consumption potential was - 605 mV versus SCE. When 250 ppm of amino benzoic corrosive was additional to the above framework, the consumption potential moved to the cathodic side (- 734 mV versus SCE). This demonstrates that the defensive film is shaped on the cathodic locales of the zinc metal surface. This stratum controls the cathodic response of zinc metal disintegration by framing the Zn^{2+}- amino benzoic acid complex on the cathodic locales of the zinc metal outer.Further, as the LPR esteem increments from 531 ohms/cm^2 to 1500 ohms/cm^2, the erosion current abatements from 8.001×10^{-5} µA to - 2.102×10^{-5} µA. Consequently, the polarityreview affirms the enlargement of a defensive coaton the zinc metal superficial**.**

Analysis of AC impedance spectra

The cell plan is like that of divergence estimations. The framework is given approximately 5-10 minutes to achieve a steady state open circuit capacity; an alternate current limit of 10 mV is imposed. The substituting current frequency utilized goes from 100 kHz to 100 MHz. The z′ and z′′ of cell impedance are determined in ohms for some frequencies. The following condition is used to calculate the speed of move opposition and twofold layer capacitance values.

$$C_{dl} = \frac{1}{2 \times 3.14 \times Rt \times f_{max}}$$

Table 2. Corrosion parameter of zinc metal is immersed in sea water and inhibition efficiencies (IE) in the absence and presence of inhibitor system obtained by potentiodynamic polarization method.

Systems	E_{corr} vs SCE (mV)	I_{corr} (A/cm^2)	b_a (mV/dec)	b_c (mV/dec)	LPR (ohm cm^2)
Blank(Sea water)	-605	8.001×10^{-5}	0.213	0.18	531
Blank + 250 ppm of ABA	-734	2.102×10^{-5}	0.104	0.235	1500

Alternate current impedance (electrochemical impedance spectra) have been utilized to affirm the development of a defensive film on the zinc metal surface (Matad *et al.*, 2014; Badiea, *et al.*, 2019; Alamiery *et al.*, 2021). In the event that a defensive film is framed on the zinc metal surface, charge move opposition (Rt) increments; twofold layer capacitance esteem (Cdl) diminishes, and the impedance log (Z/ohm) esteem increments. The alternatae impedance spectra of zinc metal drenched in ocean water in the non attendance and manifestation of inhibitors are displayed in Figs. 2 (a, b) (Nyquist plots), Figures 3 (a, b) (Bode plots), and Figures 4 (a, b) (Stage Point).

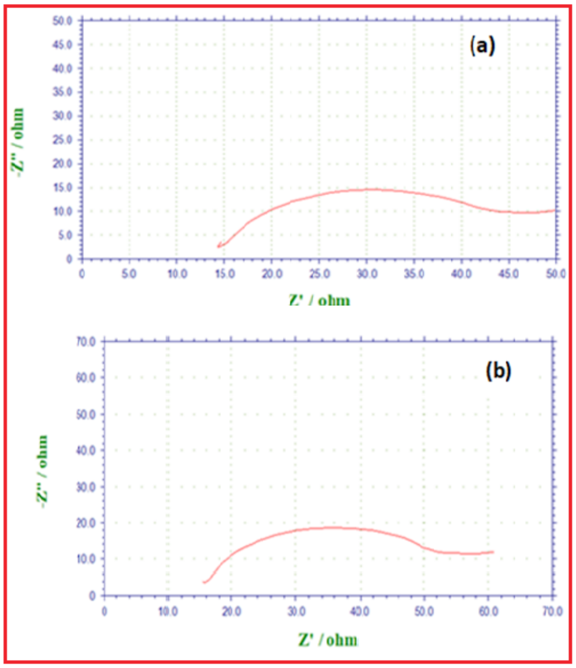

Fig. 2. AC impedance spectra(a) zinc metal immersed in sea water (blank), (b) Zinc metal immersed in sea water + 250 ppm of amino benzoic acid

The qualities are given in Table 3. It is seen that when the inhibitor (250 ppm of amino benzoic corrosive) is added to the above framework, the charge moves opposition (Rt) increments from 35.42 Ù cm^2 to 45.14 Ù cm^2 and the C_{dl} esteem diminishes

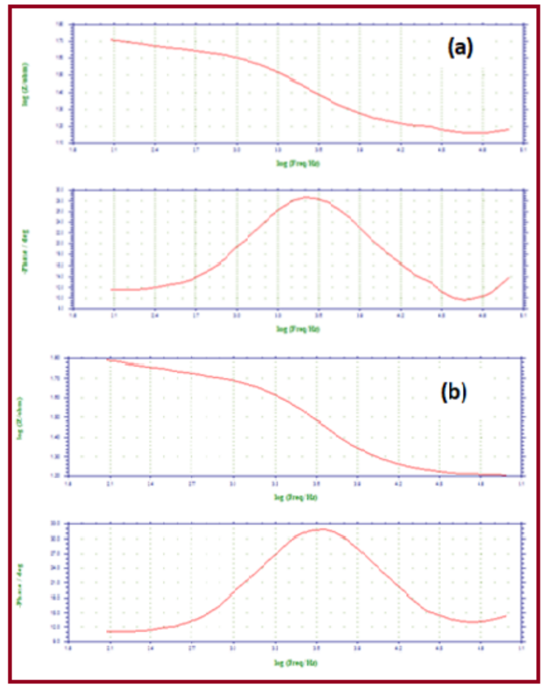

Fig. 3. Bode plot of AC impedance spectra (a) zinc metal immersed in sea water (blank), (b) zinc metal immersed in sea water + 250 ppm of amino benzoic acid

from 58.3367 × 10^{-6} F cm^{-2} to 74.3455 × 10^{-6} F cm^{-2}.

The impedance esteem [log(z/ohm)] increments from 0.531 to 0.589. Besides, the stage point esteem increments from 28.5º to 32.0º. These outcomes lead to the decision that a defensive film is framed on the zinc metal surface (Heakal *et al.*, 2011; Esmaeili *et al.*, 2015; Solomon *et al.*, 2020).

Surface examination of Zinc metal by SEM

The zinc metal is immersed in seawater solution containing inhibitor for one day. The specimen is taken out, dried and observed under the investigation of SEM.The images of fresh zinc metal is shown (control) Fig. 5a which show the smooth surface and also absence of corrosion inhibitor formed on the zinc metal surface (Prabhu *et al.*, 2008; Abdallah *et al.*, 2022; Negm *et al.*, 2012; Saxena *et al.*, 2018). The zinc metal surface has been corroded due

Table 3. Corrosion parameters of zinc metal immersed in seawater solution in the absence and presence of inhibitor system obtained from AC impedance spectra

Systems	Nyquist plot	Bode plot	
	Rt (&! cm^2)	C_{dl} (F cm^{-2})	Impedance Log (Z ohm^{-1})
Sea water (Blank)	35.42	58.3367 ×10^{-6}	0.531
Sea water + 250 ppm ABA	45.14	74.3455 ×10^{-6}	0.589

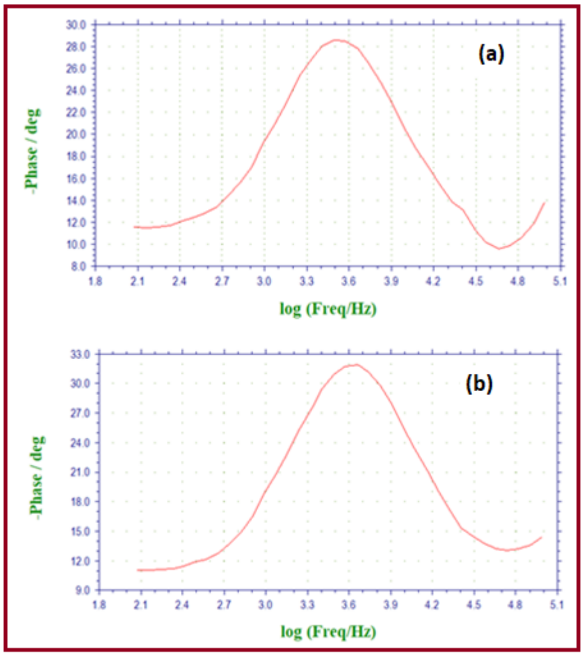

Fig. 4. Phase angle of AC impedance spectra (a) zinc metal immersed in sea water (blank),(b) zinc metal immersed in sea water + 250 ppm of amino benzoic acid

to metal dissolution in sea water is shown (blank) Fig. 5b. It is a rough zinc metal surface, which specify highly corroded area. The zinc metal surface immersed in seawater containing inhibitor is shown in Fig. 5c. However, in the presence of inhibitor (250 ppm of ABA) the rate of corrosion is suppressed, as can be seen from the decrease of corroded areas.

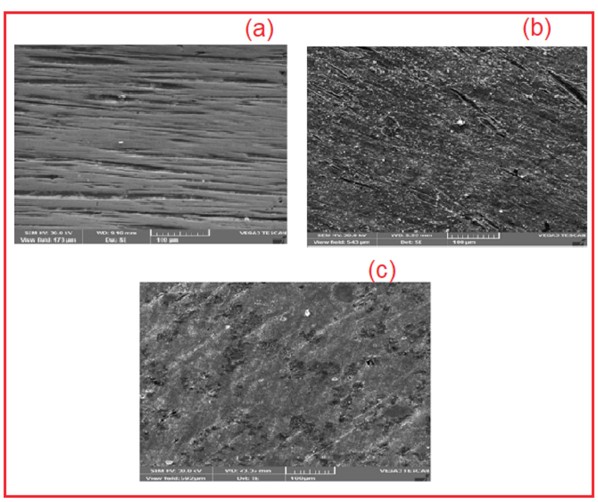

Fig. 5. SEM Image of (a) Polished Zinc Metal (b) zinc metal + Sea water (c) Zinc metal + sea water + inhibitor compound (250 ppm).

EDAX Analysis of Zinc Metal Surfaces

The EDAX spectrum of untreated zinc metal is displayed in figure 6a, highlighting the prominent peaks corresponding to key elements within the zinc metal matrix (Abdulridha *et al.*, 2022; Laadam *et al.*, 2023; Rathod *et al.*, 2021). These peaks represent the primary components present in the zinc sample, indicating the purity and baseline elemental composition before any exposure to seawater. Figure 6b shows the EDAX spectrum of zinc metal after immersion in seawater. In this spectrum, the intensity of the zinc peaks decreases, while the oxygen peak significantly increases. This shift in signal intensity suggests a corrosion process, where oxygen interactions on the zinc surface point to oxidation induced by exposure to seawater. In Figure 6c, the EDAX spectrum of zinc metal immersed in a seawater solution containing 250 ppm of amino benzoic acid is shown in figure 6b. In contrast to Figure 6b, the oxygen signal is notably

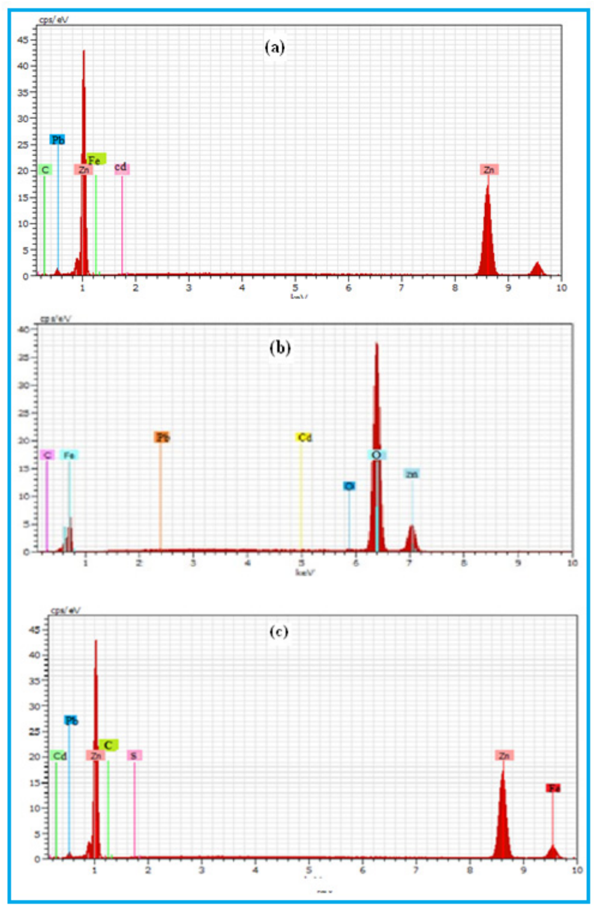

Fig. 6. EDAX spectrum(a) Zinc Metal (b) zinc metal + Sea water (c) Zinc metal + sea water + inhibitor compound (250 ppm).

reduced, and the zinc peaks are more pronounced. This alteration in the spectrum suggests that the inhibitor forms a protective film on the metal surface, suppressing direct zinc oxidation. Additionally, the presence of other elements such as palladium (Pd), aluminum (Al), and iron (Fe) in trace amounts may be observed, possibly due to slight contamination or alloying constituents in the sample.

The diminished zinc peaks observed in the inhibitor-treated sample (Figure 6c) compared to untreated seawater immersion indicate the development of a robust inhibitor layer. This layer adsorbs onto the zinc surface, effectively reducing the intensity of zinc peaks and protecting the metal from direct interaction with seawater. These findings suggest that nitrogen and oxygen atoms from the amino benzoic acid inhibitor coordinate with Zn^{2}z ions, forming a stable Zn^{2}- amino benzoic acid complex that adheres to the zinc surface. This complex acts as a protective barrier, reducing the rate of corrosion in seawater..

Topological Analysis of Zinc Metal Surfaces

The geography of the surfaces kept in 2D, 2D cross sectional profile charts, and 3D pictures was analysed, and the typical unpleasantness (Ra), surface harshness (RMS), and greatest top-to-valley distance were not set in stone from the separate pictures. In the AFM strategy, the upsides of Sp, Sq, Sa, and Sy for the cleaned zinc metal combination surface (reference) are (701.5, 108.18, 837.65, and 108.68) nm, which show a more homogeneous surface contrasted with the clear (1986, 458.63, 955.34, and 378) nm, separately. This will show that the clear surface has a greater unpleasantness than the cleaned zinc metal surface (Figure 7a). Besides, this shows that the unprotected zinc metal compound surface is more unpleasant because of the erosion of metal in a fluid arrangement of ocean water (Figure 7b). Table 4 shows when consumption inhibitors containing ocean water are present, the normal unpleasantness (Sa) value decreases from 880 nm with the inhibitor to 955.34 nm with the clear. The value shows that the enormous distinction in these boundaries affirms that the surface seems smoother (Figure 8c), because of the development of a minimised defensive film (Chung *et al*., 2019; Haldhar *et al*., 2021; Da Silva *et al.*, 2021; Kumar *et al.*, 2020).

Mechanism

- In order to clarify these specifics, the following mechanism of corrosion inhibition is proposed

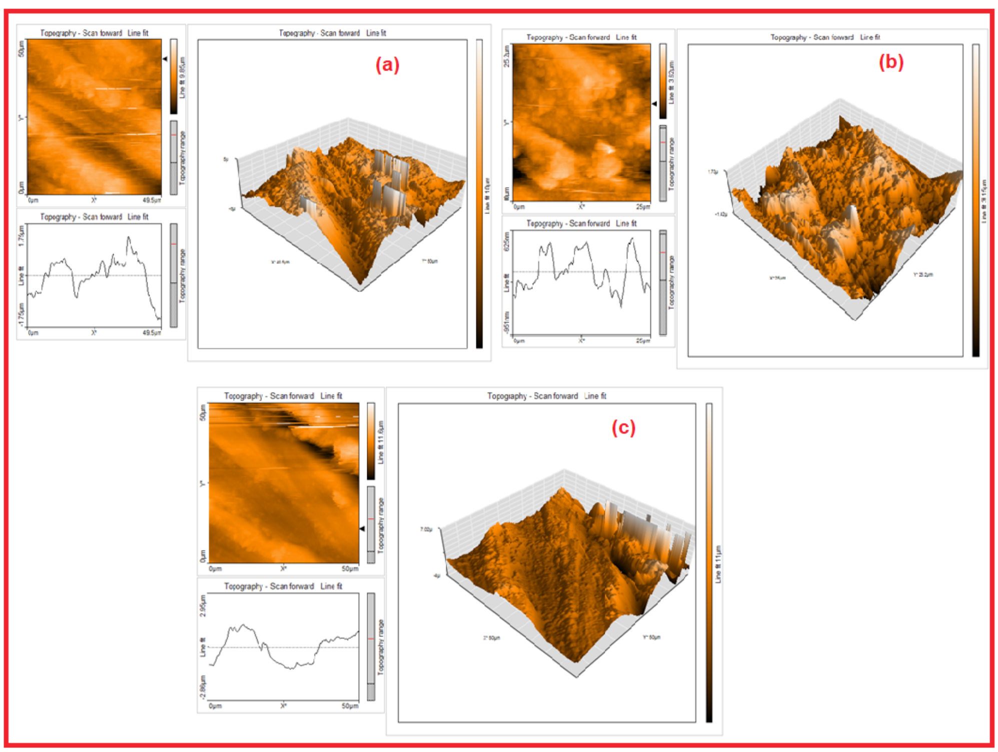

Fig. 7. AFM images(a) Polished zinc Metal (b) Zinc metal + Sea water (c) Zinc metal + sea water + inhibitor compound (250 ppm).

(Rajappa *et al*., 2008; Sheit *et al*., 2023; Sheit *et al*., 2024; Vathsala *et al*., 2010).

- When a solution of seawater and aminobenzoic acid is prepared. In this solution, aminobenzoic acid is ionized
- Zinc metal is submerged in this solution; the ionised amino benzoic acid migrates to the zinc metal's surface and is converted into a more stable Zn^{2+}-amino benzoic acid complex.

$$\text{Amino Benzoic Acid} + \text{Zn} \xrightarrow{\Delta} \text{Zn}^{2+} - \text{Amino Benzoic Acid}$$

- As a result, the protective film is made up of a Zn^{2+}-amino benzoic acid complex. This is confirmed by FTIR spectra
- The EDAX analysis and SEM micrographs confirm the formation of a protective film over the zinc metal surface.

The AFM confirms the roughness and smoothness of the zinc metal surface.

CONCLUSION

This study investigated amino benzoic acid's role as a corrosion inhibitor for zinc in seawater, focusing on its protective capabilities and inhibition mechanisms. Techniques like mass loss measurements, electrochemical studies (polarization and AC impedance), and surface analysis (FTIR, SEM, EDAX, and AFM) provided insights into its interaction with zinc. Results indicated that higher concentrations of amino benzoic acid led to increased adsorption on the zinc surface, creating a stable film that significantly reduced corrosion rates. Mass loss measurements showed a high inhibition efficiency of 83.78%, highlighting amino benzoic acid's effectiveness in corrosive environments. Polarization studies revealed that it acts as a cathodic inhibitor, reducing the cathodic reaction, which typically accelerates corrosion. Electrochemical impedance analysis showed an increase in charge transfer resistance and a decrease in double-layer capacitance, pointing to a robust barrier on the zinc surface. FTIR confirmed that the protective film comprised a Zn^{2+}- amino benzoic acid complex, which stabilized the surface. SEM images displayed a smoother zinc surface after treatment, resembling polished zinc, indicating successful protection. EDAX confirmed the layer's presence, while AFM showed reduced surface roughness due to the inhibitor. These findings suggest that amino benzoic acid is a practical corrosion inhibitor for zinc in seawater, forming a strong adsorbed layer that minimizes corrosion and strengthens the metal's resistance. This study underscores its potential for use in marine and other corrosive applications.

Conflict of Interest - None

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