Corrosion Modeling and Testing of Riveted Aluminum Alloy Panel

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Outline

- **Background**
- **Galvanic corrosion modeling**
- **Experimental method for model input (polarization curves, panel pitting measurement)**
- **Pitting modeling**
- **Results**
- **Summary**

Motivations

Riveted structure & corrosion induced mechanical stress prevalent in aircrafts & warships:

- *The structure prone to galvanic corrosion when dissimilar metals used*
- *Other localized corrosion can occur with or without galvanic influence*
- *Mechanical failure can be induced or enhanced by localized corrosion*
- *Capability in predicting the corrosion and mechanical damages useful for OEM and repair process design & maintenance scheduling*

Aircrafts experiencing severe corrosion conditions

New generation Littoral Combat Ship (aluminum triple-hull combatant) for US NAVY

Objectives & Approaches

Objectives

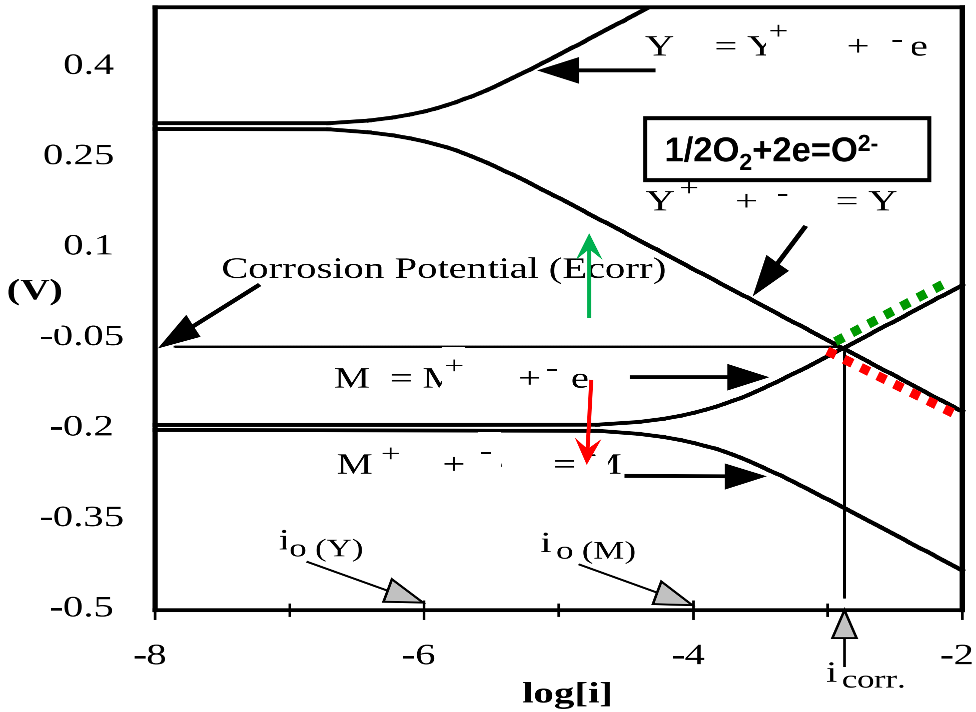
- *Using finite element based corrosion modeling tool (GalvanicMaster, Elsyca Co.) to model localized corrosion of riveted structure under galvanic influence*

Approaches

- *Galvanic corrosion finite element CAD modeling of riveted panel (Hi-lok steel fasteners & AA2219 rivets on AA7075)*
- *Electrochemical characterization of constituent materials*
- *Probabilistic pitting kinetics under dominant conditions (Cl- concn., current density) experimentally characterized*
- *Salt fog test for model calibration (in progress)*

Background

- Riveting preferred over welding for light structural metals, i.e. aluminum alloys
- Metal corrosion involves oxidation of a metal and reduction of an oxidant (O_2, H^+)
- Metal oxidation=anodic reaction; O_2 , H^+ reduction=cathodic reaction
- Polarizing by a galvanic couple can enhance pitting & other localized corrosion



Evans diagram illustration of galvanic corrosion (area anode : cathode=1:1)

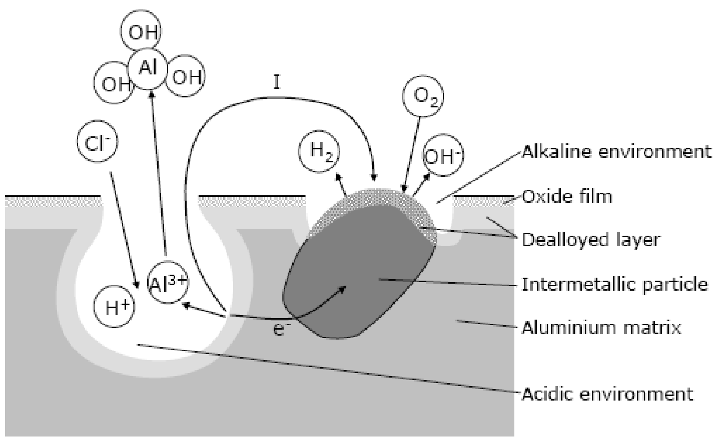
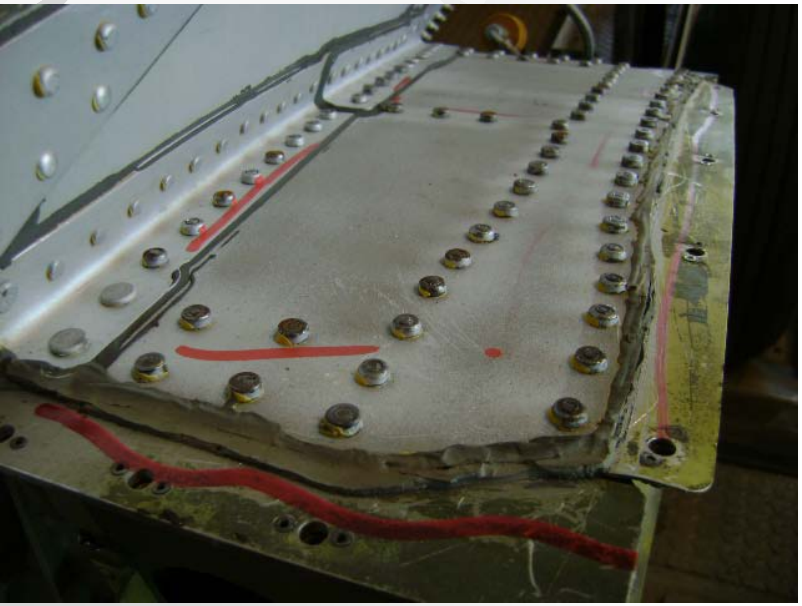


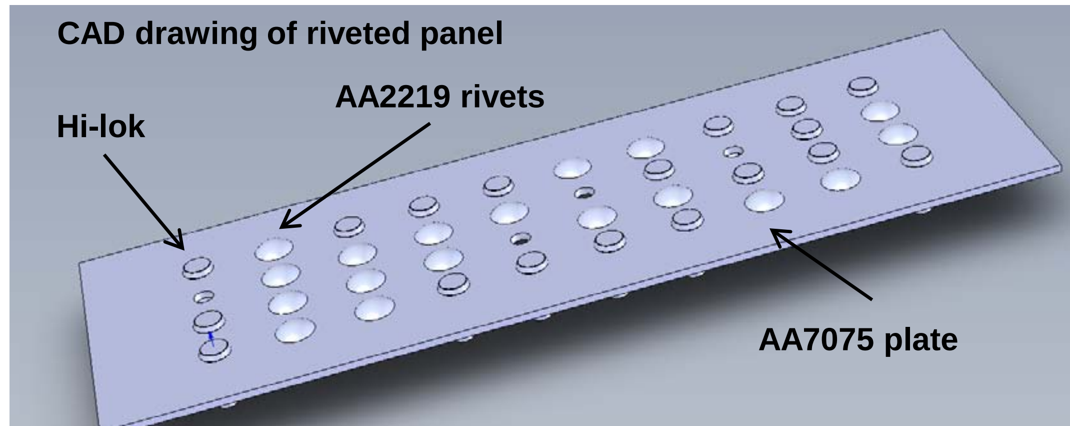
Illustration of pitting of Al alloys

Model Description

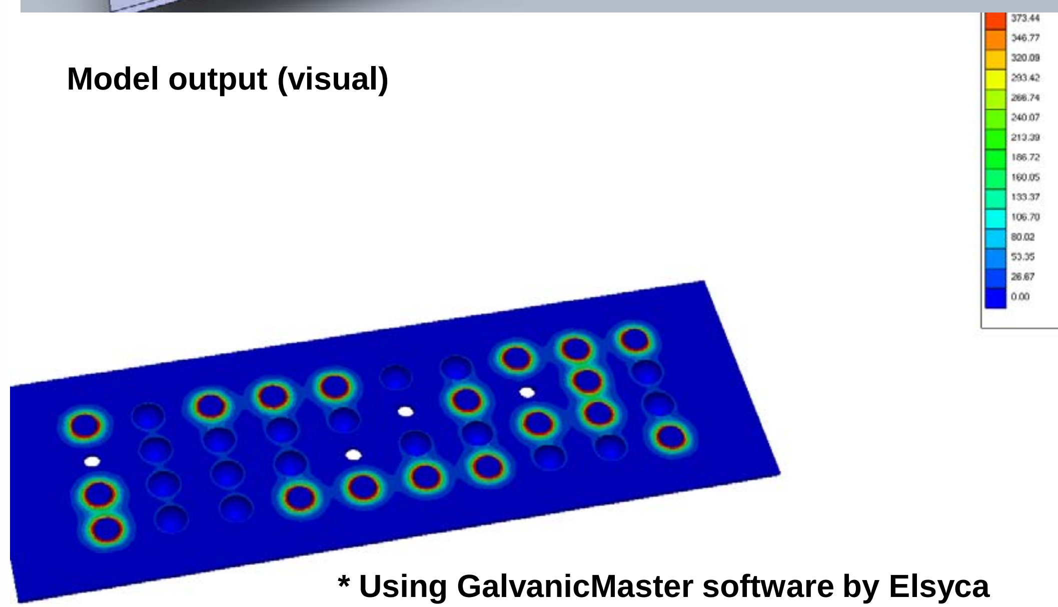
- CAD drawing of a riveted aluminum panel created in Solidworks
- Polarization curves of constituent materials measured
- Corrosion current distribution used for evaluating pitting as first attempt



Riveted structure (above landing gear) in a helicopter being maintained for corrosion



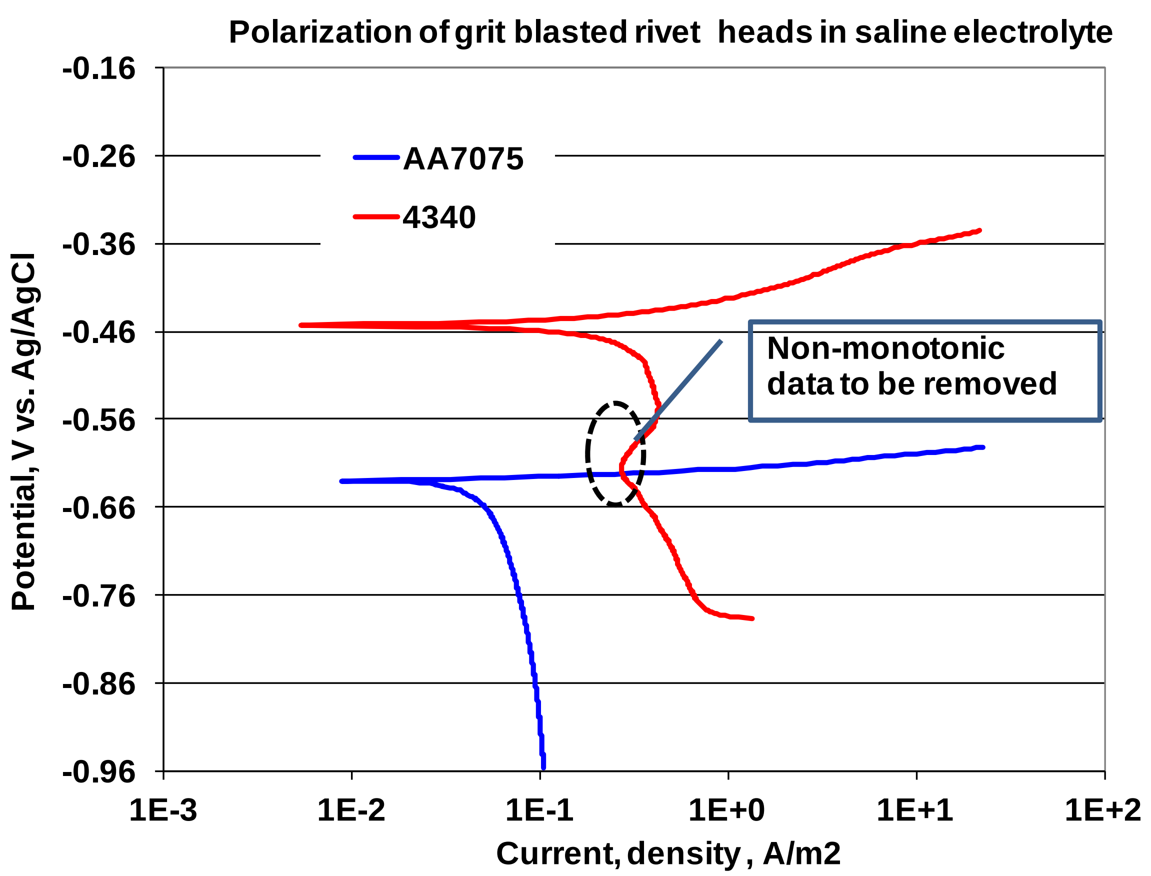
Model output (visual)



* Using GalvanicMaster software by Elsyca

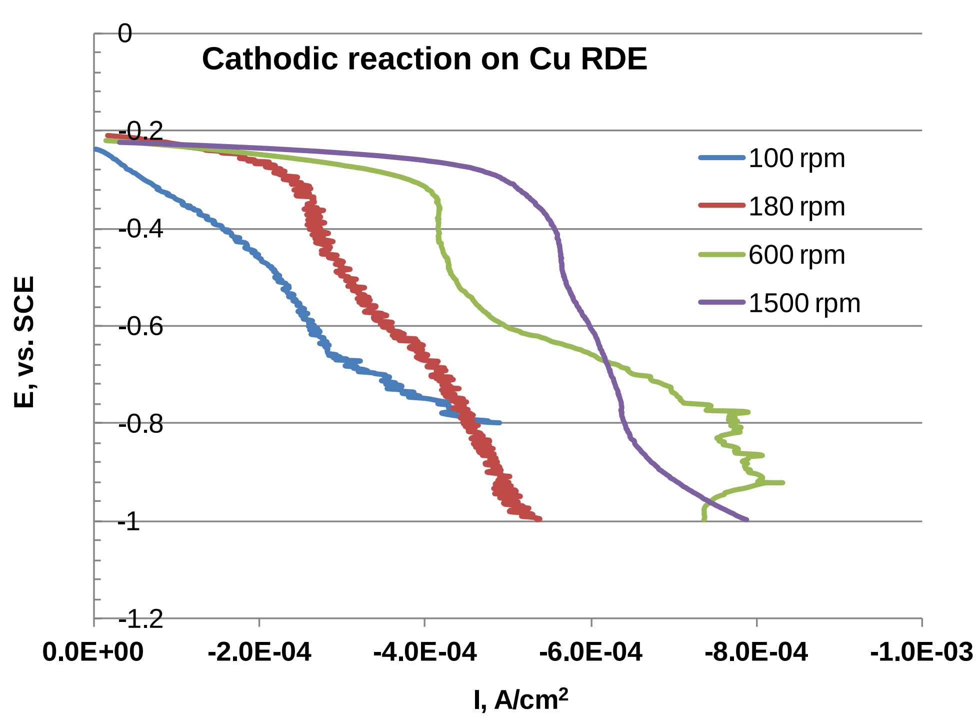
Model Input-Polarization Curve Measurement

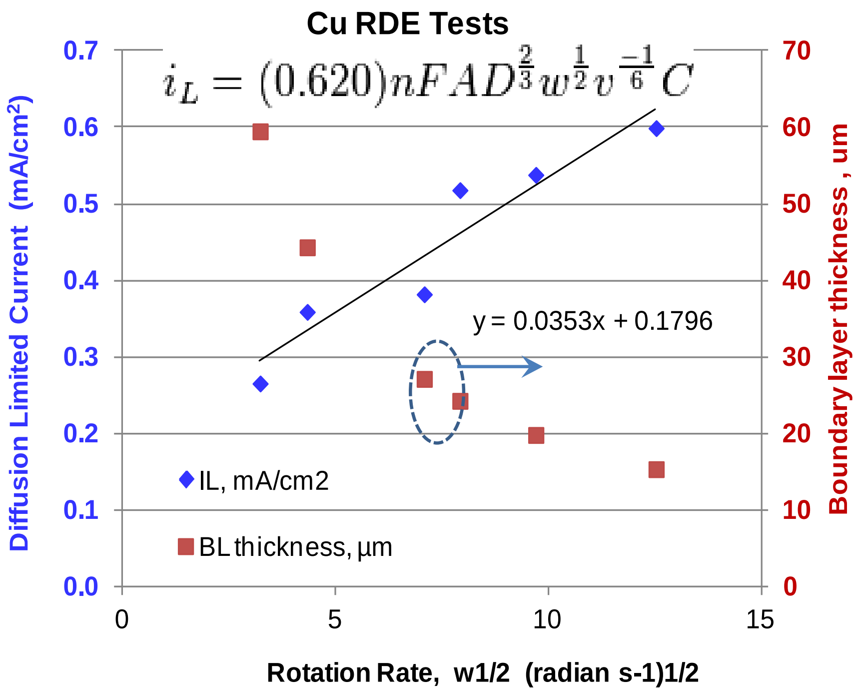
- Polarization (V-I) curves used as boundary conditions of the model
- Local current distribution determined based on potential distribution
- Pseudo-steady state measurement required in bulk electrolytes
    - Pros: Easy to perform, shorter duration (@1 mV/s) to avoid electrolyte change
    - Cons: Accurate only for bulk electrolyte environment, missing mass transport effect



Model Input-Polarization Curve Measurement

- V-I measurement using rotating disk electrode (RDE) captures mass transport contribution
- Mass transport can be important for cathode reaction in thin film
- Alternative method with thin film electrolyte better represents reality, but less accurate
- Standardization of V-I curve measurement needed





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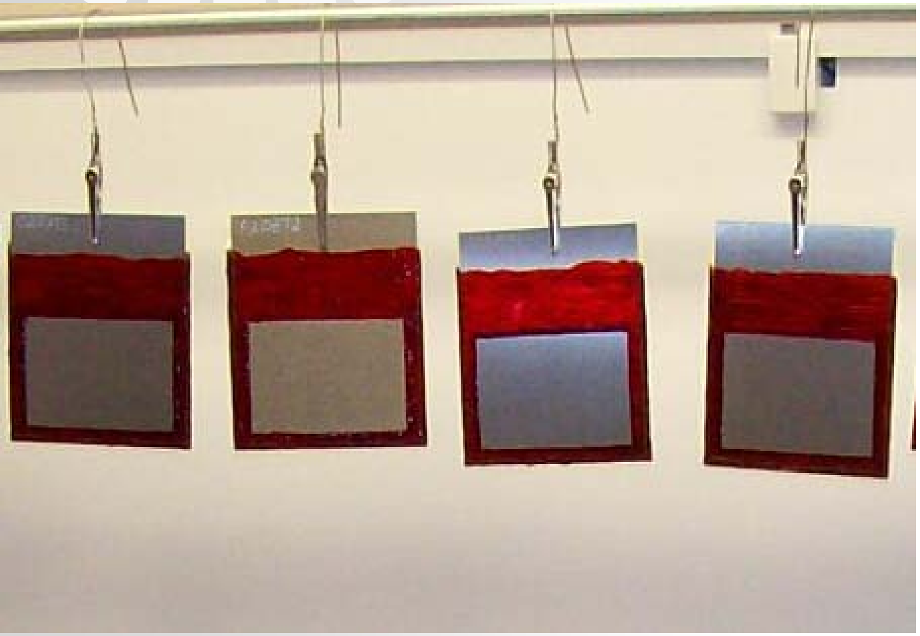
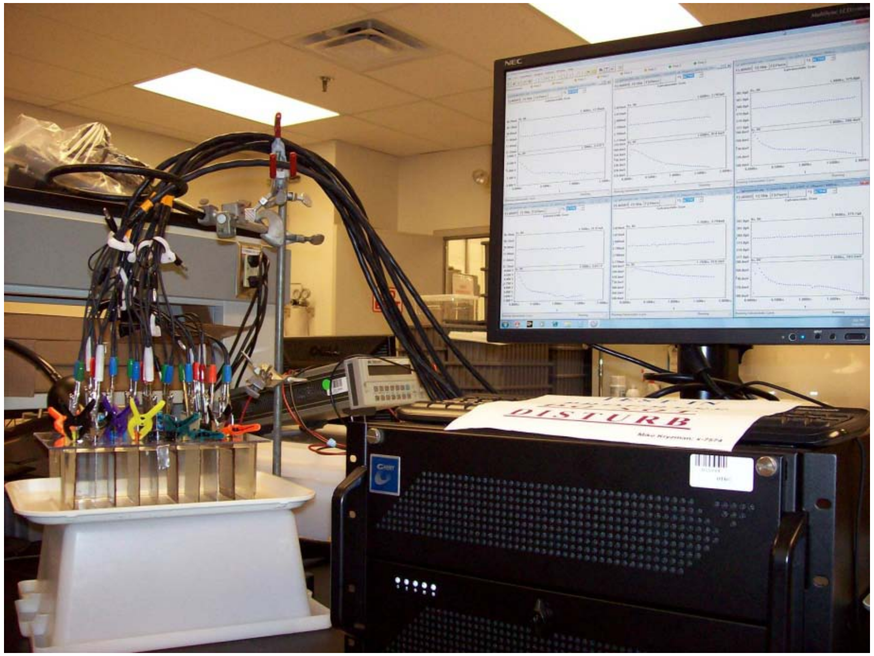
Model Input-Galvanically Induced Pitting

- Pits grown under galvanic influence in a controlled environment ([Cl-], pH, duration)
- Maximum pit depth analyzed using white light interferometer



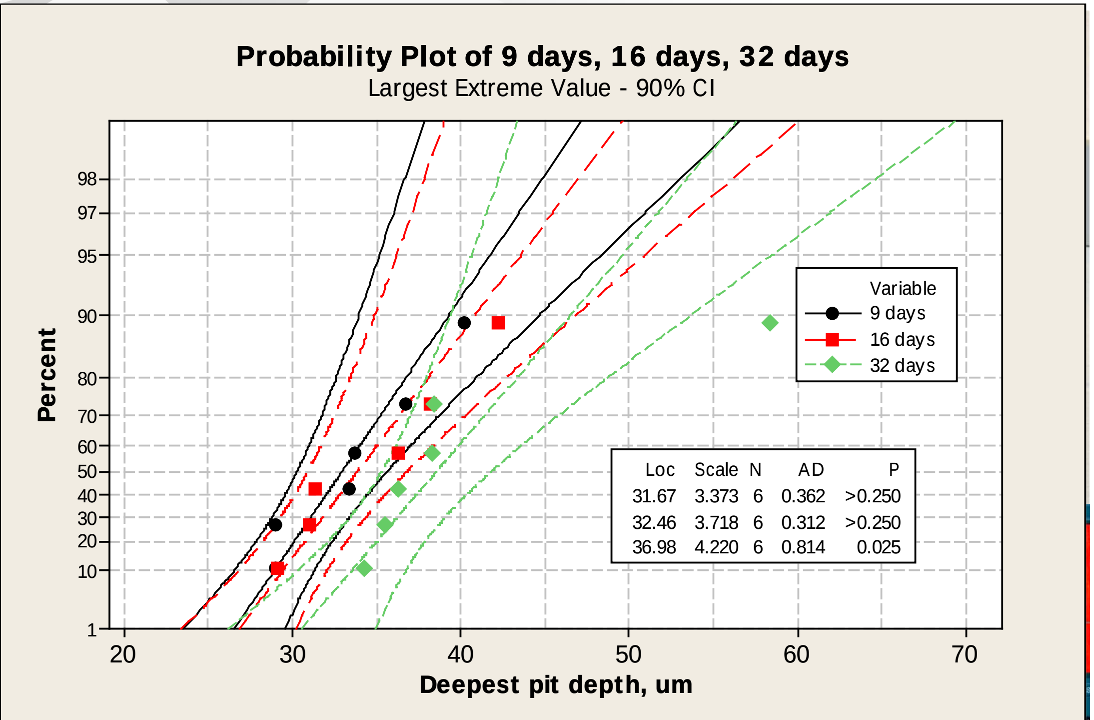
Samples masked to produce controlled surface area

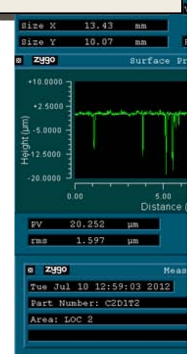


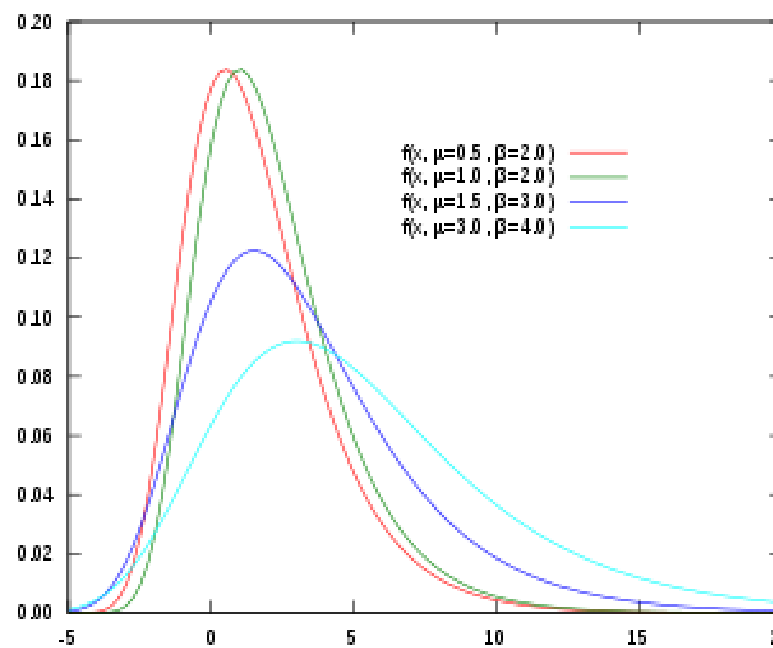
8-channel potentiostat for simulated pitting under galvanic influence

Model Input-Depth Analysis of Galvanically Grown Pit

- Interferometer used to accurately measure maximum pit depth
- Extreme value analysis applied to derive probabilistic pit growth kinetics







*Gumbel distribution

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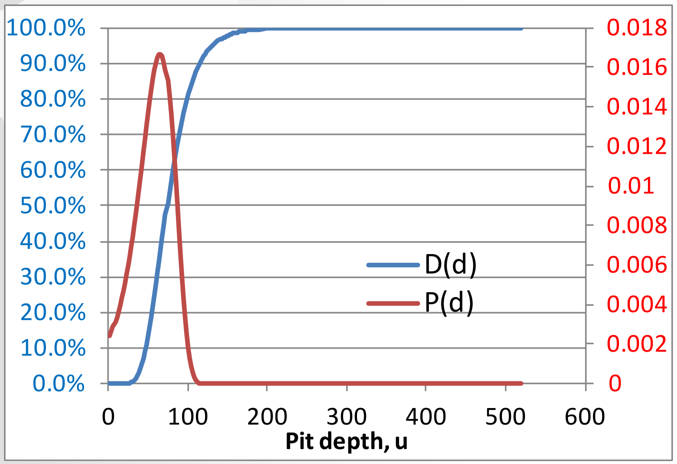
Effects of Current & [Cl-] Pit on Depth Probability Distribution*

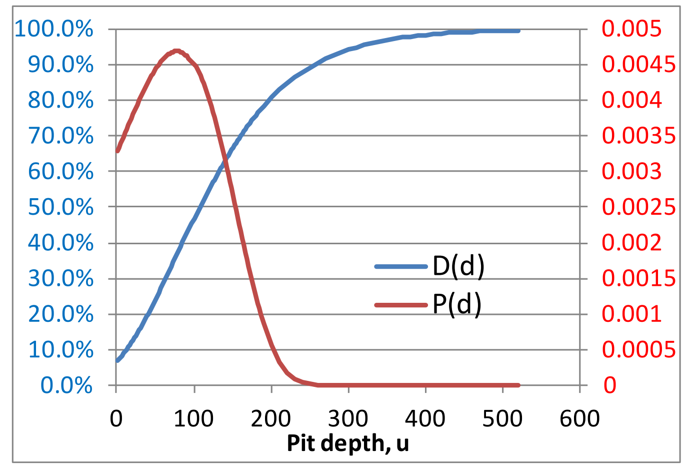
- Pitting algorithm defined by experimental data & bounded by conditions of interest

Time, hour	[Cl-] mg /l	I/A, uamp/cm2	S/s
8700	100	1	1



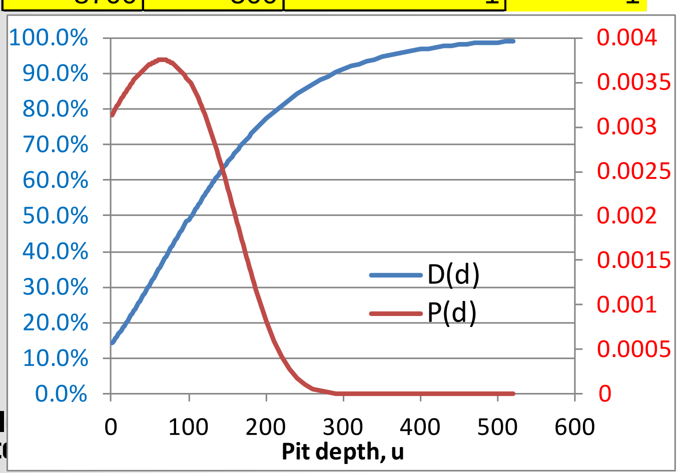
Local current density effect

Time, hour	[Cl-] mg /l	I/A, uamp/cm2	S/s
8700	100	25	1



Chloride ion concentration effect

Time, hour	[Cl-] mg /l	I/A, uamp/cm2	S/s
8700	500	1	1



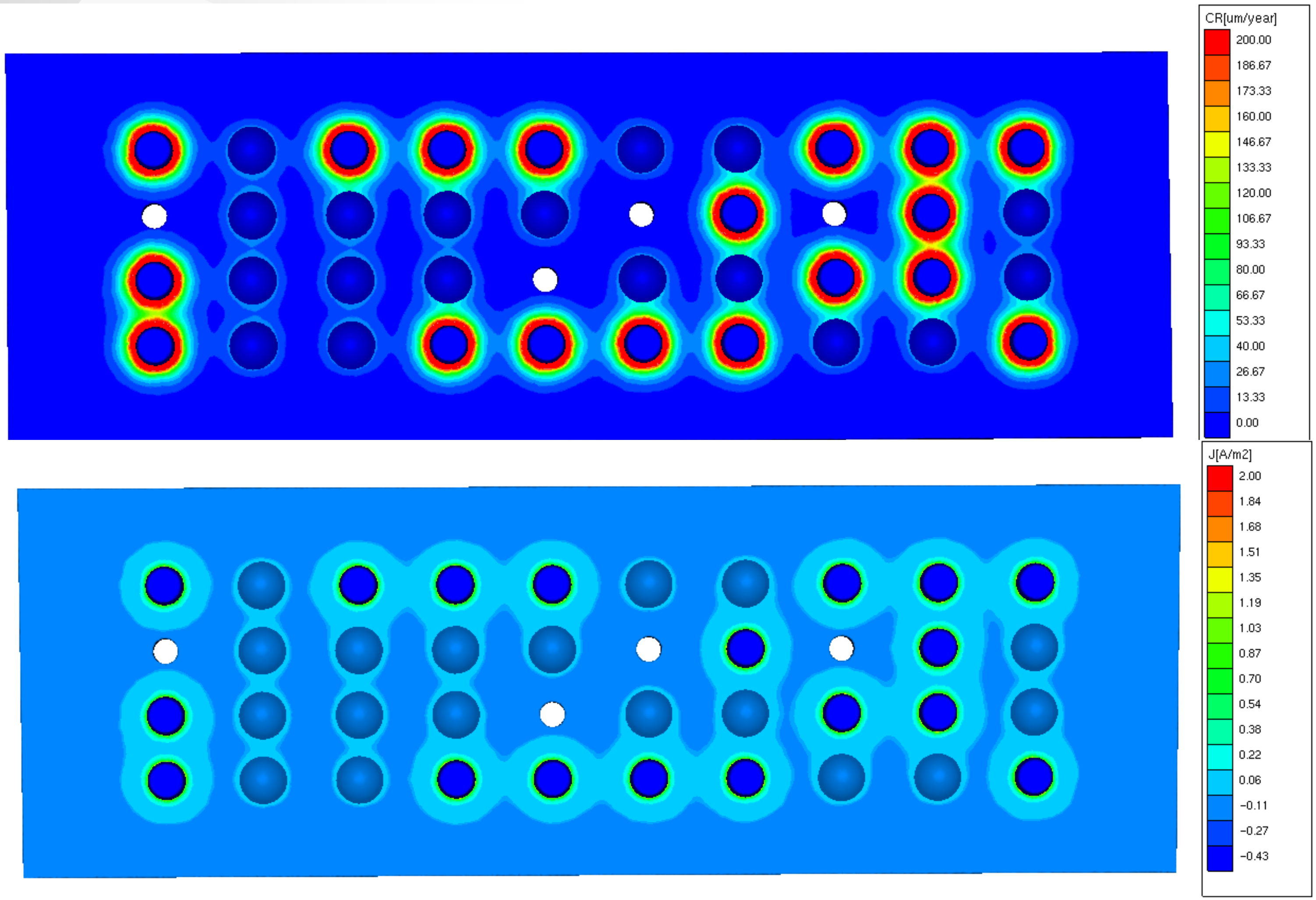
$$P(d,t) = 1 - \exp\{-\exp[-d - (u + \alpha \ln(S/s))]/\alpha\}$$

- P(d)-probability density function
- P(d,t)-Probability of failure, i.e. the probability that at least one corrosion event reached or exceeded depth "d".
- d(D)- Pit depth reached for at least one corrosion event at a given probability of failure.

*Type I: Gumbel distribution, P. M. Aziz, 1956 (10), Corrosion

Galvanic Corrosion Rate and Current Prediction

- Model predictions: Initial galvanic corrosion rate and current distribution on a riveted plate

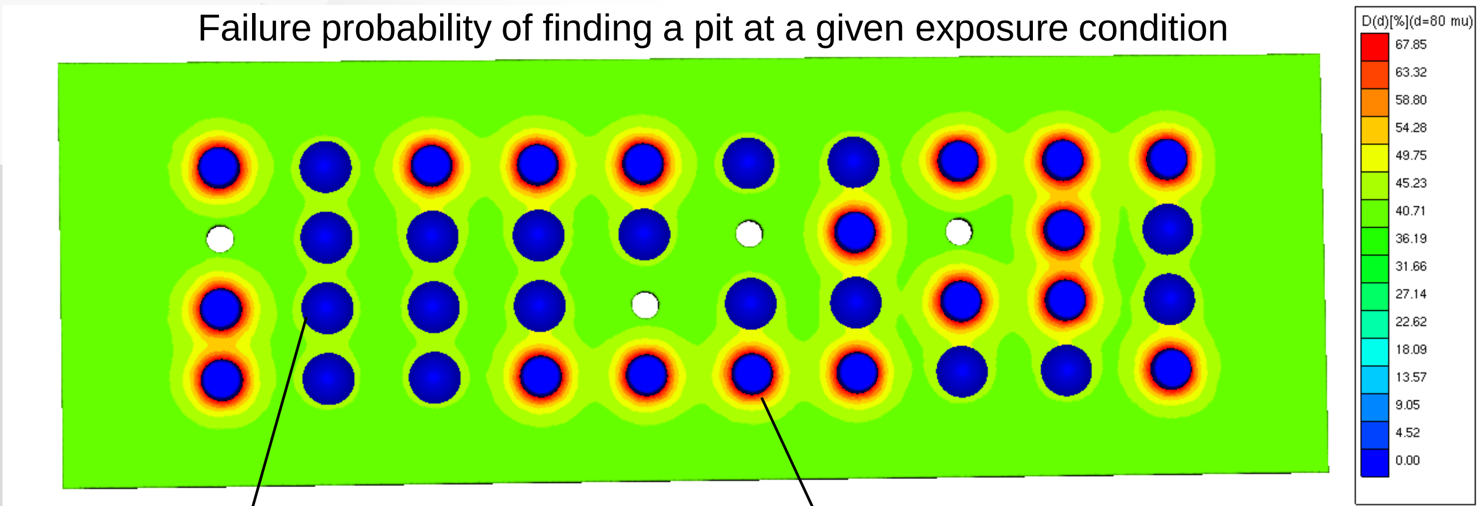


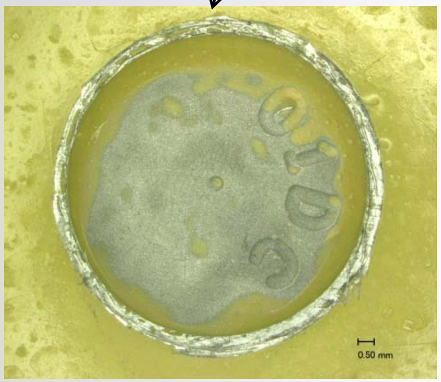
- 200 ppm
- 5000 h
- Assuming continuous exposure

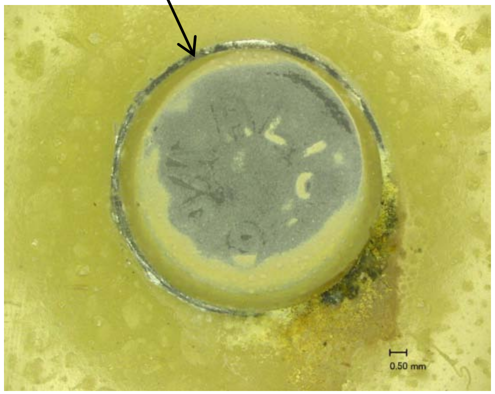
Failure Probability Prediction & Experimental Observation

- UTRC pit growth modeling predictions at given exposure environment and time under galvanic influence for a riveted panel, incorporated into the GalvanicMaster modeling tool

Failure probability of finding a pit at a given exposure condition







- 200 ppm Cl-
- 5000 h

Summary

- GalvanicMaster corrosion modeling useful as a starting point to predict/understand corrosion risk of complex structure
- Localized corrosion modeling algorithms can be incorporated in the GalvanicMaster modeling tool
- Electrochemical characterization methods for model inputs need to be better defined and implications to be examined
- Standardizing EC characterization methods to include the electrolyte thin film physics and establishing guidelines on choosing I-V curves
- Future predictive capability should include accumulation of corrosion damage and material evolution, including accurate description of electrolytes
- Advanced corrosion modeling shall be integrated with fracture mechanics modeling to predict service life

Acknowledgement

Elsyca Co.'s collaboration and help in the incorporation of the UTRC pit growth models into its GalvanicMaster software module for UTRC testing is greatly appreciated

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