Investigation of corrosion performance of aluminum and zinc alloys in three acidic media

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The consequences of corrosion are many and varied, and their effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than a simple loss of metal mass. This research investigates the corrosion performance of two nonferrous metals in three acidic media, namely sulfuric acid (98% volume of H₂SO₄), hydrochloric acid (75% volume of HCl), and trioxonitrate (V) acid (75% volume of HNO₃). The corrosion rate is determined by the weight loss method, and the characterization of metallic samples is obtained by scanning electron microscope (SEM). The SEM shows the cracking pattern of grains indicating surface erosion due to the corrosion effects which are more depicted on the zinc than aluminum samples. It is shown that the solution of H₂SO₄ has the highest impact on the corrosion rates of metallic samples, whereas the least effect is observed on the solution of HNO₃. It is observed that Zn alloy sample in 3 M H₂SO₄ records the highest corrosion rate of 138.64 mm/year, while the aluminum alloy sample has the lowest rate of 24.661 mm/year after 72 hours of exposures in the acid. The corrosion rates of the samples decrease as the exposure time increases. The weight loss intensity increases with exposure time for Al samples and varies for Zn sample in acidic media. In conclusion, the higher the acid molarity, the shorter the exposure time and the higher the corrosion rates for both zinc and aluminum alloy samples.

KEYWORDS
acidic media, aluminum and zinc alloys, characterization, corrosion rate, weight loss method

1 INTRODUCTION

The consequences of corrosion are many and varied and the effects of these on the safe, reliable and efficient operation of equipment or structures are often more serious than simple loss of a mass of a metal Adetunjiet al.¹ Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. It has been observed globally that corrosion reduces the thickness of the metal resulting in loss of mechanical...
strength and failure of the structure; it causes structural failure as it is hazardous because of the deterioration of appearance. The main aim of this research was to investigate the corrosion performance of two nonferrous metals in three acidic media.

Material deterioration occurs all around us when we look at many metallic items of common use for example; in chemical industries numerous corrosion problem occurs, some so serious as to cause the shutdown of plants and collapse of structures such submarine equipment, underground pipes, dams etc. causing hazards to human life, as such, billions of dollars are lost each year because of corrosion Umoren. Corrosion is therefore a matter of great concern due to the enormous cost involved in the replacement of metallic parts in all kinds of applications Lotto. Corrosion is a very common phenomenon that has wide ranging effect in individual, municipal, and private setting. It occurs when protective mechanisms have been overlooked, broken-down, or have been exhausted leaving the metal vulnerable to attack. Building construction, according to Uppal and Bhatia, has a menu of different approaches to corrosion control from which solutions are selected to suit client requirements. In recent industrial history, many failures due to the use of metallic structure in contact with aqueous and nonaqueous media have been reported as a consequence of corrosion. Although aluminum has the ability to form a stable thin oxide film that protects it from the corrosion phenomenon, it undergoes corrosion when being in contact with aggressive media such as hydrochloric acid (Beda et al). Pure aluminum is weak and loses its strength rapidly above 300 strengthen and hence aluminum is alloyed with small amount of other elements. A more corrosion-resistant alloy of aluminum (used for window frames, furniture, highway signs, and cooking utensils) contains mainly manganese (Ita and Offiong). Aluminum and its alloys are of economic important because of their low cost, lightness, and good corrosion resistance at moderate temperature. Paradoxically, Uppa and Bhatia observed that aluminum theoretically tends to react with air and water by some of the most energetic chemical reaction known but provided that these media are neither excessively acidic nor alkaline and are free from aggressive contaminants; the initial reaction products form a vanishingly thin impervious barrier separating the metal from its environment. The protection afforded by this condition is so effective that aluminum and some of its alloys are standard materials for cooking utensils, food and beverage container, architectural use, and other applications in which a normally bare metal surface is continuously exposed to air and water, similar effect are responsible for the utility of some other metals exploited for their corrosion resistance including cobalt and nickel. Ahmad et al revealed that the use of corrosion inhibitors is necessary in such cases like exposure of aluminum alloy to acid or salt solution. Synthetic chemical inhibitors, commonly chromates, are toxic to life in the environment upon disposal or leaks and they may be also a health and safety hazard in their handling.

Corrosion only takes place in specific environment(s) which may be damp wet or dry. Environment in corrosion studies include concentration, pH, temperature, atmosphere, sea water, chemical, and fused salts. During corrosion, the kinetic of the cathodic and anodic partials reaction controls the rate of overall corrosion reaction (Shreir et al). Lotto and Shanbhag et al worked on corrosion inhibition of zinc, and some zinc sheets having rectangular shape with an exposed area of 2 x 4 x 1 cm were used for the corrosion rate measurements. The samples were first degreased with trichloroethylene, grounded with different grades of emery papers, washed with water, and rinsed with alcohol. The dried and weighed samples were placed in 50 cm³ of 0.1 M HCl solutions with and without inhibitors for 2 hours at 303 K. The complex nature of the tea’s chemical composition and structure is expected to prove effective in corrosion inhibition of mild steel in the strong acid (H₂SO₄). In addition, an effective inhibition of a plant extract such as this will be environmental friendly (Lotto). Aluminum alloys commonly form a smooth surface oxidation that is from 0.001 to 0.0025 inches thick. This is not considered detrimental; the coating provides a hard shell barrier to the introduction of corrosive elements. Sanni et al revealed that aluminum resistance to corrosion in aqueous media can be attributed to a rapidly formed surface oxide film, because the aluminum oxide layer is very thin, it is easily degraded by physical or chemical methods. On the contrary, this alloy is highly susceptible to corrosion because of the presence of intermetallic particles at the surface resulting in need for the development of several methods in order to enhance its resistance against corrosion.

Abdallah et al stated that Zinc metal is highly susceptible to attack by acids. For scale removal and cleaning of zinc surfaces with acidic solution, the use of inhibitors is one of the most practical methods for protection of zinc against corrosion arising from the use of hydrochloric acid. Some organic compounds have been used as corrosion inhibitors for dissolution of zinc electrode in hydrochloric acid (Abdallah et al and Mamun et al). Some of the disastrous effects of corrosion can be summarized as: hazards or injuries to people arising from structural failure or breakdown (eg, bridges, cars, aircrafts etc.), reduced value of goods due to deterioration of appearance, contamination of fluids in vessels and pipes (for instance beer goes cloudy when small quantities of heavy metals are released by
corrosion), loss of technically important surface properties of a metallic component such as frictional and bearing properties, ease of fluid flow over a pipe surface, electrical conductivity of contacts, surface reflectivity or heat transfer across a surface, damage of vessel and pipes allowing escape of their contents and possible harm to the surroundings, and loss of time availability profile—making industrial equipment and reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown (Umoren²). This research therefore investigated the corrosion performance of two nonferrous metals in three acidic media.

2 | MATERIALS AND METHODS

2.1 | Sample materials

The materials used for this research study were: Aluminum, Zinc sheets, and the three acidic media of sulfuric acid (98% volume of H₂SO₄), hydrochloric acid (75% volume of HCl), and trioxonitrate (V) acid (75% volume of HNO₃) which were sourced locally (were purchased from Onipanu, Lagos State, Nigeria). The three acidic media used were prepared into three different molarities (concentrations) of 1, 2, and 3 M.

2.2 | Samples preparation

The samples for weight loss tests were prepared in accordance to the procedure recommended by ASTM G.1. The samples were cut into square sizes of 20.0 by 20.0 mm and a thickness of 10.0 mm for zinc while that of aluminum was in cylindrical shape of 20.0 by 20.0 mm (diameter and length). These samples were cut from the parent materials with the help of shears, while a steel rule and scriber were used for the dimensioning.

2.3 | Materials characterization

The characterization analyses for all sample materials were examined before and after the submersion into the different concentrations of the prepared acidic media (solutions).

2.3.1 | Chemical analysis

The chemical analysis was determined in EMDI laboratory Akure Ondo State Nigeria by using Energy Dispersive X-ray (EDX) machine model JEOL 840. The examination was done by cutting samples into square of 15 mm which were mechanically ground and polished. The mirror-like polished samples were carbon coated before carrying out the analysis in order to make samples surfaces conclusive.

2.3.2 | Scanning electron microscopy

A SEM machine was employed to conduct cross-sectional analyses of the samples’ surfaces. The microstructure and morphology of the samples were taken before and after specified period of submersion in media at Kwara State University, Ilorin, Nigeria.

2.4 | Summary procedures for corrosion examination of samples

The procedures involved in this research work can be summarized as follow:

1. dimensioning and cutting of material samples aluminum and zinc metals;
2. samples and containers were dried-clean;
3. containers and samples were labeled;
4. pouring of different concentrations of acidic media into labeled containers;
5. weighing of all prepared sample materials by electric weighing balance (initial weight);
6. weighed samples were inserted into the labeled containers. Observation: during the insertion the solutions reacted with the samples by forming bubbles (Liberation of gasses);
7. covering of containers against any foreign materials;
8. timing at 72-hour interval;
9. after the first 72 hours, a single material was taken out to measure the weight loss. Each sample removed from group was removed by tongue and spatula, was rinsed with distilled water, dried with acetone and cleaned with handkerchief;
10. each sample was weighed with electric weighing balance in order to get the final weight; and
11. calculation of weight loss intensity and corrosion rate.

The mathematical formula by Fontana,\textsuperscript{16} for calculating the corrosion rates of the samples after the weight loss measurement is stated as follow:

\[
CR = \frac{87.6W}{\rho AT} \text{ (mm/year)}
\]

where CR = corrosion rate in millimeter per year, \(w\) = weight loss in mg, this was done by subtracting the final weight measured from initial weight which gave the weight loss (weight difference), \(\rho\) = density of each sample in mg/m\(^3\), \(A\) = Area, the area of each samples was determined by calculating the total surface area in cm\(^2\) and \(T\) = Time, this was an exposure time in hours of each of the samples spent inside the different concentrations of the acidic media.

The findings showed evaluation of the immersion of nonferrous metals in different media such alkaline, marine environment, and also in acidic, this present research looked on the corrosion behavior of zinc and aluminum samples been submerged in three different acidic media with different molarities of such media.

2.5 Statistical analysis

Statistical Package for the Social Sciences SPSS of 16.0 versions was used to investigate the significance of the experimental values and Microsoft-Excel- Windows 2010 was also used in addition to the SPSS.

3 RESULTS

3.1 Materials samples

There were certain reactions between the prepared samples and the different concentrations of acidic media. There was liberation of gasses as a result of chemical reactions that took place and changing of all acidic solutions from nearly colorless to series of colorations after a long period of submersion.

3.2 Chemical analysis of sample materials

The percentage of chemical compositions of the two raw materials used for this research as determined in EMDI laboratory Akure Ondo State Nigeria by using Energy Dispersive X-ray (EDX) machine model JEOL 840, were shown in Tables 1 and 2 for aluminum and zinc, respectively. Table 1 showed that the aluminum sample used in this study was almost a pure type with less than 1% of total impurity or trace elements while in Table 2, the percentage composition of zinc metal had 95.29% while the trace elements got the remaining percentage of compositions of 4.71%.
### TABLE 1 Percentage chemical compositions of aluminum

| Elements | Mn | Ti  | Si  | Fe  | Cu  | Al  |
|----------|----|-----|-----|-----|-----|-----|
| % compositions | 0.011 | 0.116 | 0.221 | 0.397 | 0.011 | 99.32 |

### TABLE 2 Percentage chemical compositions of zinc

| Elements | Al | Mg  | Fe  | Pb  | Cd  | Ti  | Cu  | Zn  |
|----------|----|-----|-----|-----|-----|-----|-----|-----|
| % compositions | 4.3 | 0.05 | 0.1 | 0.005 | 0.004 | 0.003 | 0.25 | 95.29 |

### TABLE 3 Corrosion rate (CR) of metallic samples (mm/year) in 1 M of different solutions

| CR/Samples | CR@72 hours | CR@144 hours | CR@216 hours | CR@288 hours | CR@360 hours |
|------------|-------------|--------------|--------------|--------------|--------------|
| Al(HCl)    | 24.661 ± 1.02 | 14.994 ± 1.91 | 11.011 ± 1.00 | 8.286 ± 1.90 | 6.956 ± 1.99 |
| Zn(HCl)    | 70.741 ± 2.71 | 29.260 ± 1.77 | 20.096 ± 2.01 | 14.491 ± 1.35 | 8.628 ± 1.53 |
| Al(H2SO4)  | 75.668 ± 2.32 | 17.165 ± 1.20 | 11.998 ± 1.04 | 7.865 ± 0.68 | 6.836 ± 0.34 |
| Zn(H2SO4)  | 85.314 ± 2.06 | 44.517 ± 1.70 | 31.698 ± 1.07 | 28.776 ± 1.71 | 24.385 ± 1.52 |
| Al(HNO3)   | 45.689 ± 2.00 | 21.309 ± 1.19 | 14.771 ± 2.00 | 10.966 ± 1.56 | 9.093 ± 0.58 |
| Zn(HNO3)   | 49.548 ± 1.61 | 28.734 ± 1.40 | 24.192 ± 1.50 | 19.039 ± 1.22 | 17.092 ± 1.67 |

**FIGURE 1** Corrosion rate of metals in 2 M of different solutions

![Corrosion rate of metals in 2 M of different solutions](image)

**3.3 Corrosion rate of metallic samples**

Table 3 displays the corrosion rate of metal samples against the time of exposure in 1 M of three acidic media. The corrosion rates of metal samples in the three different acidic media in 1 M solution of hydrochloric acid (HCl), nitric acid (HNO₃), and sulfuric acid (H₂SO₄) were investigated. It was shown that the samples that were submerged inside the acidic solutions of H₂SO₄ had the highest corroded surfaces and this was followed by HCl solutions while the least was HNO₃ solutions.

The graph of corrosion rate of metallic samples against the exposure time in 2 M of all acidic solutions is shown in Figure 1. The corrosion rate of metallic samples with 2 M in different solutions showed that zinc metals in solution of HCl had the higher corrosion rate of 80.340 ± 0.00 mm/year.

Table 4 showed the corrosion rate of the two nonferrous metals against the exposure time in 3 M of all the acidic media. The corrosion rate of aluminum and zinc samples in all three solutions decrease with an increase in exposure time from 72 to 360 hours.

**3.3.1 Weight loss intensity of metallic samples in three acidic media**

Figure 2 shows the graph of weight loss intensity of metals against the exposure time in 1 M of all the acidic media. The weight loss intensity of aluminum samples in acidic solutions of H₂SO₄ and HNO₃ increased as the exposure times increased but declined in solution of HCl at final exposure time of 360 hours. The weight loss intensity of aluminum...
samples in the three acidic media all increased as the time of exposure increased and the highest weight loss intensity was seen on H₂SO₄ solution of 0.2704 ± 0.00 g/cm² and solution of HNO₃ got 0.2117 ± 0.32 g/cm² while the HCl solution has the least weight loss intensity of 0.0771 ± 1.05 g/cm² at the last time of exposure (360 hours). The zinc samples with the three acidic media had a uniform reaction; they all decreased in weight loss intensity as the time of exposure increased. It was noticed that the zinc samples in solution of H₂SO₄ had the highest weight loss intensity and decreased from 0.4434 ± 0.00 to 0.2003 ± 0.90 g/cm². The weight loss intensity of HCl also decreased from 0.4146 to 0.2528 ± 0.10 g/cm² likewise in the solution of HNO₃, it also decreased from 0.2678 ± 0.00 to 0.2664 ± 0.06 g/cm². Generally, the weight loss intensity of zinc samples in three acidic solutions was modulating with an increase in exposure times.

Table 5 shows the weight loss intensity of metallic samples in 2 M solutions of three media. The weight loss intensity of aluminum samples with the three acidic solutions did not follow regular pattern. For the case of zinc samples, the weight loss intensity with the solutions of HCl and HNO₃ did modulate with an increase in exposure time from 72 to 360 hours while the weight loss intensity of zinc with solution H₂SO₄ increased with an increase in exposure time. Figure 3 shows the graph of weight loss intensity of metals in 3 M of different solutions vs time of exposure. The weight loss of aluminum samples with HNO₃ solution increased as the exposure times increased while in solution of HCl increased with an increase in time of exposure but declined at 360 hours. The weight loss intensity of zinc samples with the acidic solutions of H₂SO₄ and HNO₃ increased as the exposure times increased but declined at final time on H₂SO₄ only. The weight loss intensity of zinc in HCl varied with an increase in exposure times (Adetunji and Owoeye17).
FIGURE 3  Weight loss intensity of metals in 3 M of different solutions

TABLE 6  Corrosion rate (CR) of metals (mm/year) in three different molarities of HCl

| CR/Samples | CR@72 hours | CR@144 hours | CR@216 hours | CR@288 hours | CR@360 hours |
|------------|-------------|--------------|--------------|--------------|--------------|
| Al in 1 M  | 24.661 ± 2.71 | 14.994 ± 0.00 | 11.011 ± 0.00 | 8.286 ± 0.00 | 6.956 ± 0.31 |
| Al in 2 M  | 54.734 ± 0.00 | 25.310 ± 1.61 | 24.492 ± 0.00 | 17.961 ± 2.10 | 17.452 ± 0.22 |
| Al in 3 M  | 50.929 ± 3.81 | 31.383 ± 0.00 | 23.515 ± 0.12 | 20.687 ± 0.00 | 16.432 ± 0.77 |
| Zn in 1 M  | 70.741 ± 2.40 | 29.260 ± 0.00 | 20.096 ± 3.08 | 14.491 ± 2.04 | 8.628 ± 0.00 |
| Zn in 2 M  | 80.340 ± 0.00 | 39.519 ± 3.05 | 28.863 ± 1.94 | 22.799 ± 0.71 | 18.404 ± 2.75 |
| Zn in 3 M  | 104.869 ± 5.91 | 61.623 ± 0.00 | 39.464 ± 0.00 | 30.982 ± 0.59 | 25.332 ± 0.44 |

FIGURE 4  Corrosion rate of metallic samples vs exposure time for different molarities of H₂SO₄ solution

3.3.2  The corrosion rate of samples in different molarities of acidic media

Table 6 shows the corrosion rate of metals against exposure time for different molarities of HCl solution. It was noticed that the corrosion rate of metals used in 2 and 3 M solutions decreased with an increase in exposure time. Generally, corrosion rates of aluminum and zinc samples decreased steadily as the exposure times increased.

Figure 4 shows the graph of corrosion rate of metallic samples vs the exposure time for different molarities of H₂SO₄. It was noticed that the corrosion rates of the samples decreased steadily as the exposure times increased. It was observed that the highest values of corrosion rate was noticed on zinc sample been immersed in 3 M.

Table 7 displays the corrosion rate of metallic samples in three different molarities of HNO₃. The corrosion rate of zinc samples with the different concentrations of HNO₃ solutions decreased steadily with an increase in exposure time. Also the corrosion rate of aluminum samples with different concentrations of HNO₃ solutions also decreased generally with an increase in exposure time except a slight deviation at 360 hours for 1 M.
### Table 7: Corrosion rate (CR, mm/year) of samples in three different molarities of HNO₃

| Samples | CR@72 hours | CR@144 hours | CR@216 hours | CR@288 hours | CR@360 hours |
|---------|-------------|--------------|--------------|--------------|--------------|
| Al in 1M | 49.548 ± 0.00 | 28.734 ± 0.00 | 24.192 ± 2.93 | 19.039 ± 1.83 | 19.092 ± 2.56 |
| Al in 2M | 56.763 ± 2.93 | 37.077 ± 1.62 | 23.684 ± 0.00 | 19.588 ± 0.66 | 17.147 ± 1.11 |
| Al in 3M | 31.567 ± 0.00 | 22.449 ± 0.40 | 20.537 ± 2.84 | 19.039 ± 2.93 | 17.711 ± 0.00 |
| Zn in 1M | 45.689 ± 4.61 | 21.309 ± 0.00 | 14.771 ± 2.06 | 10.966 ± 0.00 | 9.093 ± 0.00 |
| Zn in 2M | 72.736 ± 3.00 | 26.103 ± 0.42 | 20.971 ± 0.00 | 13.126 ± 1.29 | 11.032 ± 2.10 |
| Zn in 3M | 28.092 ± 0.00 | 16.206 ± 0.00 | 11.806 ± 1.72 | 9.199 ± 0.00 | 7.824 ± 0.45 |

### Table 8: Weight loss intensity (g/cm²) of metallic samples in three different molarities of H₂SO₄

| Samples | 72 hours | 144 hours | 216 hours | 288 hours | 360 hours |
|---------|----------|-----------|-----------|-----------|-----------|
| Al in 1M | 0.1892 ± 0.00 | 0.1974 ± 2.61 | 0.2109 ± 0.36 | 0.2553 ± 0.61 | 0.2704 ± 0.42 |
| Al in 2M | 0.0988 ± 0.00 | 0.1489 ± 0.00 | 0.1439 ± 0.33 | 0.1562 ± 0.66 | 0.1631 ± 0.00 |
| Al in 3M | 0.1010 ± 0.01 | 0.0854 ± 0.21 | 0.1094 ± 0.85 | 0.1274 ± 0.99 | 0.1586 ± 0.47 |
| Zn in 1M | 0.4434 ± 0.32 | 0.2012 ± 0.53 | 0.2109 ± 0.00 | 0.1844 ± 1.00 | 0.2003 ± 0.82 |
| Zn in 2M | 0.5876 ± 0.06 | 0.5938 ± 0.00 | 0.6188 ± 0.41 | 0.6746 ± 0.00 | 0.6959 ± 0.31 |
| Zn in 3M | 0.8125 ± 0.99 | 0.8345 ± 0.00 | 0.8543 ± 0.00 | 0.8643 ± 0.41 | 0.7961 ± 0.49 |

### 3.3.3 Weight loss intensity of metallic samples in different molarities

Figure 5 shows the weight loss intensity of metallic samples vs exposure time in HCl solution and it was observed that zinc samples in 3 M had the highest value of weight loss intensity which increased with an increase in exposure time, while the aluminum samples in 1 M had the least value of weight loss intensity against the exposure time. Generally, the weight loss intensity of aluminum and zinc in 1, 2, and 3 molarities of HCl solutions varied with an increase in exposure times Omotosho et al. 18

Table 8 shows the weight loss intensity of metal samples in three different molarities of H₂SO₄. It was observed that weight loss intensity of aluminum in 1 M and zinc in 2 M increased as the exposure times increased. Figure 6 shows the weight loss intensity of metallic samples in three different molarities of HNO₃.

### 3.4 Statistical analysis

Table 9 shows the T-test of rate of corrosion of samples at different times of exposure. The T-test compare means was used to test the significant difference in performance efficiencies at the 95% confidence interval (CI). In statistics, CI estimates and represents uncertainty or imprecision associated with estimates of population parameters from sample data. The significances of corrosion rates at different exposure times interval of 72, 144, 218, 288, and 360 hours were 0.001, 0.001, 0.001, 0.002, and 0.002, respectively, with significant level of 0.005. The means and SDs were 42.9 ± 3.35, 19.6 ± 1.51, 13.8 ± 1.08, 10.8 ± 0.89 & 8.8 ± 0.77 and 33.5 ± 4.23, 15.2 ± 1.96, 10.8 ± 1.38, 8.9 ± 1.08, and 7.7 ± 0.88 for 72, 144, 218, 288, and 360 hours, respectively.
**Figure 6** Weight loss intensity of metals vs exposure time for HNO₃ solution

**Figure 7** Scanning electron microscope (SEM) of aluminum samples before and after submersion in various acidic media. A, SEM of Al Sample before submersion; B, SEM of Al Sample after submersion in HNO₃; C, SEM of Al Sample after submersion in H₂SO₄; D, SEM of Al Sample after submersion in HCl

**Table 9** T-test analysis for corrosion rates (CRs) of metallic samples

| CR     | N  | Mean          | SD      | SE Mean | Sig.(two-tailed) | 95% Confidence interval of the diff. |
|--------|----|---------------|---------|---------|-----------------|--------------------------------------|
| CR@72h | 12 | 42.9 ± 3.35   | 33.5 ± 4.23 | 9.6630   | 0.001           | Lower: 21.6642, Upper: 64.2002       |
| CR@144h| 12 | 19.6 ± 1.51   | 15.2 ± 1.96 | 4.37022  | 0.001           | Lower: 10.0167, Upper: 29.2543       |
| CR@216h| 12 | 13.8 ± 1.08   | 10.8 ± 1.38 | 3.10662  | 0.001           | Lower: 6.9620, Upper: 20.6373        |
| CR@288h| 12 | 10.8 ± 0.89   | 8.9 ± 1.08  | 2.57508  | 0.002           | Lower: 5.1071, Upper: 16.4425        |
| CR@360h| 12 | 8.8 ± 0.77    | 7.7 ± 0.88  | 2.21539  | 0.002           | Lower: 3.9210, Upper: 13.6730        |
3.5 SEM of the samples

The SEMs of the two samples of Al. and Zn alloys before and after submersion in different concentration of acidic media are shown in Figures 7 and 8, respectively. SEM image of aluminum before submersion shows a repeated pattern of aluminum atoms in the crystal. SEM image of aluminum after submersion in HNO₃ for 10 days shows some cracks pattern of grain and surface erosion due to corrosion effects.

4 DISCUSSION

The corrosion rates of zinc and aluminum samples been immersed in the solution of HCl at first time of submersion (72 hours) were 70.741 ± 2.40 and 24.661 ± 1.02 mm/year, respectively, as shown in Table 3. It was observed that zinc samples also had the higher corrosion rates than aluminum been immersed in the solutions of H₂SO₄ and HNO₃. The rates of corrosion of aluminum and zinc samples been submerged in all the three acidic media decreased with an increase in the time of exposure from 72 to 360 hours Uppal and Bhatia.⁴ The graph of corrosion rate of metallic samples against the exposure time in 2M of all acidic solutions is shown in Figure 1. The corrosion rate of metallic samples in 2M of different solutions showed that zinc metals in solution of HCl had the higher corrosion rate of 80.340 ± 0.00 mm/year. The corrosion rates of zinc samples in H₂SO₄ solution at first and last submersion times were 100.273 ± 5.74 and 23.749 ± 0.57 mm/year, respectively. In the solution of HNO₃ it was observed that zinc sample had the higher value of corrosion rate of 72.736 ± 3.00 mm/year while aluminum sample had lower value of 56.763 ± 2.93 mm/year at 72 hours of exposure. It was observed generally that the corrosion rates of aluminum and zinc with the all the three solutions decreased as the exposure times increased.

The corrosion rates of zinc sample in solutions of H₂SO₄ and HCl at 72 hours were 138.645 ± 0.00 and 104.869 ± 5.91 mm/year, respectively, as shown in Table 4. These findings corroborated those of Sanusi et al⁵ and 27.170 ± 0.00 and 25.332 ± 0.44 mm/year were recorded at the last exposure time in that order. It was noticed that the
corrosion rates of the zinc samples were greater than that of aluminum samples was immersed in the three different acidic media Osarolube et al.\textsuperscript{20}

The result in Table 8 and Figure 6 showed that the weight loss intensity of aluminum in 1, 2, and 3 M of HNO\textsubscript{3} solutions increased as the times of exposure increased from 72 to 360 hours while the weight loss intensity of zinc varied as the exposure times increased, which was in agreement with Loto.\textsuperscript{21} The statistical analysis presented in Table 9 showed uncertainties less than 0.005 which confirmed the significance of results obtained.

SEM image of zinc before submersion showed some whitish and non uniform patterns as a result of its chemical compositions. SEM image of zinc after submersion in HNO\textsubscript{3} for 10 days exhibited a serious attack with deeper corroded portions on the sample surface and there were traces of cracks at boundary with white patches. The SEM picture of zinc sample in solution of H\textsubscript{2}SO\textsubscript{4} showed a cloudy and blocks patterns with some traces of white patches for almost all the sample surfaces. The extent of corrosion effect of zinc sample in HCl solution was also depicted in SEM image in which about three-fourth of the sample's surface was affected as shown in Figure 8. The extent of corrosion effect of aluminum sample as depicted by SEM image was about two-third of the sample's surface in H\textsubscript{2}SO\textsubscript{4} for 10 days was affected, whereas it was three-fourth of its surface that was attacked in HCl with intensive cracks and white patches as shown in Figure 7.

5 | CONCLUSIONS

This research investigated the corrosion performance of two nonferrous metals in three acidic media. The following findings can be concluded:

- The Zn alloy sample in 3 M H\textsubscript{2}SO\textsubscript{4} recorded highest corrosion rate of 138.64 mm/year while aluminum alloy sample had lowest rate of 24.661 mm/year after 72 hours of exposures in the acid. The corrosion rates of the samples decreased as the exposure time increased.
- The weight loss intensity of aluminum in 1, 2, and 3 M of HNO\textsubscript{3} solutions increased as the times of exposure increased from 72 to 360 hours while the weight loss intensity of zinc varied as the exposure times increased. The higher the acid molarity, the shorter the exposure time and the higher the corrosion rates for both zinc and aluminum alloy samples.
- The SEM images of the corroded samples showed severity of corrosion in the zinc alloy exposed to acid solutions as compared with the aluminum ones.

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CONFLICT OF INTEREST

Authors have no conflict of interest relevant to this article.

AUTHOR CONTRIBUTIONS

Femi Timothy Owoeye contributed to the conceptualization, investigation, methodology, writing of the original draft, writing of the review and editing. Olayide R. Adetunji contributed to the conceptualization, methodology, supervision, writing of the original draft. Adegbemro Omotosho contributed to the conceptualization, investigation, and methodology. Adinife P. Azodo contributed to the conceptualization, investigation, and methodology. Peter O. Aiyedun contributed to the conceptualization, funding acquisition, methodology, and resources.

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REFERENCES
1. Adetunji OR, Aiyedun PO, Alamu OJ, Surakat AS. Electrochemical properties of metals in cassava fluid. J Eng Technol Res. 2011;3(10):292-297.
2. Umoren SA. Polymers as corrosion inhibitors for metals in different media—a review. Open Corros J. 2009;2:175-188.
3. Loto CA. Electrode potential evaluation of effect of inhibitors on the electrochemical corrosion behaviour of mild steel reinforcement in concrete in H₂SO₄. J Mater Environ Sci. 2012;3(1):195-205.
4. Uppal O, Bhatia LN. Localized corrosion of passive metals. In: Revie RW, ed. Uhlig's Corrosion Handbook. Canada: John Wiley and Sons, Inc.; 2001:175-186.
5. Beda RHB, Niamien PM, Avo Bilé EB, Trokourey A. Inhibition of Aluminium corrosion in 1.0 M HCl by caffeine: experimental and DFT studies. Adv Chem. 2017;2017:6975248, 10 pp. https://doi.org/10.1155/2017/6975248.
6. Ita BI, Offiong OE. Inhibition of steel corrosion in hydrochloric acid by pyridoxal, 4- methylthiosemicarbazide, pyridoxal-(4-methylthiosemicarbazone) and its Zn (II) complex. Mat Chem Phy. 1997;48:164-169.
7. Ahmad MA, Nabeel AJ, Nuhu DM, Rihan OR. Thermodynamics and kinetics of inhibition of aluminum in hydrochloric acid by date palm leaf extract. J Appl Sci Environ Manage. 2014;18(3):543-555.
8. Shreir LL, Jarman RA, Burstein GT. Corrosion. Vol 2. New York, NY: Elsevier Inc.; 2000:2.
9. Loto CA. Electrochemical noise measurement technique in corrosion research. Int J Electrochem Sci. 2012;7:9248-9270.
10. Shanbhag AV, Venkatesha TV, Prabhu RA, Praveen BM. Inhibition effects of acetyl Coumarines and Thiazole derivatives on corrosion of zinc in acidic medium. Bull Mater Sci. 2011;34(3):571-576.
11. Loto CA. Inhibition effect of tea (Camellia sinensis) extract on the corrosion of mild steel in dilute sulphuric acid. J Mater Environ Sci. 2011;2(4):335-344.
12. Sanni O, Popoola A, Fayomi O. Oil as corrosion inhibitor for Aluminium alloy in aggressive environment. 1st Int Conf Eng Sustain World (ICESW) IOP Conf Series: Mater Sci Eng. 2018;391(2018):012004. https://doi.org/10.1088/1757-899X/391/1/012004.
13. Abdallah M, Hazazi OA, Al Jahdaly BA, Fouda AS, El-Nagar W. Corrosion Inhibition of Zinc in Hydrochloric Acid using some Antibiotic Drugs. Int J Innov Res Sci Eng Technol. 2014;3(2014):13802.
14. Abdallah M, Zaafarany IA, AL Jahdaly BA. Corrosion inhibition of zinc in hydrochloric acid using some antibiotic drugs. J Mater Environ Sci. 2016;7(4):1107-1118.
15. Mamun A, Schennach R, Parga JR, Mollah MYA, Hossain MA, Cocke DL. Passive film breakdown during anodic oxidation of zirconium in pH 8 buffer containing chloride and sulfate. Electrochim Acta. 2001;46(22):3343-3350.
16. Fontana MG. Corrosion Engineering. 3rd ed. Singapore: McGraw-Hill, International Ed; 1987 171 pp.
17. Adetunji O, Owoeye F. Corrosion resistance of aluminum plates in lime solution. Pac J Sci Technol. 2011;12(1):56-61.
18. Omotoso A, Aiyedun PO, Adetunji OR, Arowolo TA, Owoeye FT. Corrosion performance of 1014 mild and 304 stainless steels in acidic medium. J Nat Sci Eng Technol. 2017;16(1):83-92.
19. Sanusi KO, Hussein KO. Investigation of corrosion effect of mild steel on orange juice. Afr J Biotechnol. 2001;10(16):3152-3156.
20. Osarolube E, Owate IO, Oforka NC. Corrosion behaviour of mild and high carbon steels in various acidic media. Sci Res Essay. 2008;3(6):224-228.
21. Loto RT, Loto CA, Popoola API, Ranyoa M. Corrosion resistance of austenitic stainless steel in sulphuric acid. Int J Phys Sci. 2012;7(10):1677-1688.

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