Created in COMSOL Multiphysics 6.1

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 a Mg alloy component using steel fasteners.

This model example simulates a galvanic corrosion couple consisting of a magnesium alloy (AZ91D) and steel (4150), 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.

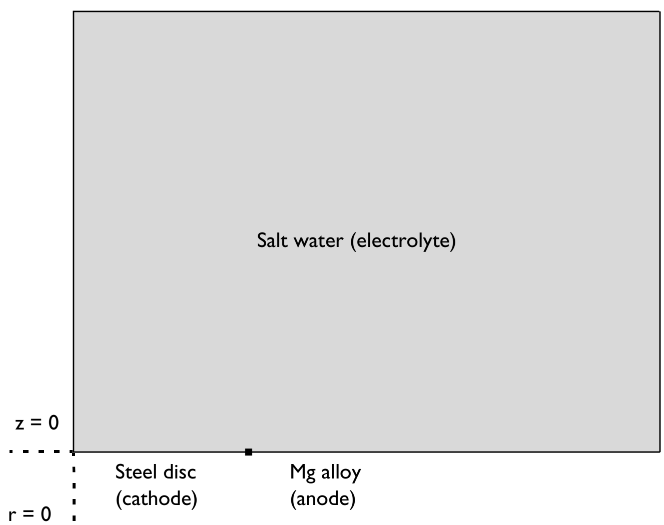


Figure 1: Model geometry. Electrolyte domain with axial symmetry.

BOUNDARY CONDITIONS

The cathode is a disc made of steel 4150, placed at the center of the geometry at z=0, extending in the r direction. Three different disc radii are investigated: 5, 10, and 30 mm.

The Mg alloy AZ91D electrode is placed outside the steel disc on the z = 0 line.

The electrode kinetics at both the steel and Mg alloy surfaces is described using the experimental polarization data available in corrosion material library.

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

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

Results and Discussion

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

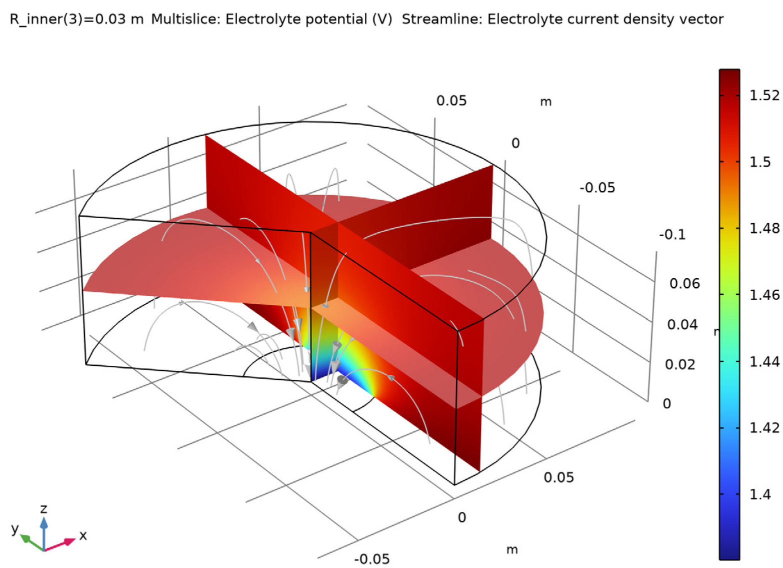


Figure 2: Electrolyte potential for a 30 mm disc radius.

Figure 3 shows the electrode current densities for the three different disc radii. The local current density of the anode reaction in the vicinity of the steel disc increases significantly with an increase in steel disc radius which is attributed to the higher cathode to anode area ratio.

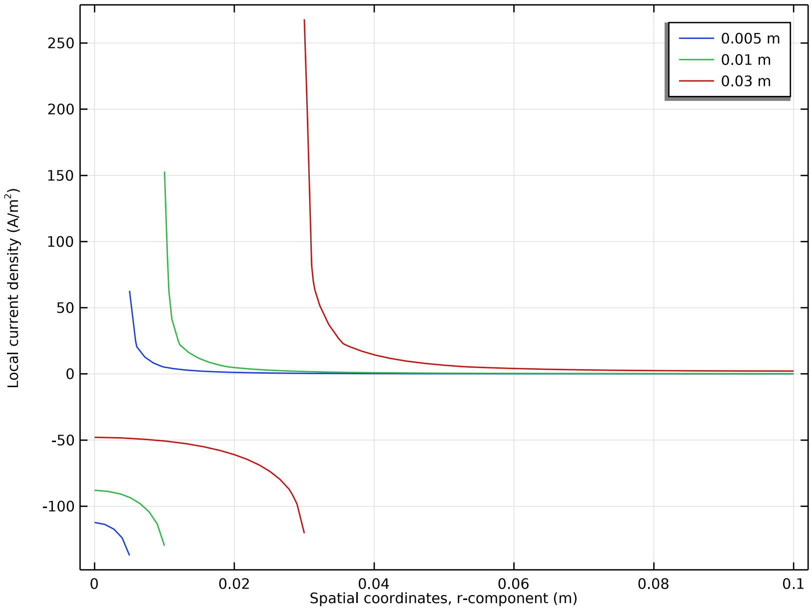


Figure 3: Electrode current densities for the three different disc radii.

Notes About the COMSOL Implementation

The Secondary Current Distribution interface is used to model the problem, using Electrode Surface 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, A. Atrens, G. Song, and T.H. Muster, "Simulation of galvanic corrosion of magnesium coupled to a steel fastener in NaCl solution," *Materials and Corrosion*, vol. 56, no. 7, pp. 468–474, 2005.

Application Library path: `Corrosion_Module/Galvanic_Corrosion/galvanic_corrosion_mg_alloy`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D Axisymmetric**.

2 In the **Select Physics** tree, select **Electrochemistry>Primary and Secondary Current Distribution>Secondary Current Distribution (cd)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Load the model parameters from a file.

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries 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 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `R_outer`.

4 In the **Height** text field, type `H`.

5 Click **Build Selected**.

Point 1 (pt1)

1 In the **Geometry** toolbar, click **Point**.

2 In the **Settings** window for **Point**, locate the **Point** section.

3 In the **r** text field, type `R_inner`.

4 Click **Build Selected**.

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

MATERIALS

Use the Corrosion Material Library to set up the material properties for the electrode kinetics at the magnesium and steel electrode surfaces.

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Corrosion>Iron Alloys (Steels)>AISI 4150 steel in 5% NaCl**.

4 Click **Add to Component** in the window toolbar.

MATERIALS

AISI 4150 steel in 5% NaCl (mat1)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Geometric entity level** list, choose **Boundary**.

3 Select Boundary 2 only.

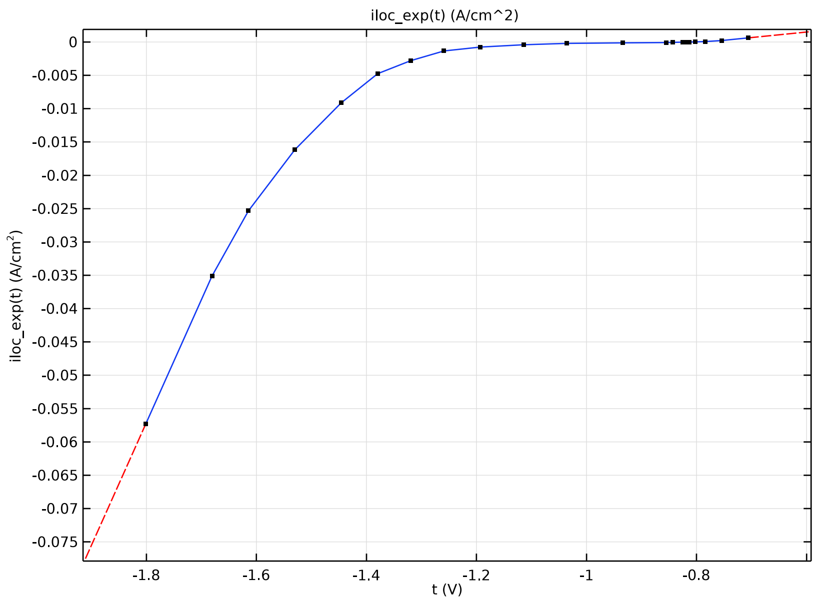
4 In the **Model Builder** window, expand the **AISI 4150 steel in 5% NaCl (mat1)** node.

Interpolation 1 (iloc_exp)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Materials> AISI 4150 steel in 5% NaCl (mat1)>Local current density (lcd)** node, then click **Interpolation 1 (iloc_exp)**.

2 In the **Settings** window for **Interpolation**, click **Plot**.

The function plot should look like this:



ADD MATERIAL

1 Go to the **Add Material** window.

2 In the tree, select **Corrosion>Magnesium Alloys>AZ91D in 5% NaCl**.

3 Click **Add to Component** in the window toolbar.

MATERIALS

AZ91D in 5% NaCl (mat2)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Geometric entity level** list, choose **Boundary**.

3 Select Boundary 4 only.

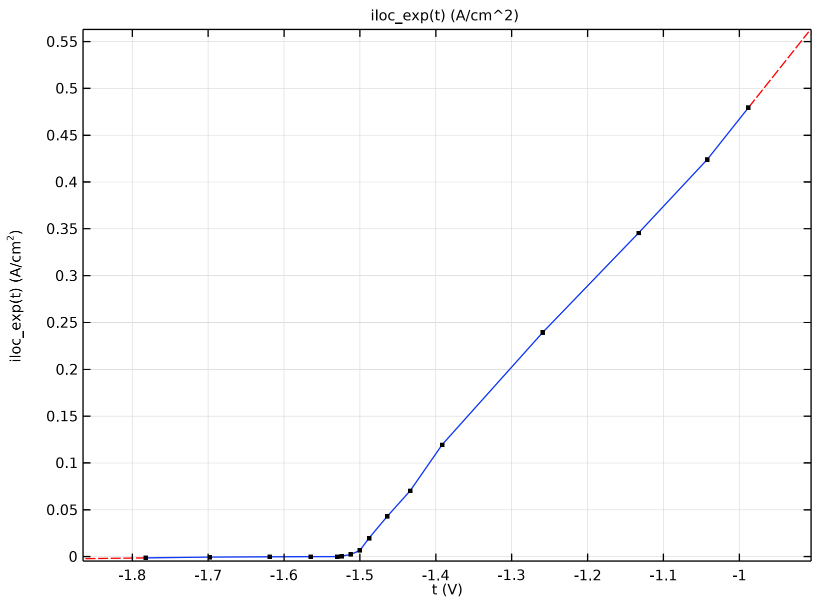
4 In the **Model Builder** window, expand the **AZ91D in 5% NaCl (mat2)** node.

Interpolation 1 (iloc_exp)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Materials>AZ91D in 5% NaCl (mat2)>Local current density (lcd)** node, then click **Interpolation 1 (iloc_exp)**.

2 In the **Settings** window for **Interpolation**, click **Plot**.

The function plot should look like this:



3 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

SECONDARY CURRENT DISTRIBUTION (CD)

Now set up the electrochemistry. Start with selecting the reference electrode.

1 In the **Settings** window for **Secondary Current Distribution**, click to expand the **Physics vs. Materials Reference Electrode Potential** section.

2 From the list, choose **0.197 V (Sat. Ag/AgCl vs. SHE)**.

Electrolyte 1

Next set up the user defined electrolyte conductivity.

1 In the **Model Builder** window, under **Component 1 (comp1)> Secondary Current Distribution (cd)** click **Electrolyte 1**.

2 In the **Settings** window for **Electrolyte**, locate the **Electrolyte** section.

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

Electrode Surface 1

The anode and cathode are modeled as Electrode Surface nodes, having the same electric potential in the electron conducting phase. Define the cathode first.

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Surface**.

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, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{\mathrm{loc,expr}}$ list, choose **From material**.

Electrode Surface 2

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

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Surface**.

2 Select Boundary 4 only.

Electrode Reaction 1

1 In the **Model Builder** window, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{\mathrm{loc,expr}}$ list, choose **From material**.

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 **Study** toolbar, click **Parametric Sweep**.

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

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
R_inner (Radius of inner disc)	0.005 0.01 0.03	m

5 In the **Study** toolbar, click **Compute**.

RESULTS

Electrolyte Potential, 3D (cd)

A revolved plot of the electrolyte potential is added by default.

Local current density

The following steps create a plot of the electrode reaction currents. (Compare with Figure 3 in the Results and Discussion section above).

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2 In the **Settings** window for **1D Plot Group**, type `Local current density` in the **Label** text field.
3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.
4 Click to expand the **Title** section. From the **Title type** list, choose **None**.

Line Graph 1

1 Right-click **Local current density** and choose **Line Graph**.
2 Select Boundaries 2 and 4 only.
3 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)> Secondary Current Distribution>Electrode kinetics>cd.iloc_er1 - Local current density - A/m²**.
4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
5 In the **Expression** text field, type `r`.
6 Click to expand the **Legends** section. Select the **Show legends** check box.
7 In the **Local current density** toolbar, click **Plot**.