



2026  
AUTOMOTIVE  
CORROSION  
Symposium

# Corrosion Prevention and Simulation: From Design to Practical Solutions

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## Agenda

- Methods and Modelling Overview
- Case Study: Bolted Plate Assembly
- Future Implementations

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# Corrosion Risk Assessment

## Methods Overview



### Look-up tables

- No consideration of geometrical characteristics
- No consideration of coatings
- No computation of corrosion rate
- No consideration of environment



### Measurements

- Need physical prototypes
- Time-consuming tests
- Difficult to reproduce exact environmental conditions



### Simulation

- Requires modeling knowledge
- Difficult to reproduce exact environmental conditions
- Can require significant computational resources

Key to success: combining the three approaches to get the most out of each



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# Corrosion Modeling Solutions

## Requirements and Usage

### Accuracy



**Dynamic**  
Electrolyte Characteristics  
& Environment



**Finite**  
Electrolyte Dimensions &  
Geometry

### Adoption



**Democratization**  
Easy-to-use  
& Deploy



**Fast**  
Fast Assessment  
& Clear Insights



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# Elsyca 3D Galvanic and Atmospheric Corrosion Simulations

## Building Blocks

### Geometry

Import of CAD geometry independent from CAD-tool

### Solver

Fast and robust solver for galvanic and uniform corrosion computation

### Environmental Conditions

Water film thickness and electrolyte chemistry based on surrounding environment meta-properties

### Materials

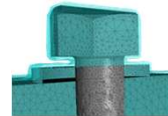
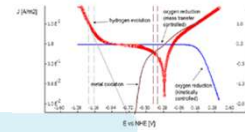
Selection of geometry materials based on user-defined library

### Connections

Automatic detection of geometry intersections for electrical connection scheme definition

### Mesh

Automatic 3D FE mesh generation based on geometry, intersections and environmental conditions

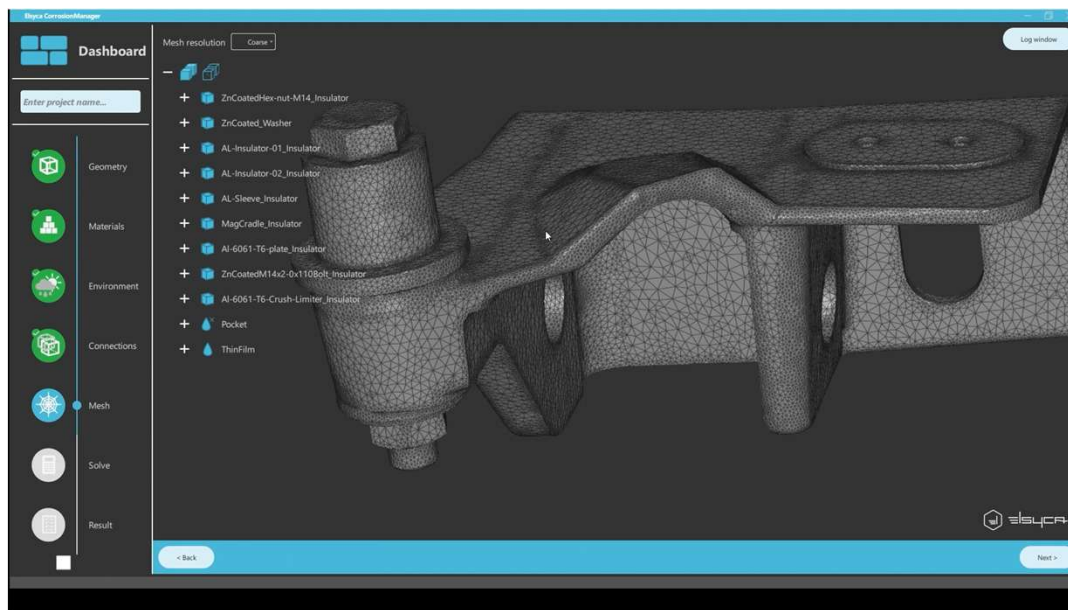


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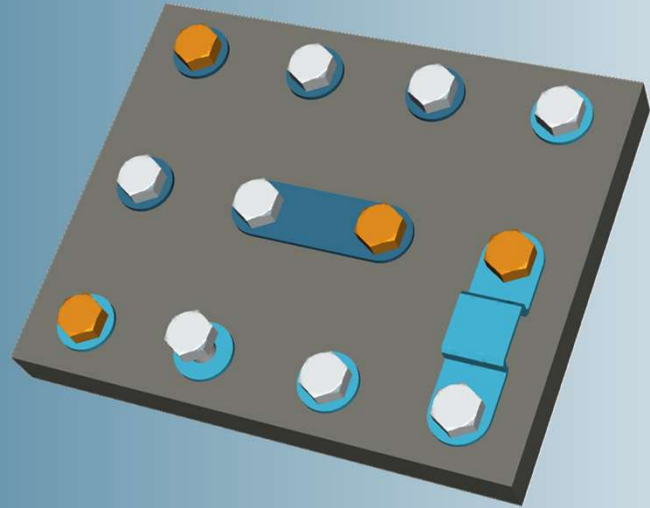
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## Case Study

Multi-material bolted plate



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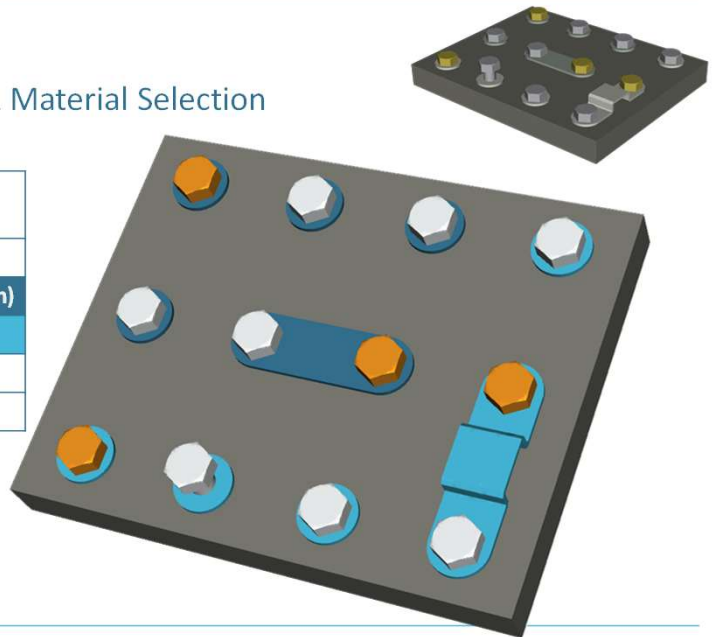
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## Case Study

Bolted Plate Assembly Geometry & Material Selection

| Surface | Base Material | Coating                    |
|---------|---------------|----------------------------|
| Plate   | Steel 235     | -                          |
| Washers | Steel 235     | Hot Dip Galvanized (10 µm) |
|         |               | Ni electroless (5 µm)      |
| Bolts   | Brass         | -                          |
| Bolts   | Steel S304    | -                          |



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## Case Study

### Simulation Assumptions and Input Conditions

|        | Mesh Resolution (mm) | Film Thickness (um) | Conductivity (S/m) |
|--------|----------------------|---------------------|--------------------|
| Case 1 | 1                    | 50                  | 0.3                |
| Case 2 | 1                    | 100                 | 4                  |



Case 2:

- Higher film thickness
- Higher conductivity

Case 1:

- Lower film thickness
- Lower conductivity



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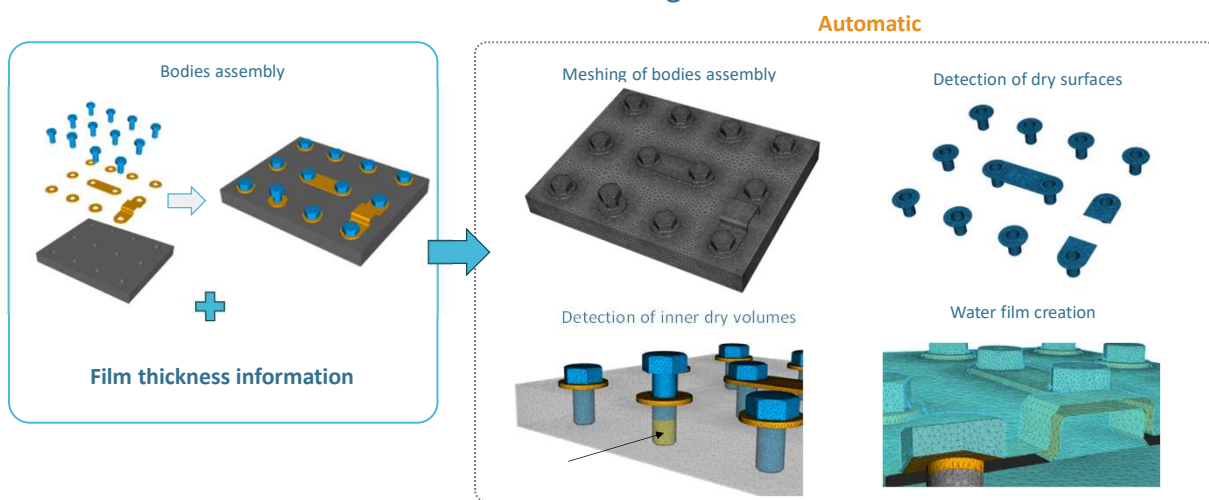
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## Geometry handling & Thin Film Meshing

### Intersections detection and automatic meshing



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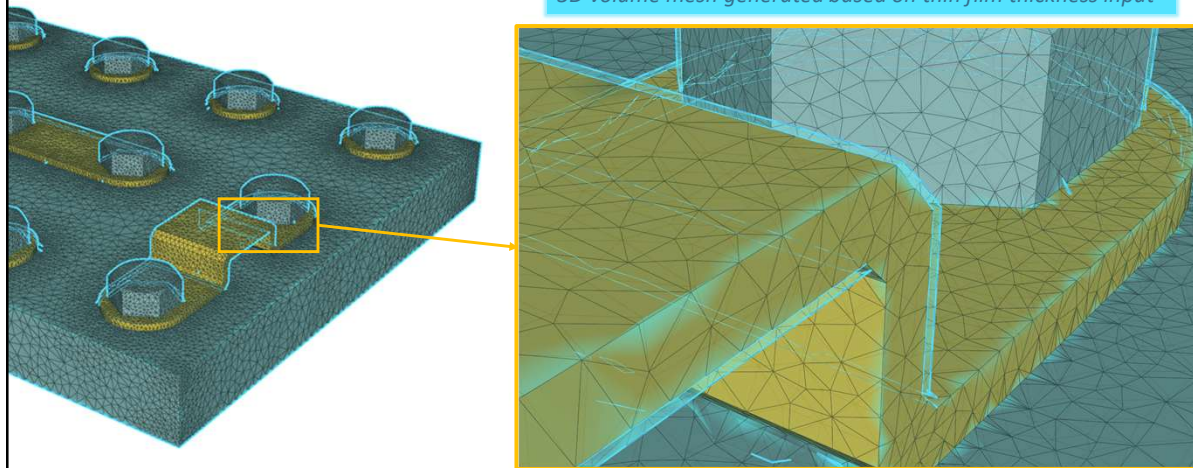
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## Computational Model

### Thin Film Approach



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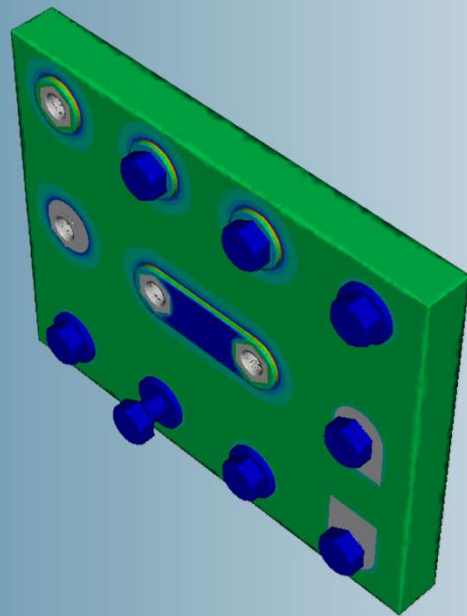
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## Simulations Results Analysis

Comparison of material behavior under various environmental conditions



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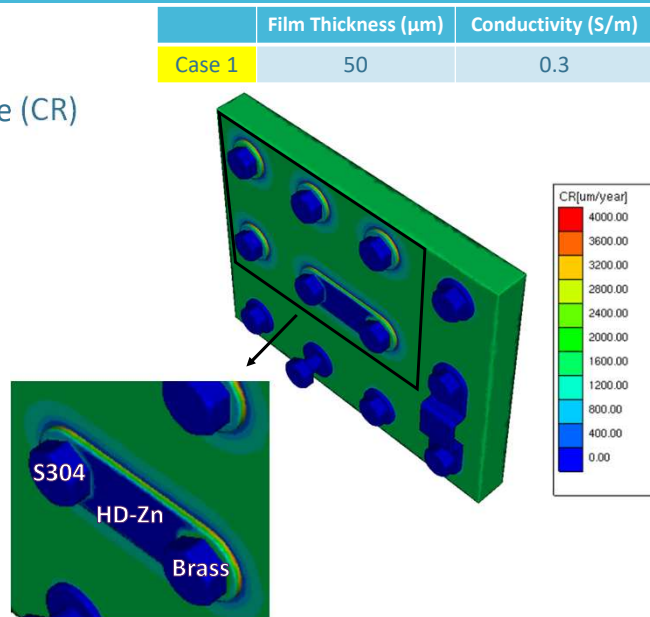
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## Simulation Results

Galvanic + Atmospheric Corrosion Rate (CR)

### HD-Zn coated washers:

- The highest CR with peak values in proximity to the steel S235 plate
- Distinct CR values in the regions close to the brass bolts and the S304 bolts
- Elevated CR near the brass bolts compared to S304 bolts
- Reduced CR on the S235 plate adjacent to the HD-Zn coated washers



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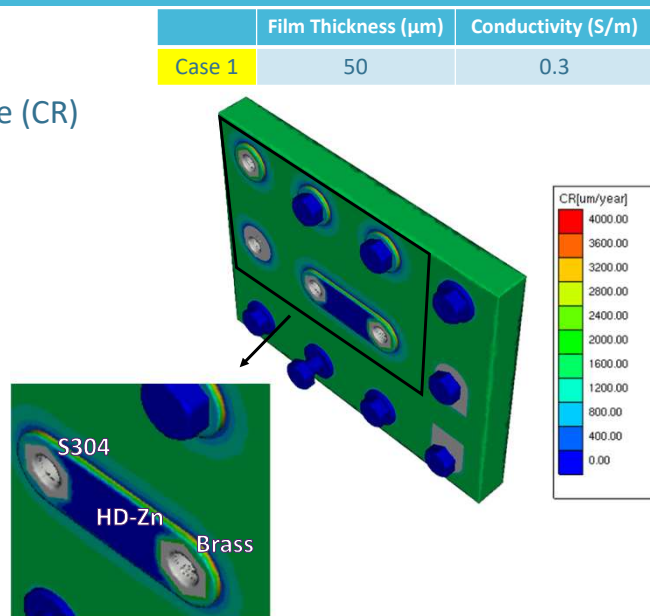
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## Simulation Results

Galvanic + Atmospheric Corrosion Rate (CR)

### HD-Zn coated washers:

- Galvanic coupling between the steel plate and HD-Zn coated washers confirms sacrificial behavior of the HD-Zn coating
- Galvanic interaction between HD-Zn coated washers and both brass and S304 bolts demonstrates distinct corrosion behavior
- Dry-zones are effectively captured with no simulation output values



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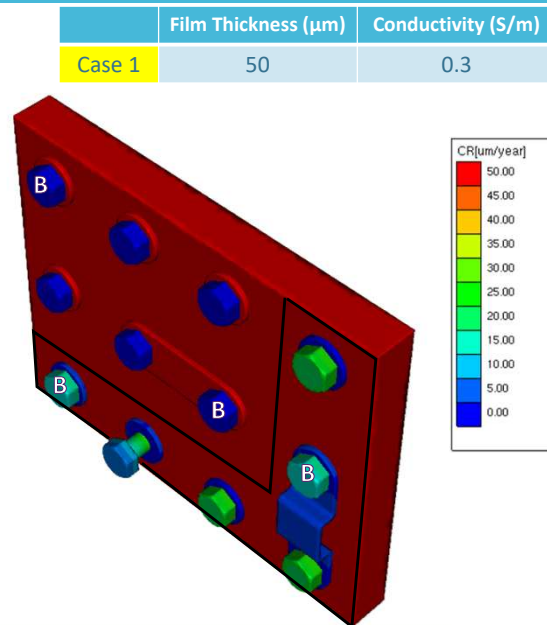
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## Simulation Results

### Galvanic + Atmospheric Corrosion Rate (CR)

#### Ni-electroless coated washers:

- Higher CR on both brass and S304 bolts compared to the washers
- Lower CR on brass bolts compared to S304 bolts when in contact with Ni electroless coated washers.
- Distinct CR gradient along the protruding bolt, with peak values at the washer contact zone
- Elevated CR on the bent tab of the lock washer



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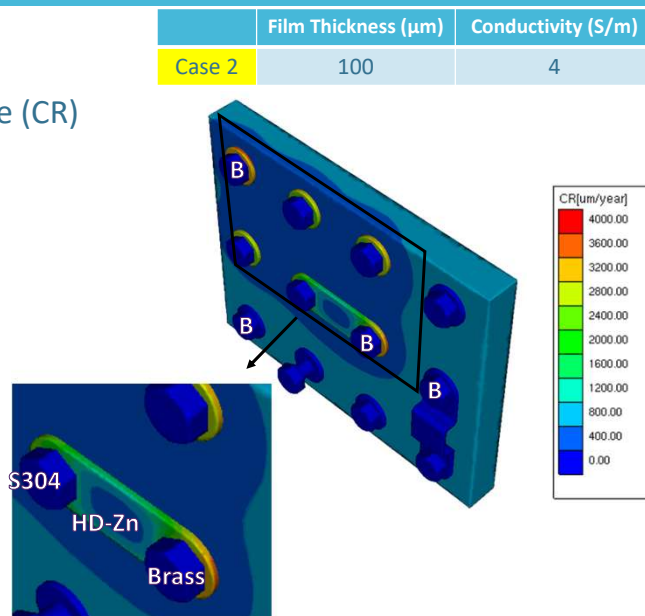
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## Simulation Results

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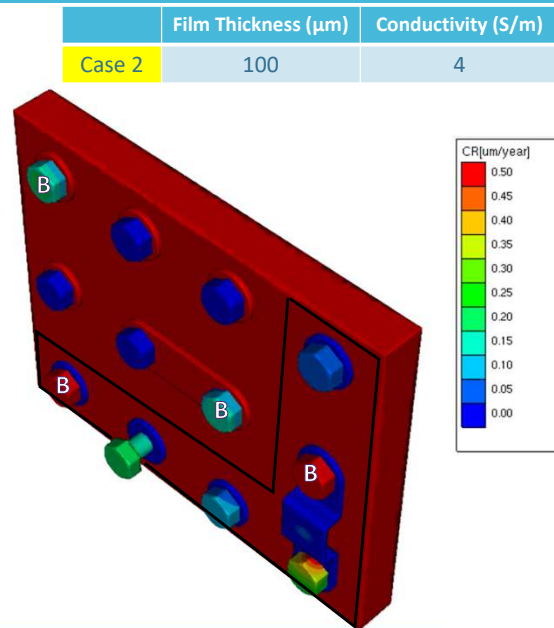
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## Simulation Results

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- Higher CR on brass bolts compared to S304 bolts
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- Elevated CR on the bent tab of the lock washer



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## Simulation Results

### Galvanic + Atmospheric Corrosion Rate (CR)

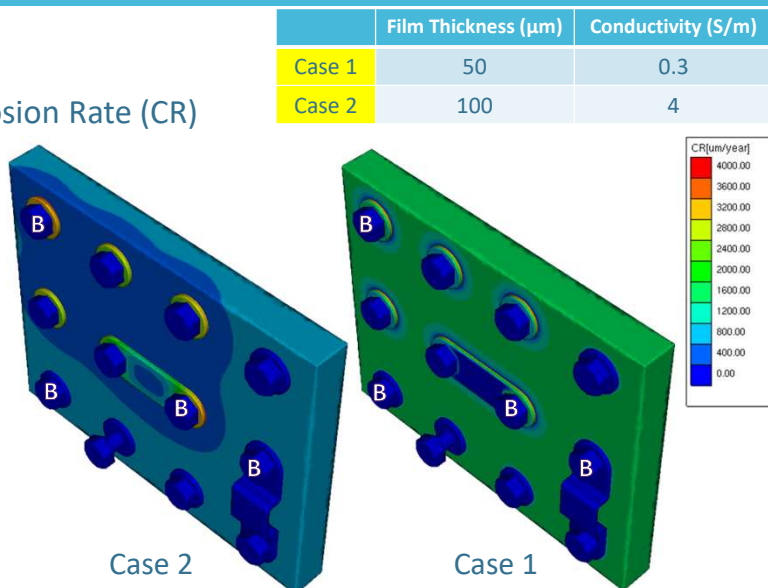
#### HD-Zn coated washers:

Greater current output and reach in Case 2 leads to:

- Higher CR for these washers
- Enhanced cathodic protection of the steel plate

The CR distinction between the Brass/HD-Zn and S304/HD-Zn galvanic couples follows a similar trend to Case 1:

- Higher CR near the brass bolt



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## Simulation Results

Galvanic + Atmospheric Corrosion Rate (CR)

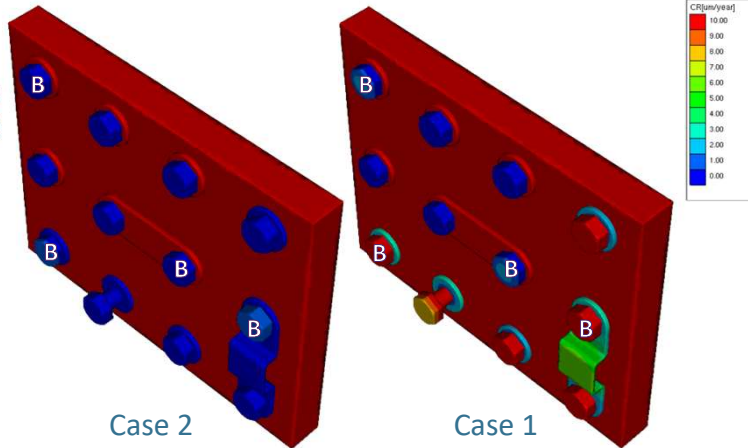
|        | Film Thickness ( $\mu\text{m}$ ) | Conductivity (S/m) |
|--------|----------------------------------|--------------------|
| Case 1 | 50                               | 0.3                |
| Case 2 | 100                              | 4                  |

### Ni-electroless coated washers:

Lower CR observed on the washers and their connected bolts in Case 2



- Higher galvanic current provided by the HD-Zn coated washers
- Reduced driving force for corrosion between the steel plate and the Ni electroless coated washers.



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## Simulation Results

Galvanic + Atmospheric Corrosion Rate (CR)

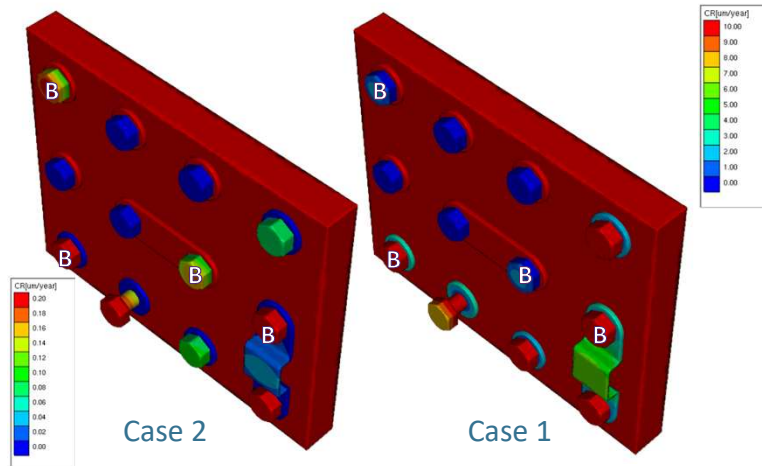
|        | Film Thickness ( $\mu\text{m}$ ) | Conductivity (S/m) |
|--------|----------------------------------|--------------------|
| Case 1 | 50                               | 0.3                |
| Case 2 | 100                              | 4                  |

### Ni-electroless coated washers:

- Different trend observed in the CR gradient along the protruding S304 bolt



Reduced Ni-electroless sacrificial effect on the steel plate enables greater protective action on S304 bolts



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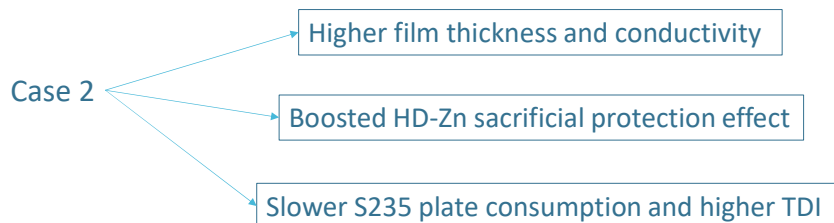
## Simulation Results

Key Performance Indicators (KPIs):

|        | Film Thickness ( $\mu\text{m}$ ) | Conductivity (S/m) |
|--------|----------------------------------|--------------------|
| Case 1 | 50                               | 0.3                |
| Case 2 | 100                              | 4                  |

Time to Dimensional Intolerance (TDI) for base material

|        | Geometry | Zone  | Tolerance [ $\mu\text{m}$ ] | TDI [days] | TE [days] |
|--------|----------|-------|-----------------------------|------------|-----------|
| Case 1 | Plate    | Plate | 100                         | 23         | n/a       |
| Case 2 | Plate    | Plate | 100                         | 38         | n/a       |



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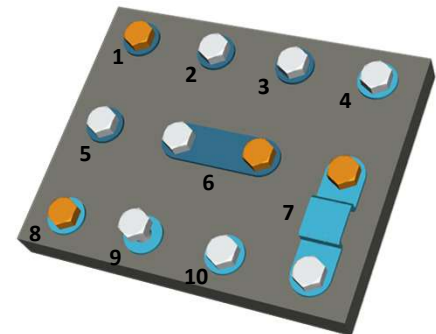
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## Simulation Results

Key Performance Indicators (KPIs):

Time to Exposure (TE) for coatings

| Zone      | Bolt material | Coating                           | Case 1<br>TE [days] | Case 2<br>TE [days] |
|-----------|---------------|-----------------------------------|---------------------|---------------------|
| Washer-1  | Brass         | HD-Zn (10 $\mu\text{m}$ )         | 1.0                 | 1.0                 |
| Washer-2  | S304          | HD-Zn (10 $\mu\text{m}$ )         | 1.0                 | 1.2                 |
| Washer-3  | S304          | HD-Zn (10 $\mu\text{m}$ )         | 1.0                 | 1.1                 |
| Washer-4  | S304          | Ni-electroless (5 $\mu\text{m}$ ) | > 600               | > 75 y              |
| Washer-5  | S304          | HD-Zn (10 $\mu\text{m}$ )         | 1.0                 | 1.1                 |
| Washer-6  | S304          | HD-Zn (10 $\mu\text{m}$ )         | 1.0                 | 1.0                 |
| Washer-7  | Brass         | Ni-electroless (5 $\mu\text{m}$ ) | > 300               | > 12 y              |
| Washer-8  | Brass         | Ni-electroless (5 $\mu\text{m}$ ) | > 550               | > 50 y              |
| Washer-9  | Brass         | Ni-electroless (5 $\mu\text{m}$ ) | > 550               | > 60 y              |
| Washer-10 | S304          | Ni-electroless (5 $\mu\text{m}$ ) | > 650               | > 70 y              |



- HD-Zn coated washers: Shorter TE in both cases; slightly longer in Case 2 due to higher film thickness & conductivity
- Ni-electroless coated washers: Longer TE overall, further increased in Case 2
- Ni-electroless + S304 bolts: Longest TE in both cases



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## Conclusions

### Case Study Findings

- **HD-Zn coated washers** exhibit the **highest corrosion rate (CR)**.
- The galvanic coupling between **Brass/HD-Zn** shows consistently **higher CR** than **S304/HD-Zn**.
- **Ni-electroless coated washers** exhibit a **less pronounced sacrificial effect** compared to HD-Zn resulting in **lower overall CRs**.
- Increasing film thickness and electrolyte conductivity (**Case 2 vs. Case 1**) **amplifies galvanic current output** from HD-Zn washers.
- In Case 2, the dominant HD-Zn galvanic effect overshadows the contribution of Ni electroless coated washers, substantially reducing the CR of the Ni-electroless washers and their connected bolts.
- A **CR gradient** is consistently observed **along protruding bolt**, with the **spatial distribution** depending on the **electrolyte conditions**.



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## Future Implementations

Time Stepping

Pitting Corrosion



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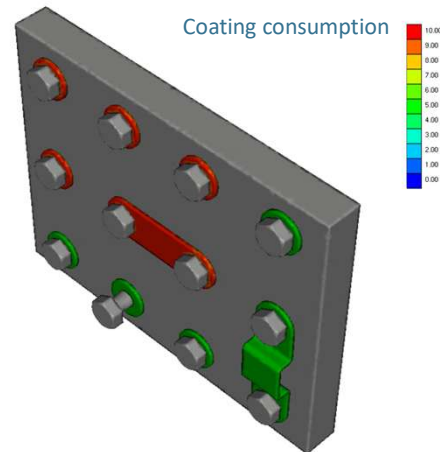
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## Future Implementations

### Time Stepping to Accommodate for Transient Features

- Consumption of sacrificial layers and topology changes (underlying metallic layers or substrate surfacing)
- Variable environmental conditions -> Variable water film thickness and salinity
- Deteriorating paint layers
- ...



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## Future Implementations

### Pitting Corrosion Model For Passivating Substrates

- Passivating substrates (e.g., aluminum, titanium, stainless steel) are susceptible to pitting corrosion
- Galvanic polarization curves are widely used to model corrosion behavior but remain highly approximate towards local and transient development of pit populations
- Pit population dynamics govern location- and time-dependent polarization behavior

#### Goal

Integrate a dedicated polarization model that tracks local pit population development over time

#### Requirement

Time-stepping capability to capture inherently transient pitting polarization behavior



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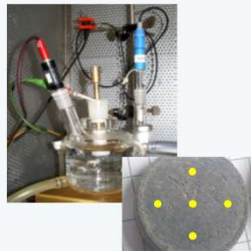
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## Future Implementations

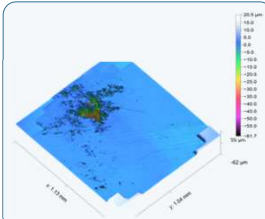
### Pitting Corrosion Model For Passivating Substrates



#### Experimental Methods



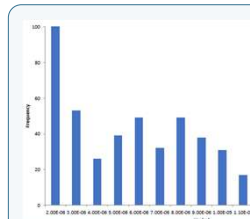
Producing pitted coupons under controlled conditions



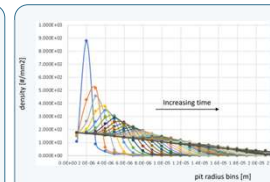
White Light Interferometry (WLI) for surface analysis of the pitted coupons



#### Data Processing



Post-processing the WLI data files to pit populations



Retro-fit kinetic parameters of deterministic pit nucleation & growth model



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