IMPROVING THE GALVANIC SERIES FOR DESIGN

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Improving the Galvanic Series for Design

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One of Many Galvanic Series Available

Metals in flowing seawater

What's the corrosion rate?

Where's Zn-Ni?

Why is this different from the EMF series?

Noble

This isn't my environment

Where's my HVOF?

Which is the cathode?

Isn't this upside down?

Active

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What’s Our Concern?

**Designer Concerns**
- Metal compatibility with environment
- Galvanic coupling of dissimilar metals
- Adding an inorganic coating
- Adding an organic coating
- Minimizing service failures

**Production and Maintenance Concerns**
- Scheduling Inspections
- Replacing Designs that don’t work
- Material and Design Trades
  - Reduce costs
  - Reduce maintenance
- Allowing Substitutions
Technical Needs

• What we do already—
  • Use “Galvanic Series”
  • Qualitatively rely on “tribal knowledge” & handbooks
  • Conduct Laboratory Tests

• What we want to do—
  • Use Engineering Tools to Propose Engineering Solutions
    – Design tools require quantitative data
  • Quantify severity of corrosion on all geometries
    – Coupled finish on substrate of detail part
    – Coupling of detailed parts of different materials
  • Reduce/Eliminate Laboratory Tests
Approach Methods

- **Galvanic Series Chart for Designers**
  - Establish Steady State Corrosion Potential
  - Measure Corrosion Rate
  - Generate anodic and cathodic polarization curves

- **Predict Galvanic Coupling Effects on Geometries**
  - For 1-D (imensional) Quick-Look
    - Superimpose polarization curves
  - For 2-D & 3-D mapping
    - Work with industrial partners for computer application solutions
      - Utilize polarization curves
      - Solve potential and current distribution equations for geometry
Initial Data Acquisition – Steel Example

Visual Documentation

Corrosion Potential Time Plots

EIS Data Generation
Polarization Curves of Steel in Salt Water

Anodic Polarization  →  STEEL  →  Steel Dissolution
Cathodic Polarization  →  Oxygen Reduction  →  Water Reduction to Hydrogen

Current Density
Data Analysis and Results

Corrosion Rate Time Plots

Polarization Resistance/Area

Steel, run 1
Steel, run 2

Capacitance

Steel, run 1
Steel, run 2

Corrosion Rate

Steel, run 1
Steel, run 2
Boeing’s Work to Date

- Generated steady-state Corrosion Potentials
- Generated steady-state Corrosion Rates
- Generated some Polarization Curves

- Initiated Next Generation Galvanic Series with 1-D Quick-Look
Next Generation Galvanic Series of Steel and Finishes with 1-D Quick-Look

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Chemical Technology

Graph showing corrosion rates and potentials for various materials:
- Steel
- Zn-Ni, chromated
- Cd
- Cd, chromated
- Cd-Ti
- Cd-Ti, chromated
- Zn
- Zn, chromated

Graphs depict corrosion potential and current density for different materials.

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So Far

• Established an initial protocol
  • Materials and finishes placed on NG Galvanic Series
  • Some polarization curves utilized for 1-D Quick-Look

• Need an industry wide protocol to address materials, finishes, and geometries
  • Complete NG Galvanic Series with 1-D Quick-Look
  • Implement polarization curves into 2-D and 3-D design
  • Verify experimentally corrosion severity mapping
  • Funding to extend DoD relevant coating systems

• Into the future
  • Investigate crevice corrosion environments
  • Include organic coatings
BACKUP
Road Forward – Phase I Methodology

- Establish industry working group
  - Identify objectives
  - Down select test variables and procedures
    - Environments of interest
    - Extent of variations of metals, alloys, and finishes
    - Electrochemical tests
    - Specimen geometries
    - Test Procedure criteria
    - Data Analysis
- Conduct Electrochemical Testing on Bare Alloys
- Conduct Galvanic Corrosion Analysis
  - Generate NG Galvanic Series with 1-D Quick-Look
    - Validate 1-D Quick-Look galvanic corrosion predictions
  - Initiate 2-D and 3-D galvanic corrosion prediction mapping
• Establish a NG Galvanic Series with 1-D Quick-Look capabilities for Design
  • Complete electrochemical testing for remaining alloy families and finishes

• Develop and execute a test plan to validate predictions for 2-D and 3-D geometries
Next Generation Galvanic Series

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Chemical Technology

Stainless Steels

Aluminum Alloys

Steel

Cadmium

Zn, Zn-Ni

Corrosion Potential vs. Corrosion Rate

-1400 -1200 -1000 -800 -600 -400 -200 0 200

0.001 0.01 0.1 1 10 100

15-5 PH
15-5 PH passivated
PH 13-8 Mo
301
347
2024-T4
Clad on 2024
2098-T8
5083-F
6061-T6
7055-T762
7075-T6
Alumiplate
Alumiplate, chromated
Cd
cd, chromated
Cd-Ti
Cd-Ti, chromated
Cr, ground & sealed
IVD Al, as deposited
IVD Al, chromated
Ni, electroless, immersion
Sn-Zn
Sn-Zn, chromated
Steel
Steel-St Louis
Ti, immersion
WCCo, sealed
WCCo, unsealed
WCCoCr, unsealed
WCCoCr, sealed
Zn
Zn, chromated
Zn-Ni
Zn-Ni, chromated