Galvanic Corrosion of a Mild Steel Bolt In A Magnesium Alloy (AZ91D) Plate Simulation Using Comsol Multiphysics

A.T Olanipekun, A.E Faola, K. E. Oluwabunmi, T.L Oladosu

Abstract— The research work focuses on the simulation of galvanic corrosion prediction of a mild steel bolt in a magnesium plate (AZ91D) immersed in 0.5 M (sodium chloride) as an electrolyte. The simulation has a model made in two dimensions using axial symmetry with electrolyte domain of radius 120mm and height 25mm. The electrolyte conductivity is set to 7.95s/m. Three different disc radii are investigated: 8mm, 12mm, and 25mm. An anodic Tafel expression is used to describe the electrode kinetics on the steel disc. The line graph of electrode currents for the three different disc radii and a revolved surface plot of the electrolyte potential for a disc radius of 25 mm shows slow kinetics due to large anode area, therefore the local current density of the anode reaction in the vicinity of the steel disc increase significantly when the disc radius increase, which predicts lesser corrosion susceptibility for the magnesium alloy plates. This model demonstrates the application of COMSOL model development and simulation to galvanic corrosion simulation.

Index Terms— corrosion, current density, electrode, electrolyte, Modeling, simulation

1 INTRODUCTION

The model was developed through reference to the modeling techniques developed in the COMSOL corrosion module guide [1]. Galvanic corrosion occurs when two metals or alloys having different compositions are electrically coupled while exposed to an electrolyte. The less noble ore more reactive metal in the particular environment will experience [2].

Magnesium to steel is a very bad combination, with magnesium being the metal that would take all the attack due to their wider distance apart in the galvanic series, other than this the relative sizes of the anode and cathode also control galvanic corrosion, if the anode is small with respect to the cathode, the attack on the anode will be great. If the situation is reversed, the attack will be low [3]. Magnesium is the most active engineering metal in the galvanic series, so it should not be coupled with other metals unless the intent is to use the magnesium as a sacrificial anode. The use of high purity AZ91D has reduced the propensity for salt corrosion, but coatings sometimes are still necessary to prevent corrosion[4].

- *Olanipekun Ayorinde Tayo, National Agency for science and Engineering infrastructure (prototype Engineering Development Ilesa), Nigeria. 07061541108. E-mail: olanipekunayo2010@yahoo.com*
- *Faola Aderonke Esther, National Agency for science and Engineering infrastructure (prototype Engineering Development Ilesa), Nigeria. 07061368352. E-mail: kemrons2000@yahoo.com*
- *Oluwabunmi Kayode Ebenezer, National Agency for science and Engineering infrastructure (prototype Engineering Development Ilesa), Nigeria. 07061541108. E-mail: kayoxemak@yahoo.com*
- *Oladosu Temidayo Lekan, National Agency for science and Engineering infrastructure (prototype Engineering Development Ilesa), Nigeria. 07061541108. E-mail: temidayooladosu@gmail.com*

2 METHODS

2.1 Materials

A mild steel bolt used to tighten two magnesium plate (AZ91D) is considered as the model that finds application when mounting an Mg alloy component using steel fasteners

2.2 The Physics

The following equations are the governing equation for the simulation,

Tafel equation

The Tafel equation is an equation in electrochemical kinetics relating the rate of an electrochemical reaction to the overpotential [5].

On a single electrode the Tafel equation can be stated as

$$\Delta V = A \times ln\left(\frac{i}{i_0}\right) \qquad (1)$$

ΔV is the overpotential, V

A is the so-called "Tafel slope", V

i is the current density, A/m^2 and

i_0 is the so-called "exchange current density", A/m^2.

Where an electrochemical reaction occurs in two half reactions on separate electrodes, the Tafel equation is applied to each electrode separately. The Tafel equation assumes that the reverse reaction rate is negligible compared to the forward reaction rate. The Tafel equation is applicable to the region where the values of polarization are high.

Electrode potential

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Electrode potential appears at the interface between an electrode and electrolyte due to the transfer of charged species across the interface, specific adsorption of ions at the interface, and specific adsorption/orientation of polar molecules, including those of the solvent. Electrode potential is the electric potential on an electrode component. In a cell, there will be an electrode potential for the cathode, and an electrode potential for the anode. The difference between the two electrode potentials equals the cell potential.

$$E_{cell} = E_{cathode} - E_{Anode} \quad (2)$$

The measured electrode potential may be either that at equilibrium on the working electrode ("reversible potential"), or a potential with a non-zero net reaction on the working electrode but zero net current ("corrosion potential", "mixed potential"), or a potential with a non-zero net current on the working electrode (like in galvanic corrosion or voltammetry). Reversible potentials can be sometimes converted to the standard electrode potential for a given electroactive species by extrapolation of the measured values to the standard state [6].

2.3 The Model

The model is configured in COMSOL Multiphysics as a 2D axisymmetric model with a single electrolyte domain of radius 10 cm and height of 7.5 cm. The electrolyte conductivity is set to 7.95 S/m.

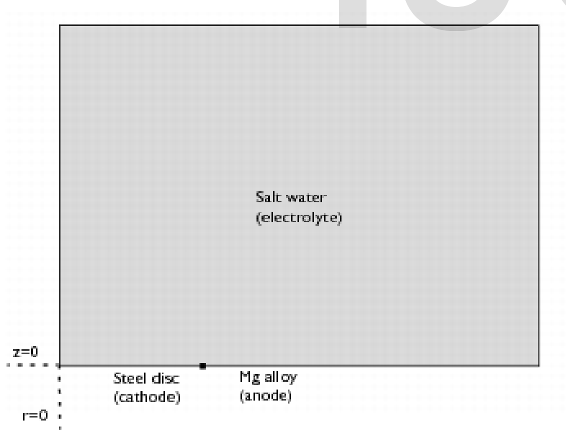

Fig. 1. Electrolyte domain with axial symmetry

2.4 Boundary Conditions

The mild steel which is the cathode, placed in the center of the geometry at *Z*=0, extending in the *r* direction. Three different disc radii are investigated: 8, 12 and 25 mm. An anodic Tafel expression is used to describe the electrode kinetics on the steel disc.

2.5 Geometry Model

Secondary Current Distribution interface is used to model the problem, busing Electrolyte-Electrode boundary Interface nodes for the two electrode surfaces.

Due to the faster kinetics and larger area of the anode, the initial value for the electrolyte is set to correspond to a zero anode polarization.

A stationary study step is used to solve the problem, with a parametric sweep to vary the disc radius. Triangular mesh is used for meshing, with an additional smaller size setting for increasing the resolution at the contact point between the anode and cathode.

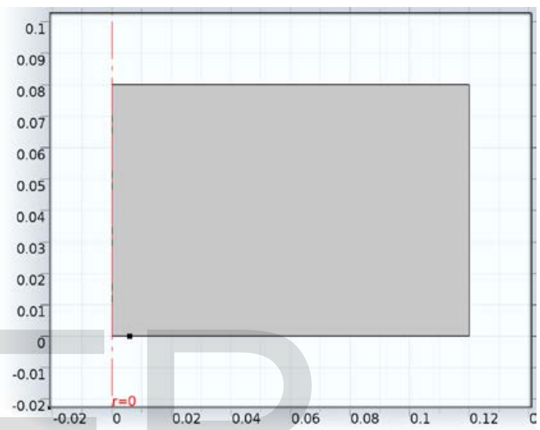

Fig. 2. Model geometry

3 RESULT

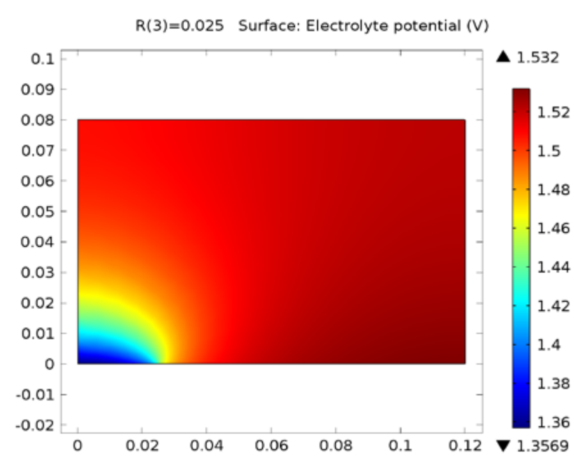

Fig.3. Showing 2D representation of electrolyte potential

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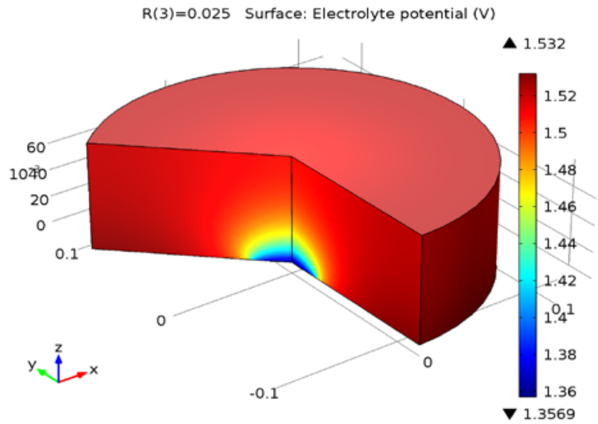

Fig. 4. Electrolyte potential for a 25 mm disc radius.

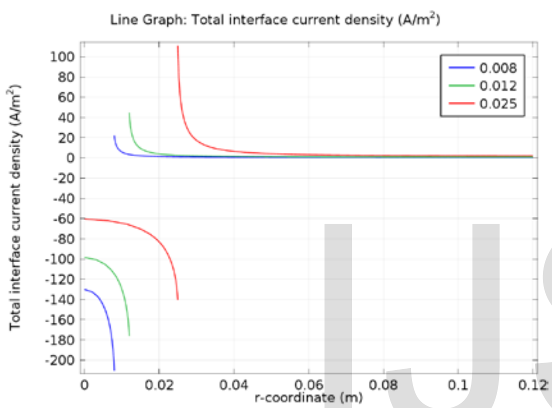

Fig. 5. Total interface current density ($^{A}/_{m^2}$)

TABLE 1
Showing the finite element size setting

Name	Value
Maximum element size	0.00804
Minimum element size	3.6E5
Resolution of curvature	0.3
Maximum element growth rate	1.3

TABLE 2
Showing the finite element size setting

Name	Value
Maximum element size	R/100
Minimum element size	3.6E5
Minimum element size	Off
Resolution of curvature	0.3
Resolution of curvature	Off
Resolution of narrow regions	Off
Maximum element growth rate	1.3
Maximum element growth rate	Off
Custom element size	Custom

TABLE 1
Parameter Table

Name	Value	Description
R	0.0050m	Radius of disc
Sigma	7.9500s/m	Electrolyte conductivity
Eeq_cathode	-0.8500V	Equlibrium potential, cathode
Eeq_anode	-1.5500 V	Equlibrium potential, anode
i0_cathode	0.300$^{A}/_{m^2}$	Exchange current density, cathode
i0_anode	1.000$^{A}/_{m^2}$	Exchange current density, anode
b_cathode	0.22000 V	Cathodic tafel slope, steel
b_anode	0.055000 V	Anodic tafel slope, Mg

4 Discussion

The local current density of the anode reaction in the vicinity of the steel disc increases significantly when the disc radius increase. This is due to the slow kinetics on steel disc, governing the total reaction current. That is if the size of the cathode is increase the susceptibility to its corrosion more than that of the anode increases. Therefore as the steel disc radii increase according to figure 5 the interface current density increases too leading to increase in corrosion, this actually validate galvanic corrosion theory.

Figure 4 shows a revolved surface plot of the electrolyte potential for a steel disc radius of 25 mm.

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