Evaluation of the Corrosion Resistance of Aluminum Alloy Matrix/ 2.5% Particulate Glass Reinforced Composite in Various Media

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ABSTRACT

Evaluation of the corrosion resistance of aluminum alloy matrix/ 2.5% particulate glass reinforced composite in various media has been carried out. The work started with the casting of the composite using stir-cast method. This was followed by sample preparation, preparation of the sodium chloride solution, hydrochloric acid solution, sodium hydroxide solution, and then the setting up of the experiment. Various equipment were used during this period which included, sample lathe used for the preparation of the specimens, electronic digital balance, flat-bottomed flask, thread, brush, stopper rubber, pH meter, hand air blower, and beakers. The result was recorded every Thursday after every seven days for five weeks. The result revealed that for the composite exposed in 5 weight percent NaCl solution the highest weight loss occurred at 336 hours of exposure time which corresponded to 0.6 percent weight loss and a corrosion rate of 18.99 mpy. The pH was between 6 – 7.62, throughout the exposure time of the specimens in the NaCl solution. For the specimens exposed in 10 weight percent HCl solution, the highest weight loss of 2220 mg occurred at 840 hours corresponding to 21.62 percent weight loss and a corrosion rate of 280.998 mpy, while the medium remained acidic throughout the period of the exposure. For the specimens exposed in 10 weight percent sodium hydroxide solution the highest weight loss of 4110 mg occurred at 840 hours corresponding to a percent weight loss of 40.45 percent and a corrosion rate of 540.227 mpy. The pH of the medium remained alkaline throughout the period of the experiment. The result of the work lead to the following conclusions: the composite can be used in an environment containing sodium chloride since the corrosion rate falls within the recommended corrosion range of 1-200 mpy for usefully resistant materials, the composite cannot be used either for holding HCl solution or as a structural material where HCl solution is found, the composite cannot be used as a container for holding NaOH solution or in an environment where NaOH solution is found, since it selectively dissolves the composite, leaving behind an altered residual structure, the weight loss, the percentage weight loss, and the corrosion rate expressed in mpy all agree with the physical appearance of the specimens after the exposure time of the test, and the monitored pH of the solution also agreed with the test results.

Keywords: *Evaluation, corrosion, aluminium alloy composite, sodium hydroxide, hydrochloric acid, and sodium chloride*

1. INTRODUCTION

Materials technology has had such a profound impact on the evolution of human civilization that historians have characterized periods in that evolution by such terms as the Stone Age, the Bronze Age, and the Iron Age. Each new era was brought about by the continuing quest for even better products, a quest that is very much in evidence today. The current 'Synthetic Materials Age' has been precipitated by humankind's demand for materials with superior performance characteristics, inspired primarily by the quest to conquer the last frontiers of space. By exploiting state-of-the-art technologies in diverse fields of science, groups of engineers, chemists, physicists and materials scientists have devised innovative interdisciplinary techniques for synthesizing, analyzing, and manufacturing new generations of engineered materials. These new classes of engineered synthetic materials comprising ceramics, plastics, and composites have had a major impact upon our lifestyles in areas as diverse as those utilizing the more traditional naturally-occurring materials [1,2]. Mathew and Rawlings [3] also has this to say about composite materials 'in the continuing quest for improved performance, which may be specified by various criteria including less weight, more strength and lower cost, currently-used materials frequently reach the limit of their usefulness. Thus materials scientists, engineers and scientists are always striving to produce either improved traditional materials or completely new materials. Composites are an example of the latter category. Not that composites are really new. A composite is a material having two or more distinct constituents or phases and thus we can classify bricks made from mud reinforced with straw, which were used in ancient civilizations, as a composite'. Composite materials are produced with the aim of having improved

properties over monolithic materials. Within sporting industry, for example, fibrous composite materials mimicking biological materials have revolutionized the design and manufacture of fishing rods, golf clubs, archery bows, skis and tennis rackets. Composite materials can be studied from a number of different viewpoints each of which requires a different kind of expertise. Thus the development of a composite material to resist a corrosive environment is primarily within the field of material science and chemistry. One important property of a material is the corrosion resistance of the material. Corrosion is defined as the destruction or deterioration of a material because of reaction with its environment [4]. Composites can be exposed to the surrounding environments either by edge exposure or by accidental surface damage. Selective corrosion of these reinforcements is dangerous because it removes the reinforcing components, and the damage is hidden from direct view. Selective corrosion of the matrix material is also undesirable, but it is more easily detected and produces less structural weakening. According to Fontana [5], Corrosion of a composite material is controlled by two factors: (1) the specificity of a given corrosive towards the individual components and (2) galvanic interactions between them. The corrosivity of an environment varies from metal to metal. Fontana explained that composites reinforced with nonmetallic behave in a similar manner to composites containing metal reinforcements. However, since these inorganic solids are very resistant to most aqueous media, their selective dissolution is less likely. Also, galvanic corrosion is not likely except for those reinforcements possessing electrical conductivity such as graphite and boron. Aluminum alloy metal matrix composite has found wide area of application in engineering. The principle of lightweight-high strength composite has found application even in aerospace. Fontana [5], stressed the need for composites to be carefully evaluated in a number of environments which might be encountered in practice. This fact has equally being pointed out by previous authors who evaluated aluminium alloy matrix composites in a number of environments [6-7]. Ogbonna et al [7], in his work evaluated aluminum based metal composite in 0.1MHCl and he discovered that as the volume fraction of the reinforcement agent alumina increased the rate of corrosion attack also increased. Asuke et al [6], evaluate aluminum alloy based matrix composite in 0.5MNaOH solution he highlighted in his work that one major limitation of aluminum metal composites has been corrosion in aqueous environment and several researchers have carried out researches on aluminum metal composites (AMCs) details of their work can be seen in the cited literatures [8-9].

The objective of this work is to evaluate or investigate the corrosion behavior of aluminum alloy metal matrix composite reinforced with glass particulates in three different environments, which include sodium chloride solution, sodium hydroxide solution and hydrochloric acid solution.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the work were aluminium alloy / 2.5% glass particulate composite prepared using stir- cast method, 5% weight sodium chloride solution, 10% weight hydrochloric acid solution, 10% weight sodium hydroxide solution, water, acetone, and distilled water.

2.2 Equipment/ Apparatus

The apparatus used for the work included, pH meter, flat-bottomed flasks, suspension rail and thread, specimen lathe, vernier calipers, brush, rubber stopper, No.120 abrasive paper, hand air blower, and digital weighing balance.

2.3 Methods

The aluminum alloy reinforced with 2.5% glass composite was produced using stir-cast method. To evaluate the corrosion resistance and behavior of the composite, samples of the composite were cut and prepared into test coupons or specimens using specimen lathe. The specimens were machined into identical 20mm x 20mm specimens. No.120 abrasive paper was used to smoothen the specimens. The specimens were then measured again using a vernier calipers to establish the initial dimensions of the specimens for calculation of the initial surface area of the specimens. After measuring, the specimens were degreased by washing in acetone, dried and weighed using a digital weighing balance to 2 decimal places or the nearest 0.1 mg. The specimens were dried using a hand air blower. The specimens were then immediately exposed to three different environments for the evaluation of the corrosion resistance of the composite in the media. The chosen environments are very severe environments, the 5 weight percent sodium chloride (NaCl) solution used was prepared according to the following international standards JIS C60068-2-52-2000 and IEC 60068-2-52: 1996 [10] The second medium was 10 weight percent HCl solution and the third medium was 10 weight percent NaOH solution. The solutions were all prepared using distilled water. The specimens were checked every Thursday, since the experiment was set up on a Thursday. The specimens which were given numbers 1-5 in each of the medium were removed starting from number 1 of each medium. On every Thursday of every week, one specimen each from the three media was removed washed under tap water and brushed, some of the specimens however were scrubbed using rubber stopper instead of brush because of their condition. After washing the specimens were dried using hand air blower. It was then weighed using a digital weighing balance and

the result recorded. This was done for five weeks: the specimens were removed according to their numbers or labeling. The pH of each solution was measured using a pH meter when they were prepared, and each time a specimen was removed for weighing, the pH of the medium was also measured. pH measurements were taken for five weeks (see plate 1). The minimum exposure time for the experiment was determined from the formula:

Hours (duration of test) = 2000/ mils per year   (1)

The data generated from the experiment was used to calculate the weight loss, the percentage weight loss, the corrosion rate in mils per year, and also to record the pH variation of the media over the 5 weeks. Precautions taken during the experiment were: care was taken not to contaminate the specimen or alter them during specimen preparation, initial measurements were taken, fixed time was kept for weighing of specimens, during washing care was taken to avoid over scrubbing, and a specimen was provided for every week once the specimen was taken out for weighing, it was not returned back to the medium. These precautions were taken for reliable results to be generated.

Plate 1: Testing of the medium using pH meter

3. RESULTS AND DISCUSSION

3.1 Results

The results of the work are as presented in Tables 1-3, Plates 2-4 and Figures 1-3.

Table 1: Weight Loss of Aluminium alloy / 2.5% Glass Reinforced Composite in 5 Weight Percent NaCl Solution and PH Variation of the Medium

S/No.	Exposure Time (hrs)	Weight loss (mg)	Percent weight loss	pH
1	0	0	0	6.68
2	168	20	0.188	7.21
3	336	60	0.600	7.26
4	504	30	0.296	6.00
5	672	20	0.196	6.76
6	840	10	0.098	7.62

Table 2: Weight Loss of Aluminium Alloy/ 2.5% Glass Reinforced Composite in 10 Weight % HCl Solution and pH Variation of the Medium

S/No.	Exposure Time (hrs)	Weight Loss (mg)	Percent weight Loss	pH
1	0	0	0	1
2	168	870	8.67	2.71
3	336	1090	10.42	2.31
4	504	1320	13.28	2.59
5	672	1330	13.38	2.65
6	840	2220	21.62	2.49

Table 3: Weight Loss of Al Alloy/ 2.5% Glass Reinforced Composite in 10 weight % NaOH Solution and PH Variation of the Medium

S/No.	Exposure Time (hrs)	Weight Loss (mg)	Percent weight Loss	pH
1	0	0	0	14.00
2.	168	590	5.67	14.91
	336	2930	27.16	14.97
	504	3680	34.78	14.96
	672	1260	12.44	14.98
	840	4110	40.45	14.59

Plate 2: the Unexposed Specimens of the Composite as Prepared

| Week 1 | week 2 | week 3 | week 4 | week 5 |

Plate 3: Specimens Evaluated in 5 Weight Percent NaCl Solution

| Week 1 | week 2 | week 3 | week 4 | week 5 |

Plate 3: Specimens Evaluated in 10 Weight Percent HCl Solution

| Week 1 | week 2 | week 3 | week 4 | week 5 |

Plate 4: Specimens Evaluated in 10 Weight Percent NaOH Solution
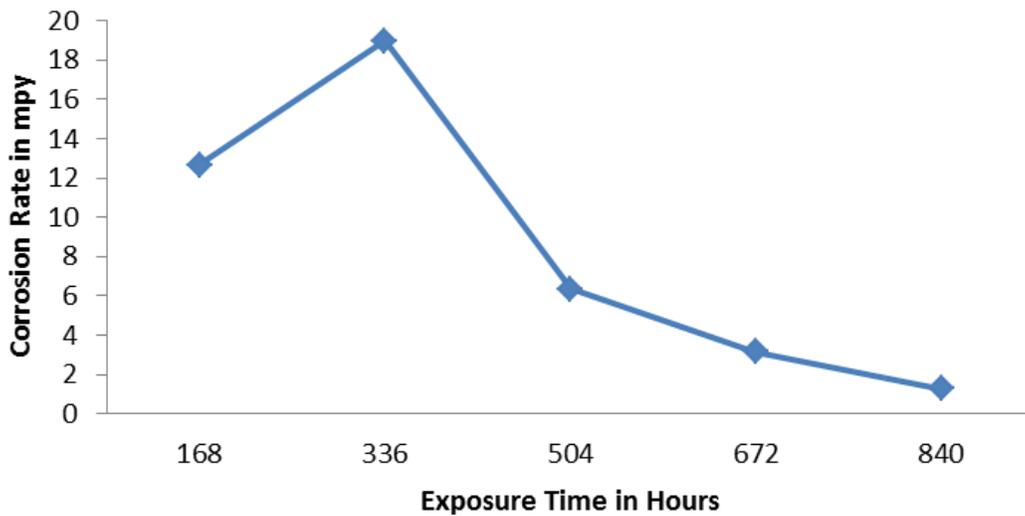
Figure1: Corrosion Rate in mpy of Aluminium Alloy/ 2.5% Glass Reinforced Composite in 5 Weight Percent NaCl Solution
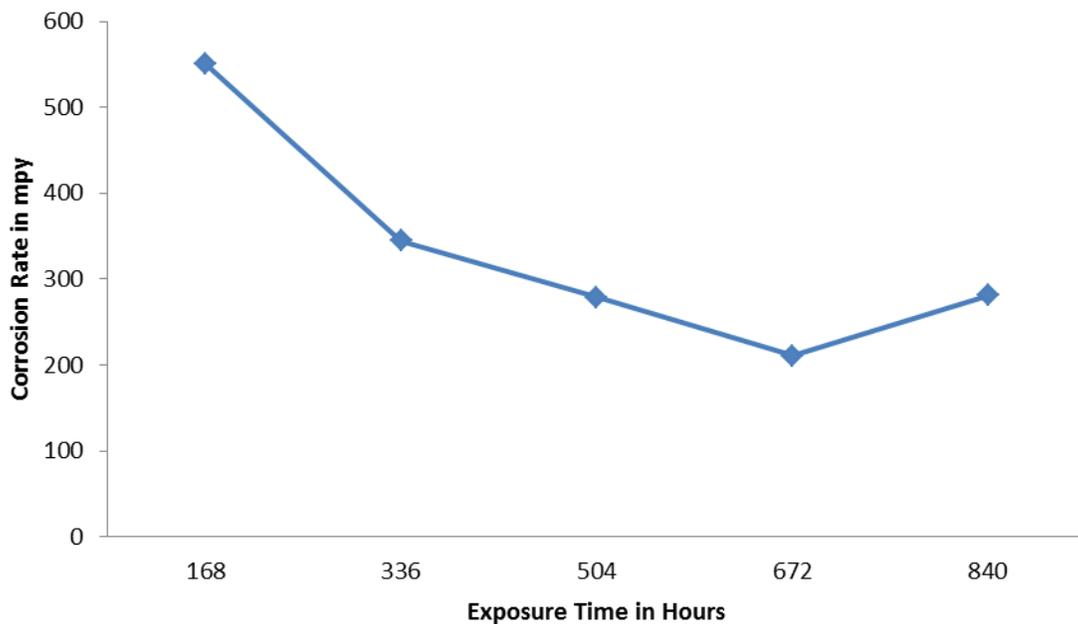
Figure 2: Corrosion Rate in mpy of Aluminium Alloy / 2.5% Glass Reinforced Composite in 10 Weight percent HCl Solution
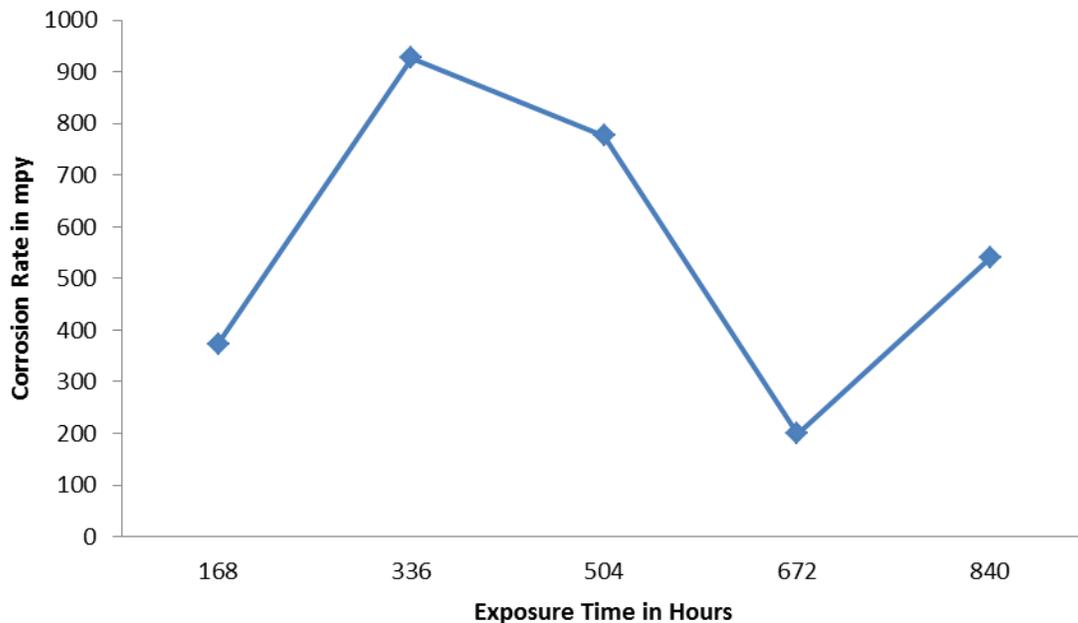

Figure 3: Corrosion Rate in mpy of Aluminium Alloy / 2.5% Glass Reinforced Composite in 10 Weight Percent NaOH Solution

3.2 Discussion

3.2.1   Weight Loss

The corrosion resistance of aluminium alloy matrix composite reinforced with glass particulates has been evaluated in three critical media. Water and the atmosphere have been excluded in the evaluation because aluminium has been known to exhibit a very high resistance to these media: any evaluation in these media will require a very long time for meaningful result or data to be generated [5].

Table 1, shows the weight loss, percentage weight loss and the pH variation of the medium when aluminium alloy matrix reinforced with 2.5% glass particulate composite was exposed in 5 weight percent NaCl solution for a total period of 840 hours. The result showed that after 168 hours the weight loss was 20mg corresponding to 0.188 % weight loss, the pH of the medium at this time increased from 6.68 to 7.21 (from slightly acidic to slightly alkaline). After 336 hours the weight loss increased to 60mg corresponding to 0.560% weight loss and the pH increased slightly to 7.26. After exposure for 504 hours the weight loss dropped to 30mg the percentage weight loss also dropped to 0.296%, the pH also dropped to 6. When the specimen was exposed for 672 hours the weight loss dropped further to 20mg corresponding to 0.196 percent weight loss and the pH moved up slightly to 6.76 still slightly acidic. At the end of the exposure time of 840 hours the weight loss dropped to 10 mg corresponding to 0.098% weight loss, and the pH became 7.62 slightly alkaline. It can be seen that the highest weight loss occurred at 336 hours of exposure; at this point the medium has become slightly alkaline. After the 336 hours the weight loss started decreasing; and it decreased to 10mg equivalent of 0.098% weight loss. The result indicates the formation of an oxide coating which might have inhibited or slowed the rate of attack on the composite. Fontana [5] agrees with this argument when he said that ''aluminium is a reactive metal, but it develops an aluminium oxide coating or film that protects it from corrosion in many environments. This film is quite stable in neutral and many acid solutions, but is attacked by alkalies''. This statement clearly explains the result of table 1. The medium or the environment of exposure was within the range of slightly alkaline, neutral, and slightly alkaline, so a very serious corrosion attack cannot be expected.

Table 2 shows the weight loss of the particulate glass reinforced aluminium alloy composite in 10 weight percent HCl solution and the variation of the pH of the medium during the exposure time. The medium remained highly acidic throughout the exposure time. The range was 1 to 2.71. This may explain why the weight loss progressively increased with the exposure time. 870 mg was recorded after 336 hours and the weight loss increased to reach the value of 2220 mg corresponding to 21.62 % weight loss at the end of the exposure time of 840 hours. With the physical examination made this medium can be use to chemically machine this composite the surface finishes produced were wonderful to behold. The length of time the composite will be exposed will determine the weight loss or the depth of chemical machining. Several authors [5,11] have argued that hydrochloric acid is the most difficult of the common acids to handle from the standpoint of corrosion and materials of construction. Extreme care is required in the selection of materials to handle the acid by itself, even in relative dilute concentrations, or in process solutions containing appreciable amounts of hydrochloric acid. This acid is very corrosive to most of the common metals and alloys. When aeration or oxidizing agents are also present, corrosive conditions may be very rugged. The corrosion of the composite was actually rugged the medium was aerated during the exposure time of the specimens. Table 3 shows the weight loss and equivalent percentage weight losses of aluminium alloy/ 2.5% glass reinforced composite in 10 weight % NaOH solution and pH variation of the medium within the exposure time. The pH remained highly alkaline throughout the exposure time and the weight loss which was 590 mg at 168 hours increased to 4110 mg at the end of the exposure time of 840 hours with a percentage weight loss of 40.45%. The weight loss dropped at 672 hours of exposure but picked up again to hit 4110 mg at 840 hours. As explained earlier aluminium composite has a poor resistance in the presence of alkalies. The specimens were leached leaving behind a porous residue with some crystalline deposit in some areas.

3.2.2 Physical Examination of the Exposed Specimens

Physical examination of the specimens exposed in 5 weight % NaCl solution using magnifying lens did not reveal any major corrosion product on the surface, Save for surface colour change indicating uniform and tenacious oxide film formation. It was not possible to see the dimensional change that has occurred just by physical examination. The specimens are shown in plate 3.

Physical examination of the specimens exposed in 10 weight % HCl solution revealed the corroded surface of the specimen. The surface was uniformly corroded and beautiful given the plainness of the corroded area. The dimensions of the specimens were reduced according to their exposure time. The longer the specimens were exposed the smaller they became. See Plate 3 for the specimens exposed in HCl solution.

Physical examination of the composite exposed in 10 weight percent NaOH solution was carried out using magnifying glasses the view showed specificity in the dissolution of the composite. The aluminium went into reaction with the NaOH solution producing a crystalline deposit alongside a porous mass residue. Several authors have confirmed that aluminium is a very poor material for handling caustic soda [5,8]. This metal its alloys and composite are rapidly attacked even by dilute solutions. Plate 4 shows the specimens that were exposed in 10 weight % NaOH solution.

3.2.3 Corrosion Rate Evaluation in mpy of the Aluminium Alloy /2.5% Glass Reinforced Particulate Composite in Three Media

Figure 1 shows corrosion rate versus exposure time , as the exposure time was increased the corrosion rate was increasing it reached a peak and then started decreasing , from the peak value of 18.99 mpy it came down to 1.27 mpy at the end of the exposure time of 840 hours. It has been said that aluminium sometimes shows better corrosion resistance in the presence of air [4,5]. The medium was aerated it is therefore likely that aluminium oxide film was formed on the surface of the aluminium composite which slowed down the corrosion rate of the composite. Evidence of this was observed during the physical examination of the specimens using magnifying lenses. The corrosion rate of usefully resistant materials generally range between 1 and 200 mpy; the aluminium composite is therefore a material that can be used in this medium. The electrochemical nature of corrosion can also be used in illustrating the behavior of the composite using these two electrochemical equations (2 and 3):
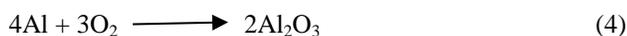
Oxidation:

$$Al \longrightarrow Al^{3+} + 3e \qquad (2)$$

Reduction:

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^- \qquad (3)$$

Overall:

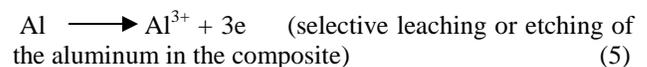$$4Al + 3O_2 \longrightarrow 2Al_2O_3 \qquad (4)$$

(formed on the surface of composite)

An oxidation or anodic reaction is indicated by an increase in valence or a production of electrons. A decrease in valence charge or the consumption of electrons signifies a reduction or cathodic reaction. Equations 2 and 3 are partial reactions-both must occur simultaneously and at the same rate on the metal surface. If this were not true, the metal would spontaneously become electrically charged, which is clearly impossible. This leads to one of the most important basic principles of corrosion: during metallic corrosion, the rate of oxidation equals the rate of reduction (in terms of electron production and consumption. The above partial reactions according to Fontana [5] can be used to interpret virtually all corrosion problems. Equation 4 is the overall equation which gave rise to deposition of aluminium oxide film on the surface of the composite; this slowed the rate of corrosion of the composite as can be seen in figure 1.

Figure 2 shows the corrosion rate in mpy of Al alloy/ 2.5% glass reinforced particulate composite in 10 weight percent HCl solution. At 168 hours the corrosion rate came to 550.61 mpy, the corrosion rate kept decreasing as the exposure time was increased. This trend was maintained up to 840 hours where again the corrosion rate showed a little rise to 280.998 mpy instead of decreasing. This can be seen in the figure as the curve was decreasing from left to right. From 550.61mpy at 168 hours the corrosion rate decreased to 280.998 mpy at the exposure time of 840 hours. The phenomena can be explained using the concept of corrosion as an electrochemical process [12] with these equations:
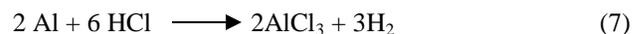
Oxidation:

$$Al \longrightarrow Al^{3+} + 3e \qquad \text{(selective leaching or etching of the aluminum in the composite)} \qquad (5)$$

Oxygen reduction:

$$O_2 + 4H^+ + 4e \longrightarrow 2H_2O \qquad (6)$$

Overall reaction:

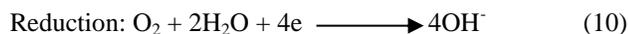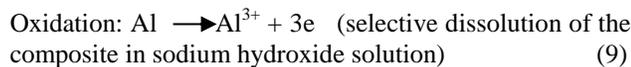$$2\,Al + 6\,HCl \longrightarrow 2AlCl_3 + 3H_2 \qquad (7)$$

From equation 5 the aluminium in the composite exposed in 10 weight percent HCl is selectively leached producing aluminium ions this is an oxidation process since it involves loss of electrons. Equation 6 is a reduction reaction which has been assisted by the presence of oxygen from the atmosphere which is in contact with the solution. Under normal circumstances the corrosion rate must have been slowed down more than what has been observed owing to the fact that in the presence of oxygen aluminium forms a tenacious oxide film [12]. This is not so because at the cathode two cathodic reactions are possible: the evolution of hydrogen and the reduction of oxygen. On the surface of the composite there are two electron-consuming reactions. Since the rates of oxidation and reduction must be equal, increasing the total reduction rate which also increases the rate of aluminium dissolution. Hence, acid solutions containing dissolved oxygen will be more corrosive than air-free acids. Oxygen reduction simply provides a new means of ''electron disposal'' [5,12]. The other reaction at the cathode is shown below:

$$\text{Hydrogen evolution: } 2H^+ + 2e \longrightarrow H_2 \qquad (8)$$
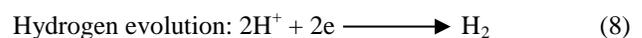
A worst corrosion rate would have been observed if the HCl had an oxidizer as an impurity which sometimes occurs in commercial hydrochloric acid, of note is ferric chloride.

Figure 3 is the corrosion rate in mpy of Al alloy/ 2.5 % glass reinforced particulate composite in 10 weight percent sodium hydroxide solution. The corrosion rate was 373.399 mpy at 168 hours it went up to 927.168 mpy at the exposure time of 336 hours as can be seen in the figure. The corrosion rate then started decreasing until it got to 672 hours, after this exposure time it started rising until it got to the exposure time of 840 hours reaching the corrosion rate of 540.227 mpy. The graph has only confirmed the behavior of aluminium composite, aluminium, and aluminium alloys in sodium hydroxide solution which has been investigated by many[5, 13].

The electrochemical nature of the corrosion of the composite is explained below with the subsisting equations:

Oxidation: $Al \longrightarrow Al^{3+} + 3e$ (selective dissolution of the composite in sodium hydroxide solution)   (9)

Reduction: $O_2 + 2H_2O + 4e \longrightarrow 4OH^-$ (10)

The two corrosion equations gave rise to an altered residual structure in selective leaching of the composite. In solution sodium aluminate and water coexisted, which on settling formed aluminium hydroxide and sodium hydroxide. For structural or holding purposes this composite cannot be used in any environment where sodium hydroxide is found [5, 12-13].

4. CONCLUSION

The corrosion behavior of aluminium alloy / 2.5 % glass reinforced particulate composite in three severe environments have been evaluated, the media are 5 weight percent NaCl solution, 10 weight percent HCl solution and 10 weight percent NaOH solution. The study has led to the following conclusions:

- The composite can be used in an environment containing sodium chloride, since the corrosion rate falls within the recommended corrosion range of 1-200 mpy for usefully resistant materials.

- The composite cannot be used either for holding HCl solution or as a structural material where HCl solution is found.

- The composite cannot be used as a container for holding NaOH solution or in an environment where NaOH solution is found, since it selectively dissolves it leaving behind an altered residual structure.

- The weight loss, the percentage weight loss, and the corrosion rate expressed in mpy all agree with the physical appearance of the specimens after the exposure time of the test.

- The monitored pH of the solution also agreed with the test results.

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