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## Technical Report

## Comparative study of corrosion behaviour of galvanized steel and coated Al 3103 roofing sheets in carbonate and chloride environments

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## ARTICLE INFO

## Article history:

Received 14 April 2008

Accepted 3 June 2008

Available online 7 June 2008

## ABSTRACT

This work studied the comparative corrosion behaviour of Al 3103 and galvanized steel roofing sheets in 1 M, 0.5 M and 0.3 M solutions of sodium carbonate and sodium chloride. Samples of the aluminium and galvanized sheets were subjected to the different environments for thirty days. The electrode potentials, in mV (SCE), were measured every day. Electrode potential measurements were taken everyday for thirty consecutive days. Weight loss or gain measurements were taken every three days for the duration of the exposure period.

The results showed sodium chloride environment had higher corrosive effect on the galvanized roofing sheet than sodium carbonate environment while the reverse was true for aluminium sheets. Also, galvanized steel roofing corroded more than aluminium roofing in both carbonate and chloride environments. Corrosion of galvanized steel roofing was continuous throughout the exposure period in all the environments used. Galvanized steel roofing sheet is not good material for roofing in carbonate and chloride environments or in industrial environments where chloride or carbonate contamination is possible.

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## 1. Introduction

Ceramic roofing is widely used in temperate and cold countries. Despite the strength of ceramic roofing, the use of galvanized steel for roofing is very common in tropical countries with the subsequent defacement of aerial view of settlements due to corrosion of the roofing sheets. The massive production of Al 3103 roofing sheets has brought an option to the building industry. It is necessary to study the comparative corrosion behaviour of the two in chloride (from sea water) and carbonate (from industrial pollutants) environments.

The aluminium metal itself is a silvery white metal, ductile and malleable; hence its alloys can be made into foil, wire and sheets. It is a good conductor of both heat and electricity. It is corrosion free, burns in air to form oxide and nitride and reacts with mercury to form amalgam. It does react with dilute HCl as well, passive because of non reaction with oil or concentrated H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub> due to protective layer of aluminium oxide and it is amphoteric [1–3]. The 3103 grade of aluminium alloy has some content of copper, magnesium and manganese which confer on it some of its hardness and toughness properties useful for roofing.

Galvanized sheet is a type of roofing sheet which consist of mild steel as the base metal but coated with zinc either by hot dip galvanizing process or metallic coating process. The rapid corrosion of

galvanized sheet is because sacrificial protection by zinc is a temporary phenomenon and it is only effective for a short time because zinc dissolves quickly once electrolytic action begins [4].

## 2. Materials and methods

## 2.1. Materials

## 2.1.1. Al 3103 roofing sheet

The Al 3103 roofing sheet samples were obtained from Tower Aluminium Company located at Ogba Industrial Estate Ikeja, Lagos, Nigeria. The chemical composition is presented in Table 1.

## 2.1.2. Galvanized steel roofing sheet

The galvanized steel sheet sample work was obtained from Qualitec Aluminium Company located at Plot 620 Idu Industrial Estate, Abuja, Nigeria. The chemical composition is presented in Table 2.

## 2.2. Preparation of corrosion media

Solutions (0.3, 0.5 and 1 M) of sodium chloride were prepared by dissolving 17.55, 29.25 and 58.5 g of sodium chloride crystals in 1 dm<sup>3</sup> of distilled water, respectively.

0.3, 0.5 and 1 M solutions of sodium trioxocarbonate (iv) were prepared by dissolving 31.8, 53.0 and 106 g of the salt in 1.0 dm<sup>3</sup> of distilled water, respectively.

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**Table 1**  
Chemical composition of aluminium roofing sheet in Wt%

Chemical composition	Al	Cu	Mg	Mn	Cr	Pb	Ni	Si	Co
Weight %	98.8	0.20	0.15	0.20	0.20	0.05	0.15	0.15	0.10

**Table 2**  
Chemical composition of galvanized steel roofing sheet in Wt%

Chemical composition	Fe	Zn	C	Co	Mn	Ni	V	Si	S
Weight %	75.8	20.4	1.2	0.35	0.35	1.3	0.4	0.15	0.05

### 2.3. Experimental method

The prepared media were poured into plastic containers and test coupons of the roofing sheets measuring 50 mm × 50 mm were immersed in the plastic containers containing the various concentrations of the corrosive media.

#### 2.3.1. Electrode potential measurement

The electrode potentials of the test specimen were read everyday for thirty days using digital multimeter (DT 830D model) with zinc rod as reference electrode. The reference electrode was immersed in the media when readings were to be taken and removed afterwards. These electrode potential values were converted into standard calomel electrode using relation:

$$\text{Electrode potential mv(SCE)} = E_{\text{zn}} - 1030 \text{ mV[5]}$$

where  $E_{\text{zn}}$  is Electrode potential reading obtained using the zinc rod. SCE is standard calomel electrode.

#### 2.3.2. Weight loss/gained measurement

The weight loss measurements were taken at intervals of three days (48 h) for thirty days using sensitive digital chemical weighing balance.

#### 2.3.3. Cumulative weight difference

This is the increase or decrease in weight of each samples of Al 3103 and galvanized steel roofing sheets after being exposed to carbonate and chloride environments.

#### 2.3.4. Corrosion rate

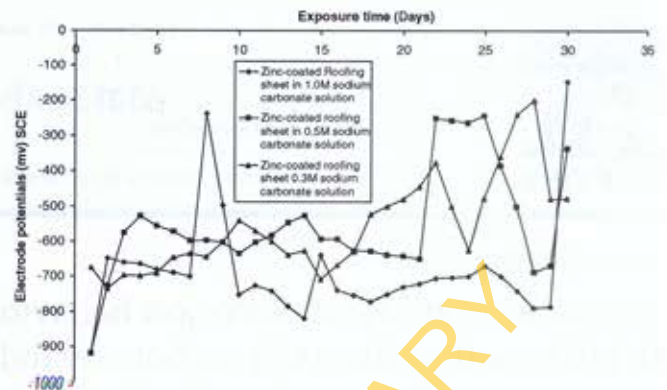
The corrosion rate of each of the specimens in different corrosion media of various concentrations were determined and calculated using the given relation below

$$R = W/AT$$

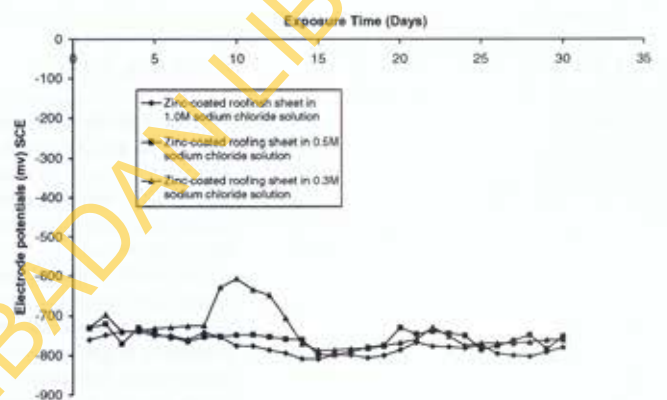
where  $R$  = corrosion rate (mg/mm<sup>2</sup>/yr),  $W$  = weight loss/gain (i.e weight difference),  $A$  = Area of the specimens and  $T$  = exposure time.

#### 2.3.5. Experimental conditions

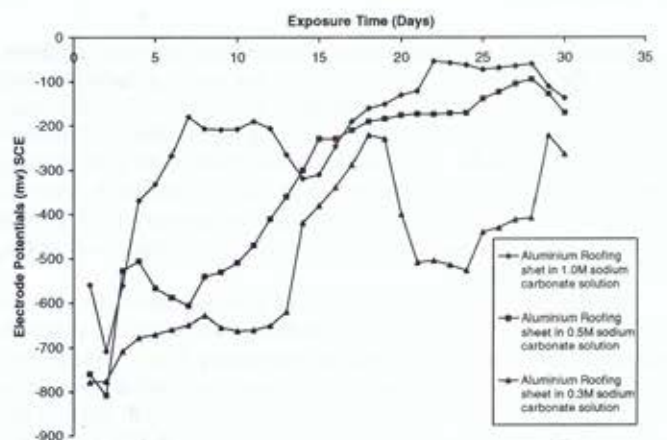
- (1) The experiment was carried out at normal room temperature.
- (2) All experiments were performed under prevailing relative humidity.
- (3) All experiments were carried out under stagnant conditions.
- (4) Pressure is 1 atm that is, normal atmospheric pressure.
- (5) Total immersion was used for all the experimented specimens in various corrosion media.



**Fig. 1.** Variation of electrode potential of galvanized steel roofing in sodium carbonate solutions with exposure time.



**Fig. 2.** Variation of electrode potential of galvanized steel roofing in sodium chloride solutions with exposure time.



**Fig. 3.** Variation of electrode potential of Al 3103 roofing in sodium carbonate solutions with exposure time.

## 3. Results and discussions

### 3.1. Results

The results of this investigation are presented in Figs. 1–3.

Fig. 1 shows variation of electrode potential of galvanized steel roofing in 0.3, 0.5 and 1 M sodium carbonate solutions with exposure time. The plot shows corrosion potential higher in the 1 M carbonate solution compared with corrosion potential in the other solutions.

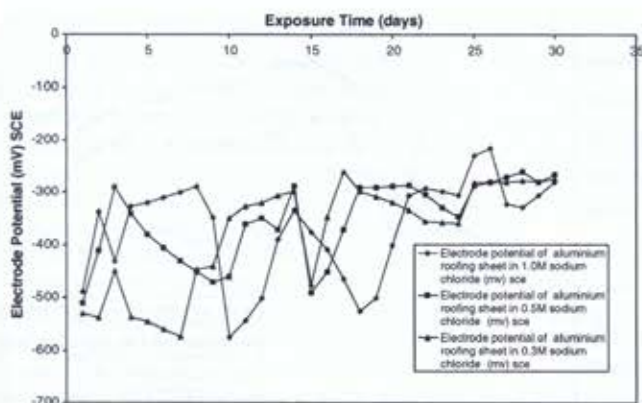


Fig. 4. Variation of electrode potential of Al 3103 roofing in sodium chloride solutions with exposure time.

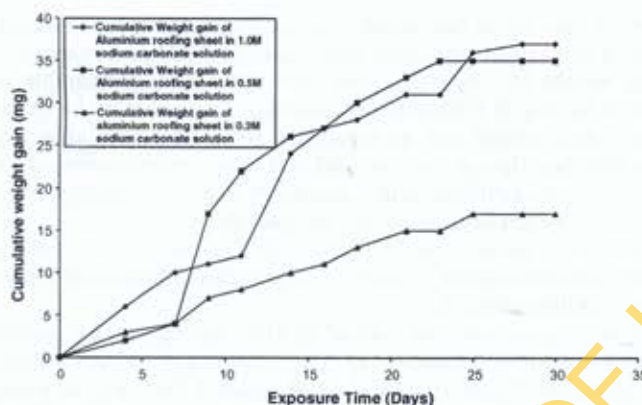


Fig. 5. Plot of comparative cumulative weight gain of Al 3103 roofing in various concentrations of sodium carbonate solution.

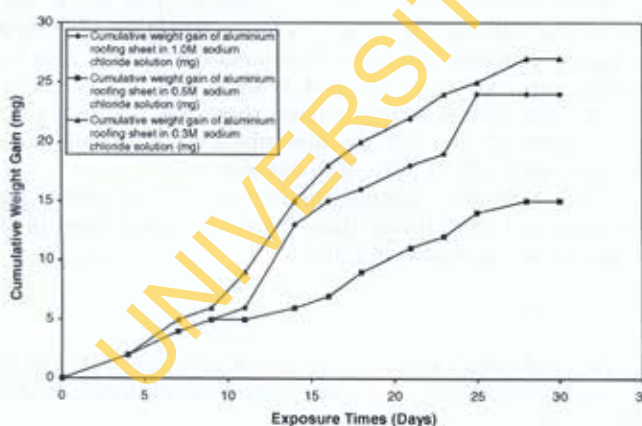


Fig. 6. Plot of comparative cumulative weight gain of Al 3103 roofing in various concentrations of sodium chloride solution.

The variation of electrode potential of galvanized steel roofing in 0.3, 0.5 and 1 M sodium chloride solutions with exposure time is presented in Fig. 2. The electrode potentials show the same trend for the various concentrations.

Fig. 3 shows variation of electrode potential of Al 3103 roofing in 0.3, 0.5 and 1 M sodium carbonate solutions with exposure time. The trend of potential with exposure time was observed to be the

same in all the carbonate concentrations, with potential in the 0.3 M solution highest followed by that in the 0.5 M solution and the potential in the 1 M solution the least.

The variation of electrode potential of Al 3103 roofing in 0.3, 0.5 and 1 M sodium chloride solutions with exposure time is presented in Fig. 4. The trend of potential with exposure time was observed to be the same in all the chloride concentrations.

Fig. 5 shows the comparative cumulative weight gain for Al 3103 sheet in all the various concentrations of the carbonate solution. The weight gain in the 1 M and the 0.5 M solutions are comparable with each other. The weight gain in the 0.3 M solution was observed to be smallest.

Fig. 6 presents the comparative cumulative weight gain for Al 3103 sheet in all the various concentrations of the chloride solution. The weight gain in the 0.3 M solution was observed to be highest followed by weight gain in the 1 M solution. The weight loss in the 0.5 M solution was observed to be smallest.

Figs. 7 and 8 show the comparative cumulative weight loss for galvanized sheet in all the various concentrations of the carbonate and chloride solution solutions respectively. The weight loss due to corrosion on the galvanized steel sheet in the 1 M carbonate solution was highest followed by the weight loss in the 0.5 M solution. The weight loss in the 0.3 M solution was observed to be smallest. The reverse is true in the chloride solution. Weight loss was observed to be highest in the 0.3 M chloride solution followed by

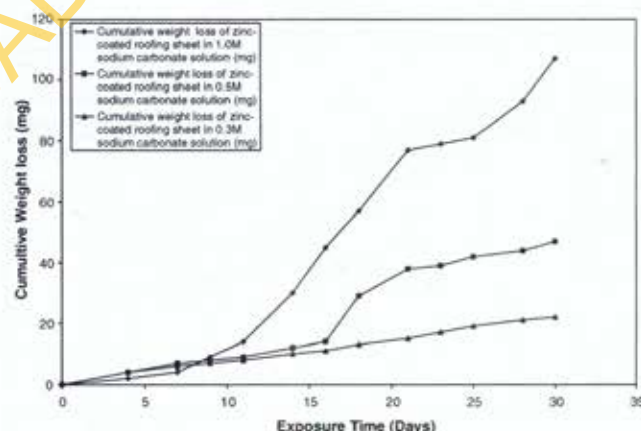


Fig. 7. Plot of comparative cumulative weight loss of galvanized steel roofing in various concentrations of sodium carbonate solution.

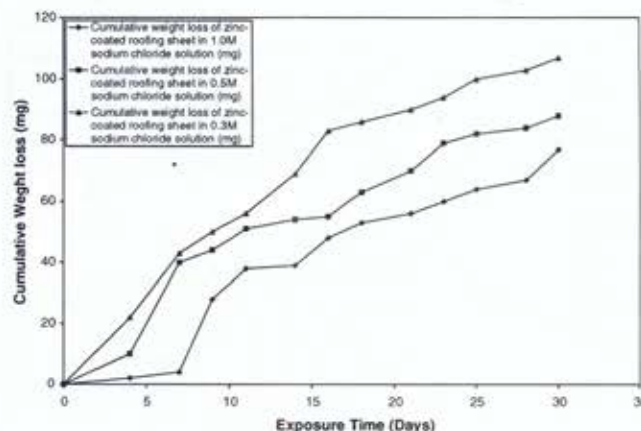


Fig. 8. Plot of comparative cumulative weight loss of galvanized steel roofing in various concentrations of sodium chloride solution.

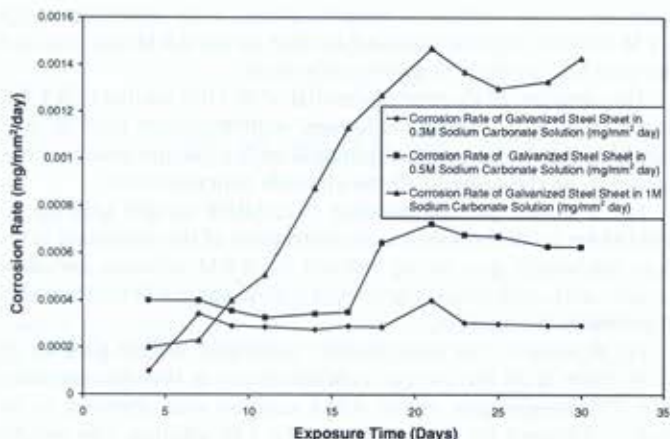


Fig. 9. Comparative corrosion rates of galvanized steel sheet in various concentrations of sodium carbonate solution.

the weight loss in the 0.5 M solution. Weight loss in the 1 M chloride solution was observed to be smallest.

These results (Figs. 5 and 7) showed weight gain for Al 3103 less than weight loss by galvanized steel sheet in 1 M sodium carbonate solution. In 0.5 M carbonate solution, weight loss by galvanized steel sheet was initially higher than weight gain by Al 3103 up till 7 days exposure. From 7 to 18 days, weight gain by Al 3103 was more and

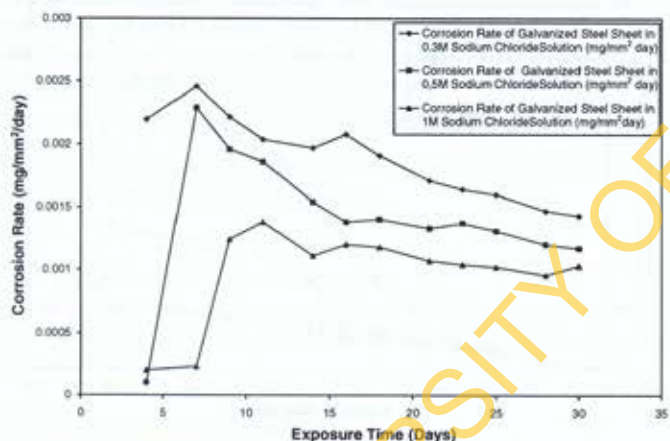


Fig. 10. Comparative corrosion rates of galvanized steel sheet in various concentrations of sodium chloride solution.

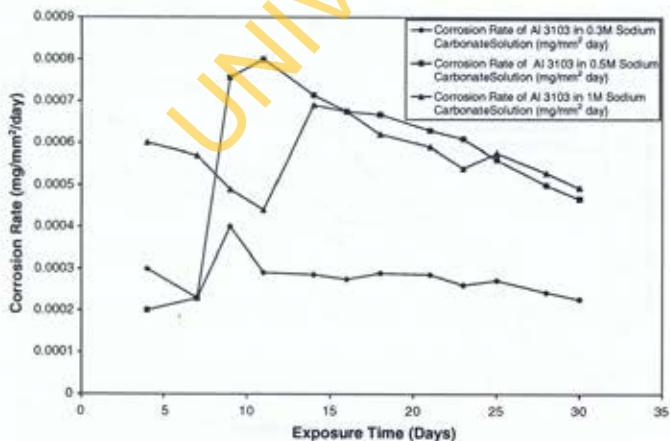


Fig. 11. Comparative corrosion rates of Al 3103 sheet in various concentrations of sodium carbonate solution.

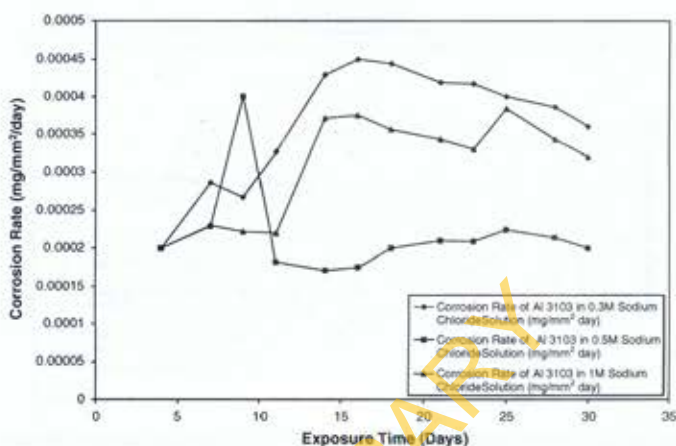


Fig. 12. Comparative corrosion rates of Al 3103 sheet in various concentrations of sodium chloride solution.

after 18 days till 30 days when the experiment was stopped weight loss by galvanized steel sheet was higher. In 0.3 M carbonate solution, weight loss by galvanized steel sheet was comparable to weight gain by Al 3103 until the 22nd day of exposure in the media after which weight loss by galvanized steel sheet was higher till the 30th day. Thus, it could be said that in all concentrations of sodium chloride solution, weight gain for Al 3103 was observed to be less than weight loss by galvanized steel sheet.

Figs. 9–12 present the corrosion rates of galvanized steel roofing sheets and aluminium 3103 in various concentrations of carbonate and chloride solutions.

Comparative corrosion rate of Al 3103 roofing and galvanized steel roofing in 1, 0.5 and 0.3 M concentrations of sodium carbonate solutions showed that for the 1 M solution, there was an initial high corrosion rate of Al 3103 in the carbonate solution up till the 9th day of exposure after which it fell below the corrosion rate of galvanized steel till the 30th day when the experiment was stopped. In the 0.5 M solution, there was an initial increase of corrosion rate of galvanized steel over Al 3103 for the first seven days after which corrosion rate of Al 3103 overtook that of the steel sheet till the 19th day after which corrosion rate in the steel sheet was higher again than that of the aluminium sheet till the 30th day when the experiment was stopped. In the 0.3 M carbonate solution, corrosion rate in the aluminium sheet was higher than in the steel sheet till the 15th day after which corrosion rate in the steel sheet was higher till the 30th day of exposure.

In sodium chloride solution, the results showed corrosion in galvanized steel sheet higher than in the aluminium sheet in all the concentrations of sodium chloride.

### 3.2. Discussions

#### 3.2.1. Electrochemical corrosion behaviour of galvanized steel and Al 3103 roofing sheets exposed in various carbonate and chloride solution concentrations

The trend observed in the variation of electrode potential with exposure time for galvanized steel sheet in various concentrations of sodium carbonate solutions (Fig. 1) wherein the steel sheet in 1 M sodium carbonate had the highest corrosion potential followed by the sheet in 0.5 M solution with the least being the steel sheet in the 0.3 M solution translated into the steel sheet in the 1 M solution having the highest weight loss (Fig. 7), hence corrosion rate (Fig. 9) followed by the sheet in the 0.5 M solution with the least being the steel sheet in the 0.3 M solution.

The behaviour of the steel sheet in the sodium chloride solutions (Fig. 2) was the opposite of what obtained in the sodium car-

bonate solutions. The electrode potentials of the steel sheet samples in the various concentrations being very close but there was more activity in the 0.3 M solution followed by the 0.5 M solution. The electrode potential variation in the 1 M solution was very minimal showing less corrosion activity. This behaviour translated into what obtained in Figs. 8 and 10; highest corrosion rate in the 0.3 M solution, followed by corrosion in the 0.5 M solution with the least corrosion rate occurring in the 1 M Chloride solution.

The Al 3103 sheet in 0.3 M sodium carbonate had the highest corrosion potential followed by electrode potentials in 0.5 M and 1 M solutions which are comparable (Fig. 3). The high negative potential of the 0.3 M solution notwithstanding, the activity in the 1 M and 0.5 M solutions from insertion of sample into the corrosive fluids showed the high oxidation of the aluminium samples in the 1 M and 0.5 M carbonate solutions and hence weight gain (Fig. 5) and high oxidation rate (Fig. 11). Thus, aluminium sheet in the 1 M and 0.5 M solutions had high weight gains, hence corrosion rates (Fig. 11) with the least corrosion rate being that of the sample in the 0.3 M solution.

The behaviour of the aluminium sheet in the sodium chloride solutions (Fig. 4), was almost the opposite of what obtained in the sodium carbonate solutions. The electrode potentials of the sheet samples in the various concentrations were very close but there was more oxide build-up activity in the 0.3 M solution followed by the 1 M solution. The electrode potential variation in the 0.5 M solution was very minimal showing less oxidation activity. This behaviour translated into what obtained in Figs. 6 and 12; highest corrosion rate in the 0.3 M solution, followed by that in the 1 M solution with the least corrosion rate occurring in the 0.5 M Chloride solution. Thus, the weight gain behaviour of Al 3103 roofing rather than weight loss makes the interpretation of the effect of the electrode potential like 'upside down' compared to the straight interpretation for the galvanized steel. Aluminium roofing was highly protective due to lower negative electrode potential as a result of oxide film built up and this passivating effect was most severe in the sheet immersed in 0.3 M sodium chloride solution.

### 3.2.2. Comparative electrochemical corrosion behaviour of aluminium and galvanized steel roofing sheets in various concentrations of carbonate and chloride solutions

For corrosion in sodium carbonate solutions, the plots of electrode potentials for aluminium and galvanized steel roofing cannot be compared just on the basis of the values of the potentials, because galvanized steel was losing weight while the aluminium sheets were gaining weight (Figs. 1, 3, 5 and 7). The magnitude of the weight gained or lost was observed to decrease with decrease in concentration. It was observed as well that at the end of 30 days of continuous exposure in the corrosive environment, cumulative weight loss by the galvanized steel was observed to be higher than weight gained by the aluminium sheets. Corrosion rates were observed to follow the same pattern (Figs. 9 and 11). Thus, oxide film was built-up to protect the aluminium sheets from corrosion [6], but zinc-coated sheet was continuously corroding in spite of the zinc sacrificial anode.

In sodium chloride environment, however (Figs. 2 and 4), the negative electrode potential of the steel sheets were higher than those of the aluminium sheets right from after insertion in the corrosive environments signifying the higher propensity for corrosion to occur in the galvanized sheet. The slow rate of descent of the electrode potential of the aluminium sheets in sodium chloride solutions also signified the smaller rate of oxide film formation on the aluminium samples. The magnitude of weight loss by the steel sheets was observed to increase with decrease in concentration of corrosive environment. For the aluminium sheets, the magnitude of weight gained was seen to be highest in 0.3 M solution followed by the 1 M solution and least in the 0.5 M solution. It

was observed as well that at the end of 30 days of continuous exposure in the corrosive environment, cumulative weight loss by the galvanized steel was observed to be higher than weight gained by the aluminium sheets. The corrosion rates (Figs. 9–12) followed the same pattern.

Aluminium was observed to oxidize more in the sodium carbonate solutions than in the sodium chloride solutions (Figs. 3 and 4). The attack of aluminium roofing sheet by carbonate and chloride solution resulted into an increase in weight continuously till the 25th day of exposure when the weight remained constant for the rest of exposure time. This was due to formation of oxide film on the aluminium sheet which resulted to decrease in negative electrode potential. This resulted in reduction in corrosion rate (Figs. 11 and 12) because of the protective film that had formed already.

Galvanized steel on the other hand, lost more weight (hence corroded more), in the sodium chloride solutions than in the sodium carbonate solutions (Figs. 7 and 8). The attack of galvanized steel roofing sheet by carbonate and chloride solution resulted into loss in weight continuously till the end of the exposure period. This was due to continuous corrosion of the galvanized steel.

### 3.2.3. Corrosion rate of aluminium and galvanized steel roofing sheets in sodium carbonate and sodium chloride environments

Fig. 4–8 showed aluminium roofing sheet continuously gaining weight whereas zinc-coated roofing sheet continuously losing weight. The weight gained by aluminium roofing sheet was due to film formation when it was attacked by the environments. Thus, aluminium was passive and protective hence smaller rate of corrosion than that of galvanized steel sheets. At the end of 30 days exposure about 40 mg weight of aluminium roofing sheet had been gained, while about 120 mg weight of zinc-coated sheet was lost in 1.0 M sodium carbonate solution. The weight gain of aluminium and weight loss of zinc-coated roofing sheets were equal in 1.0 M sodium carbonate on the 11th day of exposure, the situation of which changed as the days went by, the galvanized steel sheet corroding more a similar situation was noticed in chloride environment. On the seventh day of exposure, weight loss of galvanized steel and weight gained by aluminium roofing sheets in 1.0 M sodium chloride were equal but for the rest of exposure time, galvanized steel sheet corroded more than aluminium.

Corrosion rate of aluminium 3103 was observed to be more in the 0.5 M carbonate solution than in the chloride (Figs. 11 and 12) and comparable to that of galvanized steel for the first eighteen days after which corrosion in galvanized steel was more. In the chloride solution of same concentration, weight loss of zinc-coated roofing sheet was about 90 mg compared to 15 mg weight gained by aluminium roofing sheet.

In 0.3 M sodium carbonate solution, the corrosion rates were comparable for the duration of the test (Figs. 9 and 11). However, in 0.3 M chloride solution, weight loss of zinc-coated sheet was about 120 mg within 30 exposure days, while about 30 mg weight gain of aluminium sheet was observed (Figs. 6 and 8). This showed corrosion rate very rapid in the zinc-coated sheet (Figs. 10 and 12.)

## 4. Conclusion

The electrochemical corrosion behaviour of aluminium 3103 and galvanized roofing sheets immersed in 1.0, 0.5 and 0.3 M sodium carbonate and sodium chloride solutions have been extensively investigated. In the experimental work, the following findings were obtained.

- (i) Corrosion behaviour of aluminium and galvanized steel roofing sheets in the simulated environments could be predicted on the basis of electrochemical corrosion mechanism.

Sodium chloride media had the highest corrosion on the galvanized roofing sheet than sodium carbonate media while the reverse was true for the aluminium sheets.

- (ii) The zinc-coated roofing sheet test specimen had severe corrosion than aluminium roofing sheet test specimen immersed in all the corrosive media.
- (iii) The corrosion of zinc-coated roofing sheet was continuous throughout the exposure period.
- (iv) Galvanized steel roofing sheet is not good roofing material in carbonate and chloride environments. Also the material is not recommendable to be used in an industry where chloride or carbonate contamination is possible.

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