



Developing digital tools for prediction of galvanic corrosion in mixed materials



SIEMENS

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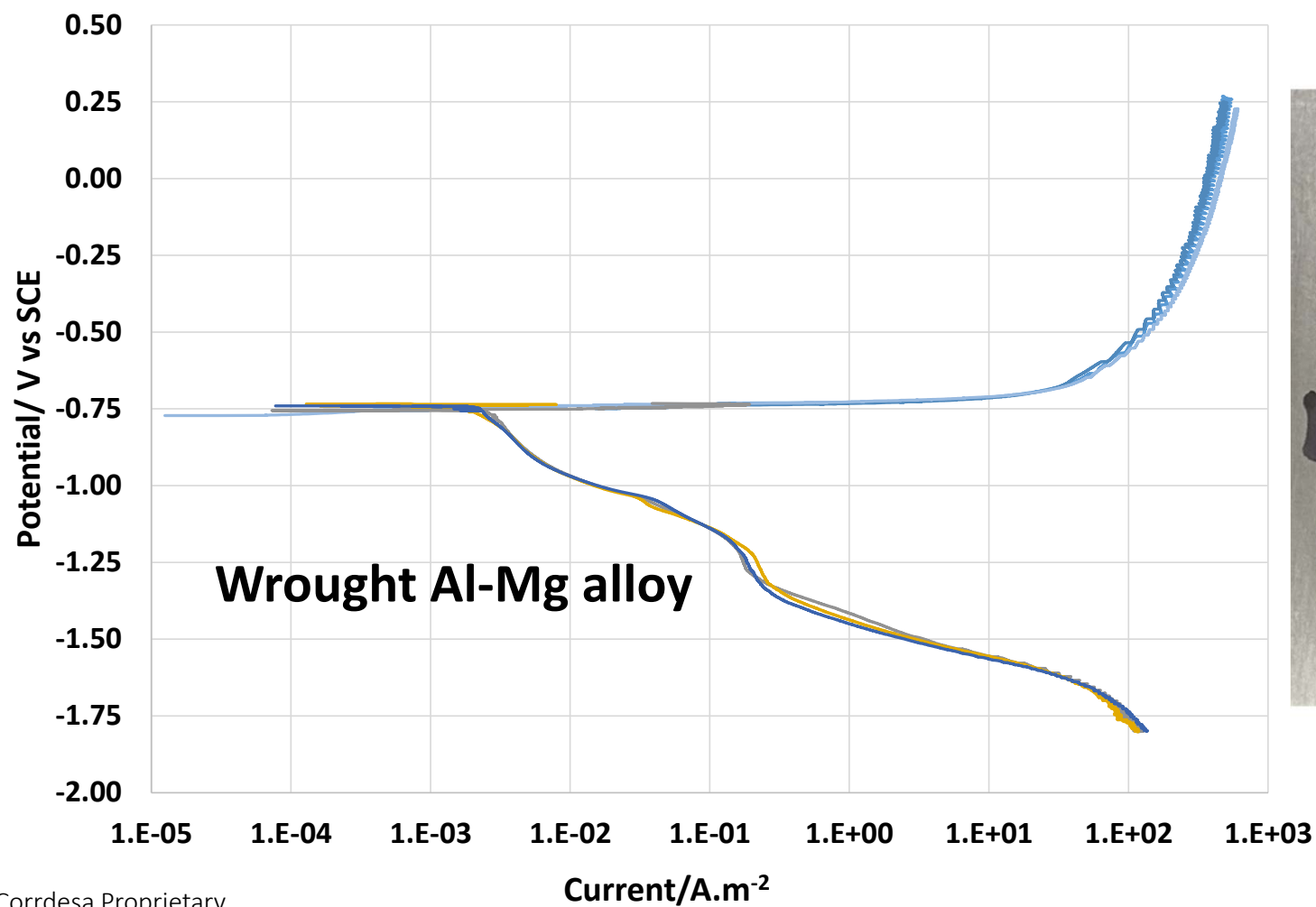
Outline

- Polarization data acquisition for automotive relevant materials IAW MIL-STD-889D protocol
- Polarization Curve fitting/Deconvolution for corrosion studies
 - Significance of curve fitting
- Database expansion-1D Galvanic Corrosion prediction tool
- PLM Teamcenter
 - Computational Strategy for Corrosion Mitigation and Prevention using pre-configured templates
 - Data management and workflow orchestrator

Project Goal

- Establish an electrochemical database for automotive construction materials to enable virtual galvanic corrosion prediction in mixed-material vehicles.

Example - Polarization curve for Wrought AlMg based alloy



Data Post processing-Curve Fitting /Deconvolution

Background:

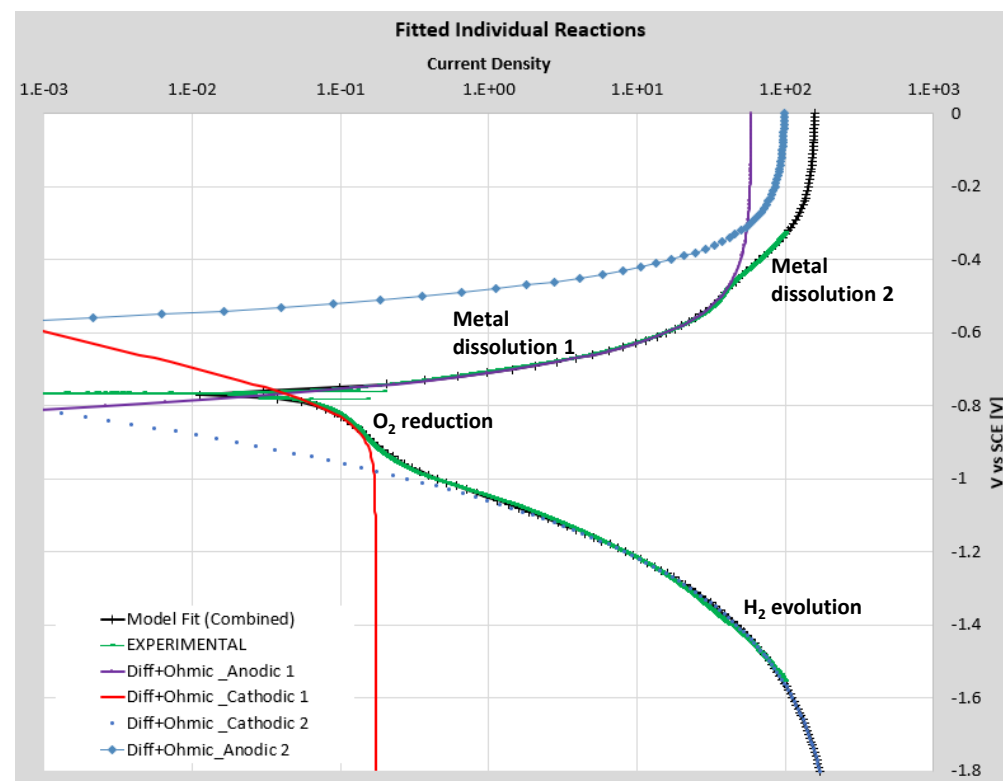
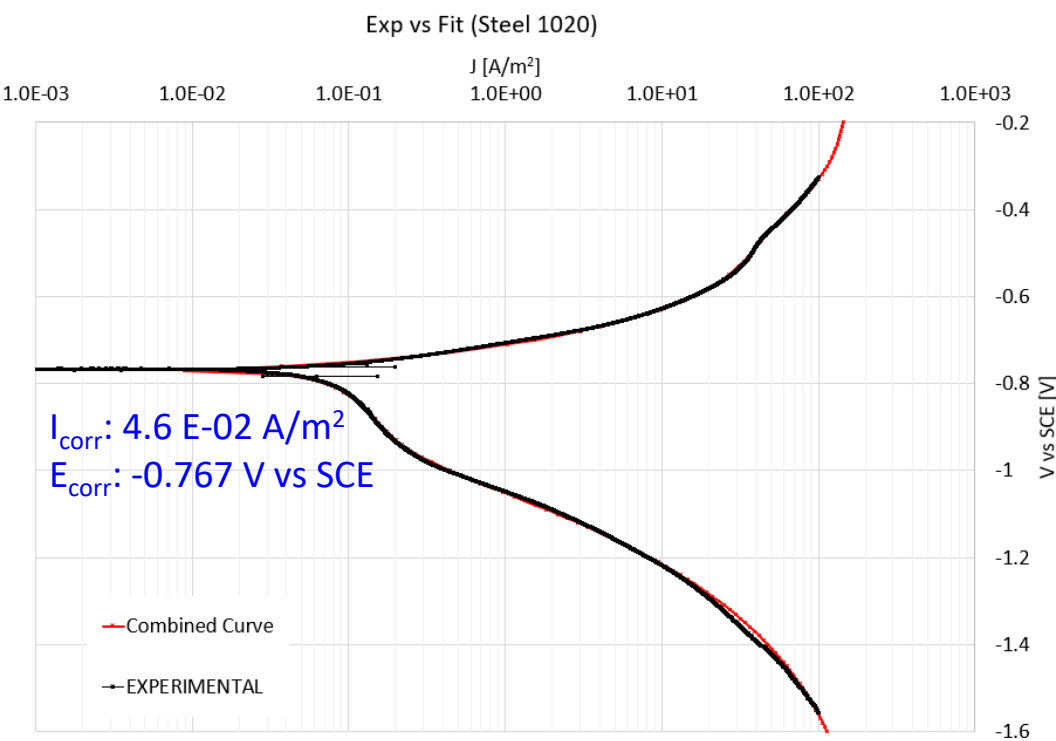
The characteristic shapes of polarization curves can be partially described by several electrochemical parameters developed in mixed potential theory for each participating electrochemical reaction. The partial current densities from the participating reactions are then summed to arrive at a total applied current density of the final polarization curve.

Fitting:

- **Parametric fitting** of all the acquired polarization data is essential in order to extract electrochemical parameters e.g. self-corrosion current/rate for material. This method appears to be useful in characterizing the polarization behavior of a particular metal because the parameters involved have physical significance to the corrosion engineer or a electrochemist. Besides, there is a need to post-process all the acquired experimental data, modeling software requirements and also for data reduction purposes. In order to do that, we need a robust yet easy to use method or tool.
- Corrdesa developed own fitting algorithm that could be used for fitting from a very simple to very complex experimental polarization data. In addition, we have also incorporated a model for **thin film curve** calculation for simulating polarization curves under atmospheric conditions at various film thicknesses and not only under bulk conditions.

Example: Curve Fitting/Deconvolution – 1020 Steel

- Data fit using the developed fitting model.

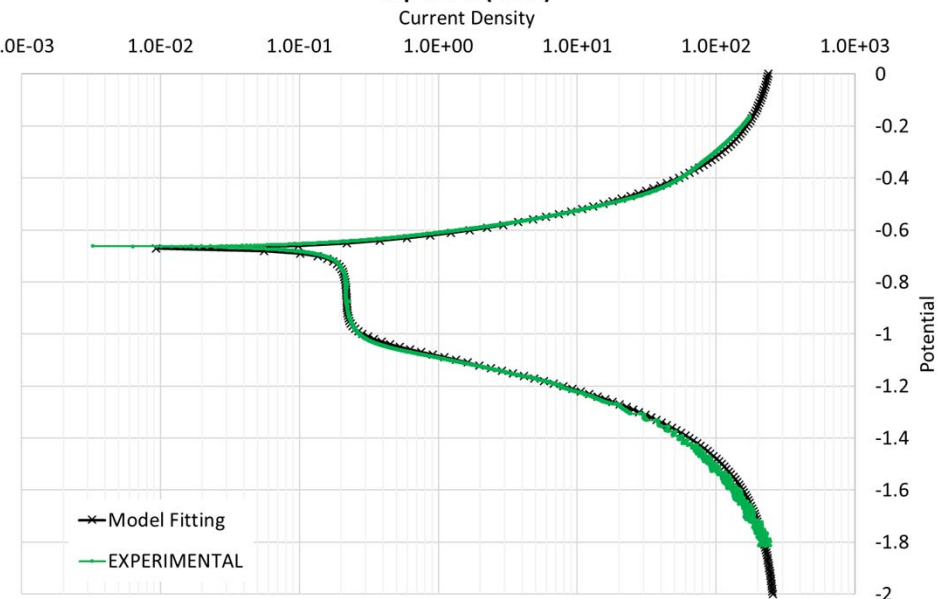


Curve Fitting/Deconvolution Example- HSS 4130

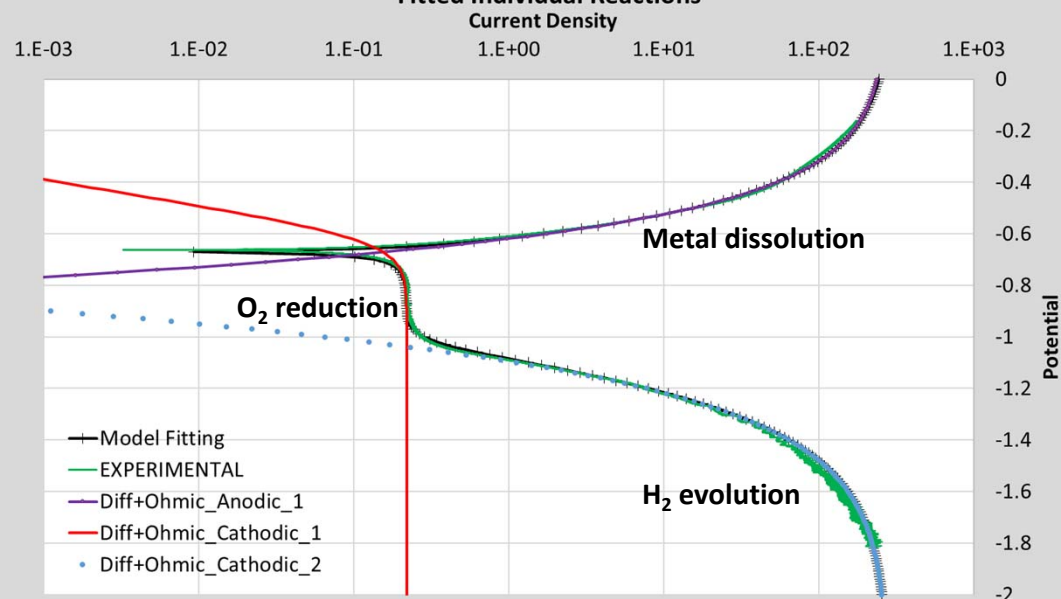
Simple Straight Forward Curve- HSS 4130

Deconvoluted 3 partial reactions

Exp vs Fit (4130)



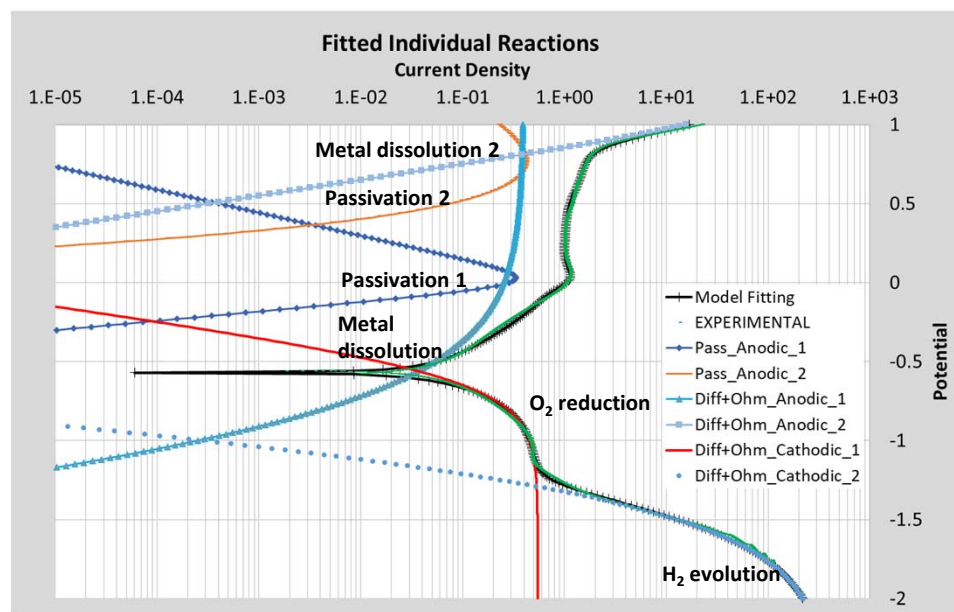
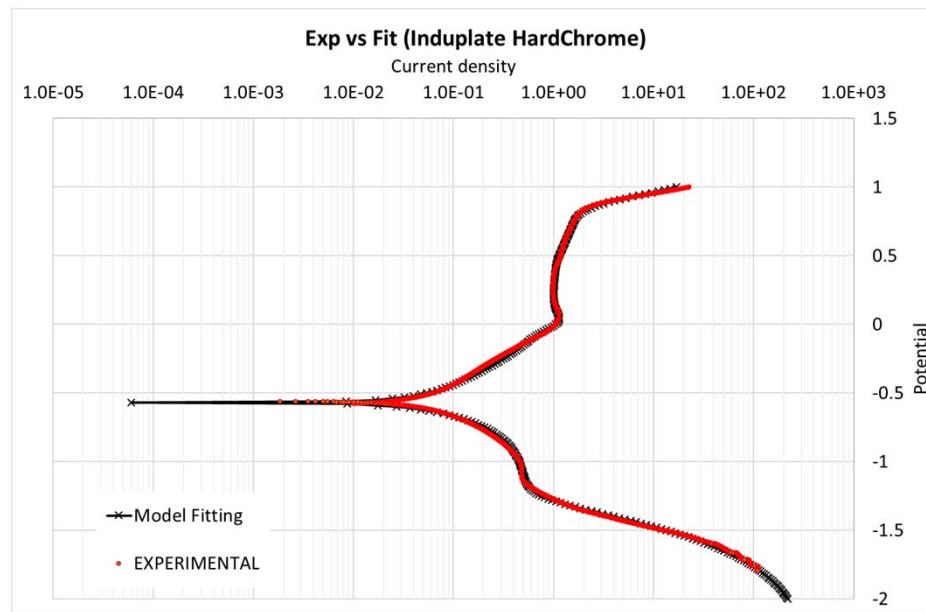
Fitted Individual Reactions



Curve Fitting/Deconvolution Example- EHC

Complex Multi reaction curve- Hard Chrome (EHC)

Deconvoluted 6 partial reactions



Main benefits of the this fitting methodology:

- Can fit curves with any number of electrochemical partial reactions at a time
- Can fit almost all curve features that could represent any type of electrochemical partial reactions e.g. **Pitting, Metal dissolution, Passivation, ORR, HER, Ohmic...**
- Additionally it could also simulate the impact of atmospheric conditions on cathodic O₂ reduction reactions for simulating different film thicknesses

Corrosion Djinn®

- An easy to use engineering web application enabling materials and design engineers to quickly assess galvanic corrosion risk
 - MIL-STD-889D, Sea Water ASTM 1141
 - 3.5% NaCl
- Scientifically based on a qualified materials database
- Instantly calculates galvanic corrosion rate across dissimilar material interfaces and self corrosion rate of each materials
- Material alternatives can be quickly compared
- Effect of area ratios can be compared
- Djinn® can be installed on your IT systems, allowing to use and manage your own electrochemical data



CORROSION
Djinn

- Galvanic Corrosion Analysis
- MIL-STD-889D
- Materials
- My Account

Galvanic Corrosion Analysis

① Frequently Asked Questions

Summary **Group 1** + Add Group

Group 1

Environment

Include Material Areas ☐

Adding material area information provides a better prediction of galvanic corrosion by taking into account the cathode to anode area ratios.

Material One

Type

Substrate

Designation

Coating

Treatment

Run Analysis

Material Two

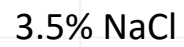
Type

Substrate

Designation

Coating

Treatment



Fitted data on Corrosion Djinn

Material One

Substrate	Aluminum
Designation	7075-T6
Coating	None
Treatment	None
Electrode	Cathode

OCP	-7.18E-1 V _{SCE}
Self Corrosion Rate	1.91E+1 microns/year
	7.51E-1 mils/year

Material Two

Substrate	Magnesium
Designation	AZ31-B
Coating	None
Treatment	None
Electrode	Anode (Corroding Material)

OCP	-1.61E+0 V _{SCE}
Self Corrosion Rate	1.43E+3 microns/year
	5.64E+1 mils/year
Galvanic Acceleration Factor	8.84E+1

3.5% NaCl

Galvanic Compatability

For this pairing Magnesium AZ31-B will undergo galvanic corrosion at a rate of 1.27E+5 microns/year.

Potential Difference	8.89E-1 V
Mixed Potential	-1.49E+0 V _{SCE}
Galvanic Corrosion Current Density	5.50E+1 Am ⁻²
Galvanic Corrosion Rate	1.27E+5 microns/year
	4.99E+3 mils/year
MIL-STD-889D Rating	6

Fitted data on Corrosion Djinn



Fitted data on Corrosion Djinn

Material One

Substrate	Aluminum
Designation	7075-T6
Coating	None
Treatment	None
Electrode	Cathode

OCP	-7.48E-1 V _{SCE}
Self Corrosion Rate	1.87E+2 microns/year
	7.35E+0 mils/year

Material Two

Substrate	Magnesium
Designation	AZ31-B
Coating	None
Treatment	None
Electrode	Anode (Corroding Material)

OCP	-1.55E+0 V _{SCE}
Self Corrosion Rate	2.54E+2 microns/year
	1.00E+1 mils/year
Galvanic Acceleration Factor	1.70E+2

Galvanic Compatability

For this pairing Magnesium AZ31-B will undergo galvanic corrosion at a rate of 4.33E+4 microns/year.

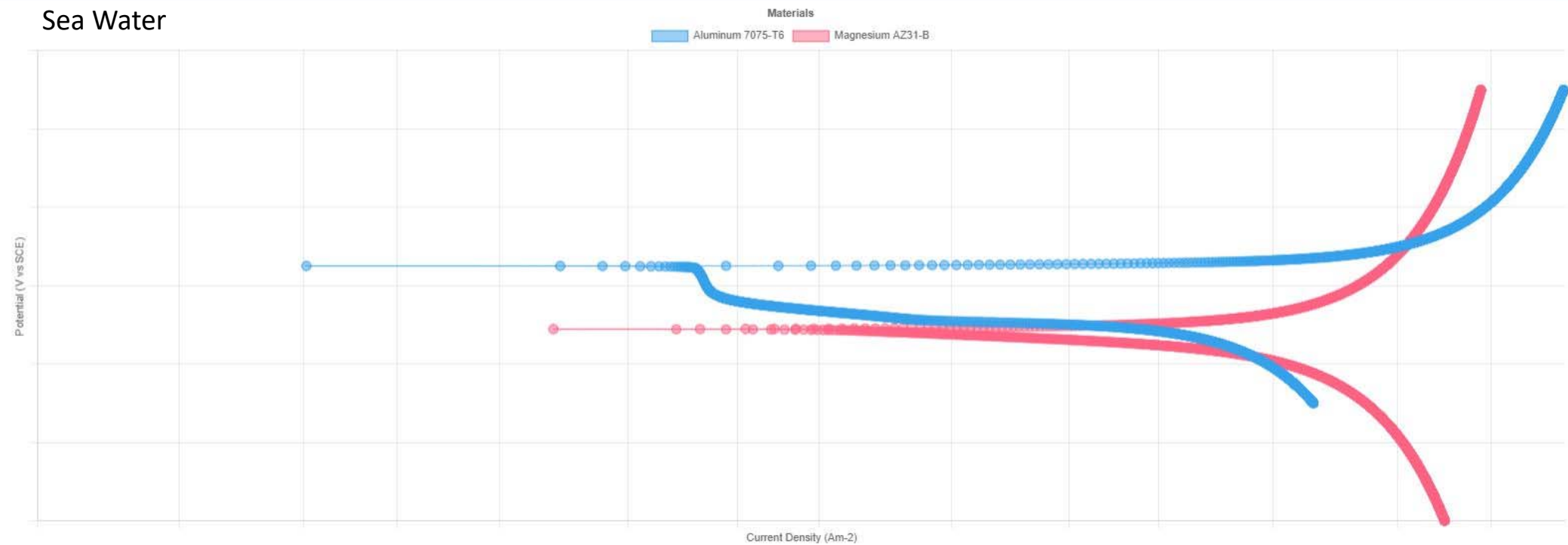
Potential Difference	8.06E-1 V
Mixed Potential	-1.47E+0 V _{SCE}
Galvanic Corrosion Current Density	1.88E+1 Am ⁻²
Galvanic Corrosion Rate	4.33E+4 microns/year
	1.70E+3 mils/year
MIL-STD-889D Rating	6

Fitted data on Corrosion Djinn

Galvanic Corrosion Analysis

Frequently Asked Questions

Sea Water



Fitted data on Corrosion Djinn

Material One

Substrate	Aluminum
Designation	7075-T6
Coating	None
Treatment	None
Electrode	Cathode
Area	1 cm2

OCP	-7.48E-1 V _{SCE}
Self Corrosion Rate	1.87E+2 microns/year
	7.35E+0 mils/year

Material Two

Substrate	Magnesium
Designation	AZ31-B
Coating	None
Treatment	None
Electrode	Anode (Corroding Material)
Area	10 cm2

OCP	-1.55E+0 V _{SCE}
Self Corrosion Rate	2.54E+2 microns/year
	1.00E+1 mils/year
Galvanic Acceleration Factor	4.96E+1

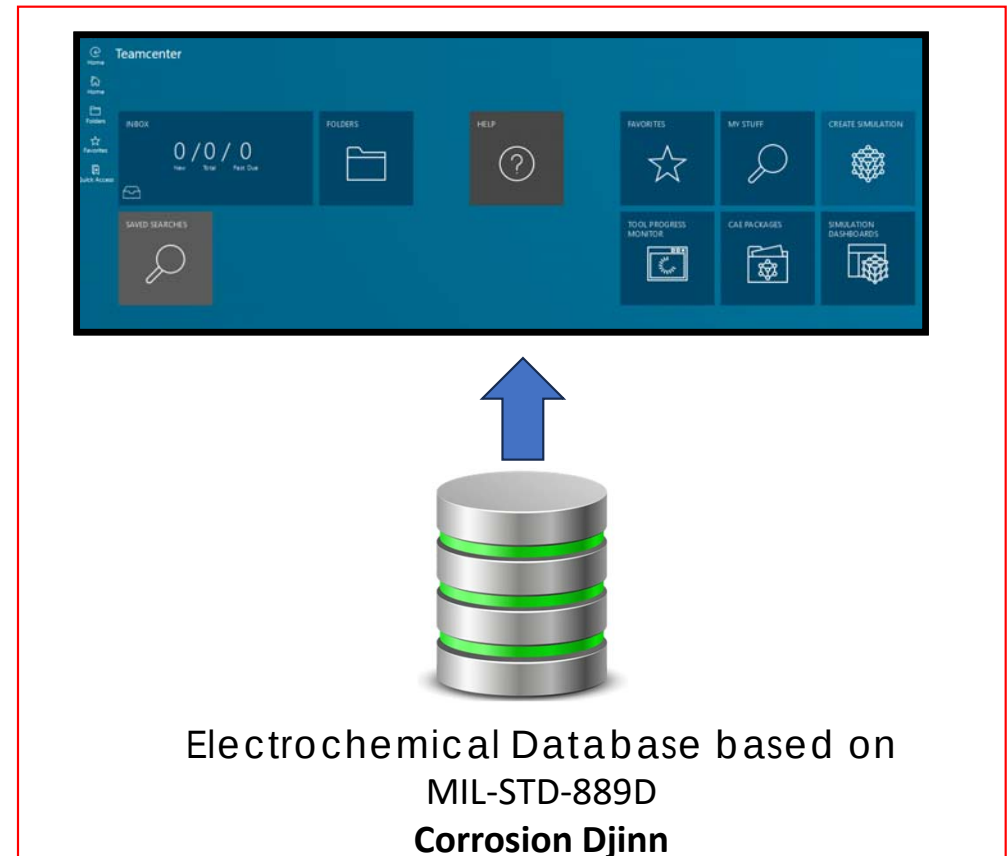
Galvanic Compatability

For this pairing Magnesium AZ31-B will undergo galvanic corrosion at a rate of 1.26E+4 microns/year.

Potential Difference	8.06E-1 V
Mixed Potential	-1.51E+0 V _{SCE}
Galvanic Corrosion Current Density	5.48E+0 Am ⁻²
Galvanic Corrosion Rate	1.26E+4 microns/year
	4.96E+2 mils/year
MIL-STD-889D Rating	6

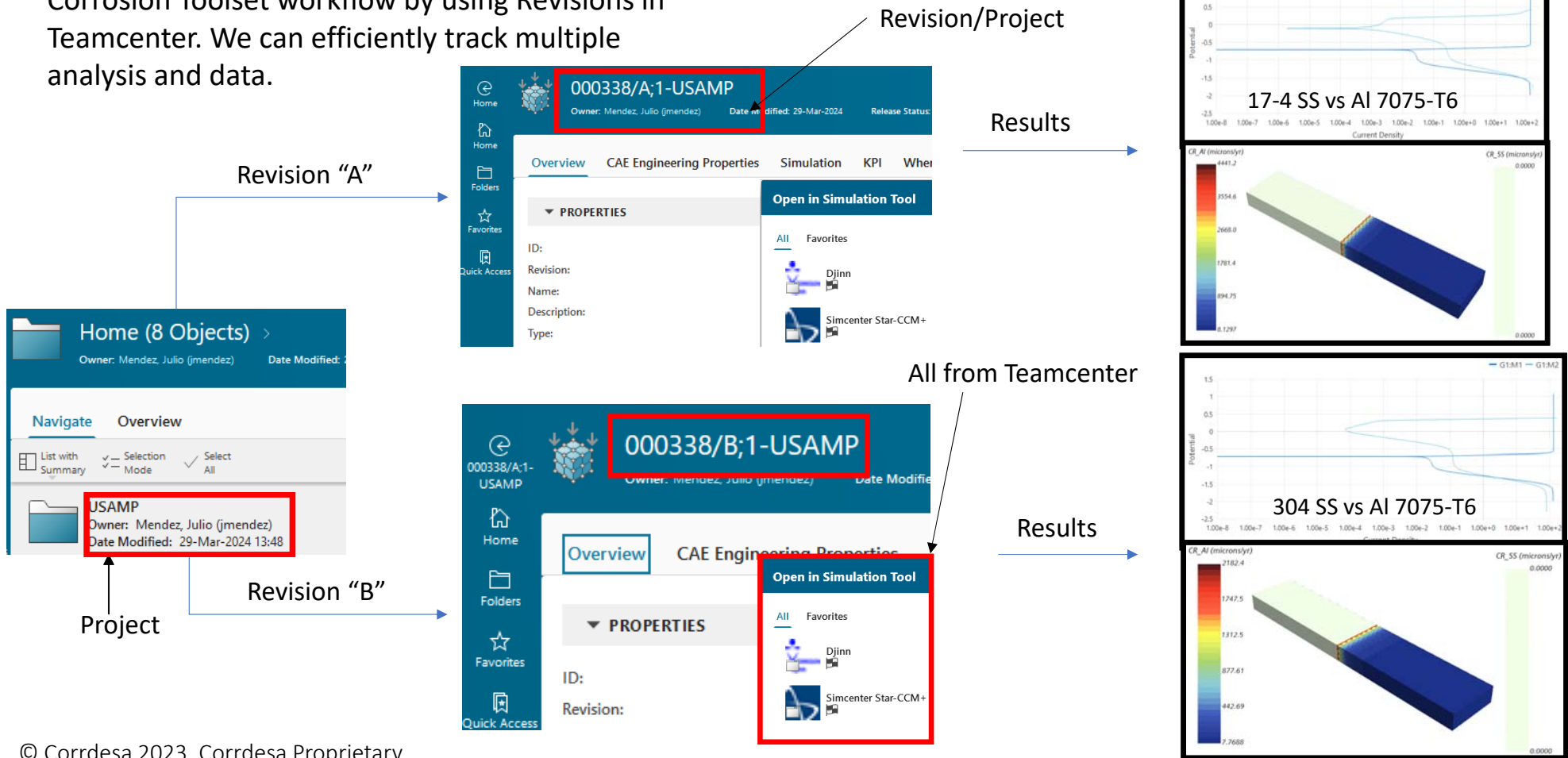
PLM – Teamcenter, a Computational Strategy for Corrosion Mitigation and Prevention

- The computational workflow uses the Corrosion Djinn Database.
- In most cases, the data gathered by corrosion scientists can easily propagate downstream to the engineering organization, where CAE Engineers can use it almost in real time.
- Collaboration is seamless, and multiple stages of the process can be synchronized.
- This enables digital twins and simplifies digital transformation.
- Users can work on multiple projects, and each project can have numerous studies and sensitivities analyses are tracked using revision.



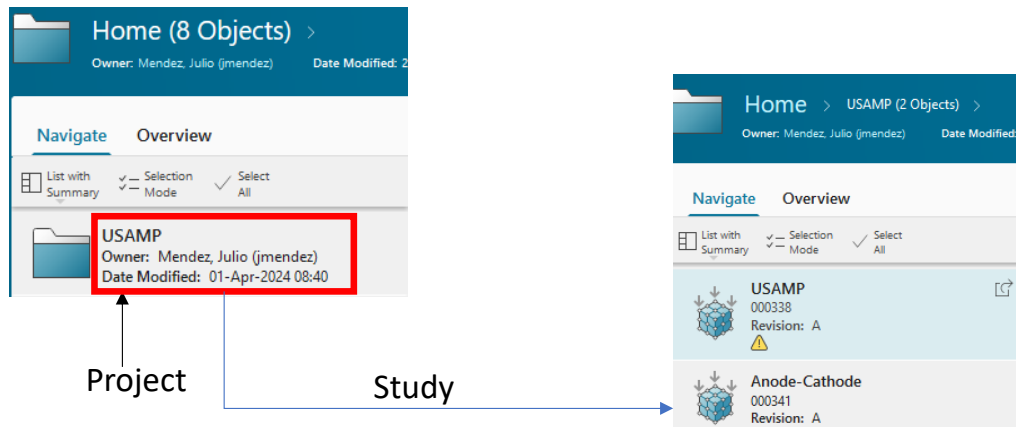
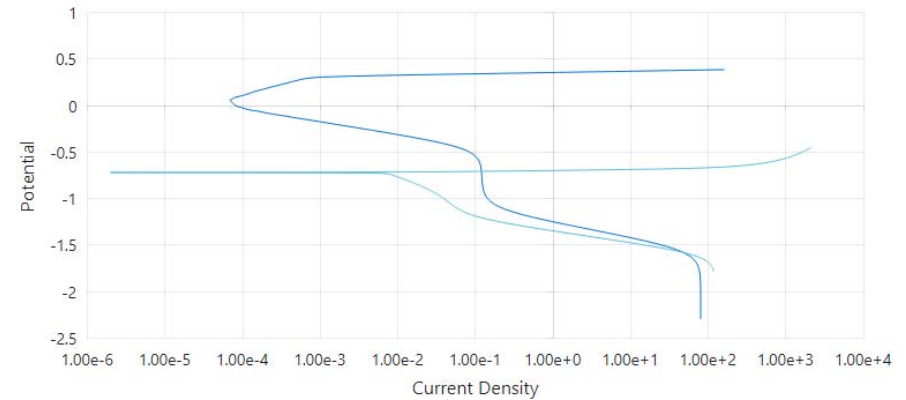
PLM – Teamcenter: Investigating mismatch materials

- We enabled rapid “what-if” scenarios using Corrosion Toolset workflow by using Revisions in Teamcenter. We can efficiently track multiple analysis and data.



PLM – Teamcenter. Variations in Anode-Cathode Ratio

- We evaluate the Anode-Cathode ratio when SS 304 and Al 6061-T6 using the automatic workflow in Teamcenter called “Corrosion Toolset.”
- This workflow is intuitive for Corrosion Scientists and M&P. No previous experience in CAE or CFD is needed.
- We developed a set of pre-configured geometries that apply to automotive applications. More templates can be generated and added to the pre-configured workflow.



- We call Corrosion Djinn from Teamcenter, and the polarization curves are sent straight to Simcenter StarCCM+.
- If the database is updated, the workflow has access to the latest dataset in real time

PLM – Teamcenter. Anode-Cathode Ratio



- We developed the “Corrosion Toolset” thinking on non-CFD Experts.
- It requires simple inputs.
- The template pool is relevant to multiple applications, including automotive and aerospace.
- It can be easily expanded.

Corrosion Modeling Interface v1.2

Project Name

Project Name

Geometry Type

03_LapJoint_Bolted

CAD Directory

Browse...

Units

☒ mm ☐ in

Standard

☒ 3.5% NaCl ☐ MIL-STD-889D

Design Parameters

Length-01	40.0 mm	Thick-01	5.0 mm
Length-02	30.0 mm	Thick-02	5.0 mm
Length-03	5.0 mm	Thick-03	0.0 mm
Lap-03-01	0.0 mm	Lap-03-02	0.0 mm
Width	10.0 mm	Bolt Dia.	3.0 mm
Bolt-CL	5.0 mm	Bolt Top Height	3.0 mm
Washer OD	0.0 mm	Washer Thick	1.0 mm
Gunk OD	2.5 mm	Gunk Thick	1.0 mm
Bush OD	0.0 mm	Bush ID	0.0 mm

Geometry Reference (Right-click to toggle full resolution)

Assume bolt on centerline (of each half), that is at Width/2

If washer height = 0, then no washer

If gunk height = 0, then no gunk

Gunk diameter must be equal to or larger than washer diameter

Fluid Domain Type

☒ BULK ☐ FLUID FILM

Fluid Film Thickness

0.0 mm

Material-01

Name

304

Polarization Curve

94\3.5% NaCl-Stainless Steel-304-None-None.csv

...

Material-02

Name

Al

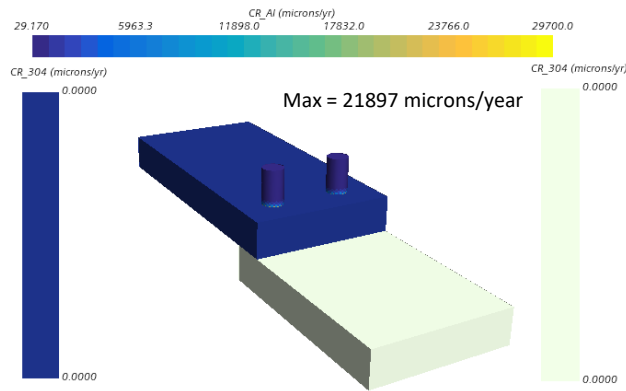
Polarization Curve

94\3.5% NaCl-Aluminum-6061-T6-None-None.csv

...

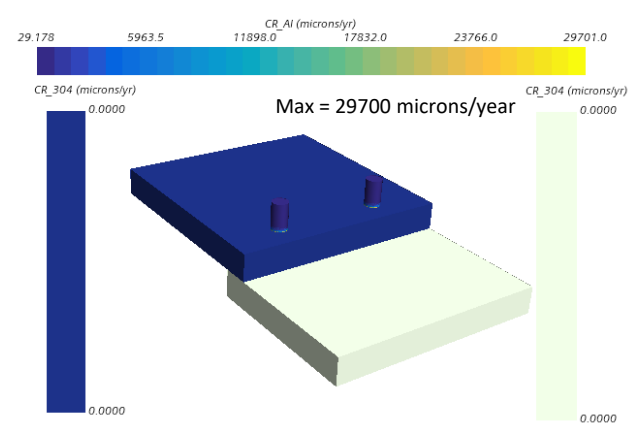
PLM – Teamcenter. Anode-Cathode Ratio

Anode/Cathode = 0.0109



Thin film (0.01 mm)

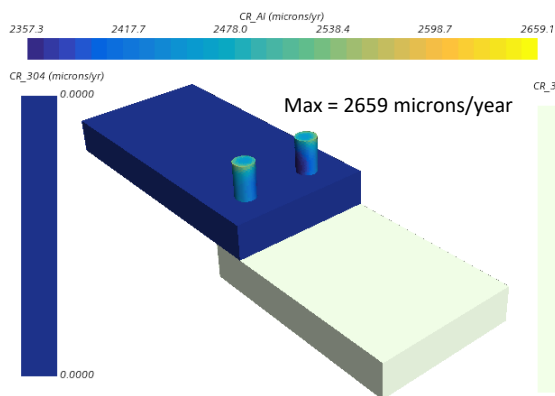
Anode/Cathode = 0.00543



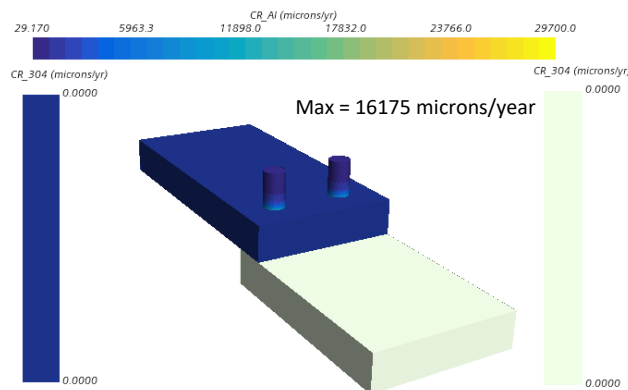
Thin film (0.01 mm)
+ Bigger Cathode

Effect of electrolyte thickness, bulk and thin film

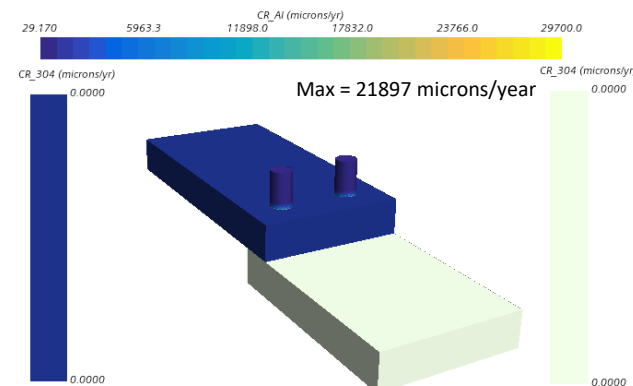
Anode/Cathode = 0.0109



Bulk



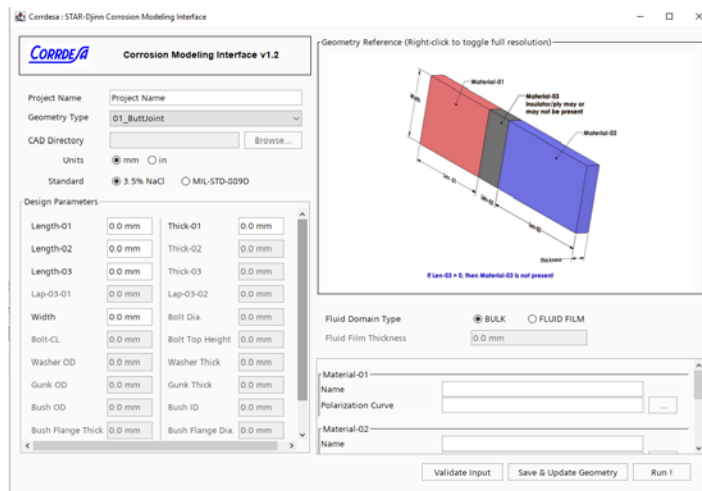
Electrolyte film thickness(0.1 mm)



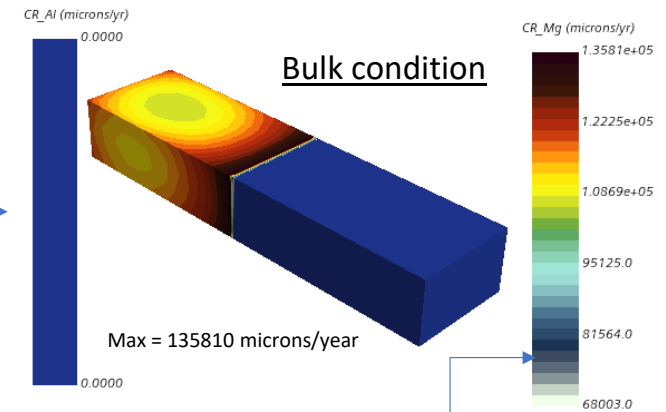
Electrolyte film thickness(0.01 mm)

- Mixed metal interaction under Bulk electrolyte shows lower corrosion compared to thin film
- Thinner is the electrolyte, higher is the corrosion rate

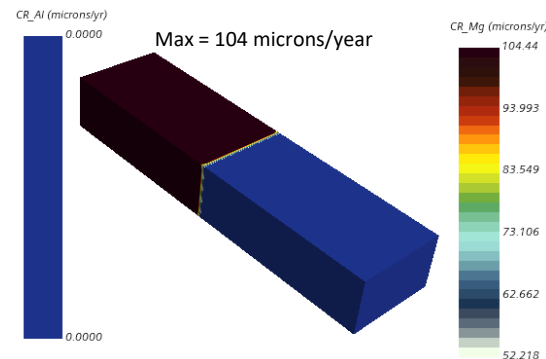
PLM – Teamcenter. Coating Modeling



Solution

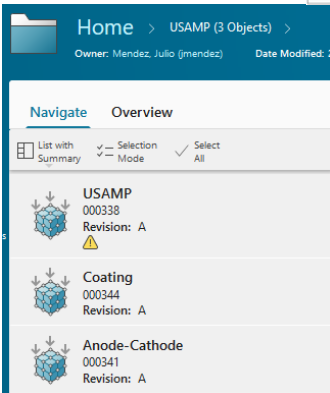


High Corrosion rate, not a feasible solution*



Bulk condition + Electrical Resistance (100 m² ohm)

Data (polarization Curves) +Pre-configured templates



Quick Assessment by M&P Engineers

Understanding where it occurs
Examine changing the design
 Examine changing material finishes

Understanding the degree of corrosion
 Understanding how complex assemblies will corrode in multiple environments

