Evaluation of Plant-Based Inhibitor for Corrosion Protection of Zinc and Aluminum Roofing Sheets in Acidic Environments

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ABSTRACT

This study investigates the effectiveness of (waste mango fruits) in reducing the corrosion rate of zinc and aluminum roofing sheets in acidic environments. The corrosion inhibition efficiency of the fruit was evaluated using weight loss measurements and corrosion rate calculations. The results showed that, the fruit are highly effective in reducing the corrosion rate of both zinc and aluminum, with inhibition efficiencies increasing with rising inhibitor concentrations. The maximum inhibition efficiency for zinc was 96.6% at an inhibitor concentration of 20%, while for aluminum it was 95.60% at an inhibitor concentration of 80%. The findings of this study highlight the potential of readily available plant-based material as a cost-effective and environment friendly and sustainable solution for corrosion control in industries that utilize zinc and aluminum materials in acidic environments. This research contributes to the growing body of evidence on the importance of inhibitor in corrosion control and underscores the significance of local inhibitors in promoting sustainable practices in industries.

Keywords: Acidic environments, aluminum roofing sheet, corrosion inhibition, sustainable solution, zinc roofing sheet

INTRODUCTION

The quest for suitable substances to prevent corrosion of iron and its alloys has been a persistent pursuit among researchers globally. Corrosion inhibitors play a crucial role in mitigating the degradation of metals, thereby extending their lifespan and reducing economic losses. Recent studies have focused on developing environmentally friendly corrosion inhibitors, shifting away from toxic synthetic compounds towards green alternatives. Green corrosion inhibitors, derived from natural sources, have emerged as a promising solution for corrosion protection. These inhibitors are biodegradable, non-toxic, and cost-effective, making them an attractive option for industries [3, 9]

The mechanism of corrosion inhibition by green corrosion inhibitors involves the adsorption of inhibitor molecules onto the metal surface, forming a protective layer that prevents corrosive species from interacting with the metal. The heterocyclic nature of these inhibitors, characterized by the presence of heteroatoms such as sulfur, oxygen, or nitrogen, and pi electrons, contributes to their efficiency as corrosion inhibitors [3].

Recent studies have explored the potential of various natural substances as corrosion inhibitors. Researchers have investigated the corrosion inhibition properties of plant extracts, such as those from the leaves of Solanum macrocarpon, which have shown promising results. Biopolymers, such as xanthan gum, have been studied for their corrosion inhibition properties, demonstrating effective protection for metals in acidic environments. Amino acids, such as tryptophan and histidine, have been investigated for their corrosion inhibition properties, showing excellent efficiency in preventing metal corrosion [5, 6] This study aimed to develop novel, eco-friendly corrosion inhibitors leveraging waste mango fruits as a sustainable and cost-effective solution. By harnessing the potential of natural waste, this research sought to create efficient and environmentally benign corrosion inhibitors that can mitigate metal degradation in various industrial applications.

MATERIALS AND METHODS

Materials

Aluminum roofing sheet (ARS) and Zinc roofing sheet (ZRS) were purchased from Kara market, Sokoo Sstate. The fruits of mango (*Mangifera indica* L.) were collected randomly from Umaru Ali Shinkafi Polytechnic Sokoto, Nigeria.

Chemicals

Acetone, ethanol and hydrochloric acid were used in this research, all of analytical grades from Sigma Aldrich Chemical Company UK.

Sample Preparations

Corrosion media samples were prepared for zinc roofing sheet and aluminum roofing sheet needed in calculating the weight loss of the material. The samples are 0.1 M and 0.2 M of HCl prepared using double-distilled water. The experiments were conducted under naturally aerated conditions without stirring.

Preparation of plant extract

The mango fruits (1 kg) were sun dried. Then, the mango nut was separated from the other parts of the dried fruits. After which the dried waste fruit was pulverized. The ground dried waste mango nut powder was weighed (75 g) and soaked in 250 ml of ethanol for 24 hours, before filtration, and then concentrated using rotary evaporator and water bath. The resulting extract was in semi-solid form.

Preparation of Roofing Sheet samples

Zinc roofing and aluminum roofing sheet were cut into specific dimensions (2.0 cm x 1.0 cm x 0.01 cm) and were used for this test. These samples were cleaned with distilled water and ethanol and then treated using emery paper. Thereafter, the samples were washed using distilled water and degreased with acetone before the samples were stored in the desiccator.

Weight Loss Measurements

The gravimetric method (weight loss) was used to investigate the weight loss measurements that were conducted under total immersion using 250 mL capacity beaker containing 20 - 100% test solution at 30 - 35°C maintained in the laboratory (temperature). The test samples (zinc roofing sheet and aluminum roofing sheet were weighed and suspended in the containers with the help of rod and hook. For the effect of temperature on the inhibition efficiencies, all the tests were carried out in the same temperature range of 30 – 35 °C.

Procedure

The test samples were immersed in 200 mL of 0.1 M and 0.2 M HCl in triplicate. Various concentrations of the inhibitor (0%, 20%, 40%, 60%, 80%) were prepared. Then various percentages of the inhibitor were added to the containers containing the various test samples. The specimens were totally immersed in test solutions and left for 336 hours during which readings were carried out at intervals of 48 hours. A total of 7 readings were recorded and the results were reported accordingly. Control experiments for HCl were also investigated. The mass of the specimens before and after immersion was recorded after every 48 hours using electronic weighing balance. The corroded specimens were rinsed thoroughly with distilled water, dried and then weighed to determine their weights.

The inhibition efficiency (IE) was calculated using equations 1 and 2:

$$\frac{W - W1}{W} \, x \, 100 \qquad (1)$$

$$\frac{W - W2}{W} \, x \, 100 \qquad (2)$$

Where W is the initial weight of the specimen, W_1 is the weight of specimen after corrosion in the absence of the inhibitor, and W_2 is the weight of specimen after corrosion in the presence of the inhibitor [2].

Weight Loss Method

The corrosion of mild steel in 0.1 M HCl solution containing various concentrations of inhibitor at room temperature was studied by weight loss measurements. The corrosion rate of mild steel was determined via the formula:

$$W = \frac{\Delta m}{S \times t} \qquad (3)$$

Where Δm is the mass loss (g) S = 2.0cm^2= 0.0004m^2 [the area (cm^2)] t= 48 hours [immersion period (hours)]. The percentage inhibition efficiency [IE%] was calculated using the relationship:

$$IE\% = \frac{\Delta m}{M1} \times 100 \qquad (4)$$

$$IE\% = \frac{\Delta m}{M2} \times 100 \qquad (5)$$

Where M_1 is the corrosion rate in the absence of the inhibitor, and M_2 is the corrosion rate in the present of the inhibitor.

RESULTS AND DISCUSSION

Table 1 indicates that there was no corrosion at all on the control samples (Aluminum Roofing Sheet (ARS) and Zinc Roofing Sheet (ZRS)) during the 366 hours corrosion test duration. Table 2 showed that the ZRS recorded highest % corrosion of more than 38% in 0.1 M HCl while the ARS reported 19.5%. This is an indication that, the zinc roofing sheet is only coated with certain concentration of zinc material which when faded exposed the roofing sheet to acid attacks. This is probably one of the reasons why the zinc roofing sheet used in house at some of the Nigerian towns with many industries turn brown (corroded) within short period of time due to acid rain. The results also showed the ARS under the test condition recorded better performance compared to ZRS. This may be due to the better acid resistance that the ARS has in comparison to ZRS. Similar trend was observed when the samples were treated in 0.2 M HCl. The ZRS reported the highest % corrosion of more than 79.7%, while ARS recorded the lowest % corrosion (30%) in the same medium.

Table 1: Mass loss (%) data of Aluminum Roofing Sheet and Zinc Roofing Sheet in distilled water without an inhibitor during 336 hours of corrosion test

S/N	Sample	Treatment	M_B(g)	M_{AF}(g)	M_{Loss}(g)	%M_{Loss}(g)	SD
1	ARS	Control	0.4629	0.4628	0.0001	0.0216	0.0001
2	ZRS	Control	0.6112	0.6110	0.0002	0.0327	0.0000

ARS = Aluminum roofing sheet; ZRS = Zinc roofing sheet; M_B = Mass of specimen before the corrosion test; M_{AF} = Mass of specimen after the corrosion test; M_{loss}= Mass loss

Table 2: Mass loss (%) data of Aluminum Roofing Sheet and Zinc Roofing Sheet in 0.1M HCl without an inhibitor during 336 hours of corrosion test

S/N	Sample	M_B(g)	M_{AF}(g)	M_{Loss}(g)	%M_{Loss}(g)	Corrosion rate (g/m^2.hr)	SD
1	ARS	0.4639	0.3711	0.0928|	20.0000	1.3810	0.0001
2	ZRS	0.6122	0.3673	0.2449	40.0000	3.6443	0.0001

Two samples, ARS and ZRS, were tested for corrosion. ZRS showed a higher mass loss (0.2449 g) and percentage mass loss (40%) compared to ARS (0.0928 g and 20%, respectively). The corrosion rate for ZRS (3.6443 g/m^2.hr) is significantly higher than that of ARS (1.3810 g/m^2.hr). This suggests that ZRS is more susceptible to corrosion than ARS. The standard deviations (SD) for both ARS and ZRS is very low (0.0001), indicating minimal variability in the results. The results also suggest that the material properties or environmental conditions for ZRS may be more conducive to corrosion.

Table 3: Results of the determination of concentration rates of Aluminum Roofing Sheet in 0.1M HCl with different concentrations of inhibitor during 336 hours of corrosion test

Inhibition Concentration (%)	Corrosion rate (g/m^2.hr)	Δm	IE (%)
0	1.3810	-	-
20	0.093	0.0188	79.7
40	0.091	0.0185	80.1
60	0.090	0.0183	80.3
80	0.088	0.0178	80.8

Table 4 shows the concentration rates data of zinc roofing sheet in 0.1 M HCl with different concentrations of inhibitor. It reveals that the corrosion rate of zinc roofing sheet in 0.1 M HCl decreases significantly with the addition of an inhibitor, even at a concentration as low as 20%. The inhibition efficiency (IE) is highest at 20% inhibitor concentration, with an IE of 96.6%. This suggests that the inhibitor is effective in reducing the corrosion rate of zinc in acidic environments. Similar findings have been reported in other studies. For example, a study by [1] found that the corrosion inhibition efficiency of zinc in acidic media increased with increasing concentration of inhibitor, with a maximum IE of 95% at an inhibitor concentration of 5×10^{-4} M. Another study by [4] reported that the corrosion rate of zinc in 0.1M HCl decreased significantly with the addition of an inhibitor, with an IE of 93% at an inhibitor concentration of 100 ppm.

Table 4: Concentration rates data of Zinc Roofing Sheet in 0.1M HCl with different concentrations of inhibitor during 336 hours of corrosion test

Inhibition Concentration (%)	Corrosion rate ($g/m^2.hr$)	Δm	IE (%)
0	3.6443	-	-
20	0.244	0.0451	96.6
40	0.248	0.0457	92.54
60	0.249	0.0459	92.50
80	0.251	0.0463	92.44

The data in Table 5 shows that the mass loss of both aluminum and zinc roofing sheets is significant in 0.2 M HCl without an inhibitor. However, the mass loss is higher for zinc roofing sheet (93.85%) compared to aluminum roofing sheet (49.05%). This suggests that aluminum is more resistant to corrosion in acidic environments compared to zinc. Similar findings have been reported in other studies. For instance, a study by [8] found that aluminum has a higher corrosion resistance in acidic environments compared to zinc due to the formation of a protective oxide layer on the aluminum surface.

Table 5: Mass loss (%) data of Aluminum Roofing Sheet and Zinc Roofing Sheet in 0.2 M HCl without an inhibitor

S/N	Sample	M_B(g)	M_{AF}(g)	M_{Loss}(g)	%M_{Loss}(g)	SD
1	ARS	0.4832	0.4595	0.0237	49.05	0.0001
2	ZRS	0.5402	0.4895	0.0507	93.85	0.0001

The data in Table 6 demonstrate that the corrosion rate of aluminum roofing sheet in 0.2 M HCl decreases significantly with the addition of an inhibitor, even at a concentration as low as 20%. The inhibition efficiency (IE) increases with increasing inhibitor concentration, with a maximum IE of 95.60% at an inhibitor concentration of 80%. Similar findings have been reported in other studies. For example, a study by [7] found that the corrosion inhibition efficiency of aluminum in acidic media increased with increasing concentration of inhibitor, with a maximum IE of 97% at an inhibitor concentration of 1000 ppm.

Table 6: Concentration rates data of Aluminum Roofing Sheet in 0.2 M HCl and in the presence of different concentration of inhibitor.

Inhibition Concentration (%)	Corrosion rate (g/m^2.hr)	Δm	IE (%)
0	0.4832	-	-
20	0.146037	0.0237	95.10
40	0.142956	0.0232	95.20
60	0.139259	0.0226	9532
80	0.131864	0.0214	95.60

From Table 7 the corrosion rate of zinc roofing sheet in 0.2 M HCl decreases significantly with the addition of an inhibitor, even at a concentration as low as 20%. The inhibition efficiency (IE) increases with increasing inhibitor concentration, with a maximum IE of 92.06% at an inhibitor concentration of 80%.

Table 7 Concentration rates data of Zinc Roofing Sheet in 0.2M HCl and presence of different concentration of inhibitor

Inhibition Concentration (%)	Corrosion rate (g/m^2.hr)	Δm	IE (%)
0	0.5402	-	-
20	0.312408	0.0507	90.67
40	0.288376	0.0468	91.34
60	0.276669	0.0449	91.70
80	0.264345	0.0429	92.06

Comparing the results of Tables 4 and 7 show that the inhibition efficiency of zinc roofing sheet is higher in 0.1 M HCl (96.6%) compared to 0.2 M HCl (92.06%) at an inhibitor concentration of 20% and 80% respectively. This suggests that the inhibitor is more effective in reducing the corrosion rate of zinc in lower concentrations of HCl.

CONCLUSION

The findings of this research underscore the crucial role of inhibitors in mitigating the corrosion of zinc and aluminum roofing sheets in acidic environments, which is a significant concern in various industries. The results demonstrate that mango fruit highly effective in reducing the corrosion rate of both zinc and aluminum, with inhibition efficiencies increasing with rising inhibitor concentrations. This is consistent with previous studies, highlighting the potential of plant-based materials as a potential solution for corrosion control. The use of locally available inhibitors, derived from natural or locally sourced materials, can offer a cost-effective and environmentally friendly alternative to traditional corrosion inhibitors. Plant-based inhibitors can provide a sustainable solution for corrosion protection, particularly in regions where access to commercial inhibitors is limited. By harnessing the potential of readily available plant-based inhibitors, industries can reduce their reliance on synthetic inhibitors, minimize environmental impact, and promote sustainable practices.

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