Research article

THE INFLUENCE OF ENVIRONMENTAL ACIDIFICATION ON THE ATMOSPHERIC CORROSION OF CORRUGATED IRON ROOF (ZINC)

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Abstract

Atmospheric corrosion is the gradual destruction of a metal by contact with substances present in the atmosphere, such as oxygen, carbon dioxide, water vapour, sulphur and nitrogen compounds. Zinc is resistant to corrosion in neutral environment but very sensitive to arty change of atmospheric acidity. This project covers the effect of environmental acidification on atmospheric corrosion of zinc. A coupon immersion test was carried out in the laboratory to determine the rate of corrosion of zinc in various acid concentrations. The result of this experiment proved that the corrosion rate of zinc in nitric acid and sulphuric acid is relatively higher than the rate in hydrochloric acid. This is due to the fact that sulphuric acid is more aggressive than hydrochloric acid. To reduce or prevent atmospheric corrosion, it is recommended that air pollutants such as oxides of sulphur and nitrogen should be effectively controlled. **Copyright © IJACSR, all rights reserved.**

Keywords: zinc, iron, corrosion

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1.   Introduction

The ability of zinc to galvanically protect iron has made this metal important from an industrial point of view. Zinc

is relatively resistant to corrosion in neutral environment but very sensitive to any change of atmospheric acidity,

example is Sulphur (iv) oxide.

Acidification is one of the most serious environmental problems. Among the effects of acid deposition mainly by

sulphur pollutant, corrosion of construction material such as corrugated iron sheet (zinc) exposed to the atmosphere

is a well-known problem. The effects of sulphur (iv) oxide on different materials have been subject to many laboratory and field investigations, and the corrosive effects of polluted atmosphere on corrugated iron sheet (zinc) are obvious. Current knowledge of the effects of acidic air pollutants on atmospheric corrosion of corrugated iron sheet (zinc) is summarized in this research (Barton, 1997; Graedel and Schwartz, 1997; Haynie, 1982).

This can be defined as the degradation of a material usually metals due to reaction with its environment. This means electro-chemical oxidation of metals in reaction with an oxidant such as oxygen. Corrosion of material is a major problem facing various industries as millions of dollars are lost each year due to this. There are different types of corrosion namely: Galvanic corrosion, pitting corrosion, microbial corrosion, crevice corrosion and atmospheric corrosion. This work will focus on corrosion of zinc when exposed to atmosphere Cox, 1994; Dillion, 1996; Gerhard and Hayine 1994; Falk and Johansson, 1998).

This is defined as corrosion by air in the open and in enclosed spaces of all kinds. Deterioration in the atmosphere is sometimes called weathering. However, the corrugated iron sheet (zinc) during atmospheric exposure has been closely examined and the performance of zinc can be predicted within reasonable limits. It is generally accepted that the corrosion rate of zinc is low; it ranges from 0.l3μmlyr in dry rural atmospheres to 0.0l3mmlyr in more moist industrial spheres. Compared to other metals, zinc (corrugated iron sheet) is more corrosion resistant in most natural environments (Vernon, 2004; Yocum, 2002; Zakipour et al., 1995; Skerry et al., 1990). For example, in seacoast atmospheres the corrosion rate of zinc is about 1/25 that of steel. There are important factors that control the rate at which zinc corrodes in atmospheric exposure. These are: the duration and frequency of moisture, the rate at which the surface dries and the extent of industrial pollution of the atmosphere (Martin, 2001; Preston and Sanya, 2001; Rozenfeild, 2000; Sereda, 2009; Shrier, 1991 and Oesch, 1996).

In atmospheric corrosion the electrolyte is moisture from precipitation, fog or dew, or other sources. In all atmospheric environments, there is an excess of oxygen, thus the corrosion of corrugated iron sheet (zinc) in atmospheric environment is not limited by the amount o oxygen present and can proceed rapidly when the electrolyte is present. In general, the least corrosive atmospheres are found in dry inland (desert) sites and the most corrosive sites are industrial sites. Most tropical locations are very corrosive due both to the time of wetness and the high temperature experienced. The aim of this work include to study the atmospheric corrosion of corrugated iron sheet (zinc), to determine the influence of environmental acidification on zinc corrosion in atmosphere and to determine the corrosion rate of zinc when exposed to atmosphere (Schweitzer, 2007; Morcillo et al., 2011).

Corrosion is a very broad topic. However, this work is concentrated on the atmospheric corrosion of corrugated iron sheet (zinc) and the influence of environmental acidification on this type of corrosion. Zinc is more corrosion resistant than other metals like steel, and coatings of metallic zinc are generally regarded as the most economical means of protection against corrosion. Thus, the need for carrying out this research (influence of environmental acidification on atmospheric corrosion of corrugated iron roof) is important Mercer and Lumbard, 1995; Mattson, 1999; Kucera, 2000).

2.   Materials and Methods

The first step in corrosion testing concerns the materials. This is an important step and if complete information of materials is not known, the data obtained may be practically useless. Chemical compositions and metallurgical history of specimen are required.

The tested metal is of high purity to avoid impurities, which may affect its corrosion behaviour. The surface of the metal was cleaned by metal brush to remove any contamination. To check the influence of acidification, dilute hydrochloric, sulphuric, and nitric acid were used. The acid used is of high purity to avoid altering the result and also distilled water was used to dilute the acid. A small container (in which the acid and the metal are placed) is first rinsed and dried before use so as to obtain accurate result. A measuring scale was used to measure the various masses of the metal to be subjected to acidification. This is done before and after the experiment in order to obtain the difference in mass as a result of corrosion (Haynie and Upham, 1994; Heimler and Vannerberg, 2003).

2.1 Corrosion Testing

The most effective method for, determining the acidification effect of a material on corrosion is to physically subject it to the actual process. There are many reasons for running laboratory corrosion tests and many considerations in their design and utilization.

The purpose of the test or the technique must be clearly defined and understood and this usually involves the determination of changes in mass loss and observation of corroded surfaces. Various tests were carried out to achieve the goal of this work, before carrying out the corrosion test, outer surface of the specimens was removed to ensure homogeneity of the composition, whereas the specimens were brushed with a metal brush to remove the top surface. This is very important since the corrosion rate depends greatly on the method of surface preparation.

2.1.1 Laboratory Tests

These tests arc sometimes called accelerated tests because atmospheric corrosion tests require long exposure times and this is speeded up by acidification. There are numerous laboratory methods used for atmospheric corrosion testing. Duplicate samples were used in all laboratory test. The laboratory tests is as follows

2.1.2 Zinc Accelerated Hydrochloric, Sulphuric, Nitric Acid Test

This is useful for specification acceptance and research. The temperature and time of each test is monitored. The test solution was prepared by diluting hydrochloric, sulphuric and nitric acid to 0.05M, 1.05M and 2.05M. The pH of this solution was checked using an indicator. The test specimens were brushed by metal brush, rinsed with distilled water, degreased with acetone, dried then weighed before being exposed to the test conditions for weeks. At the end of the test, the specimen was rinsed gently by running warm water to remove acidic deposits from the surfaces of the specimens, dried and reweighed.

2.2 Procedure

The test specimens are 45 samples of zinc with dimensions (4.6 cm x 4.3cm x 1.0mm), holes were drilled in each coupon and a rope passed through it to hold the coupon, the coupons were brushed using a metal brush to remove any form of contamination on the metal surface, the coupons were washed and rinsed in distilled water to avoid impurities, After which they were degreased with acetone to remove oily dirt., the coupons were dried and then weighed on a weighing being exposed to the test conditions.

Three test solutions A, B and C are hydrochloric acid (33%, concentration and 1.l9kg/L Density), sulphuric acid (98% concentration and 1.84kg/L Density) nitric acid (70% concentration and 1 .42kg/L Density) respectively.

Each test solution was prepared in three various concentrations of 0.05M, 1.05M and 2.05M For solution A, 2.3ml hydrochloric acid was added to 500ml distilled water to get 0.05Mhydrochloric acid, 49ml was added to 500ml distified water to get 1 .05M and 95ml was added to 500ml distilled water to get 2.05M For solution B, 1 .35ml sulphuric acid was added to 500ml distilled water to get 0.05M sulphuric acid, 28.Sml was added to 500ml distified water to get 1 .05M and 55.5ml was added to 500ml distified water to get 2.05M. For solution C, 2.0ml nitric acid was added to 500ml distilled water to get 0.05M nitric acid, 40.7ml was added to 500ml distilled water to get 1.05M and 79.4ml was added to 500ml distilled water to get 2.05M

Five coupons were immersed in each of 0.05M, 1.05M, and 2.05M of test solutions A, B and C for five weeks. At the end of each week, 1 coupon was removed from each test solution concentration Rinsed gently by running warm water to remove acidic deposits, brushed with toothbrush to remove the corrosion product, dried and reweighed. Weight loss was calculated by subtracting the final mass from the initial mass

Corrosion rate was determined using the formular given in equation 2.

The dilution is shown below

Solution A (Hydrochloric Acid): 33% w/w by weight, Density, ρ =1.19kg/b, Molar mass = 36.5g/moL, 33% x 1.19kg/L = 0.3927kg/L, 0.3927kg/L = 0.3927kg/L

$$\frac{0.3927 kg/L}{36.5 g/mol} = 10.76M \quad Or \quad \frac{1000C_p \rho}{M}$$

$$1000 \text{ x } \frac{33}{100} \times \frac{1.19}{36.5} = 10.76M$$

10.76M = 1000ml(lL), 1M = 93ml, 93ml to 1000ml = 1M, 46.5ml to 500ml = 1M

2.3ml to 500ml = 0.05M, 49ml to 500ml = 1.05M, 95ml to 500ml = 2.05M

Solution B: (Sulphuric Acid): 98% w/w by weight**,** Density, ρ = 1.84kg/L**,** Molar Mass = 98g/mol

$$1000 x \frac{98}{100} x \frac{1.84}{98} = 18.4M$$

18.4M = 1000ml (1L), 1M = 54ml, 54ml to 1000ml = 1M, 27ml to 500ml = 1M

1.35ml to 500ml = 0.05M, 28.5ml to 500ml = 1.05M, 55.5ml to 500ml = 2.05M

Solution C: (Sulphuric acid):70% w/w by weight**,** Density, ρ = 1.42kg/L

Molar Mass =   77g/mol

$$1000\,x\,\frac{70}{100}\,x\,\frac{1.42}{77} \quad = \quad 12.91M$$

12.91M = 1000ml (1L), 1M = 77ml, 77ml to 1000ml = 1M, 38.5ml to 500ml = 1M

20ml to 500m   l = 0.05M, 40.7ml to 500ml = 1.05M, 79.4ml to 500ml = 2.05M

2.3   Corrosion rate expressions

Mostly the rates of corrosion of metals are expressed as mpy or mmpy. The relative scale for corrosion of metal is given as

Safe: Less than 5mpy or 0.125mmpy, Moderate: 5mpy to 50mpy or o.125mmpy to 1.25mmpy, Severe: greater than 50mpy or 1.25mmpy. The rate of corrosion of metal is usually measured either by gravimetric method or by electrochemical methods. The conversion factors for the gravimetric method.

$$\text{Corrosion rate (mmpy)} = \frac{87.6\,x\,weight\,loss\,(mg)}{Area\,(cm^2)\,x\,Time\,(hrs)\,x\,Density} \tag{1}$$

Where mpy is mils per year

Also the formular for calculating the corrosion rate is given as:

$$MPY = \frac{534W}{DAT} \tag{2}$$

Where W = weight loss, mg: D = Density of specimen, g/cm^3, A = Area of specimen (in^2) and T = Exposure time, hr mpy = mils per year

3.   Results and Discussion

The results from the investigation are presented in Tables and Figures for weighty loss upon the influence of corrosion on the sample studied.

Table 1: Weight loss after one week for various concentration of acid component

Acid	Initial (g)	Final (g)	Loss (mg)
No. 1 (0.05m hydrochloric acid)	2.603	2.601	2
No. 2 (1.05m hydrochloric acid)	2.757	2.506	251
No. 3 (2.05m hydrochloric acid)	2.448	1.756	692
No. 4 (0.05m sulphuric acid)	2.702	2.692	9
No. 5 (1.05m sulphuric acid)	2.162	1.595	567
No. 6 (2.05m sulphuric acid)	2.855	1.292	1563
No. 7 (0.05m nitric acid)	2.948	2.938	10
No. 8 (1.05m nitric acid)	2.866	2.294	512
No. 9 (0.05m nitric acid)	2.549	0.978	1511

Table 2: Weight loss after two week for various concentration of acid component

Acid	Initial (g)	Final (g)	Loss (mg)
No. 1 (0.05m hydrochloric acid)	2.610	2.601	9

No. 2 (1.05m hydrochloric acid)	2.509	2.245	264
No. 3 (2.05m hydrochloric acid)	2.766	2.046	720
No. 4 (0.05m sulphuric acid)	2.771	2.752	19
No. 5 (1.05m sulphuric acid)	2.428	1.853	575
No. 6 (2.05m sulphuric acid)	2.716	1.141	1575
No. 7 (0.05m nitric acid)	2.783	2.756	27
No. 8 (1.05m nitric acid)	2.548	1.967	581
No. 9 (0.05m nitric acid)	2.744	1.043	1701

Table 3: Weight loss after three week for various concentration of acid component

Acid	Initial (g)	Final (g)	Loss (mg)
No. 1 (0.05m hydrochloric acid)	2.837	2.827	10
No. 2 (1.05m hydrochloric acid)	2.835	2.553	282
No. 3 (2.05m hydrochloric acid)	2.639	1.903	736
No. 4 (0.05m sulphuric acid)	2.604	2.574	301
No. 5 (1.05m sulphuric acid)	2.515	1.739	776
No. 6 (2.05m sulphuric acid)	2.642	1.064	1578
No. 7 (0.05m nitric acid)	2.326	2.261	65
No. 8 (1.05m nitric acid)	2.320	2.010	810
No. 9 (0.05m nitric acid)	2.760	0.959	1801

Table 4: Weight loss after four week for various concentration of acid component

Acid	Initial (g)	Final (g)	Loss (mg)
No. 1 (0.05m hydrochloric acid)	2.642	2.623	19
No. 2 (1.05m hydrochloric acid)	2.628	2.329	299
No. 3 (2.05m hydrochloric acid)	2.716	1.965	751
No. 4 (0.05m sulphuric acid)	2.621	2.560	61
No. 5 (1.05m sulphuric acid)	2.816	2.015	801
No. 6 (2.05m sulphuric acid)	2.784	1.137	1652
No. 7 (0.05m nitric acid)	2.823	2.739	85
No. 8 (1.05m nitric acid)	2.625	1.800	825
No. 9 (0.05m nitric acid)	2.723	0.860	1863

Table 5: Weight loss after five week for various concentration of acid component

Acid	Initial (g)	Final (g)	Loss (mg)
No. 1 (0.05m hydrochloric acid)	2.781	2.754	27
No. 2 (1.05m hydrochloric acid)	2.612	2.297	315
No. 3 (2.05m hydrochloric acid)	2.682	1.861	821
No. 4 (0.05m sulphuric acid)	2.912	2.841	71
No. 5 (1.05m sulphuric acid)	2.854	2.030	824
No. 6 (2.05m sulphuric acid)	2.362	0.571	1791
No. 7 (0.05m nitric acid)	2.362	2.249	99
No. 8 (1.05m nitric acid)	2.348	1.926	855
No. 9 (0.05m nitric acid)	2.821	0.929	1892

The present work is carried out to study the effect of environmental acidification on atmospheric corrosion behaviour of zinc; namely, the effects of sulphuric acid, nitric acid and hydrochloric acid. The choice was based on the expectation of forming corrosion product which increase the atmospheric corrosion of zinc.

The atmospheric corrosion process depends on a large number of factors as discussed. Experience in the field and experimental research works have indicated that there is a complex mutual interaction of the factors. Factors are divided into two groups, Internal factors and External factors

Internal Factors: Are those connected with the metal itself. The most important internal factors are the chemical nature and the structure of the metal. Other important factors are the internal stresses, deformation in metals and the surface conditions.

External Factors: which affect the atmospheric corrosion rate and corrosion products, are both the surrounding media and the working conditions This present work has taken both internal and external factors in consideration. The proposed zinc was tested by using the weight loss coupon method. This technique was applied to enable the corrosion rate measurements to be done without disturbance. It has the advantage that corrosion which actually occurred can be observed on the sample. Moreover, this technique allows a visual examination, physical measurements and the chemical analysis of the corrosion products. After a prescribed period of exposure, the tested coupons were chemically cleaned, weighed and measured. The corrosion rate is calculated from the weight loss, time of exposure and original surface area of the material by the following formular

$$ MPY = \frac{534\, x WL}{A\, X\, T\, X\, D} $$

Where, MPY = Mils per year, WL = Weight loss, mg, A = area of specimen in^2
T = Exposure time, hr and D = Density of specimen, gm/cm^3

Visual Observation

Acidification is a proven method for the determination of the atmospheric corrosion behavior of zinc. The velocity of rust formation and any protective properties therefore depend on the type and concentration of the atmospheric pollutant. This test has been started on the first day of the month of September, 2012 and ended on the fifth day of the month of October, 2012. After one week, visual observation shows that corrosion took place over the specimens and the colour of the corrosion products was varying from light brown for acid No. 1 to dark red brown for acid No.9 A summary of visual observation was given in table 6.

Table 6: Atmospheric corrosion of zinc in acids after five weeks of exposures

No. 1 (0.05m hydrochloric acid)	Thin flakes of corrosion products but the least among the acids
No. 2 (1.05m hydrochloric acid)	Thin flakes of corrosion products but more than that of acid No. 1
No. 3 (2.05m hydrochloric acid)	Thick flakes of corrosion products and more than that of acid No.2
No. 4 (0.05m sulphuric acid)	Thin flakes of corrosion products but more than the hydrochloric acid
No. 5 (1.05m sulphuric acid)	Thick flakes of corrosion products and more than acid No.4
No. 6 (2.05m sulphuric acid)	Thick flakes of corrosion products and more than acids No.5

No. 7 (0.05m nitric acid)	Thin flakes of corrosion products and more than the sulphuric acid
No. 8 (1.05m nitric acid)	Thick flakes of corrosion products and more than acid No.7
No. 9 (0.05m nitric acid)	Thick flakes of corrosion products and more than all acids

Weight loss

The zinc mass loss increases with time. This is due to the fact that increase in concentration of acid increases the corrosion rate and this is shown in table 7 and they are illustrated graphically in figure 1 to figure 3

Table 7: Weight loss of zinc after five weeks as a function of sulphuric acid deposition

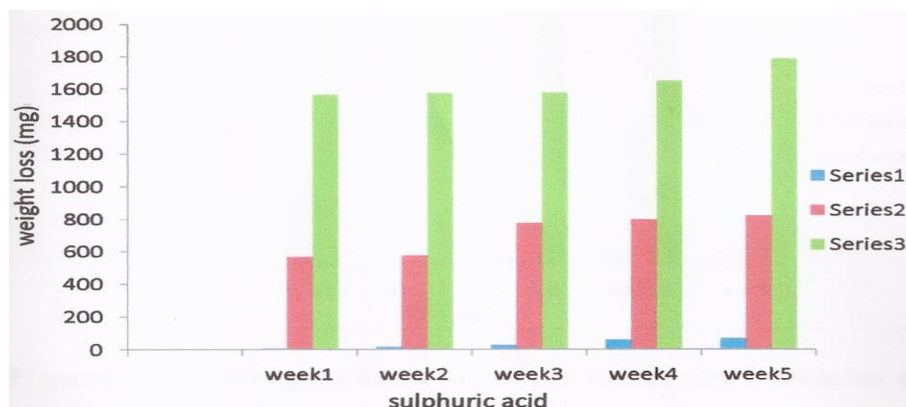| ACID	WEIGHT LOSS (mg)				
	Week 1	Week 2	Week 3	Week 4	Week 5
No. 1 (0.05m hydrochloric acid)	2	9	10	19	27
No. 2 (1.05m hydrochloric acid)	251	264	282	299	315
No. 3 (2.05m hydrochloric acid)	692	720	736	751	821
No. 4 (0.05m sulphuric acid)	9	19	30	61	71
No. 5 (1.05m sulphuric acid)	567	575	776	801	824
No. 6 (2.05m sulphuric acid)	1563	1515	1578	1652	1791
No. 7 (0.05m nitric acid)	10	27	65	85	99
No. 8 (1.05m nitric acid)	572	581	810	825	855
No. 9 (0.05m nitric acid)	1571	1701	1801	1863	1892

Figure 1: Weight loss of zinc after five weeks as a function of sulphuric acid deposition
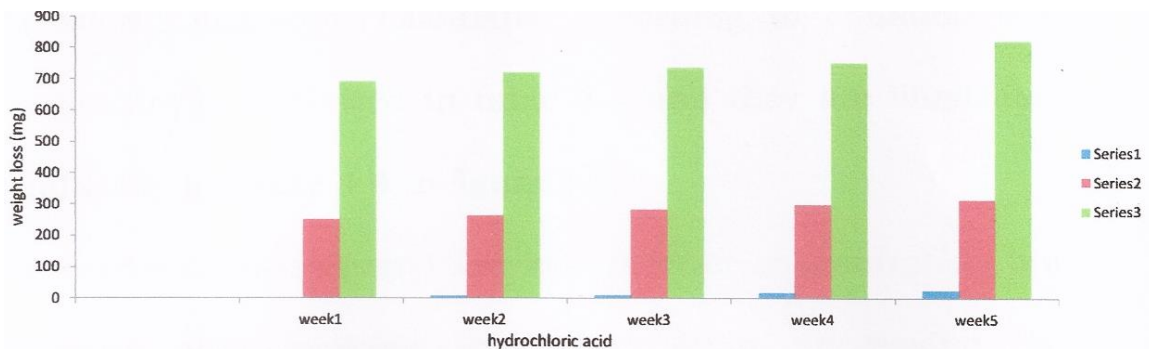
Figure 2: Weight loss of zinc after five weeks as a function of hydrochloric acid deposition
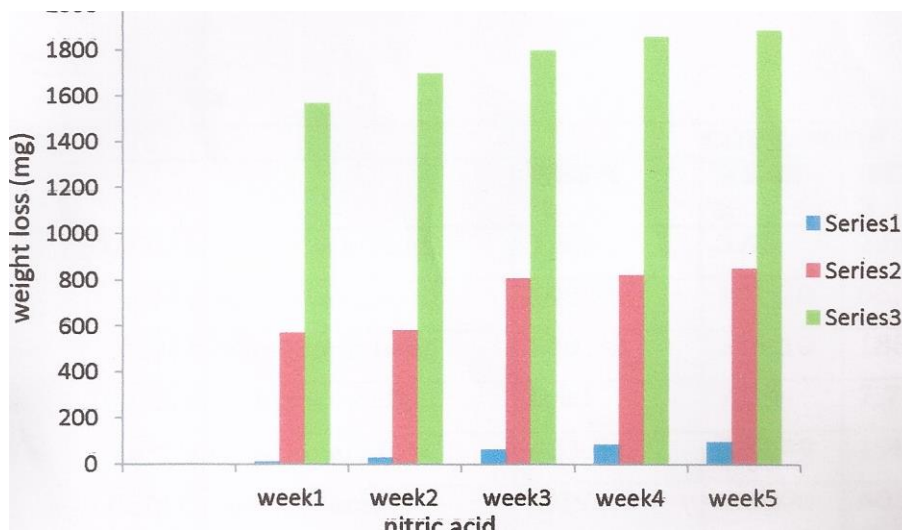

Figure 3: Weight loss of zinc after five weeks as a function of nitric acid deposition

Corrosion rate calculations

After each week of exposure, the specimens were removed test solution for calculation of weight loss. The specimens reweighed after removing the corrosion products, and corrosion rates were calculated according to equation 4.1. Results are summarized in table 4.3 and they are illustrated graphically in figure 4 to figure 8. The corrosion rates (mpy) are low at lower concentration but increases with increase in concentration. Increasing the concentration of hydrochloric, nitric or sulphuric acid from 0.05M to 2.05M increases the corrosion rate.

Table 8: Corrosion rate for five weeks for various concentration of acid component

ACID	CORROSION RATE (mpy)				
	Week 1	Week 2	Week 3	Week 4	Week 5

No. 1 (0.05m hydrochloric acid)	1.53	3.45	2.60	3.60	4.10
No. 2 (1.05m hydrochloric acid)	192.50	101.20	66.98	57.30	48.30
No. 3 (2.05m hydrochloric acid)	530.72	276.10	188.20	144.00	125.90
No. 4 (0.05m sulphuric acid)	6.90	7.29	7.70	11.70	10.90
No. 5 (1.05m sulphuric acid)	434.84	220.49	198.40	153.60	126.40
No. 6 (2.05m sulphuric acid)	1,198.7	603.96	403.40	316.70	275.60
No. 7 (0.05m nitric acid)	7.67	10.35	16.60	16.30	15.20
No. 8 (1.05m nitric acid)	438.69	222.29	79.30	158.20	131.10
No. 9 (0.05m nitric acid)	1,204.86	652.28	409.30	357.20	290.20

Comparing the three acids, hydrochloric acid shows the minimum corrosion rate, sulphuric acid shows a higher one while nitric acid shows the maximum corrosion rate. The corrosion rate of 0.05M hydrochloric acid after one week of exposure is 1.53mpy, sulphuric acid is 6.90mpy and for nitric acid, it is 7.67mpy. in conclusion from the test carried out, increasing the concentration of the acid from 1.05M to 2.05M increases the corrosion rate by 60%.
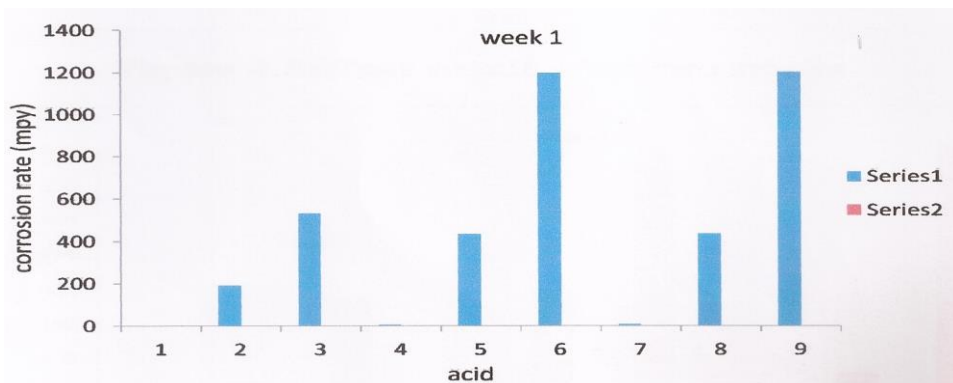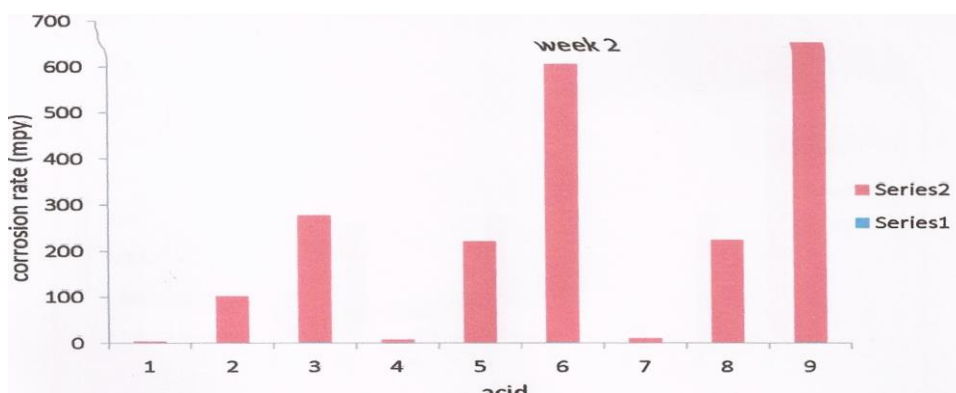

Figure 4: Test Result after one week
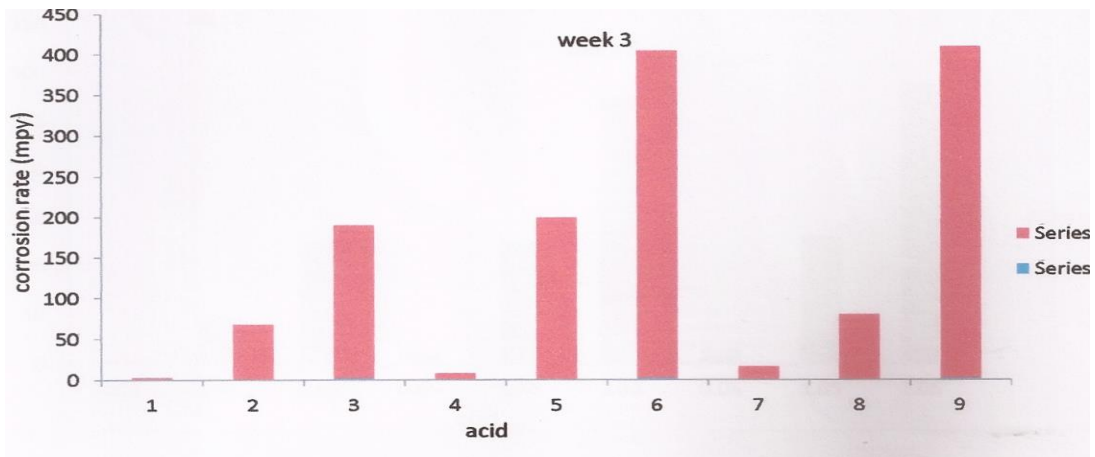

Figure 5: Test Result after two week
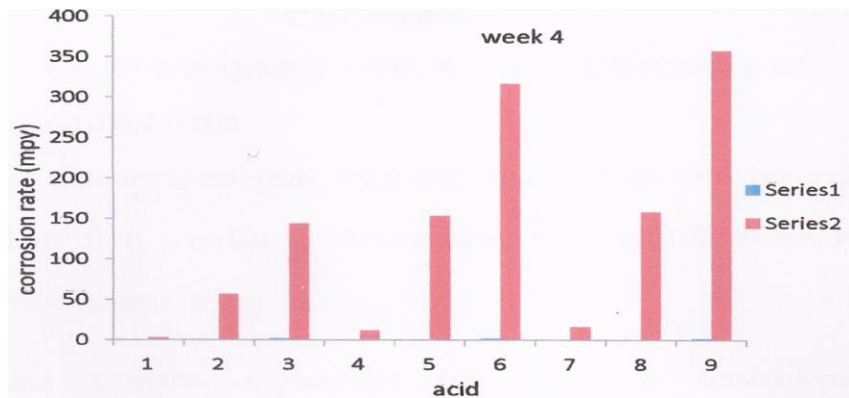
Figure 6: Test Result after three week
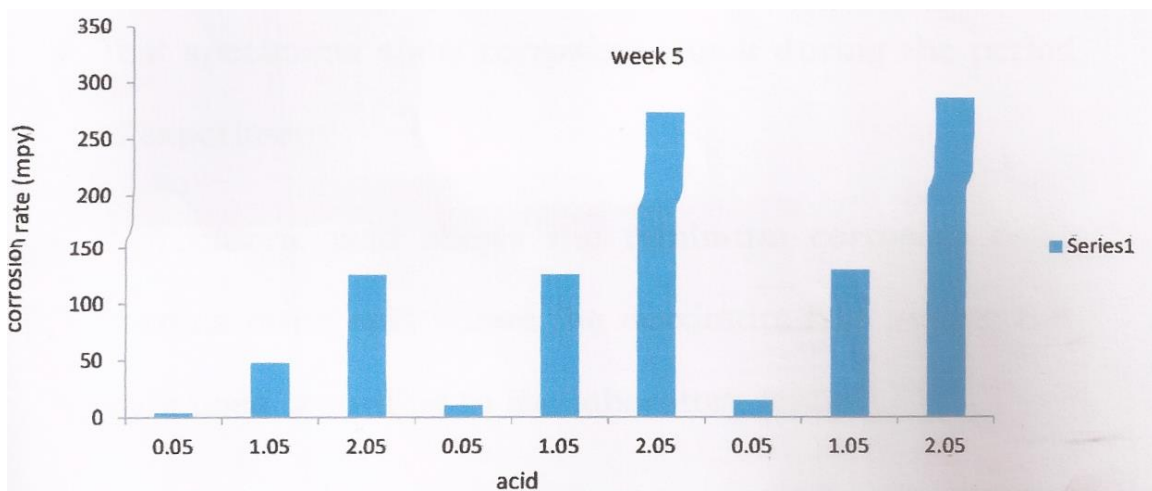

Figure 7: Test Result after four week

Figure 8: Test Result after five week

4.   Conclusion

A coupon immersion test was carried out in the laboratory for a period of five weeks to determine the acidification effect on corrosion of zinc.

From results obtained by different techniques, the following conclusions may be drawn: Test specimens show corrosion attack during the period of experiment Hydrochloric acid shows the minimum corrosion rate, whereas nitric acid shows the maximum rate among the acids used according to the laboratory test. More flakes of corrosion products of test specimens were observed in nitric acid. An overall view of the corrosion rates obtained from the tests carried out in this work gives an indication about the concentration increase of acid. It is clear from these results that an increase in concentration of acid affect the corrosion resistance of zinc.

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