Galvanic Corrosion of a Magnesium Alloy in Contact with Steel

Introduction

Magnesium alloys are attractive alternatives as lightweight materials in various fields of engineering. Magnesium is however relatively non-noble and may suffer considerable galvanic corrosion when being used in conjunction with other metals, for instance when mounting an Mg alloy component using steel fasteners.

This model example simulates a galvanic corrosion couple consisting of a magnesium alloy (AZ91D) and mild steel, with salt water (5% NaCl) as electrolyte. The example is based on a paper by J.X. Jia and others (Ref. 1).

Model Definition

The model is made in two dimensions using axial symmetry, see Figure 1, 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.

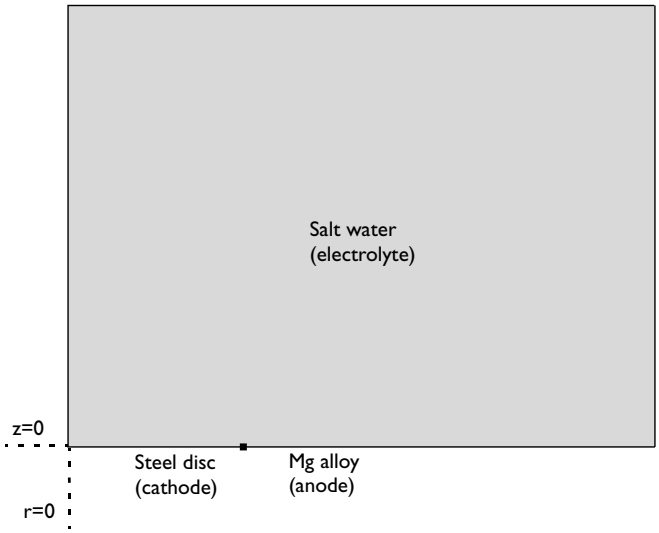

Figure 1: Model geometry. Electrolyte domain with axial symmetry.

BOUNDARY CONDITIONS

The cathode is a disc made of mild steel, placed in the center of the geometry at z=0, extending in the r direction. Three different disc radii are investigated: 5, 10 and 30 mm. An anodic Tafel expression is used to describe the electrode kinetics on the steel disc, with parameter values according to Table 1.

TABLE 1: ELECTRODE REACTION PARAMETERS

PARAMETER	UNIT	ANODE	CATHODE
Equilibrium potential	V	-1.55	-0.85
Exchange current density	A/m^2	1	0.3
Tafel slope	mV	55	-220

The Mg alloy electrode is placed outside the steel disc on the z = 0 line. For this electrode surface a cathodic tafel expression is used to describe the electrode kinetics, with values as shown in Table 1.

The electric potential of both electrode surfaces is set to ground.

The outer (r=10 cm) and top boundaries (z=7.5 cm) are isolated.

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Results and Discussion

Figure 2 shows a revolved surface plot of the electrolyte potential for a disc radius of 30 mm.

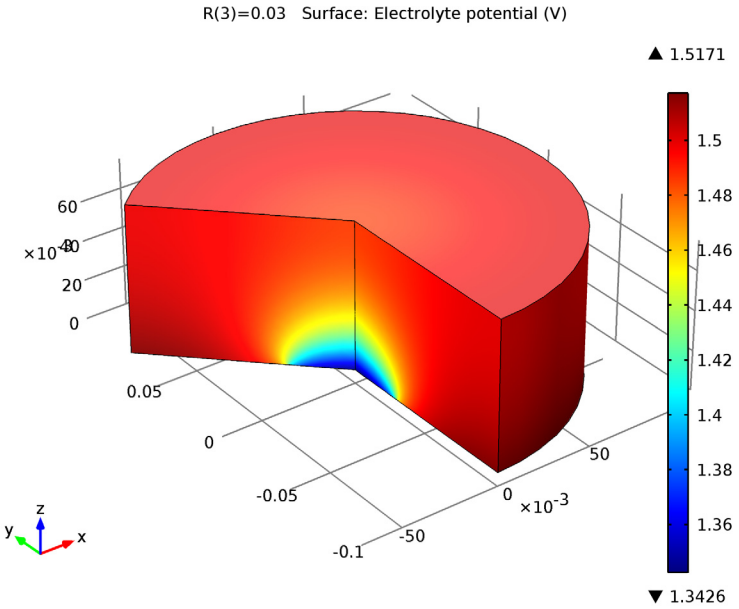

Figure 2: Electrolyte potential for a 30 mm disc radius.

Figure 3 shows the electrode reaction currents for the three different disc radii. The local current density of the anode reaction in the vicinity of the steel disc increase significantly when the disc radius increase. This is due to the slow kinetics on steel disc, governing the total reaction current.

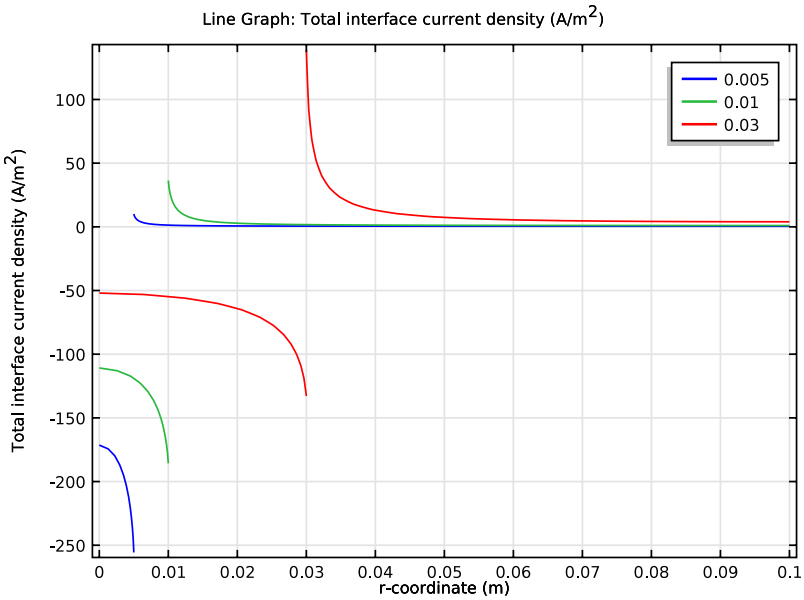

Figure 3: Electrode currents for the three different disc radii.

Notes About the COMSOL Implementation

The Secondary Current Distribution interface is used to model the problem, using 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.

A free 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.

Reference

1. J.X. Jia and others, "Simulation of galvanic corrosion of magnesium coupled to a steel fastener in NaCl solution," *Materials and Corrosion*, vol. 56, no. 7, 2005.

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Model Library path: `Corrosion_Module/Verification_Models/galvanic_corrosion_mg_alloy`

Modeling Instructions

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Click the **2D axisymmetric** button.

3 Click **Next**.

4 In the **Add physics** tree, select **Electrochemistry>Secondary Current Distribution (siec)**.

5 Click **Next**.

6 Find the **Studies** subsection. In the tree, select **Preset Studies>Stationary**.

7 Click **Finish**.

GLOBAL DEFINITIONS

Load the model paramaters from a file.

Parameters

1 In the **Model Builder** window, right-click **Global Definitions** and choose **Parameters**.

2 In the **Parameters** settings window, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Model Library folder and double-click the file `galvanic_corrosion_mg_alloy_parameters.txt`.

GEOMETRY 1

Draw the geometry as a rectangle. Use a point to divide the bottom boundary into two sections. (The two sections will be the anode and cathode, respectively, when setting up the physics).

Rectangle 1

1 In the **Model Builder** window, under **Model 1** right-click **Geometry 1** and choose **Rectangle**.

2 In the **Rectangle** settings window, locate the **Size** section.

3 In the **Width** edit field, type `10[cm]`.

4 In the **Height** edit field, type `7.5[cm]`.

5 Click the **Build Selected** button.

Point 1

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Point**.

2 In the **Point** settings window, locate the **Point** section.

3 In the ***r*** edit field, type `R`.

4 Click the **Build Selected** button.

5 Click the **Zoom Extents** button on the Graphics toolbar.

SECONDARY CURRENT DISTRIBUTION

Now set up the physics, beginning with the electrolyte conductivity.

Electrolyte 1

1 In the **Model Builder** window, expand the **Secondary Current Distribution** node, then click **Electrolyte 1**.

2 In the **Electrolyte** settings window, locate the **Electrolyte** section.

3 From the σ_l list, choose **User defined**. In the associated edit field, type `sigma`.

Electrolyte-Electrode Boundary Interface 1

The anode and cathode are modeled as Electrolyte-Electrode Boundary Interface nodes, having the same electric pontential in the electron conducting phase. Define the cathode first.

1 In the **Model Builder** window, right-click **Secondary Current Distribution** and choose the boundary condition **Electrolyte>Electrolyte-Electrode Boundary Interface**.

The cathode is located at the center of the bottom boundary.

2 Select Boundary 2 only.

Electrode Reaction 1

1 In the **Model Builder** window, expand the **Electrolyte-Electrode Boundary Interface 1** node, then click **Electrode Reaction 1**.

2 In the **Electrode Reaction** settings window, locate the **Equilibrium Potential** section.

3 In the $E_{0,\mathrm{ref}}$ edit field, type `Eeq_cathode`.

4 Locate the **Electrode Kinetics** section. In the i_0 edit field, type `i0_cathode`.

5 From the **Kinetics expression type** list, choose **Cathodic Tafel equation**.

6 In the A_c edit field, type `b_cathode`.

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Electrolyte-Electrode Boundary Interface 2

Now define the anode surface, located on the outer part of the bottom boundary.

1. In the **Model Builder** window, right-click **Secondary Current Distribution** and choose the boundary condition **Electrolyte>Electrolyte-Electrode Boundary Interface**.
2. Select Boundary 4 only.

Electrode Reaction 1

1. In the **Model Builder** window, expand the **Electrolyte-Electrode Boundary Interface 2** node, then click **Electrode Reaction 1**.
2. In the **Electrode Reaction** settings window, locate the **Equilibrium Potential** section.
3. In the $E_{0,\mathrm{ref}}$ edit field, type `Eeq_anode`.
4. Locate the **Electrode Kinetics** section. From the **Kinetics expression type** list, choose **Anodic Tafel equation**.
5. In the i_0 edit field, type `i0_anode`.
6. In the A_a edit field, type `b_anode`.

Initial Values 1

Provide a suitable initial value for the electrolyte potential. In this case the initial value is based on the anode equilibrium potential. (The reason for this is the larger anode area and faster kinetics.

1. In the **Model Builder** window, under **Model 1>Secondary Current Distribution** click **Initial Values 1**.
2. In the **Initial Values** settings window, locate the **Initial Values** section.
3. In the phil edit field, type `-Eeq_anode`.

MESH 1

1. In the **Model Builder** window, under **Model 1** click **Mesh 1**.
2. In the **Mesh** settings window, locate the **Mesh Settings** section.
3. From the **Sequence type** list, choose **User-controlled mesh**.

   Impose a finer mesh size at the contact point between the anode and cathode.

Size 1

1. Right-click **Model 1>Mesh 1** and choose **Size**.
2. In the **Model Builder** window, under **Model 1>Mesh 1** right-click **Size 1** and choose **Move Up**.
3. In the **Size** settings window, locate the **Geometric Entity Selection** section.

4 From the **Geometric entity level** list, choose **Point**.

5 Select Point 3 only.

6 Locate the **Element Size** section. Click the **Custom** button.

7 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

8 In the associated edit field, type `R/100`.

9 In the **Model Builder** window, right-click **Mesh 1** and choose **Build All**.

STUDY 1

The model is now ready to solve. Add a parametric sweep to study the impact of different cathode radii.

Parametric Sweep

1 In the **Model Builder** window, right-click **Study 1** and choose **Parametric Sweep**.

2 In the **Parametric Sweep** settings window, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

PARAMETER NAMES	PARAMETER VALUE LIST
R	`0.005 0.01 0.03`

5 In the **Model Builder** window, right-click **Study 1** and choose **Compute**.

RESULTS

A revolved plot of the electrolyte potential is added by default. The following steps create a plot of the electrode reaction currents. (Compare with Figure 3 in the Results and Discussion section above.)

1D Plot Group 3

1 In the **Model Builder** window, right-click **Results** and choose **1D Plot Group**.

2 In the **1D Plot Group** settings window, locate the **Data** section.

3 From the **Data set** list, choose **Solution 2**.

4 Right-click **Results>1D Plot Group 3** and choose **Line Graph**.

5 Select Boundaries 2 and 4 only.

6 In the **Line Graph** settings window, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Secondary Current Distribution>Electrode kinetics>Total interface current density (siec.itot)**.

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7 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

8 In the **Expression** edit field, type `r`.

9 Click to expand the **Legends** section. Select the **Show legends** check box.

10 Click the **Plot** button.

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