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Inhibitory effect of expired glavox tablets on A36 carbon steel for optimized service life

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Abstract

This research delves into the potential of expired Glavox tablets, containing Amoxicillin and Clavulanic acid, as environmentally friendly substances to inhibit corrosion on A36 carbon steel in solutions of 1M HCl and 3.65 wt% NaCl. The findings from weight loss experiments in 1M HCl indicated a decrease in the corrosion rate, dropping from 1.24 mm y^{-1} for untreated specimens to 0.17 mm y^{-1} for specimens treated with 7.5 ml of Glavox solution. Similarly, in the 3.65 wt% NaCl solution, the corrosion rate reduced from 0.98 mm y^{-1} to 0.23 mm y^{-1} with the same concentration of inhibitor. Electrochemical assessments conducted in the HCl medium unveiled alterations in the corrosion potential (E_{corr}) from −0.48 V to −0.35 V, and a decline in the corrosion current density (i_{corr}) from 3.2 mA cm^{-2} to 0.42 mA cm^{-2}, indicating a blend of inhibitory characteristics. Within the NaCl medium, E_{corr} transitioned from −0.45 V to −0.30 V, while i_{corr} decreased from 2.9 mA cm^{-2} to 0.57 mA cm^{-2}. Studies on adsorption affirmed the robust adsorption capacity of Glavox on the steel surface, aligning well with Langmuir, Freundlich, and Temkin isotherm models. The formation of a barrier of protection on the inhibited samples was revealed by SEM/EDS examination of the surface morphology. The outcomes propose that expired Glavox tablets exhibit efficacy as corrosion inhibitors in acidic and saline settings, attaining an inhibition efficiency of up to 86%, predominantly through adsorption and the formation of a protective film.

1. Introduction

Corrosion incurs a global cost of approximately $2.5 trillion, nearly 3.5% of the world's GDP. Therefore, studying corrosion inhibition is both theoretically and practically significant [1–4]. Mild steel is widely used across various industries due to its excellent mechanical properties, but it exhibits poor corrosion resistance, particularly in acidic environments. Acids are commonly employed in industrial procedures such as pickling, cleaning, and descaling. Because of their aggressive nature, inhibitors are used to slow metal breakdown [5–9]. Inhibitors generally consist of compounds containing nitrogen, sulphur, and oxygen. The efficiency of an organic inhibitor is largely determined by its capacity to adsorb on the metal surface, which requires replacing water molecules at the corrosive contact. Adsorption is controlled by the electronic structure of the inhibitor molecules, steric variables, aromaticity, electron density at donor sites, the presence of functional groups (e.g., -CHO, R-OH), as well as the inhibitor's molecular area and weight [10–13]. While numerous natural substances are efficient corrosion inhibitors for mild steel, only a few non-toxic and ecologically friendly alternatives have been investigated [14, 15].

Drugs which consist of heteroatoms and are environmentally friendly show promise as corrosion inhibitors. Gece's analysis identified 17 medication classes such as Penicillin G, Ampicillin, Dicloxacillin, etc that are effective in corrosive settings, including HCl, H_2SO_4, NaCl, and H_3PO_4 [16]. However, medications are typically more expensive than current industrial organic inhibitors, making new drugs economically impractical for corrosion prevention. Investigating expired pharmaceuticals, which retain at least 90% of their efficacy but are unfit for medicinal use due to regulatory and liability difficulties, could be a cost-effective solution [17–20].

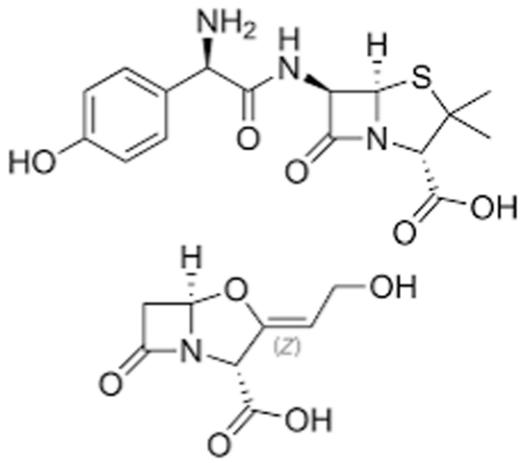

Figure 1. Chemical structure of Glavox [22].

Table 1. Elemental composition of A36 carbon steel.

Elements	C	Si	Mn	P	S	Cr	Ni	Sn	Cu	Fe
% wt.	0.2985	0.1204	0.5456	0.101	0.080	0.0266	0.0278	0.093	0.0165	Bal.

Gupta *et al* (2017) used two expired medications, atenolol and nifedipine, in a 1 M HCl solution to study the corrosion prevention capabilities of mild steel. Density Functional Theory (DFT), scanning electron microscopy (SEM), and electrochemical studies were used to assess their inhibitory efficiency. At a low concentration of 200 ppm, atenolol and nifedipine achieved efficiencies of 91.30% and 93.91%, respectively. Polarisation investigations revealed that these expired medicines function as mixed-type inhibitors, reducing both anodic and cathodic processes on a mild steel surface. Electrochemical Impedance Spectroscopy (EIS) revealed that the medicines improve polarisation resistance by adsorbing at the metal/electrolyte interface [17]. Hameed *et al* (2021) also evaluated the use of expired Megavit zinc tablets, which are known to improve physical and mental activity, as a non-toxic corrosion inhibitor for steel in 1.0 M HCl. The results showed that corrosion inhibition increased with higher concentrations of the expired medication and reduced with increasing temperature. Potentiodynamic polarisation results showed that the expired medication works as a mixed inhibitor, slowing both anodic and cathodic processes. Electrochemical impedance spectroscopy (EIS) data revealed that the expired medication improves polarisation resistance by adsorbing onto the metal/electrolyte interface using the Langmuir adsorption isotherm model [21].

Glavox tablet is a Nigerian commercial drug name of Amoxicillin (Amoxicillin Trihydrate) and Clavulanic Acid (Potassium Clavulanate) (figure 1) which is used in the treatment of various bacterial infections such as infection of lungs, airways, ears, urinary tract, skin, bone, joints, soft tissue and tooth [22]. In the same way, Glavox has made clear earlier, there is the phenomenon of their degradation over a period which, among other things, results in lessened therapeutic action as well as alteration in the chemical structure of the compounds. It is, however, no more recommended for the treatment of any diseases; it certainly finds its alternative usage in the inhibitors of corrosion which raised the interest of present study. This study aims to investigate the inhibition effect of expired Glavox drug on mild steel. Weight loss studies, electrochemical analysis, and adsorption evaluations were conducted to assess Glavox effectiveness on mild steel.

2. Methodology

2.1. Material procurement and preparation

The steel sample used for experimentation was the A36 Carbon Steel and it was purchased from the iron market in Ota, Ogun state. Upon procurement, the samples were characterized to determine the elemental makeup as shown in table 1. Expired glavox used was given for research purposes by a local pharmacy in Ota, Ogun state. The A36 carbon steel samples were cut into circular shapes with a diameter of 15 mm and a thickness of 5 mm using a hacksaw to prevent structural deformation. The samples were then ground with various abrasive sizes, including P60D, P120C, and P320C. Following grinding, the samples were polished with emery cloths of

different grades, namely P600D, P800D, P1000D, and 2000CW, to achieve a smooth surface. The samples were rinsed with distilled water to remove any surface contaminants.

2.2. Weight loss study

Corrosive solutions (1M of HCl and 3.65 wt% NaCl) containing different inhibitor concentrations (1.5 ml, 3.0 ml, 4.5 ml, 6 ml and 7.5 ml) were poured in 200 ml conical flasks. A36 Carbon Steel samples were weighed prior to immersion. Each test lasted 1–24 days, with five samples per each 48 h period. Each test was duplicated to guarantee reproducibility. Following exposure, corrosion products were mechanically removed from the specimens, which were then cleaned, dried, and weighed again. The corrosion rate was computed using the weight loss metric (equation (1)). Equation (2) uses corrosion rate to calculate inhibitor efficiency across different days.

$$CR = \frac{W_l}{(\rho * SA * t)} \quad * \quad 87.6 \tag{1}$$

Where:

CR, W_l, ρ, SA, t are the Corrosion Rate (mm/y), sample weight loss (g), Steel density (8.03 g cm^{-3}), Surface Area (cm^2) and corrosion exposure time (hours) of the test sample.

$$\%IE = \frac{CR_{uninhibited} - CR_{Inhibited}}{CR_{Inhibited}} \times 100 \tag{2}$$

2.3. Electrochemical/adsorption evaluation

In a three-electrode cell arrangement, the mild steel samples were polished with various emery paper grades before being flushed with acetone. The working electrode measured 1.5 cm^2 and was made of mild steel. Platinum wire served as the counter electrode and silver/silver chloride (Ag/AgCl) as the reference electrode. Corrosion behaviour in both acidic and alkaline solutions with concentrations of 1M of HCl and 3.65 wt% NaCl was examined using potentiodynamic polarisation techniques at 30 °C operating temperature. Different inhibitor volumes (1.5 ml, 3.0 ml, 4.5 ml, 6 ml, and 7.5 ml) were scanned at 0.001 V s^{-1}. Tafel plots were utilised to determine the optimal adsorption model as well as corrosion metrics such as surface coverage (θ), corrosion potential (Ecorr), corrosion current density (icorr), and %IE (from equations (3) and (4)) [23–26].

$$\text{Surface Coverage}(\theta) = \frac{j^0corr - jcorr}{j^0corr} \tag{3}$$

$$\%IE = \frac{i^0corr - icorr}{i^0corr} \times 100 \tag{4}$$

2.4. Post-corrosion micrograph

The corroded sample surface was examined using a JOEL JSM-7600F scanning electron microscope in conjunction with energy dispersive spectroscopy (EDS), while EDS assisted in identifying components within the inhibited layer. The Rigaku D/Max-IIIC x-ray diffractometer was used to undertake x-ray diffraction (XRD) investigation.

3. Results and discussion

3.1. Weight loss analysis

3.1.1. Weight loss response in NaCl

The weight reduction trend of carbon steel and the efficiency of Glavox tablets as an inhibitor when exposed to a corrosive NaCl medium for different durations ranging from 48 to 576 h are illustrated in figure 2 and figure 3, correspondingly. Within figure 2, the untreated sample exhibited the most substantial weight decrease as the exposure time increased, with the carbon steel enduring a weight loss of 0.0008 mg after being immersed in NaCl for 48 h. Following 336 h in the alkaline solution without any inhibition, the carbon steel experienced a weight reduction of approximately 0.088 mg, indicating a surge of 0.0872 mg in mass loss after an additional 288 h in the solution. By the end of the 576 h mark, the untreated sample had shed more than 0.19046 mg of its metallic composition. The introduction of Glavox as an inhibitor induced notable alterations, leading to a decrease in weight loss for the carbon specimens. The corrosive setting containing 1.5 g of Glavox resulted in percentage reductions in mass loss of 12.5%, 24.54%, and 194.53% when compared to the uninhibited weight loss specimens at 48, 336, and 576 h of exposure, respectively.

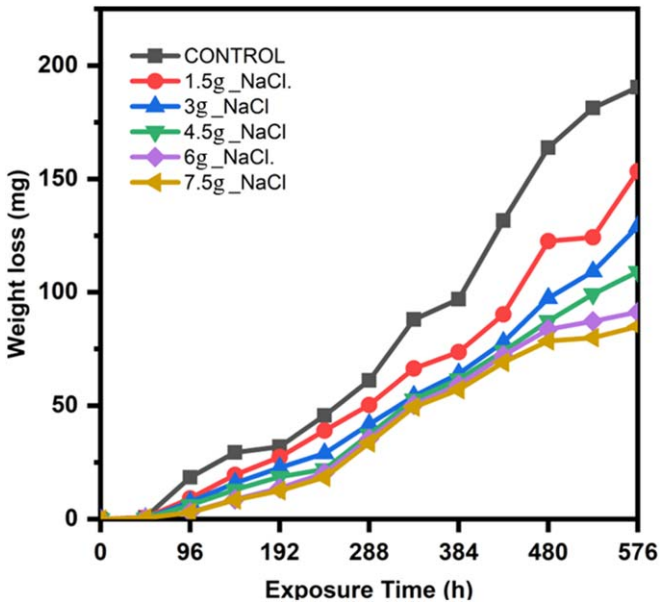

Figure 2. Weight loss of inhibited samples in NaCl environment.

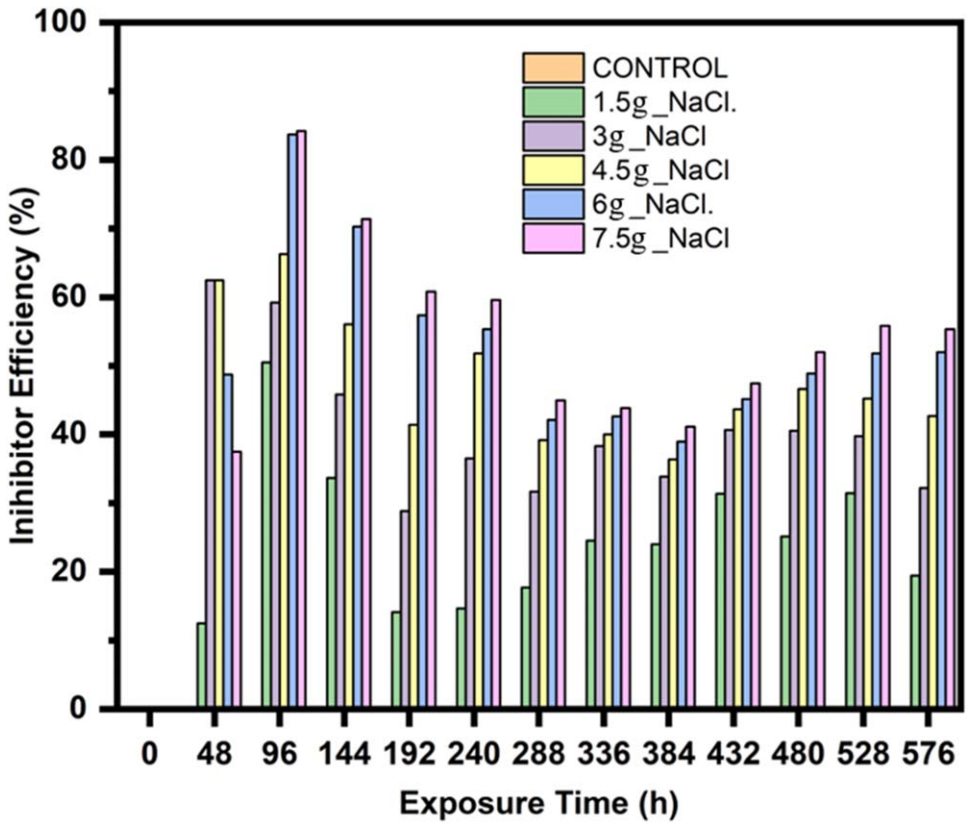

Figure 3. Inhibitor efficiency versus exposure time in NaCl environment.

As the inhibitor concentration in the alkaline medium increased, a reduction in weight loss for carbon steel was observed. The specimen in the highest inhibition concentration solution (7.5G_NaCl) exhibited a mass loss of 85.002 mg after 576 h of degradation, a significant improvement compared to samples in less concentrated Glavox-inhibited environments (1.5G, 3G, 4.5G, and 6G), which displayed final weight loss values of 153.41, 129.1, 109.1, and 91.37 mg, respectively. The weight loss trend is ascribed to the presence of molecules in the Glavox tablet, which aid in safeguarding the active sites of carbon steel through the formation of a barrier layer

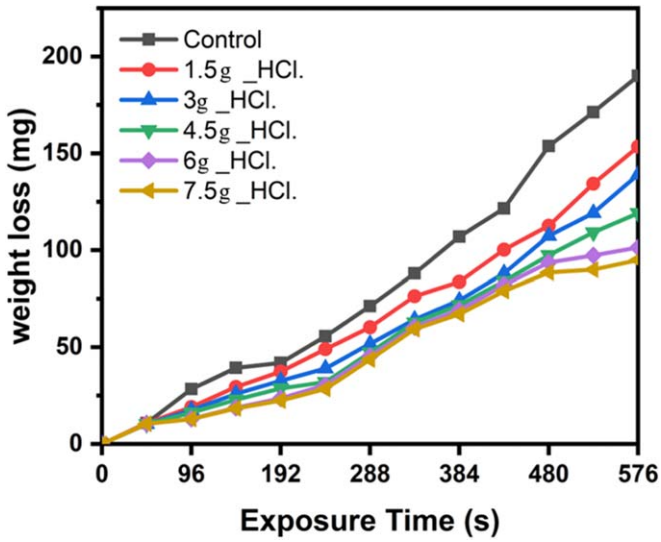

Figure 4. Corrosion rate of inhibited samples in HCl environment.

on the interacting surface, thus inhibiting the adsorption of Cl^- ions [27, 28]. The efficacy of the specimens at specified exposure durations is illustrated in figure 3. It can be deduced from the graph that the inhibitory efficiency escalates with concentration yet diminishes as the exposure time increases.

The environment with 1.5 g of Glavox showed efficiency rates of 50.54%, 14.16%, 17.72%, 24.02%, 25.15%, and 19.45% in the Cl^- ion active solution after exposure times of 98, 192, 288, 384, 480, 576 h respectively, while the most inhibited sample exhibited notably higher efficiency percentages of 84.23%, 71.39%, 60.83%, 45.01%, 41.13%, 52.04%, and 55.37% for the same time intervals of 98, 192, 288, 384, 480, 576 h respectively. A similar result was observed by Sanni *et al* [29] the weight loss results for mild steel in 1 M HCl solution revealed that the corrosion rate significantly decreased with the addition of Eggshell agro-industrial waste (ESAW). This trend was attributed to the increased interaction of Glavox molecules with the metal surface, forming protective films that prevent corrosion by blocking reaction sites and altering anodic and cathodic processes.

3.1.2. Weight loss response in HCl

The change in mass of carbon steel samples in a Glavox-inhibited HCl environment over a period of 48 to 576 h is shown in figure 4. From figure 4, we can observe the control sample having the highest weight loss throughout the 576 h of corrosive exposure. After the first 144 h in HCl, the control sample had a weight loss of 0.0419 mg, which was 0.0311 mg higher than the control sample at the first weighing after 48 h. Over the next 288 h, the sample had already lost more than 0.1108 mg in comparison to the first weight loss measurement. The weight loss followed the same trend towards the final hour mark of 576, having a net loss of 0.19005 mg, which was 0.179 mg more than the initial weighting at the 48th-hour mark. Moving on to inhibited samples, we could observe a significant drop in weight loss as the gram content of Glavox present in the acidic medium increased. Taking significant hour marks of 48, 288, and 576 h, we could see that the 1.5G_HCl, 3G_HCl, 4.5G_HCl, 6G_HCl, and 7.5G_HCl had weight loss values of 107, 60.3, and 153.4 mg; 103, 51.8, and 139.1 mg; 103, 47.2, and 119.1 mg; 104, 45.4, and 101.3 mg; and 105, 43.65, and 95.0 mg, respectively. This weight loss progression can be ascribed to the inhibitive effect of Glavox earlier displayed in the alkaline environment of NaCl, whereby the presence of molecules within the expired drug helped in forming a barrier layer against the penetration of Cl- ions into the active sites of carbon steel [30–33].

Figure 5 depicts the inhibitor efficiency of the inhibited samples in an HCl medium for a time frame of 0 to 576 h. The plot shows an increase in efficiency with an increase in Glavox content, although there was a decrease in efficiency as the exposure time in HCl increased. The most efficient sample (7.5G_HCl) had efficiency values of 54.57%, 46.27%, 38.69%, 37.29%, 42.42%, and 50.01%, respectively. Inhibition efficiency (IE) from the weight loss method in 1 M HCl and 1 M H_2SO_4 was shown by [34], who also observed similar weight loss results. Additionally, data displayed the corrosion rate (CR) at different inhibitor concentrations, showing that while the corrosion rate dropped, the inhibition efficiency improved as the studied inhibitor concentration increased. This behaviour is explained by the fact that as the inhibitor's concentration rose, the inhibitor's adsorption at the mild steel–acid interface increased. These findings imply that the inhibitor under investigation might function as a potent corrosion inhibitor.

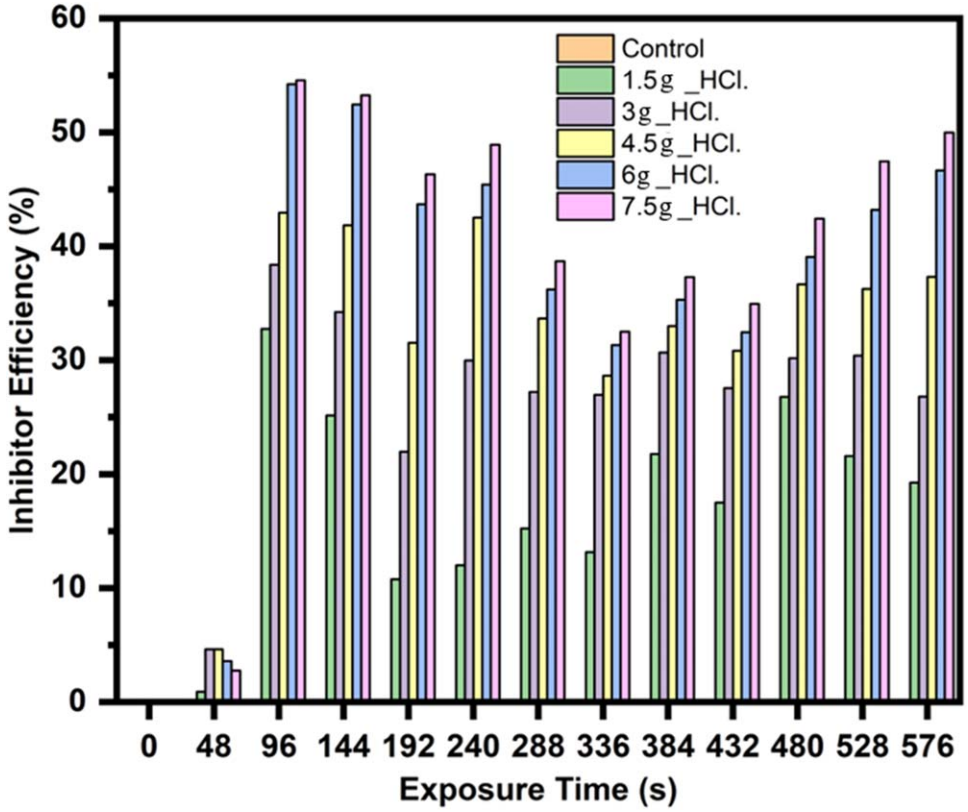

Figure 5. Inhibitor efficiency versus exposure time in HCl environment.

Table 2. Tafel data of inhibited samples in NaCl.

Sample	E_{corr} (V)	i_{corr} (A/cm^2)	CR (mm/y)	PR (Ω)
Control	−0.767	5.67E-04	9.320	2.67
1.5G_NaCl	−0.74	4.86E-04	4.470	2.71
3G_NaCl	−0.726	4.16E-04	4.020	2.88
4.5G_NaCl	−0.712	4.09E-04	3.970	3.04
6G_NaCl	−0.679	3.89E-04	3.820	3.27
7.5G_NaCl	−0.663	3.54E-04	3.380	3.53

3.2. Electrochemical evaluation

3.2.1. Glavox response in NaCl medium

The polarization data, OCP plot, and LSV trend of the carbon steel under inhibition in a NaCl environment are presented in table 2, figure 6, and figure 7, respectively. Analysis of table 2 reveals essential parameters such as current potential (Ecorr), current density (i_{corr}), corrosion rate (CR), and Polarization resistance (PR). These parameters indicate that the control sample exhibited the highest Ecorr, i_{corr}, CR, and the lowest PR values of −0.767V, 5.67E-04 A cm^{-2}, 9.320 mm y^{-1}, and 2.67 Ω, respectively among all corroded samples. The introduction of Glavox into the corrosive environment led to significant changes in the tafel data, with 1.5G_NaCl showing a 15.3% decrease in current density to 4.86E-04 A cm^{-2}, resulting in a substantial decrease in CR to 4.47 (53.14% lower than the control sample) and an increase in PR (2.71 Ω). This pattern persisted as the inhibitor concentration rose from 1.5g to 7.5 g, causing a notable decline in current density and corrosion rate by 1.32E-04 A cm^{-2} and 1.09 mm y^{-1}., respectively, in comparison to the least inhibited sample (1.5G_NaCl). The open circuit potential plot depicted in figure 6 illustrates the stability of the corrosion process over a 600 s duration. The control sample exhibited an initial potential of −0.869 V, which swiftly rose to −0.647 V after 140 s, then maintained a relatively constant potential throughout the remainder of the experimental duration.

Upon the addition of Glavox, the initial potential was notably lower at −0.795 V compared to the control, gradually increasing to −0.649 V by the 600 s mark. Variations in the starting potential concerning the control

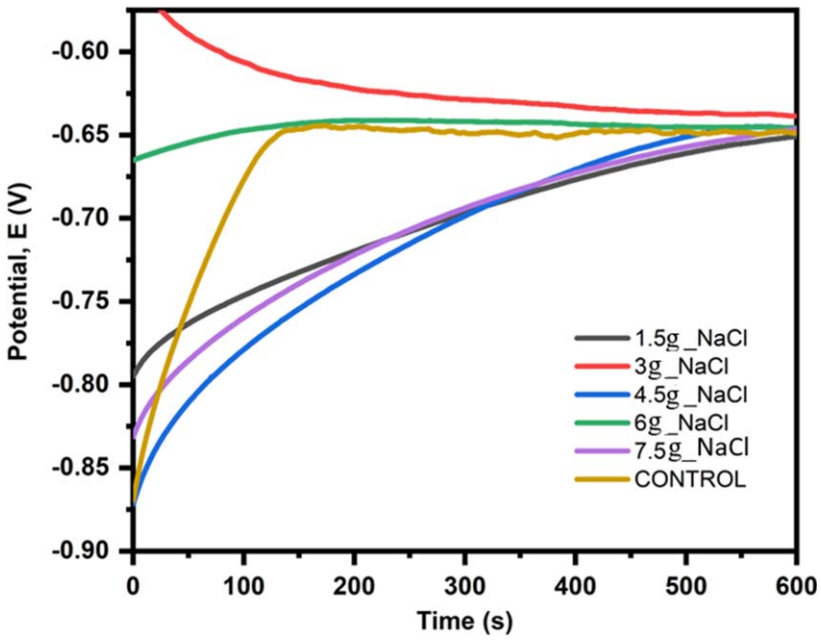

Figure 6. OCP Plot of inhibited samples in NaCl.

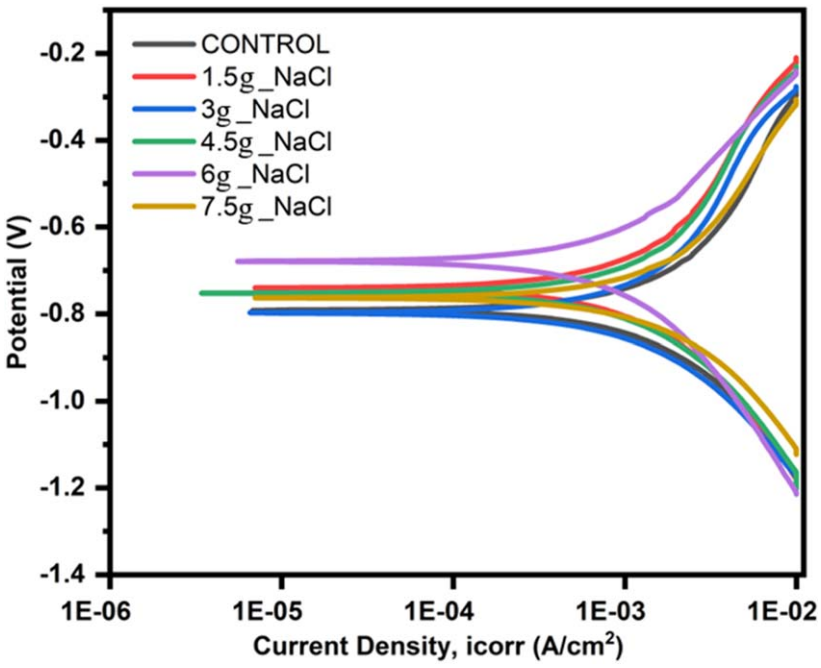

Figure 7. LSV Plot of inhibited samples in NaCl.

were observed with the introduction of increasing inhibitor concentrations, where 3G_NaCl and 6G_NaCl displayed higher initial potentials that stabilized after 600 s, indicating a shift favoring anodic processes during the degradation of carbon steel. Conversely, samples such as 1.5G_NaCl, 4.5G_NaCl, and 7.5G_NaCl showed a negative trend, suggesting a significant impact of cathodic reactions. The mixed inhibitory properties of the experimental drug are further evident in the LSV plot depicted in figure 7, illustrating a reduction in both anodic and cathodic processes with higher concentrations of Glavox in the corrosive environment [35, 36]. The investigation conducted by [37] revealed similar patterns as illustrated in the potentiodynamic polarization curves of an aluminum alloy immersed in a 3% NaCl solution at 298 K, both with and without varying concentrations of TIPA (Triisopropanolamine).

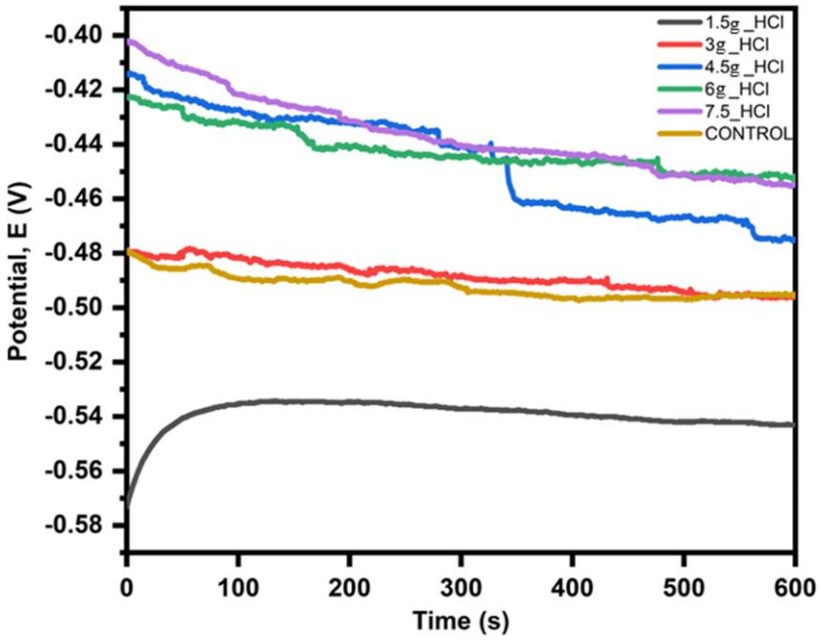

Figure 8. OCP Plot of inhibited samples in HCl.

Table 3. Tafel data of inhibited samples in HCl.

Sample	E_{corr} (V)	i_{corr} (A/cm^2)	CR (mm/y)	PR (Ω)
Control	−0.495	8.47E-04	9.82	3.04
1.5G_HCl	−0.425	8.12E-04	4.62	3.22
3G_HCl	−0.412	8.00E-04	4.41	4.16
4.5G_HCl	−0.403	7.47E-04	4.12	4.64
6G_HCl	−0.398	7.21E-04	3.87	5.21
7.5G_HCl	−0.356	6.98E-04	3.43	6.04

3.2.2. Glavox response in HCl medium

Table 3 shows the polarization data of the corroded samples in HCl environment. The control sample showed a similar trend in corrosion data in relation to the other degrading samples in HCl in comparison to the NaCl in the section 3.21. The control sample had a corrosion potential (E_{corr}), current density (i_{corr}) and corrosion rate (CR) values of −0.495V, 8.47E-04 A cm^{-2} and 3.04 Ω. The presence of Glavox in the corrosive medium changed the dynamics of the tafel plot with reduced CR, i_{corr} and E_{corr}, the 1.5G_HCl sample had aforementioned tafel values of −0.425V, 8.12E-04 A cm^{-2} and 3.22 Ω respectively. The reduction in tafel data followed onto the final sample with the 7.5G_HCl sample having E_{corr}, i_{corr} and CR values of −0.356 V, 6.98E-04 A cm^{-2} and 3.43 mm y^{-1} respectively. Figure 8 show the OCP graph of the inhibited samples with the inhibited samples shifting towards the positive region of the plot in respect the control sample. This shows the Glavox acting as an anodic inhibitor favoring anodic reactions. Similarly, the LSV plot in figure 9, showed the reduction of both anodic and cathodic processes with increasing Glavox content [38–40]. The investigation conducted by [41] reported similar findings with the potentiodynamic behavior of aluminum in 0.5 M HNO_3, with and without the presence of Dicloxacillin and Cefadroxil drugs. Analysis of the potentiodynamic results indicated that the inhibitors had a mitigating effect on both the anodic and cathodic processes, leading to a reduction in the corrosion current density (i_{corr}). Despite being classified as mixed-type inhibitors, their predominant impact was on the anodic reactions.

3.3. Adsorption study

In order to better understand the mechanism for adsorption, the indication of adsorption isotherms helps us understand the interactions between the metal surface and Glavox as an inhibiting agent. Three common models were used to show this mechanism: the Langmuir, Freundlich, and Temkin isotherms. For this study, all

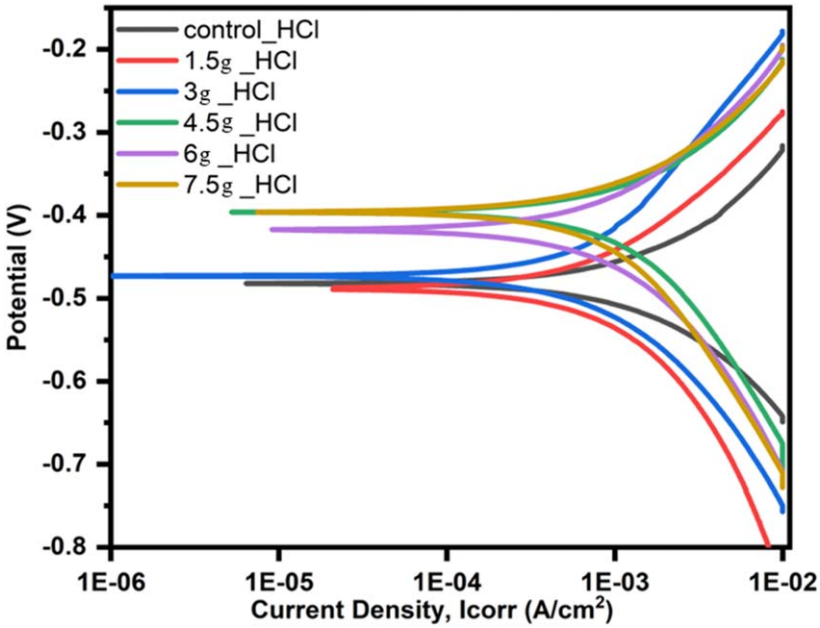

Figure 9. LSV Plot of inhibited samples in HCl.

Table 4. Langmuir and Freundlich isotherm adsorption parameters.

Temperature (°C)	Corrosive medium	Adsorption Model	$K_{ads}(mol^{-1})$	R^2
30	NaCl	Langmuir	1.1452	0.9996
		Freundlich	0.4608	0.9051
	HCl	Langmuir	0.8275	0.9980
		Freundlich	0.4542	0.9009

Table 5. Temkin isotherm adsorption parameter.

Temperature (°C)	Corrosive medium	K_{ads} (mol^{-1})	ΔG_{ads} ($KJmol^{-1}$)	R^2	ln (K_{ads})	1/T	$\Delta G_{ads}/T$	B = Slope
30	NaCl	12.187	−28.2471	0.8898	7.1946	0.0033	−0.0932	0.0625
30	HCl	5.8162	−25.9048	0.8823	6.2650	0.0033	−0.0855	0.0701

three mechanisms were used to understand the Glavox adsorption mechanism on carbon steel interface when operating in HCl and NaCl medium at 30 °C, as summarised in table 4, table 5, and figure 10 respectively. The models all showed good fit for the mechanism study as the R^2 were on the high side. The Langmuir model's R^2 values in corrosive conditions containing HCl and NaCl were 0.9980 and 0.9996, respectively. The R^2 values of the Freundlich isotherm model in HCl and NaCl media, respectively, were comparatively lower at 0.9051 and 0.9009. Of the three models, the Temkin model fit the data the least well, with R^2 values in HCl and NaCl of 0.8823 and 0.8898, respectively.

The force between the absorbent and the adsorbate is measured in K_{ads}, where a higher value indicates better inhibitory efficacy. Table 3 shows that the Langmuir and Freundlich adsorption models have comparatively lower K_{ads} values when operating in NaCl and HCl, with values of (1.1452, 0.4608 mol^{-1},) and (0.8275, 0.4542 mol^{-1}), respectively. Table 5 illustrates the Temkin model's slightly greater K_{ads} force of attraction values when carbon steel is in HCl and NaCl, respectively, at 12.1877 and 5.8162 mol^{-1}. Furthermore, an extensive plot (figure 10) from the Temkin model indicates that the heat of adsorption of all molecular layers decreases linearly with coverage rather than logarithmically, demonstrating the spontaneous nature of the adsorption mechanism and the stability of the adsorbed barrier covering. Table 4's ΔG_{ads} values of − 28.2471 $KJmol^{-1}$ and −25.9048 $KJmol^{-1}$ in NaCl and HCl operating conditions further support a chemical adsorption mechanism (figure 11).

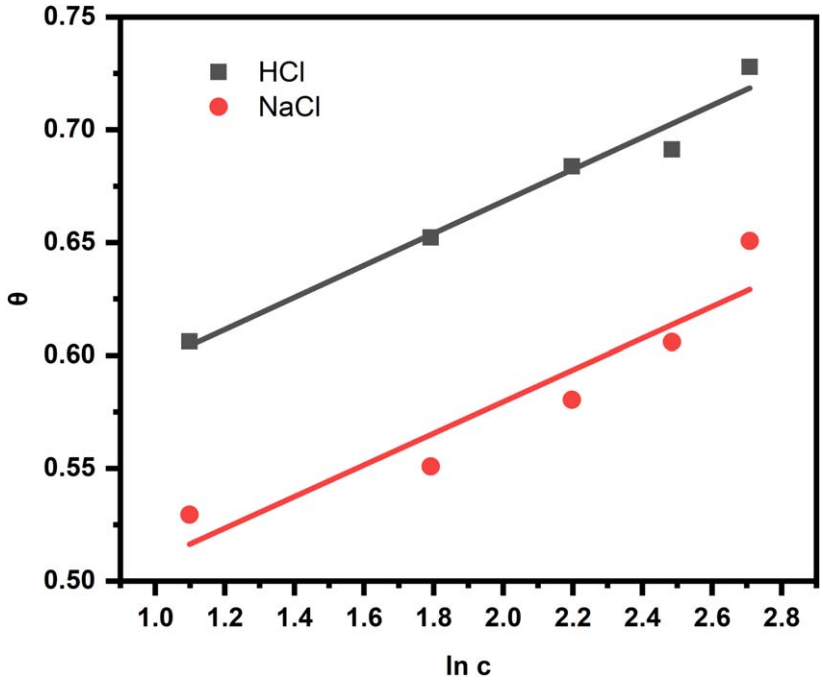

Figure 10. Θ against ln C plot (NaCl Environment).

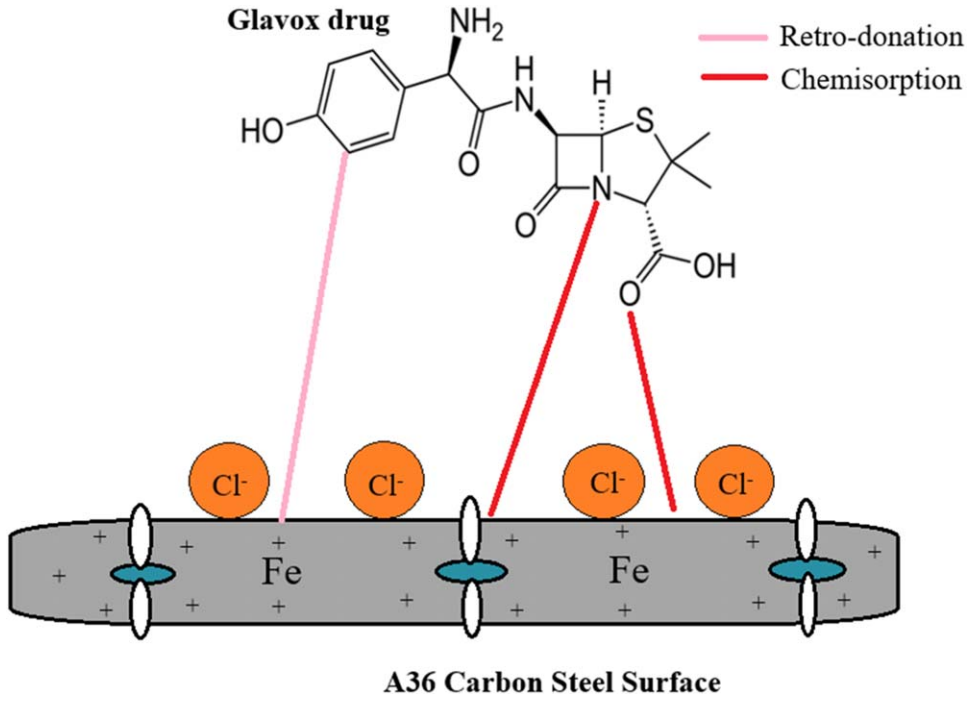

Figure 11. Adsorption mechanism of Glavox on steel surface in chloride environment.

These results provide more evidence for the effectiveness of the particulate matter and, thus, the models' efficiency [42–45].

3.4. Post corrosion surface morphology

The visualization obtained through SEM/EDS of unaltered carbon steel immersed in NaCl is depicted in figure 12. It is evident from the image that a notable deterioration of the carbon steel surface has occurred.

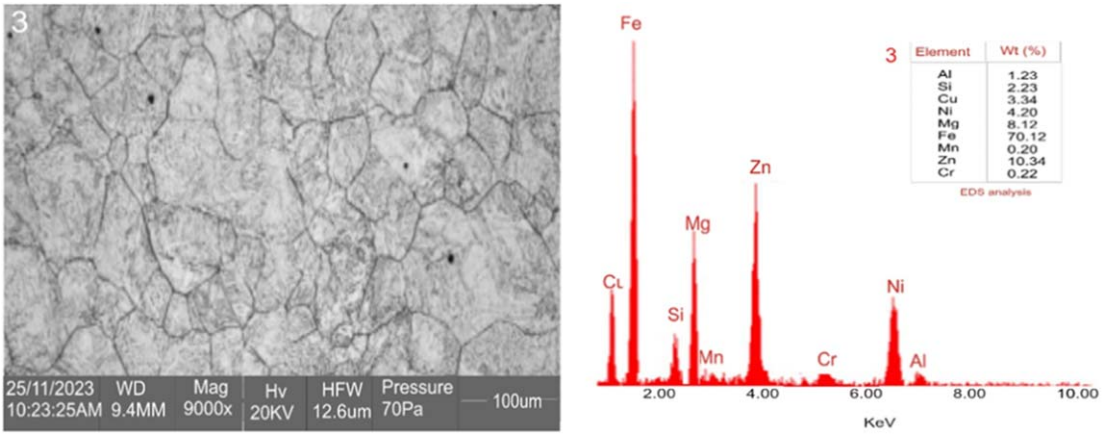

Figure 12. SEM/EDS of control sample in NaCl.

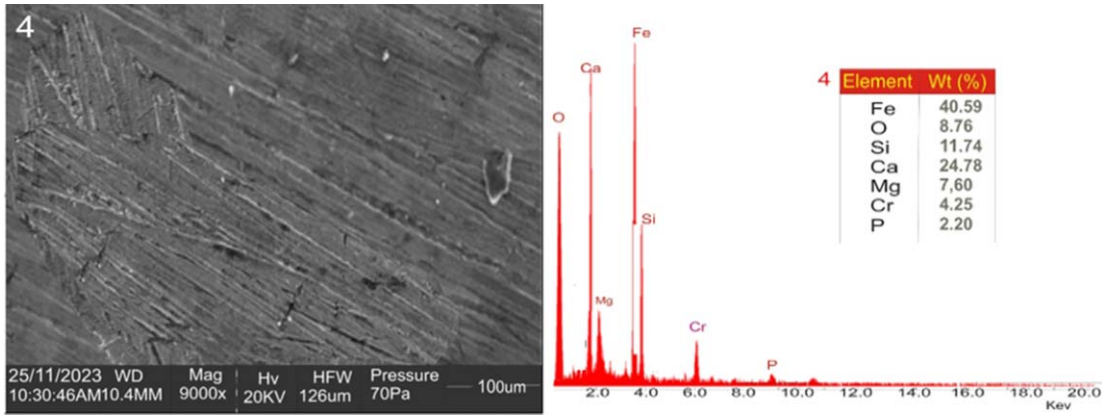

Figure 13. SEM/EDS of the 7.5 ml glavox inhibited in NaCl.

Examination of the microstructure exposes the existence of large, irregularly shaped corrosion pits scattered throughout the surface. The presence of distinct grain boundaries indicates extensive deterioration and compromise of the structural integrity of the material matrix due to the corrosive NaCl environment. Analysis of the EDS spectrum reveals the existence of various elements, with iron (Fe) being the predominant constituent at 70.12 wt%. Additional elements identified include zinc (Zn) at 10.34 wt%, magnesium (Mg) at 8.12 wt%, and nickel (Ni) at 4.20 wt%. Figure 13 presents the SEM/EDS investigation of the most inhibited specimen in a NaCl setting.

The SEM image of the specimen treated with 7.5 ml of expired Glavox in NaCl exhibits a considerably smoother surface in comparison to the control specimen. The occurrence of corrosion by-products seems to be diminished, and the visibility of grain boundaries is reduced, suggesting an efficient inhibition of the corrosion mechanism by the expired Glavox. The EDS spectrum of the inhibited specimen displays a decreased iron (Fe) content at 40.59 wt%, with noticeable elevations in other elements like calcium (Ca) at 24.78 wt%, silicon (Si) at 11.74 wt%, and oxygen (O) at 8.76 wt%. The elevated presence of Ca implies the development of a protective calcium-rich layer on the surface, which, in conjunction with the existence of Si and O, implies the establishment of a protective film that impedes further corrosion. The detection of Cr (4.25 wt%) and P (2.20 wt%) further corroborates the formation of a sophisticated protective barrier [46, 47].

The uninhibited carbon steel sample suspended in HCl atmosphere is shown in figure 14 together with the SEM/EDS results. We can see from the SEM image that the surface is quite rough and has a lot of corrosion products on it. Granular structure and widespread cracking show that when carbon steel was exposed to HCl without an inhibitor, it experienced aggressive corrosion. The EDS spectrum analysis indicates the presence of many elements, with iron (Fe) accounting for 52 weight percent. The elements zinc (Zn), magnesium (Mg), and nickel (Ni) have also been recognised. In comparison to the control, the inhibited sample's SEM picture

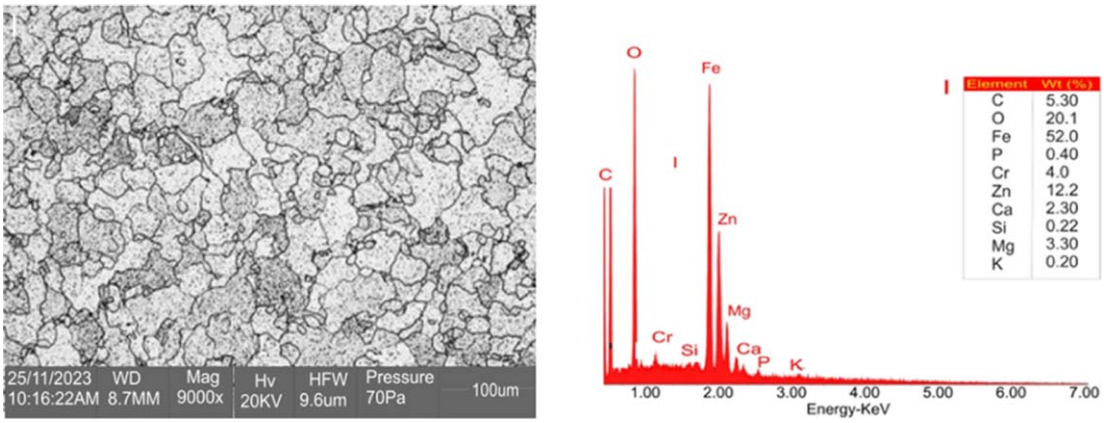

Figure 14. SEM/EDS of control sample in HCl.

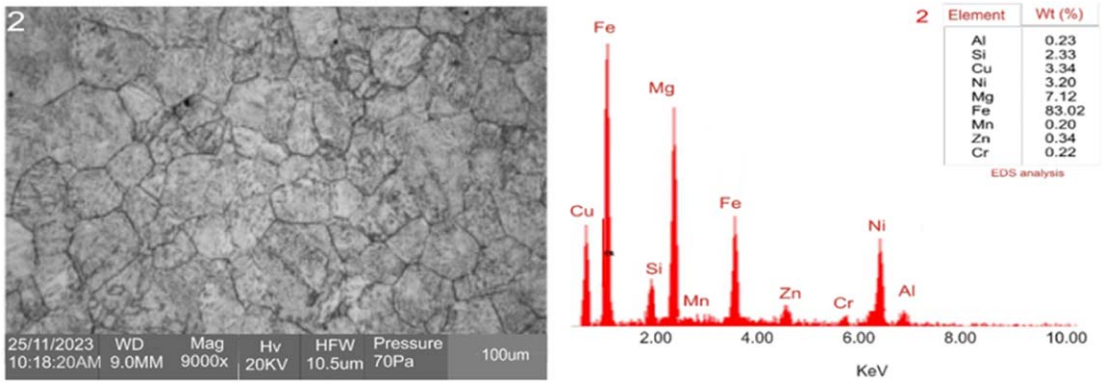

Figure 15. SEM/EDS of 7.5 ml glavox inhibited sample in HCl.

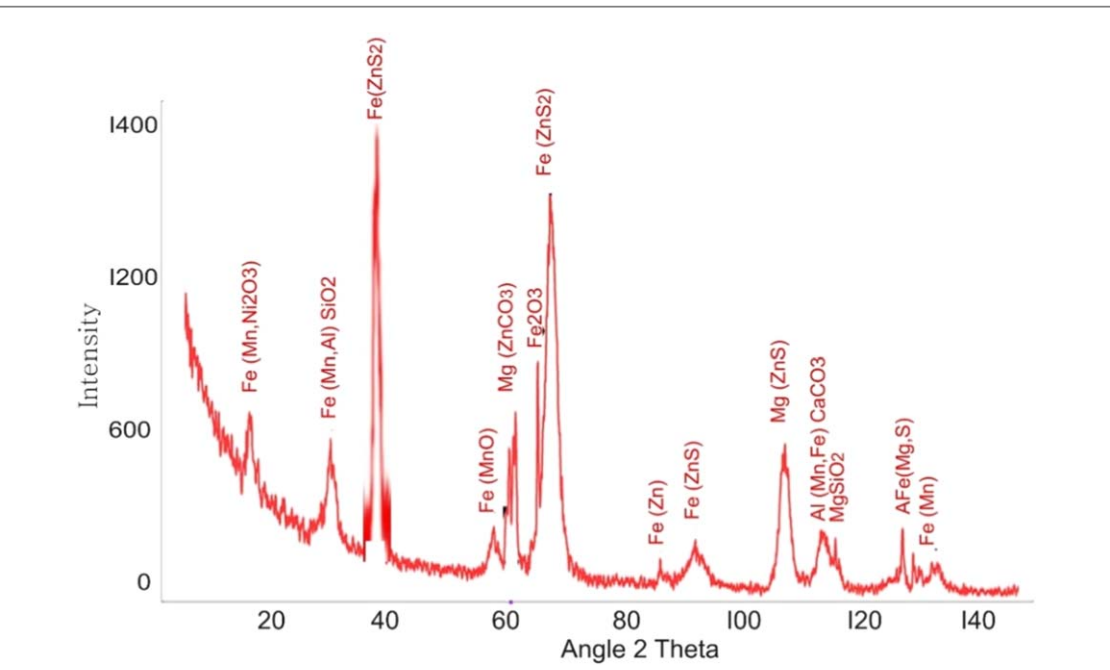

Figure 16. XRD plot of 7.5 ml glavox inhibited sample in NaCl.

(figure 15) shows a noticeably smoother surface. The lack of noticeable cracking and the drop in detectable corrosion products suggest that the carbon steel surface is adequately shielded from the acidic environment by the Glavox expired prescriptions. Fe was identified by the EDS spectrum as the primary element in the inhibited carbon steel, accounting for 83.02% of its composition. Other elements, including Al, Si, Cu, Ni, Mg, and Cr, were present in trace amounts.

The carbon steel suspended in NaCl and inhibited with expired Glavox drug yielded an x-ray diffraction (XRD) plot (figure 16) with multiple distinct peaks representing different phases on the surface: iron (Fe), iron oxides (Fe_2O_3, Fe_3O_4), and complex compounds like Fe(Mn, Ni_2OC) and Fe(ZnS_2); the presence of Fe(Mn, Al) and SiO_2 suggests possible corrosion products or residues from the inhibition process; peaks corresponding to magnesium carbonate ($MgCO_3$) and zinc compounds (ZnS, ZnO) indicate interactions between the carbon steel and the expired drug. These compounds imply that the medication may have reduced corrosion on the steel surface by forming these complex phases, which would have served as a multi-elemental protective layer. Furthermore, the existence of calcium and aluminium compounds suggests further interactions that might improve the expired medication's ability to stop corrosion.

4. Conclusion

This research illustrates the efficacy of expired Glavox tablets, which consist of Amoxicillin and Clavulanic Acid, as environmentally friendly substances to inhibit corrosion of A36 carbon steel in both acidic (1M HCl) and saline (3.65 wt% NaCl) environments. The empirical data obtained from weight loss and electrochemical analyses exhibited substantial decreases in corrosion rates, shifts in corrosion potentials, and alterations in current densities, demonstrating that Glavox functions as a mixed-type inhibitor. Within 1M HCl, the corrosion rate declined from 1.24 mm y^{-1} to 0.17 mm y^{-1}, whereas in the 3.65 wt% NaCl solution, it dropped from 0.98 mm y^{-1} to 0.23 mm y^{-1} at the highest inhibitor concentration (7.5 ml). Electrochemical assessments validated the robust adsorption of Glavox onto the steel surface, as indicated by variations in E_{corr} and i_{corr} values, aligning well with Langmuir, Freundlich, and Temkin isotherm models. The creation of a protective layer on the restrained samples was revealed by scanning electron microscopy/energy-dispersive x-ray spectroscopy (SEM/EDS) analysis, which validates the inhibitory mechanism. These results propose that expired Glavox tablets are not solely cost-efficient but also serve as environmentally sustainable substitutes for traditional corrosion inhibitors. Through the repurposing of expired pharmaceuticals, this strategy contributes to sustainable methodologies and waste minimization in industrial settings. Future investigations could delve into the enduring stability and efficacy of Glavox in diverse corrosive settings, along with its potential utilization on various metals and alloys.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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