Prediction of Corrosion rate of Magnesium and its alloy-Modeling

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ABSTRACT

Corrosion is the destruction of the material due to its reaction with the environment. Magnesium alloys are the most suitable material for next generation due to low density, high damping capacity and high strength to weight ratio. It finds widespread application in aerospace, automobile, bio-medical and casing for cameras, mobiles but its usage is restricted by poor corrosion resistance. In this work, magnesium (Mg) and AZ31 Mg alloy were used to investigate the corrosion rate in 3.5%, 5% and 7.5% by weight of sodium chloride (NaCl) using weight loss method. Experimental data obtained revealed that as increase concentration of in chloride ion, increases the corrosion rate and even as time of exposure increase the material loss was found to increase. Empirical model equation was developed to predict the corrosion rate using the dimensional analysis of Buckingham Pi theorem. Regression analysis was used to curve fit the experimental values, thus obtained the correction factor value. Model equation was used to predict the rate of corrosion for Mg and AZ31 Mg alloy. Finally, empirical model's corrosion rate has over 90% efficiency and concordance with the experimental result.

Keywords: Corrosion, Modeling, Magnesium

1.INTRODUCTION

Corrosion is surface disintegration of metals by the chemical reaction with the environment thereby reducing its quality properties. It is one of the oldest problem which still remains as a challenge to the fast growing industrial field. Water and water vapour containing salt combine with oxygen in the atmosphere which is the primary source corrosion. Recent statistics have also reported that 10% decrease in weight leads to 6-8% improvement in the fuel efficiency which is the major concern of automotive industries. Magnesium alloys gains its significance role next aluminium and steel in the field of aerospace, aircraft, automotive, military and other sectors due to its low density and excellent mechanical properties. Use of magnesium alloy in vehicles can on the whole reduce the overall weight, improves the fuel efficiency and performance thus making it environment friendly. However corrosion of magnesium and its alloy is a serious problem which restricts its usage[1]-[6].

Most of the corrosion data in the reference source are unreliable because it is not a property. Corrosion is a process that exhibits in different forms and are affected by various factors. Thus corrosion rate are not therefore fixed values but remains unpredictable in quantitative sense. Moreover the corrosion process is controlled by stochastic phenomena. Corrosion data can be obtained by monitoring of corrosion process and from mathematical model that predicts the corrosion rate of metal or equipment. Mathematical model is an equation or set of equations whose solution provides physical behaviour of system being modeled. Mathematical models involve the use of appropriate mathematical equation to predict the corrosion rate of metal or equipment. Mathematical modeling could save huge time, labour and cost thus enabling better design and proper method of fabrication of material[9]. Corrosion may occur due to the reaction within the components, impact of environment, environment and components. However models for predicting the extent and corrosion rate of magnesium and its alloys was focused less. In the present work a simple model to predict the corrosion rate of magnesium and its alloy in different environment is analyzed and developed.

2.EXPERIMENTAL PROCEDURE:

2.1TEST MATERIALS

Magnesium(Mg) and AZ31 are used for investigation of corrosion rate .Chemical composition of the tested magnesium and its alloys are listed in table 1.

Table1 Nominal composition of materials tested(Mg, AZ31)

Materials	Elements (wt %)								
	Al	Zn	Mn	Si	Cu	Fe	Ni	Others	Mg

Mg(99%)	0.006	0.014	0.03	0.01	0.001	0.004	<0.001		Bal
AZ31	3.1	0.73	0.25	0.02	<0.001	0.005	<0.001	<0.30	Bal

Die cast material was available in cylindrical rod form with a diameter of 20 mm. Circular specimen of thickness 10 mm were cut from the ingot.

2.2CORROSIVE MEDIA

The effect of chloride ion concentration plays a major role in corrosion. The experiments were conducted at room temperature in different concentration 3.5%, 5% and 7.5% by weight. The solution was prepared using Sodium Chloride (NaCl) in distilled water. The pH of the solution was adjusted with NaOH.

2.3 IMMERSION TEST

The test samples were polished upto finer grade of SiC emery sheet upto 1000 grit then washed and dried In the immersion test, the test specimens are preweighed and then immersed vertically using polypropylene thread tied at one end of the samples in 200 ml of test solution.The immersed samples were removed from the test solution in different interval of time period. They are washed carefully, dried and weighed. The test is repeated using in varying chloride ion concentration (3.5%, 5% and 7.5% by weight). The specimen was exposed upto the time period of 36 hours in the test solution. The corrosion rate was calculated for each sample in different environment. Thus the data's obtained from the experiment was used to find experimental corrosion rate using the equation.

Corrosion rate (CR_{exp}) =$87.6Wl/\rho At$ (1)

where

$Wl = weight\ loss\ in\ mg$

$\rho = density\ of\ the\ test\ material(\frac{g}{cm^3})$

$A = surface\ area\ of\ the\ test\ sample\ (m^2)$

t= time of exposure in hours

3. THEORETICAL MODEL DEVELOPMENT FOR CORROSION RATE

Theoretical model was developed using the method of dimensional analysis. It's a pure mathematical technique to establish a relationship between physical quantities involved in a fluid phenomenon by considering their dimensions. The Dimensional analysis using Buckingham's π method[9] [10].

The **corrosion rate** depends on the parameters like density of the fluid (**ρ**), velocity of the fluid (**V**), viscosity of the fluid (μ), exposure time (**t**), area of the Specimen (**A**).

The theoretical corrosion rate model

$$CR_{mod} = D_f\ (V.t.\mu/A.\rho) \quad (2)$$

The corrosion rate can be written in terms of known experimental parameters

$$CR_{mod} = D_f\ (\frac{m}{s}.s.kg/ms)/(A.\rho)$$

On rearranging

$$CR_{mod} = D_f\ (kg/(s.A.\rho)$$

Therefore Modeled Corrosion rate

$$CR_{mod} = D_f\ Wl/(A.\rho.t) \quad (3)$$

where D_f is the dimensionless corrosion rate correction factor.

3.1 DIMENSIONLESS CORROSION RATE CORRECTION FACTOR

The empirical model developed is expected to predict the corrosion rate obtained experimentally. Therefore $CR_{exp} \equiv CR_{mod}$ (4)

Hence the equation (4) can written as

$$CR_{exp} = D_f\ Wl/(A.\rho.t) \quad (5)$$

To obtain D_f equation (5) was rewritten in the form of straight line equation $y = mx + c$ as

$$\ln\left(\frac{1}{\mathrm{CRexp}}\right) = \ln\left(\frac{A.\rho}{\mathrm{Df}}\right) + \ln\left(\frac{t}{Wl}\right) \qquad (6)$$

where m is the slope of the equation and c is the intercept corresponds to $\ln\left(\frac{A.\rho}{\mathrm{Df}}\right)$. The experimental corrosion rate data of the magnesium andAZ31 test samples in 3.5%,5% and 7.5% by weight were used to plot the graph of $\ln\left(\frac{1}{\mathrm{CRexp}}\right)$ versus $\ln\left(\frac{t}{Wl}\right)$ **.**The Newton non-linear regression method of polymath was used to fit linear equation experimental plots were generated. The intercepts from those equations were equated to obtain the value of dimensionless corrosion rate correction factor(D_f). The graphs and corresponding linear equation are shown in figure1,2,3,4 and 5

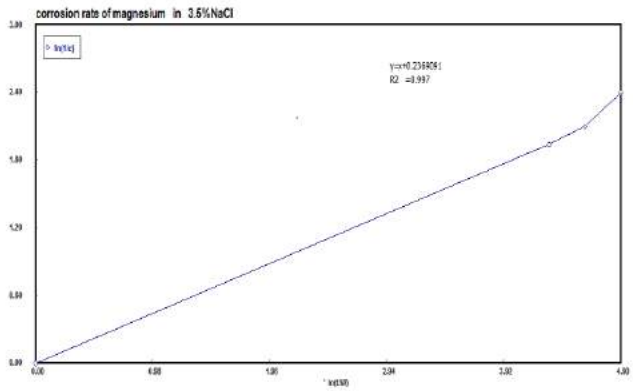


Fig-1 Determination Df for Mg in 3.5% NaCl

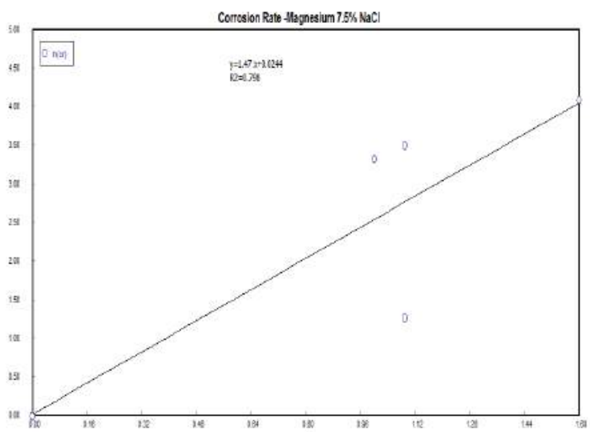


Fig-3 Determination Df for Mg in 7.5% NaCl

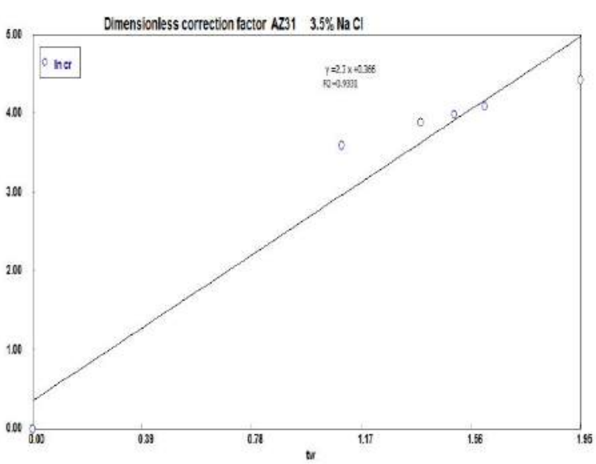


Fig-5 Determination Df for AZ31 in 3.5% NaCl

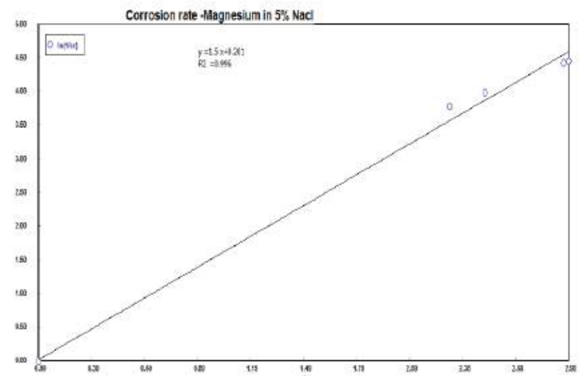


Fig-2Determination Df for Mg in 5% NaCl

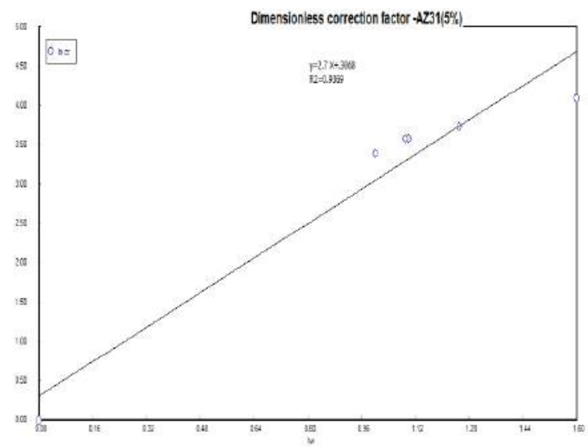


Fig-4 Determination Df for AZ31 in 5% NaCl

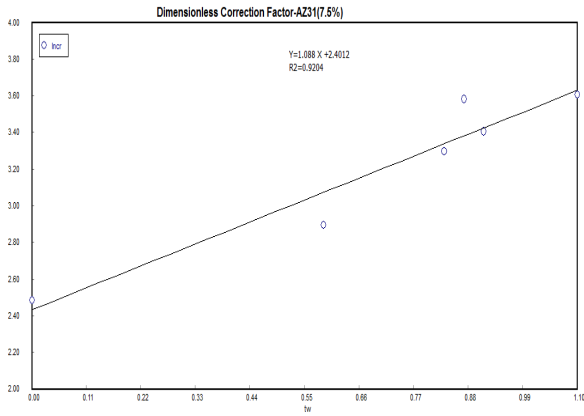


Fig-6 Determination D_f for AZ31 in 7.5% NaCl

4. RESULTS AND DISCUSSION

4.1 RESULTS

Experimental investigation of corrosion rate of magnesium and AZ31 magnesium alloy showed

1. Weight loss measurement shows initially an increase of corrosion rate in order of Mg< AZ31 in the different concentration of chloride ions 3.5%, 5% and 7.5 % by weight.
2. Presence of pure hydroxide containing layer at the Magnesium surface seems to be more protective than mixed hydroxide layers formed on AZ31 alloy.
3. Measurement of a decrease of corrosion rate with immersion time for Magnesium metal indicated the formation of continuous layer of magnesium hydroxide at the surface which increases the corrosion resistances than the formation of mixed oxide films in the alloys [2]
4. Corrosion rate is increased as the concentration of Cl^- ion increases in the test solution. As chloride ion concentration increase their aggressivity permeates through the protective layer and they break the oxide film thus the damaging the metal surface.
5. It was found that as the time of exposure increases the rate of corrosion seems to increase steadily.(Fig-7and Fig-8)
6. The effects of corrosion rate due to weight loss are shown in Fig-9 and Fig-10 for magnesium and AZ31 alloy respectively.

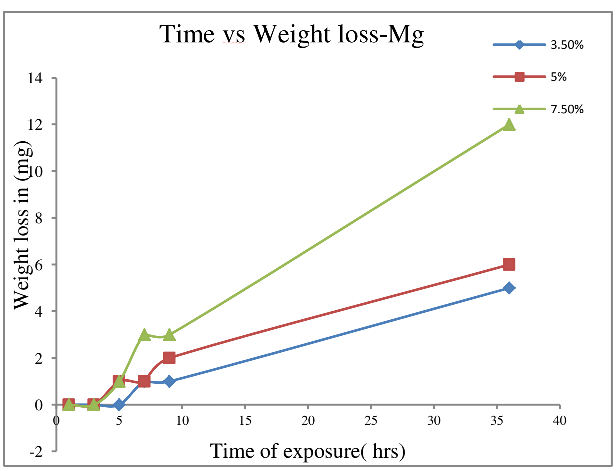


Fig-7 Time Vs Weight loss-Mg for various concentration of NaCl

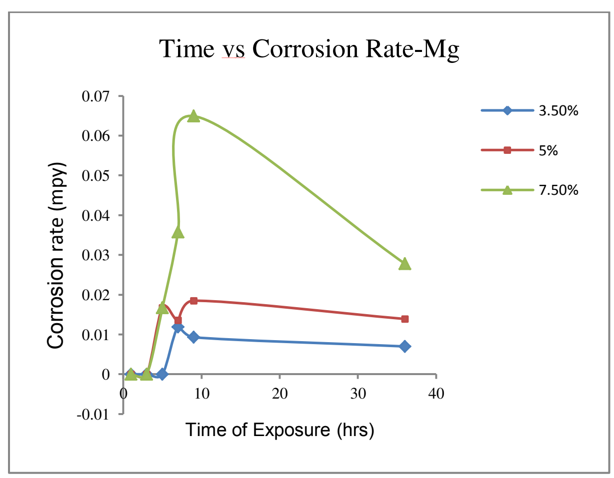


Fig-9 Time Vs Corrosion rate-Mg for various concentration of NaCl

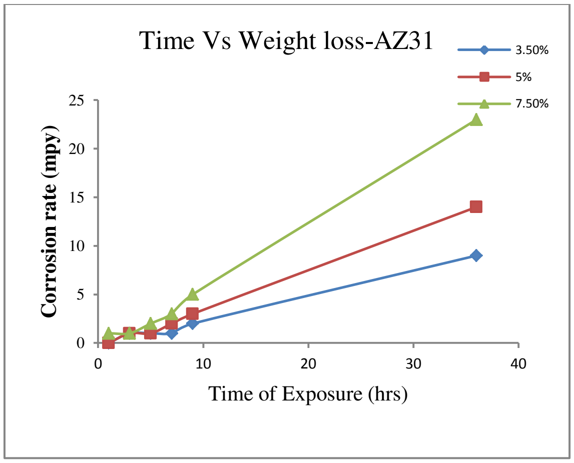


Fig-8 Time Vs Weight loss-AZ31 for various concentration of NaCl

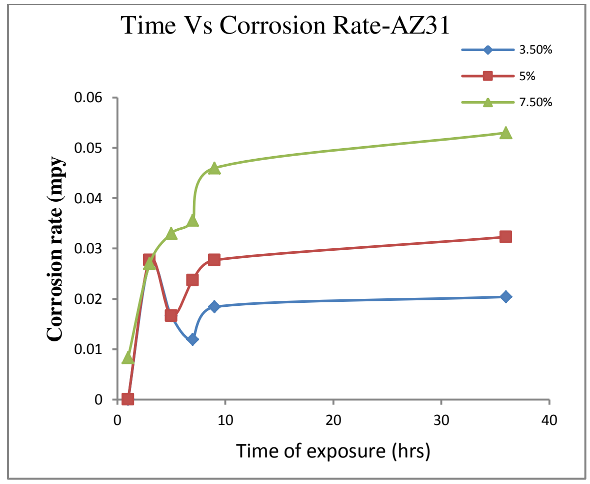


Fig-10 Time Vs Corrosion rate –AZ31 for various concentration of NaCl

4.2DISCUSSION

4.2.1COMPARISON OF THEORETICAL AND EXPERIMENTAL CORROSION RATES

The linear equations generated from Fig1, 2, 3, 4, 5 and 6 were used to obtain the corresponding dimensionless corrosion rate correction factor for magnesium and AZ31 test samples in different environment were substituted in the developed empirical model equation for determining the corrosion rate .The corrosion rate predicted by the model equations were plotted and compared with experimental corrosion rate in Fig-11 ,12,13 , 14,15 and 16.

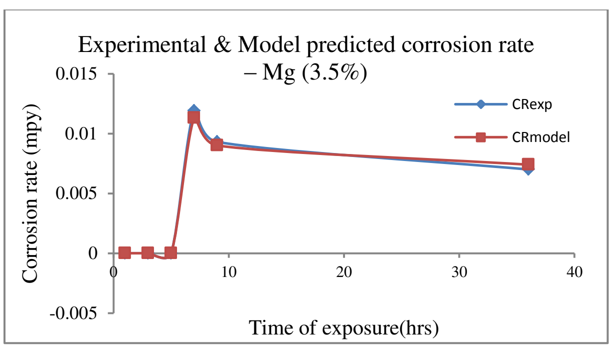


Fig-11 Experimental & Model predicted corrosion rate - Mg (3.5%)

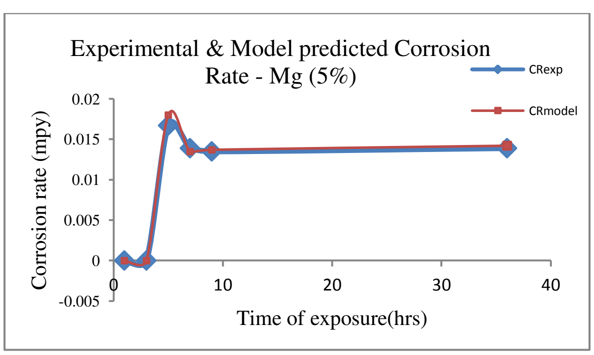


Fig-12 Experimental & Model predicted corrosion rate - Mg (5%)

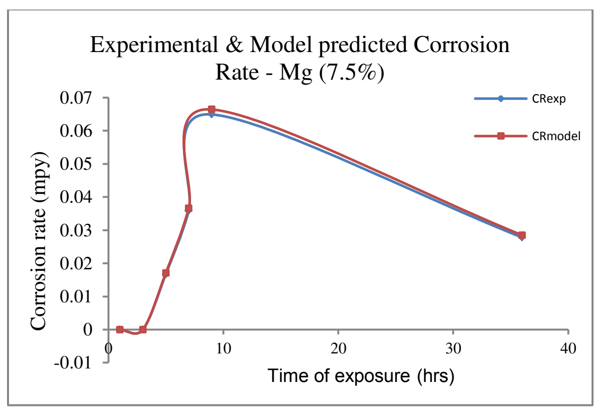


Fig-13 Experimental & Model predicted corrosion rate - Mg (7.5%)

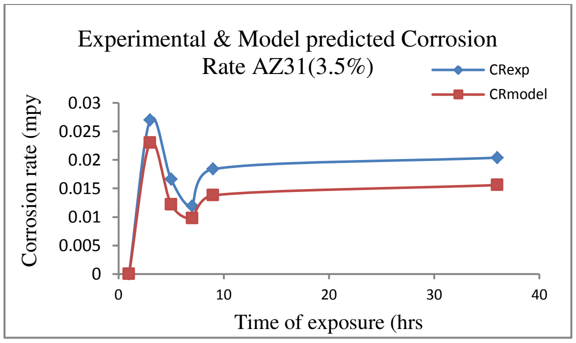
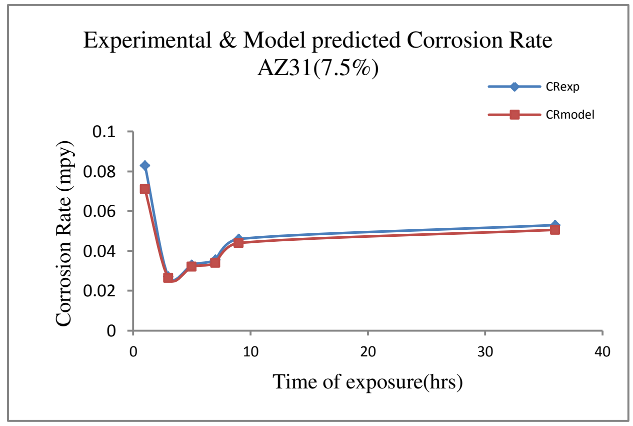


Fig-14 Experimental & Model predicted corrosion rate – AZ31 (3.5%)

Fig-15 Experimental & Model predicted corrosion rate – AZ31 (5%)



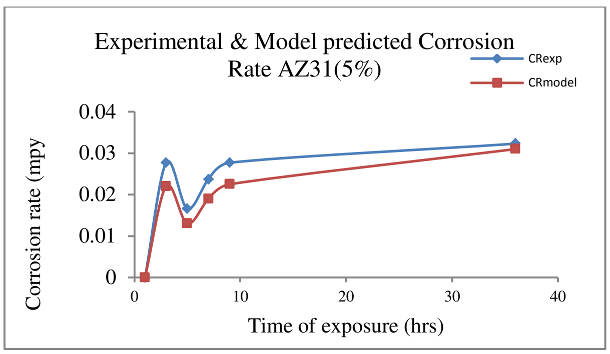


Fig-16 Experimental & Model predicted corrosion rate – AZ31 (5%)

5.CONCLUSION

Corrosion rate data of magnesium and AZ31 magnesium alloy when subjected to corrosive environment have been generated experimentally using immersion test as per ASTM G1 standards. Empirical model equations for predicting the corrosion rates of magnesium and AZ31 were developed using the dimensionless analysis of Buckingham Pi theorem. Regression analysis was used to curve fit the experimental values, thus obtained the correction factor value in corrosion rate model equation developed. The model equations were used to predict the corrosion rate for Mg and AZ31 alloy was found to match with the experimental corrosion rate in the time of exposure investigated. Thus the corrosion rate model equation developed can be used to predict the corrosion rate of Mg and its alloy AZ31 structures when exposed to corrosive environment.

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