Open Journal of Applied Sciences, 2023, 13, 76-88
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Outdoor Corrosion Performance Study of Selected Construction Materials in Bonny Island

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How to cite this paper: Ekuma, C.M. and Ogunyemi, T.C. (2023) Outdoor Corrosion Performance Study of Selected Construction Materials in Bonny Island. *Open Journal of Applied Sciences*, **13**, 76-88.
https://doi.org/10.4236/ojapps.2023.131007

Received: June 28, 2021
Accepted: January 16, 2023
Published: January 19, 2023

Abstract

Corrosion studies are important due to the enormous cost involved in the replacement of materials in all kinds of applications. The outdoor study on corrosion behavior of aluminum sheet, chequered aluminum plate and zinc alloys roofing sheet commonly used as construction material within a highly industrial settlement were examined using the gravimetric technique. The outdoor corrosion of these alloys at different sites was observed via its exposure to atmospheric conditions, monitored and recorded for 12 months at an interval of 2 months. Results depicted a process spanning the initial and intermediate stages of corrosion. The samples of construction materials at Bonny island showed substantial weight losses and rate of corrosion which varied largely on percentage of atmospheric humidity, salt precipitations, industrial aerosols and corrosive gases present at the exposure site as well as the nature of the material and the presence of protective coating formed during corrosion process. The rapid rate of deterioration of these materials causes severe economic importance on the indigenes' activities including the oil and gas industries and other construction companies on the island. Thus, there is urgent need for research concerned with methods to control or prevent excessive deterioration of metals in Bonny Island.

Keywords

Corrosion, Outdoor Environment, Construction Materials, Weight Loss and Alloys

1. Introduction

Atmospheric corrosion of materials encompasses wide spectrum of chemical, electrochemical and physical processes in the interfacial domain of a material which spans from the gaseous, liquid to solid phase [1]. It occurs as a result of the interaction between an exposed material and its atmospheric environment which usually results in changes in the properties of metals resulting in the impairment of the metal function, environment, or technical system [2]. Collaborative damaging effects of corrosion are usually costly to repair; costly in terms of lost, environmental damage and possibly human [3] [4] and [5]. Thus, the rate of corrosion and the major corrosion products formed vary from one material to another [1].

Earlier research has shown that high corrosion rate was observed in coastal atmosphere and magnified by dense industrial activities [6] and [7]. The rate of corrosion is mostly dependent on the nature of the material (metal), nature of the environment (such as temperature, humidity, exposure time, presence of corrosive gases and aerosols) and the type of surface film formed after a material reacts with its environment. Over the years, research has recommended adequate corrosion prevention measure such as coating to prevent the deterioration of the underlying substrate when exposed to various environments. However, coating can fail prematurely, which could be attributed to an unsuitable coating composition in given environmental conditions. Chemical, physical, and/or mechanical damage to a coating system during exposure can initiate premature corrosion of the metallic surface [8].

An exposure condition such as airborne salinity, acid rain, washing effect of precipitation has been reported to have significant effect on corrosion in an outdoor environment [5]. Furthermore, the effect of gas flaming on roofing sheets in gaseous and non-gaseous flaring area has also been documented by earlier [4] and [9]. In addition, some materials (aluminum alloys) develop severe pitting and a voluminous white corrosion product under some exposure conditions such as marine atmospheres [10]. However, constant exposure to moisture with a limited supply of oxygen to the aluminum surface leads to the rapid corrosion of any aluminum apparatus or equipment. And this is due to the highly reactive nature of aluminum that leads to formation of oxides or hydroxides [10]. In the presence of oxygen, a protective aluminum oxide film which is substantially unreactive develops on any aluminum surface. If the film is removed by mechanical or chemical means corrosion is activated [10].

Thus, aluminum and its alloy are regularly exposed to outdoor atmosphere as it is mainly used in the telecommunications, electronics, construction and automotive decorative industries. In addition, Zinc-based alloys are important materials in outdoor applications such as construction, architectural applications owing to their capacity to reduce the corrosion rate by orders of magnitude compared to other corrosion vulnerable metals. However, the resistivity depends on the prevailing exposure conditions and coating thickness coupled with the nature of exposed environment [10].

Furthermore, most recent research on corrosion rate of materials have been in a stimulated environment [11], which does not fully depict the deterioration of metals within any geographical location. Therefore, this investigation is aimed at providing a database for selected construction alloy materials such as Aluminum and Zinc Alloys, Chequered Aluminum commonly used in Bonny Island, Nigeria. This area is known for its high oil exploration activities and close proximity to the Atlantic Ocean and thereby, giving an insight to the chemistry of these construction materials and their corrosion rate which will be useful for designers, engineers, builders and architects.

2. Materials and Methods

2.1. Study Area

The study was carried out in Bonny Island, Rivers State, Nigeria. The Island is about 40 kilometers from the state capital Port Harcourt. The island lies between Latitude (4.21N to 4.32N) and Longitude (7.730E to 7.721E) as depicted in the map shown in **Figure 1** below. The climate of the area is generally hot and very humid. The description of land use could be categorized into several heading; Housing, Industry, Commercial, and other land uses. The principal Industrial activities are extraction, processing, storage and exportation of petroleum products [12]. The major companies operating in the island are;

- Shell Petroleum Development Company (SPDC) whose responsibilities are extraction, storage and export of crude oil.
- Nigeria Liquefied Natural Gas (NLNG) deals mainly with the processing and export of liquefied natural gas.
- Exxon Mobil oil company are involved in the collection, storage and export of petroleum products.
- Other industries are involved in activities such as construction, fabrication, manufacturing and service provision.

2.2. Materials

The alloy materials investigated are 1) Coated and uncoated aluminum roofing sheet; 2) Coated and uncoated chequered aluminum plate; 3) Aluminum/zinc alloy; 4) Galvanized steel as listed in **Table 1** below.

2.3. Coupon Preparation

Sample sheets were obtained from the market within Bonny Island, Rivers State, Nigeria and were mechanically press-cut into coupons of precise surface area at Mechanical Engineering Workshop, Federal Polytechnic of Oil and Gas, Bonny, Nigeria.

2.4. Exposure Site Environment

Three exposure sites were used during the study as presented in **Table 2** below.

Weight Loss and Corrosion Rate Measurement

The weight loss measurement was carried out at the exposure site as reported earlier by [13] using the formula:

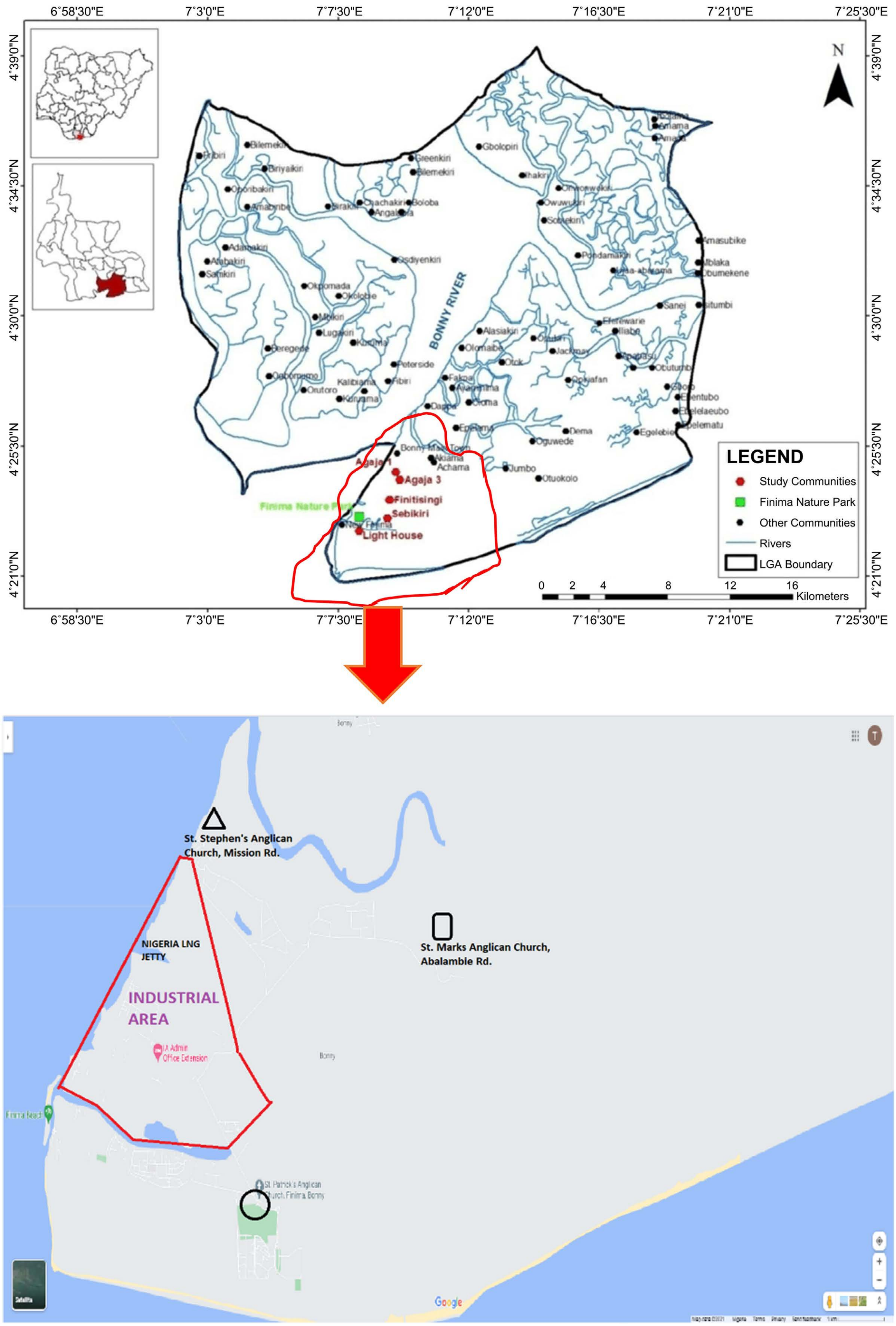

Figure 1. Map of bonny island, rivers state showing sampling site in the main metropolis.

Table 1. Alloy materials under study and their composition.

SAMPLE	COMMON NAME
Sample 1	Coated Aluminum Roofing Sheet
Sample 2	Uncoated Aluminum Roofing Sheet
Sample 3	Coated Chequered Aluminum Plate
Sample 4	Uncoated Chequered Aluminum Plate
Sample 5	Aluminum/Zinc Alloy (Cameroon Roofing Sheet)
Sample 6	Galvanized Steel Sheet (Nigerian Roofing Sheet)

Table 2. Outdoor exposure sites with their proximity to industrial area and shorelines.

Exposure Sites	Site Location	Proximity to Industrial Area (Approximate meters)	Proximity to Shorelines (Approximate meters)
SITE-1	Ablamabie, Bonny Island	5900	4900
SITE-2	Finima, Bonny Island	3500	1700
SITE-3	Mission Road, Bonny Island	4800	500

$$\Delta W = W_i - W_{f(t)} \quad (1)$$

where ΔW = Weight loss (g);

W_i = Initial Weight of the material at the start of the experiment;

$W_{f(t)}$ = Weight of the material at exposure time (t);

The thickness of the samples was measured using a Vernier caliper.

The corrosion rate was determined using gravimetric (weight loss) method of the samples during the corrosion study according to [14] and [15] using the formula

$$\text{Corrosion Rate}(\text{mpy}) = \frac{534W}{DAT} \quad (2)$$

where W = Weight loss (g);

D = Density of the material (g/cm^3);

A = Area of Material (cm^2);

T = Exposure Time (year).

3. Results and Discussion

The response of selected materials exposed in an outdoor environment to corrosion within Bonny Island is presented in **Table 3** below. Each coupon material exhibited different phenomenon in its stages of corrosion.

Based on the result presented, some of the coupon exhibits reduction in weight while it was also observed that there was weight gain in some materials. The weight gains were indicated in "-" value. Hence, corrosion process of a material could span through weight loss and weight gain. The weight gain could be attributed to the formation of protective film on the material and the potential

Table 3. Weight loss and corrosion rate of selected materials at exposure sites within bonny island, Nigeria.

SITES	SAMPLE	WEIGHT LOSS (g)						CORROSION RATE (mpy)					
	MONTHS	2	4	6	8	10	12	2	4	6	8	10	12
ABLAMABIE	S1	0.01	0.02	0.08	−0.09	−0.09	0.01	0.04	0.04	0.11	−0.10	−0.08	−0.07
	S2	−0.08	−0.07	−0.04	−0.36	−0.56	−0.62	−0.34	−0.15	−0.06	−0.38	−0.48	−0.44
	S3	0.28	0.19	0.47	0.44	0.36	0.35	0.52	0.18	0.29	0.20	0.13	0.11
	S4	19.63	17.57	17.09	17.13	15.16	15.24	39.24	17.56	11.39	8.56	6.06	5.08
	S5	0.02	0.01	−0.01	−0.05	−0.07	−0.04	0.06	0.02	−0.01	−0.04	−0.04	−0.02
	S6	−0.19	−0.36	−0.23	−0.26	−0.33	−0.34	−0.25	−0.24	−0.10	−0.09	−0.09	−0.08
FINIMA	S1	4.73	4.75	4.87	4.89	4.92	4.93	20.05	10.07	6.88	5.18	4.17	3.48
	S2	−0.13	−0.04	−0.01	−0.02	−0.04	−0.02	−0.55	−0.08	−0.01	−0.02	−0.03	−0.01
	S3	0.19	0.06	0.01	0.05	0.69	0.68	0.35	0.06	0.01	0.02	0.26	0.21
	S4	−1.64	−2.88	−3.24	−4.37	−4.60	−4.62	−3.15	−2.77	−2.08	−2.10	−1.77	−1.48
	S5	−0.09	−0.07	0.04	0.05	0.02	0.01	−0.27	−0.10	0.04	0.04	0.01	0.01
	S6	−0.54	−0.42	−0.39	−0.33	−0.25	−0.24	−0.72	−0.28	−0.17	−0.11	−0.07	−0.05
MISSION	S1	−0.02	−0.04	−0.02	0.01	0.03	0.04	−0.08	−0.08	−0.03	0.01	0.03	0.03
ROAD	S2	0.01	−0.06	−0.05	−0.03	−0.07	−0.06	0.04	−0.12	−0.07	−0.03	−0.06	−0.04
	S3	0.12	0.10	0.18	0.43	0.58	0.52	0.22	0.09	0.11	0.20	0.21	0.16
	S4	−0.97	−1.64	−2.12	−1.98	−2.95	−2.97	−1.92	−1.63	−1.40	−0.98	−1.17	−0.98
	S5	−0.03	−0.07	−0.07	−0.06	−0.10	−0.31	−0.09	−0.10	−0.07	−0.04	−0.06	−0.15
	S6	−0.13	−0.30	−0.16	0.05	0.10	0.06	−0.17	−0.20	−0.07	0.02	0.03	0.01

*S1 - S6 denotes samples of alloy materials under study. Refer to Table 1.

presence of other molecules cleaved within the material such as H_2O and H_2. Presented in **Figures 2-4** below are the weight loss of the selected materials considering the type of the material and exposure site. These charts establish that the nature of a material determines the types of protective film formed while the atmospheric environmental conditions influence the rate of film formation and corrosion process [1].

There was a significant weight loss of coated aluminum at Finima area of bonny island compared to the results obtained from Ablamabie and Mission road within the same metropolis (**Figure 2**). This could be attributed to the aerosol particle deposition which is high at the industrial zone (Finima) and the climatic condition of the zone with high proximity to the Ocean. However, the results obtained from Ablamabie and Mission Road could be ascribed to the above condition but with a low effect as described for coated aluminum. Furthermore, the positive values denote that the coated aluminum may be peeling off based on its possible chemical degradation catalyzed by environmental parameters. The weight loss at Finima was obvious in the aluminum samples as a result of the degradation of the protective coating owing to the harsh environmental condition. The loss of the coating layer could be attributed to the permeation via the layer's

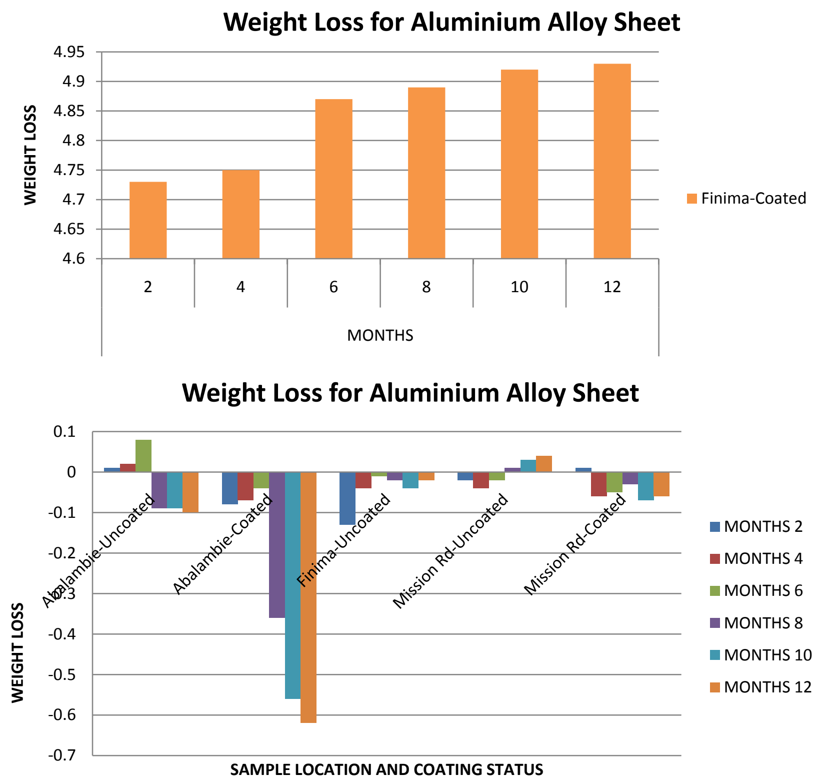

Figure 2. Weight loss of coated and uncoated aluminum alloy sheet.

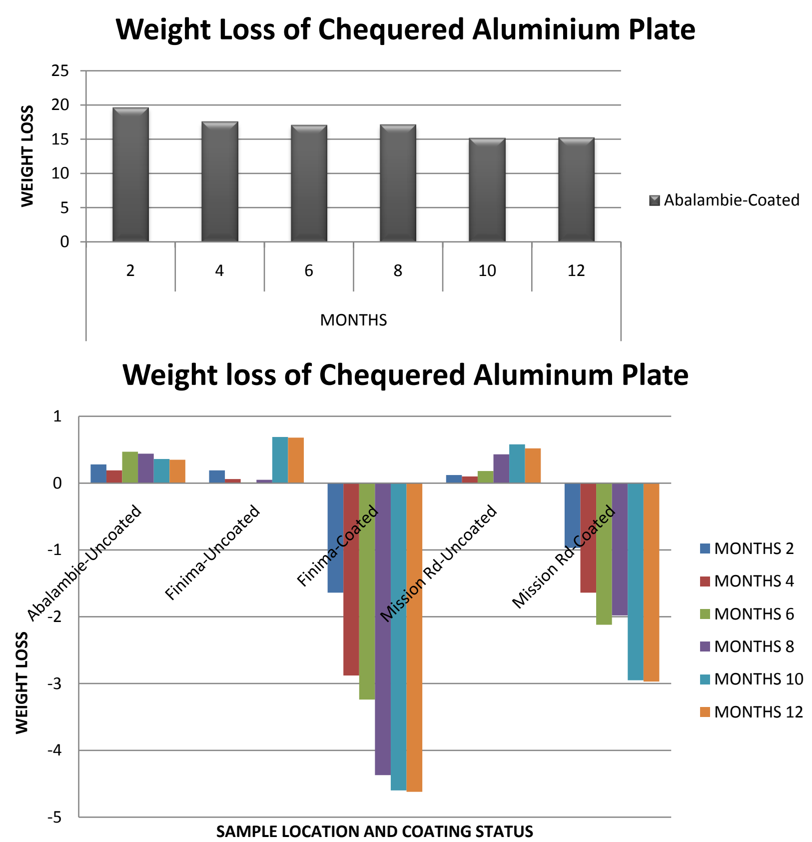

Figure 3. Weight loss of chequered aluminum plate.

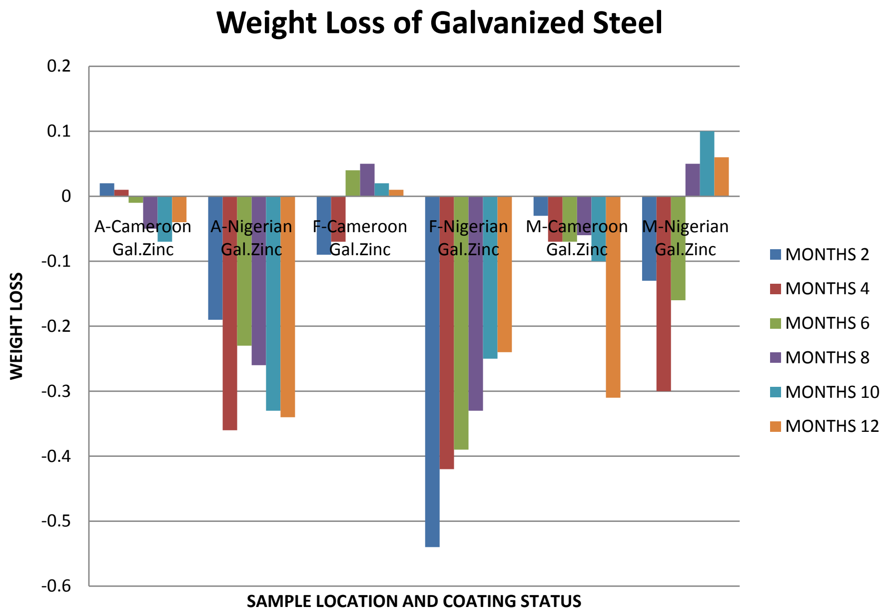

Figure 4. Weight loss of Cameroon and Nigeria galvanized steel sheet.

reaction with the salt deposit, gaseous acidic oxides and aerosols in the presence of atmospheric moisture domicile at the industrial zone.

Furthermore, it was observed that the uncoated aluminum underwent continuous depletion owing to the unprotected material's exposure to various corrosion enhancing conditions. Although, aluminum forms a stable thin aluminum oxide layer that protects it from corrosion phenomenon, it is still susceptible to chemical degradation especially in an aggressive medium justifying the observed depletion.

At each of the exposure site, uncoated Aluminum sheet tends to form protective film which resulted in weight increase. Thus, the use of protective coating on aluminum sheet tends to improve the durability and corrosion resistivity especially in an environment that is more susceptible to corrosion process.

Chequered aluminum plate which is widely used in the construction of caravans within the island showed different trend of corrosion mechanism across the exposure sites and its coating. It was observed that coated chequered aluminum plate at Finima and Mission Road, had an increase in weight compared to the uncoated chequered aluminum which had loss of weight. This could be associated to the fact that some of the environmental influences such as energy, permeation (moisture, solvent, chemical, and gas), stress and biological influences acting on the protective coating film can result in deterioration [16].

Uncoated Chequered aluminum plate showed weight loss at all exposure site. It implies that there will be a consistently corrosion taking place with loss of parts of the material. This could be attributed to the embossment enclave on the plate which permits the retention of corrosion enhancing entities such as dust, O_2, H_2O, etc. on the surface thereby, creating sufficient surface area for corrosion to take place. However, coated chequered aluminum plate had an increasing weight as a result of the possible add-up of moisture which gradually depreciates with time. Though the weight gain is highest at Finima which could be due to high salt and water content of the environment along anthropogenic and industrial activities in the area.

The loss in weight of galvanized steel can be related to the extent of additional film formed on the surface of the material upon reactions with the atmospheric entities. Hence Nigerian galvanized steel is more reactive to environmental conditions compared to the Cameroon galvanized steel across the exposure sites. However, Nigerian galvanized steel at Finima, Bonny Island had the highest extent of film formation. This could be attributed to the high industrial activities sequel to industrial effluents, particulate deposits, aerosol deposition and its proximity to the Atlantic Ocean.

Cameroon galvanized zinc sheet at Ablamabie and Mission road follows the same trend as there was a gradual weight gain as a result of protective film oxide formed on the material. However at Finima, Cameroon galvanized zinc sheet showed possibility of undergoing depreciating corrosion via consistent loss of some fraction of the sheet and formation of unstable protective film which after precipitation will undergo dissolution. This accounts for the consistent weight gain and loss procedure. Based on this understanding, galvanized zinc could have been reactive to the atmospheric entities from the industrial and salty water environment more than Cameroon galvanized steel environments, having less of this corrosion enhancing entities.

Furthermore, Nigerian galvanized zinc at Ablamabie showed an inconsistent weight gain which suggests that there was a continuous gradual precipitation and film formation which subsequently underwent dissolution and loss of weight. However at Finima, the rate of film formation was highest within the first two month and the gradual losses of the material oxides in the subsequent months, suggest that the film formed are not a stable film. This also accounted for a gradual decline of the initial weight gain. At Mission road which is close to bonny estuaries, gradual film formation was observed, followed by dissolution as a result of the high humidity.

The corrosion process of Nigerian galvanized zinc sheet is in the following order: Finima (F) > Mission Road (M) > Ablamabie (A). While, corrosion process of Cameroon galvanized zinc sheet are in the following order: Finima (F) > Abalambie (A) > Mission Road (M).

Therefore, the mechanism that governs corrosion of a material differs greatly based on the nature of the material and its surrounding environmental conditions.

Corrosion Rate

Based on the corrosion rate of aluminum alloy sheet shown in **Figure 5** below. Coated aluminum sheet at Finima, Bonny island exhibited huge corrosion which could be due to high reactiveness of industrial aerosols, corrosive gases and high moisture content synergistically reacting and reducing the corrosion resistivity

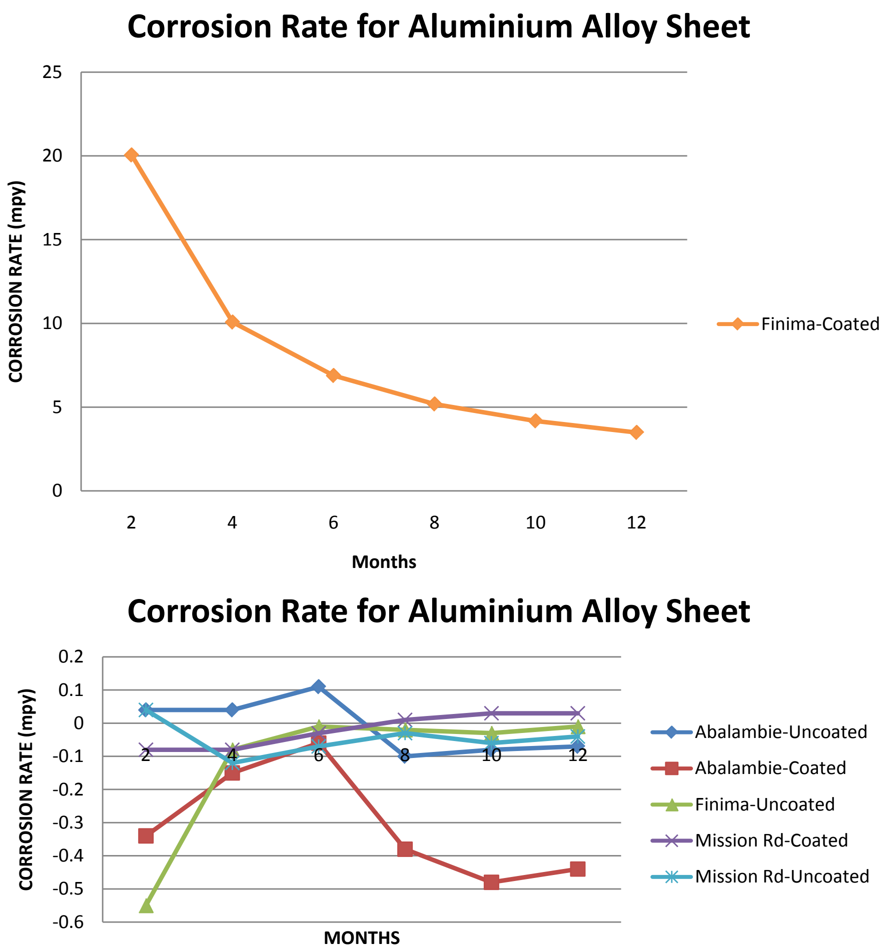

Figure 5. Corrosion rate of coated and uncoated aluminum alloy sheet.

of the aluminum sheet [8]. Generally, the decrease in corrosion rate could be due to passivation [15] while increase in corrosion rate could be attributed to depassivation when the protective corrosion oxide is broken [3].

Furthermore, coated and uncoated chequered aluminum plate profile corrosion rate within 12 months of study is depicted in **Figure 6** below. The profile showed an irregular pattern of corrosion. The corrosion reduction is due to the formation of the protective oxide formed on the structure, and corrosion rate could slightly increase as a result of depassivation of the protective corrosion oxide [17]. The corrosion rate profile showed that uncoated chequered aluminum was unfit as a construction material owing to its vulnerability to chemical reaction from moisture and other gas permeation prevalent at Abalambie environment. A mid corrosion resistance was observed in coated chequered aluminum at Abalambie, Finima and Mission Road. The uncoated chequered aluminum at Finima and Mission Road showed high resistivity to corrosion.

Corrosion of the field exposed galvanized Cameroon and Nigerian roofing sheets is represented in **Figure 7** below. The corrosion rate of Cameroon roofing sheet at Finima was moderate compared to the same samples at Abalambie and Mission road which could be attributed to intense industrial activities and anthropogenic

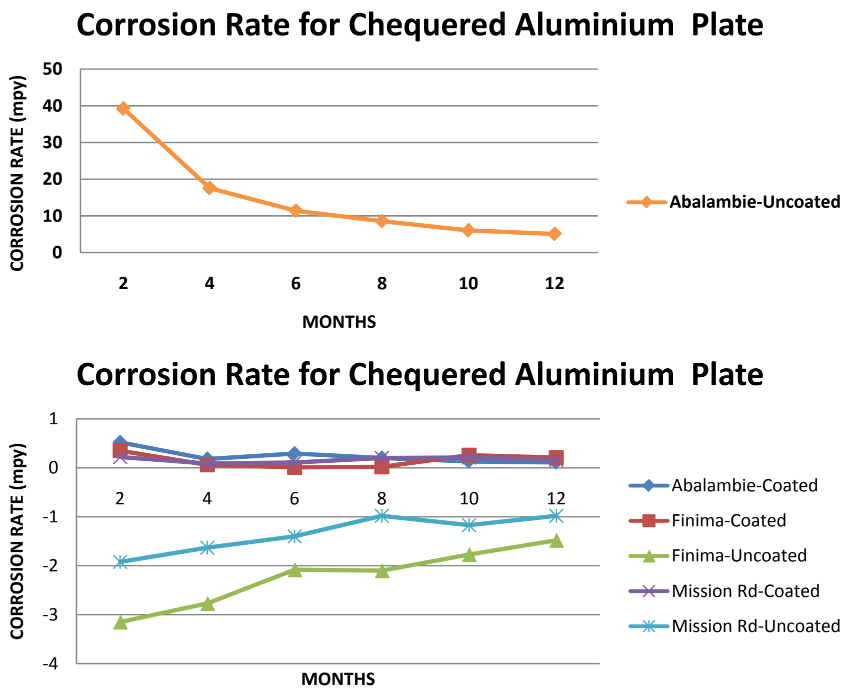

Figure 6. Corrosion rate of coated and uncoated chequered aluminum plate.

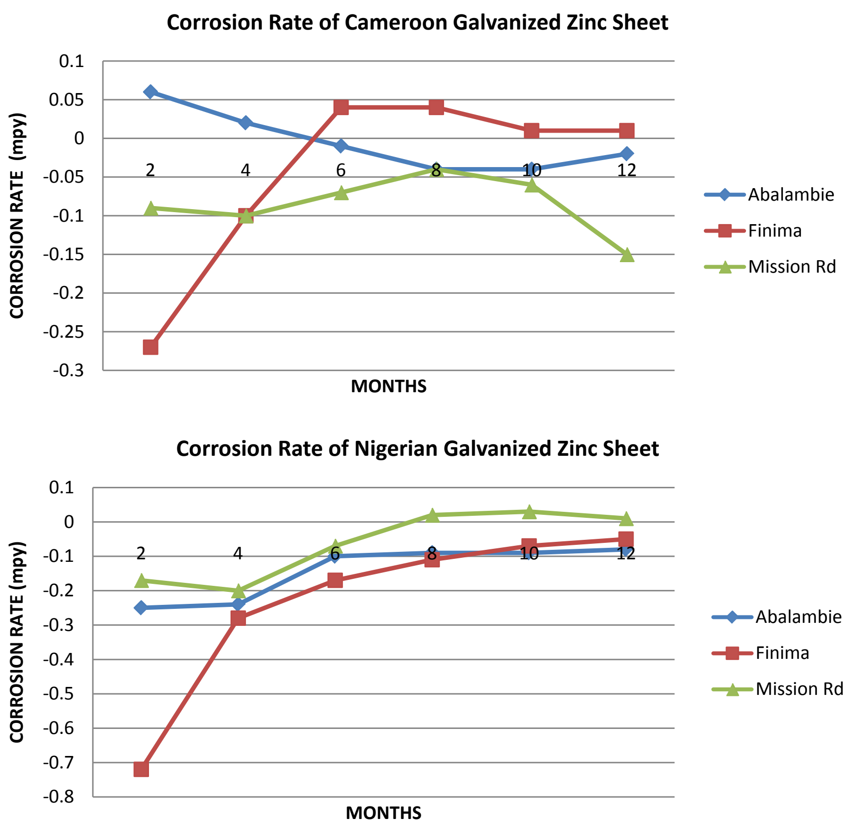

Figure 7. Corrosion rate of Cameroon and Nigerian roofing sheet.

resultant effects in the area. In addition, a uniform and speedy corrosion was observed for the Nigerian roofing sheet which is highest in Finima when compared to the same samples at Ablamabie and mission road. This could be ascribed to permeation effects (water, solvents and chemical), coupled to its proximity to the sea alongside oil and gas industries domicile in the area. It can also be stated that an increase in temperature is usually accompanied by an increase in reaction rate therefore, increase in temperature of the environment (green house effects) must have influenced the rate of corrosion of this galvanized zinc sheets [10].

Zinc and zinc-coated products corrode easily in some environments forming white corrosion products [18]. As revealed in the two charts above (**Figure 7**), the rate of corrosion of Nigerian galvanized zinc sheet was faster which shows that the Cameroon roofing sheet is preferably better roofing material for construction in such industrialized area based on its extreme corrosion resistant properties. It has been reported that Cameroon zinc sheets is a product made from the alloy of rust resistance metals.

4. Conclusions and Rcommendation

Metals and metal alloys used in outdoor constructions interact with the environment forming surface oxides and other corrosion products, either speedily or moderately. Daily recurrent wet-dry humidity/temperature cycle processes and dissimilarities in prevailing environmental conditions could result in continuous dissolution–reprecipitation processes with time, chemical changes, and varying thickness of corrosion products. Furthermore, the variation in corrosion rate of the material across the exposure site proved that the degree and severity of corrosion is a function of its environment and nature of material. The required level of maintenance largely depends on the severity of corrosion phenomenon. Therefore, an informed decision can be made as to the type, cost, and urgency of possible control or remedial measures.

Finally, there is a need to fund research on an extensive outdoor corrosion study over a longer period in Bonny Island to identify the mechanisms of corrosion attack and reasonable intervention program (material change, selection of a corrosion inhibitor, or a more drastic design change to the metal) to enhance reduction in the cost accompanying corrosion experienced within the island.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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