Electrochemical Impedance Spectroscopy with Surface Contact Sensors for Corrosion Detection

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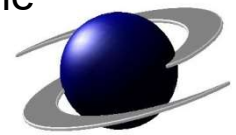
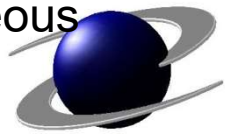
Problem Background

- In order for the Air Force to extend the life of its aircraft, the monitoring and detection of corrosion is crucial
- Evaluation of aging military equipment involves inspecting large areas of plates including lap joints, bonded material, and other complex geometries
- Corrosion is a leading cause of reduced mission availability
  - Need extensive inspection, troubleshooting, and repair
  - Disassembly and re-assembly of components is costly
- Over $1B spent annually by the Air Force on corrosion issues related to aircraft
  - Approximately 15% is allocated to the removal of paint, inspection for corrosion, and re-paint operations
- The Air Force requires an improved corrosion detection system to assess corrosion in multi-layer metallic structures on its aircraft without removing the skin
- The development of a reliable, rapid, and portable hand-held nondestructive evaluation (NDE) method for detecting corrosion would result in considerable savings to the military



Hidden Corrosion Detection Issues

- Corrosion detection methods include eddy current probes, ultrasonics, and thermal imaging
  - These methods are comparative based – measured responses are compared to known standards without corrosion
  - Difficult to apply to complex geometries that interfere with the response signals
- Present technologies have low detection probabilities, high false alarm rates, and low scan rates
- These technologies require a significant loss of material to exist before reliable detection can be realized
  - This is undesirable since severe structural damage may result from stress corrosion cracking
- A preferred method of detecting hidden corrosion would be to detect the actual corrosion products or by-products of the corrosion reaction
- Since the corrosion products do not have any appreciable vapor pressure, detecting them via gas-phase sensors or some other spectroscopic approach is not feasible
- However, the corrosion products may be used to generate a gaseous component via applying an induced reaction

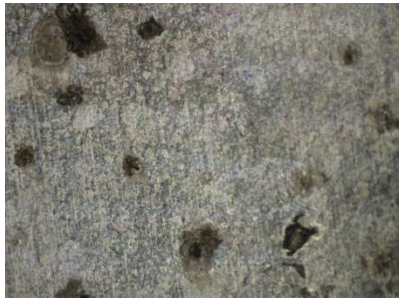


Technical Approach – Reactive Electrochemical Impedance Spectroscopy (REIS)

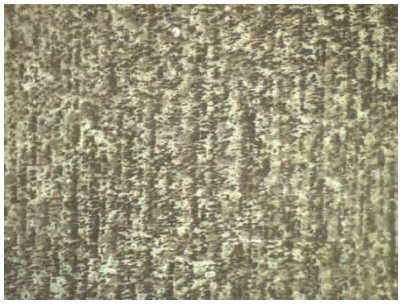
- Process is based on comparing the electrochemical impedance spectra (EIS) of the substrate taken before and during the generation of a small quantity of gas at the site of corrosion in the substrate
- The rate of gas evolution is dependent on kinetic factors that relate directly to the presence and quantity of corrosion products in the metal
- The proposed process functions in a two-step manner
  - 1) a standard electrochemical impedance spectra is obtained with a hand held probe that touches the substrate
  - 2) a cathodic potential is briefly applied to the surface generating a small amount of hydrogen gas due to the reduction of water present in the sample. A second EIS scan is taken while this electrochemical reaction occurs
- These two spectra responses are compared with any differences in the responses due to the presence of hydrogen gas generated by the cathodic potential
  - Furthermore, the magnitude of the difference in the two spectra responses indicates the degree of corrosion with large differences indicative of severe corrosion

Varying Hydrogen Evolution Rates Dependent on Severity of Corrosion on Al2024-T3

(polished)

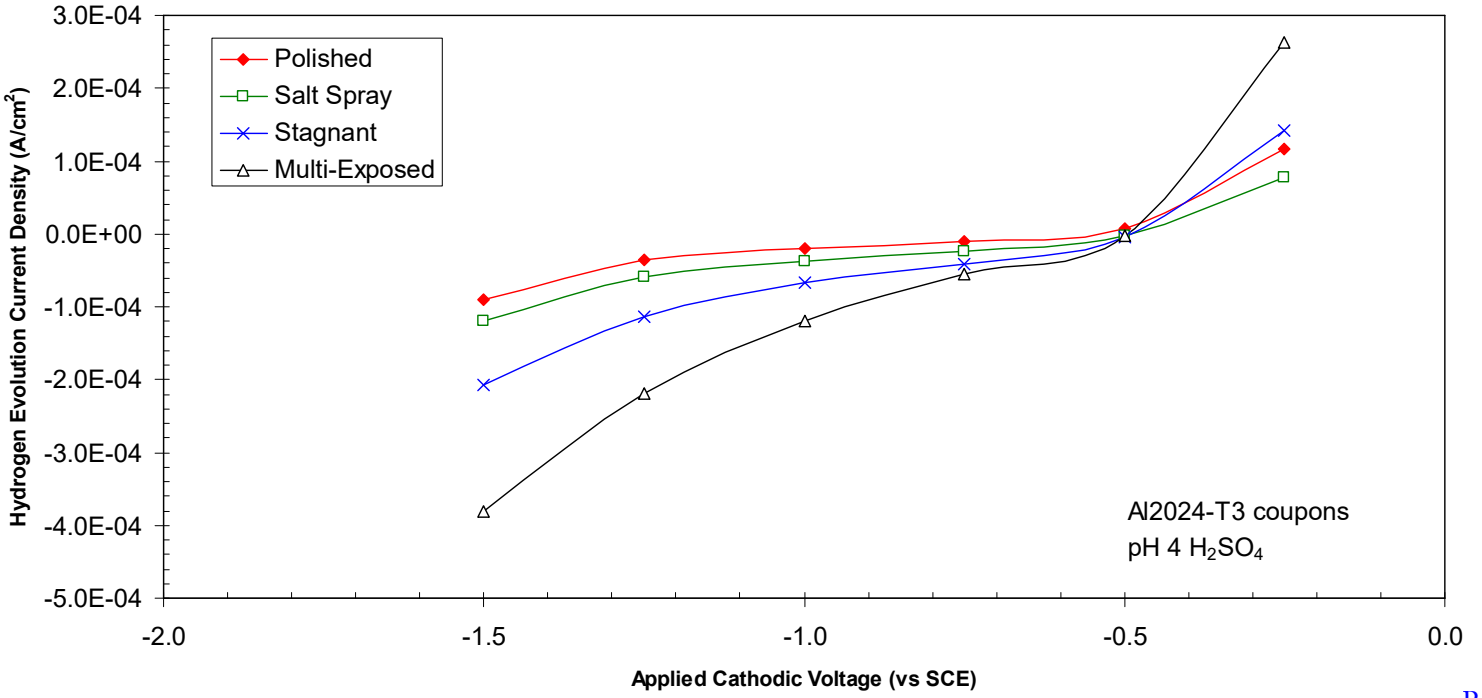


(salt spray)



(stagnant)

(multi-exposed)



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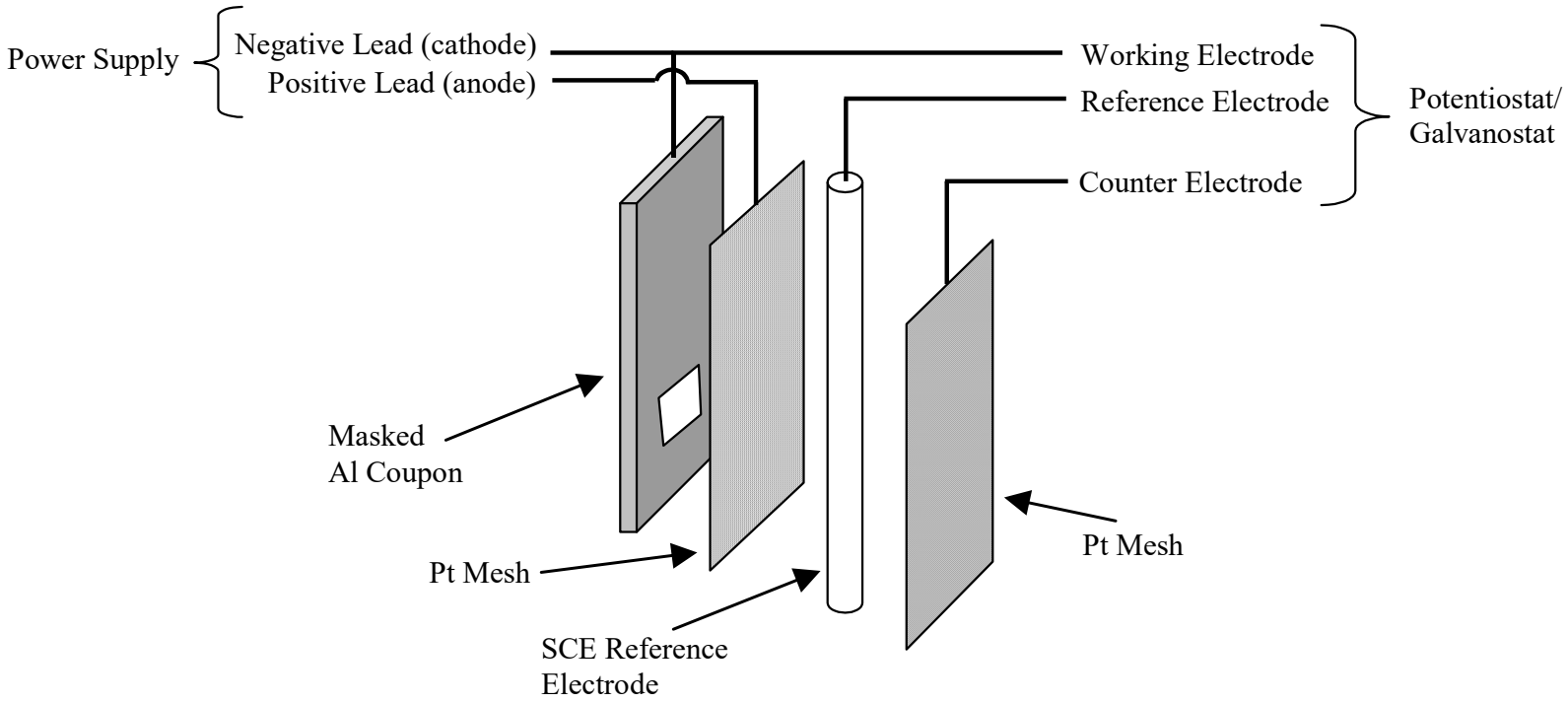
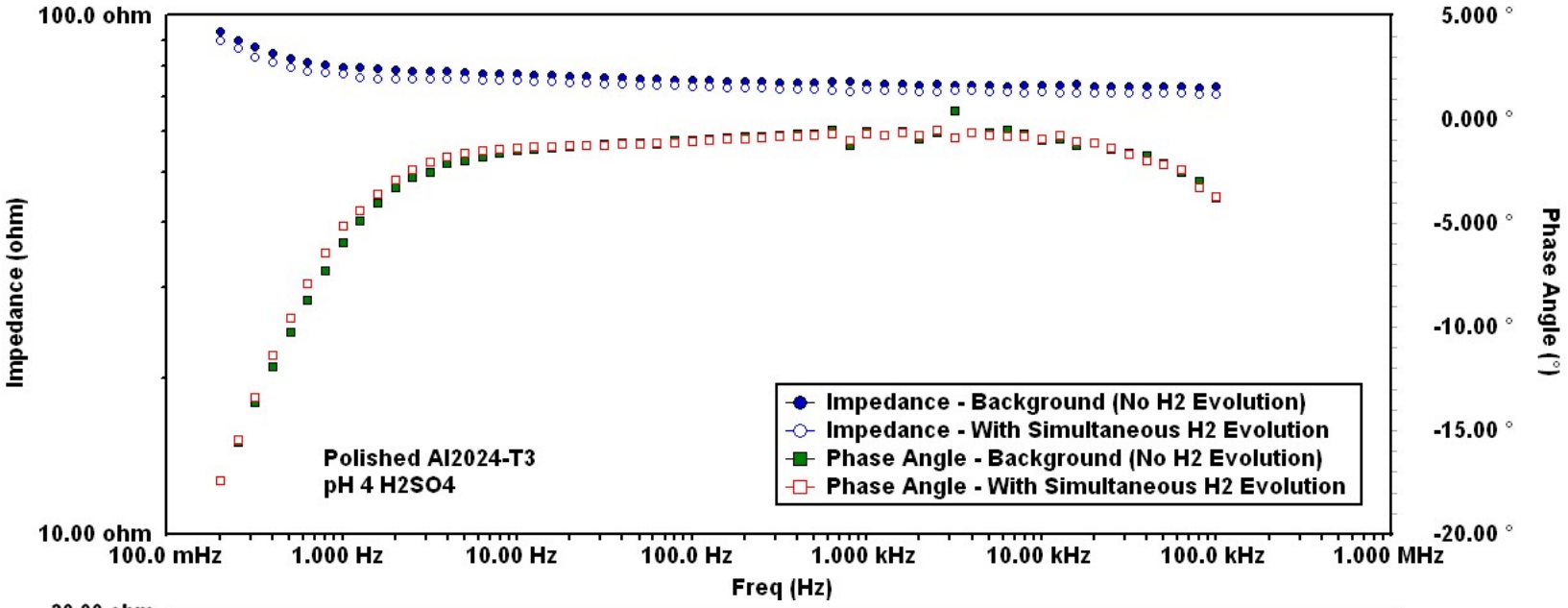
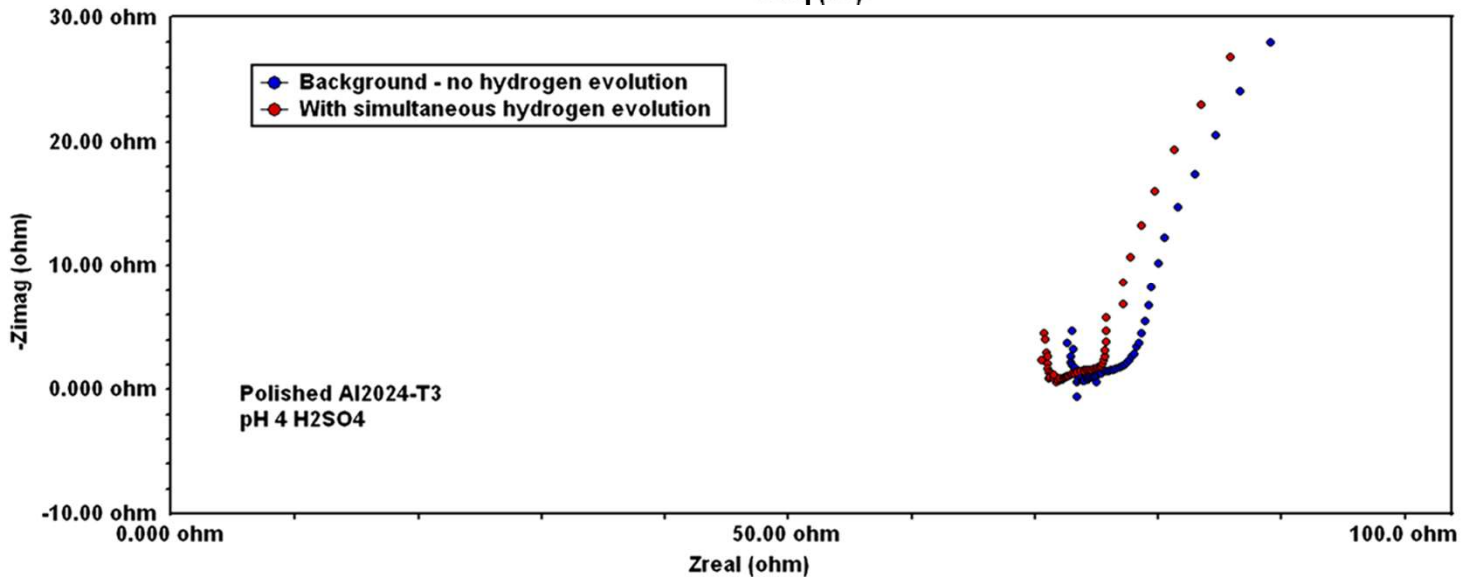
Experimental Setup for Simultaneous EIS and Induced Hydrogen Evolution



Similar EIS Response on Polished Al2024-T3 for Background and Induced Hydrogen Evolution





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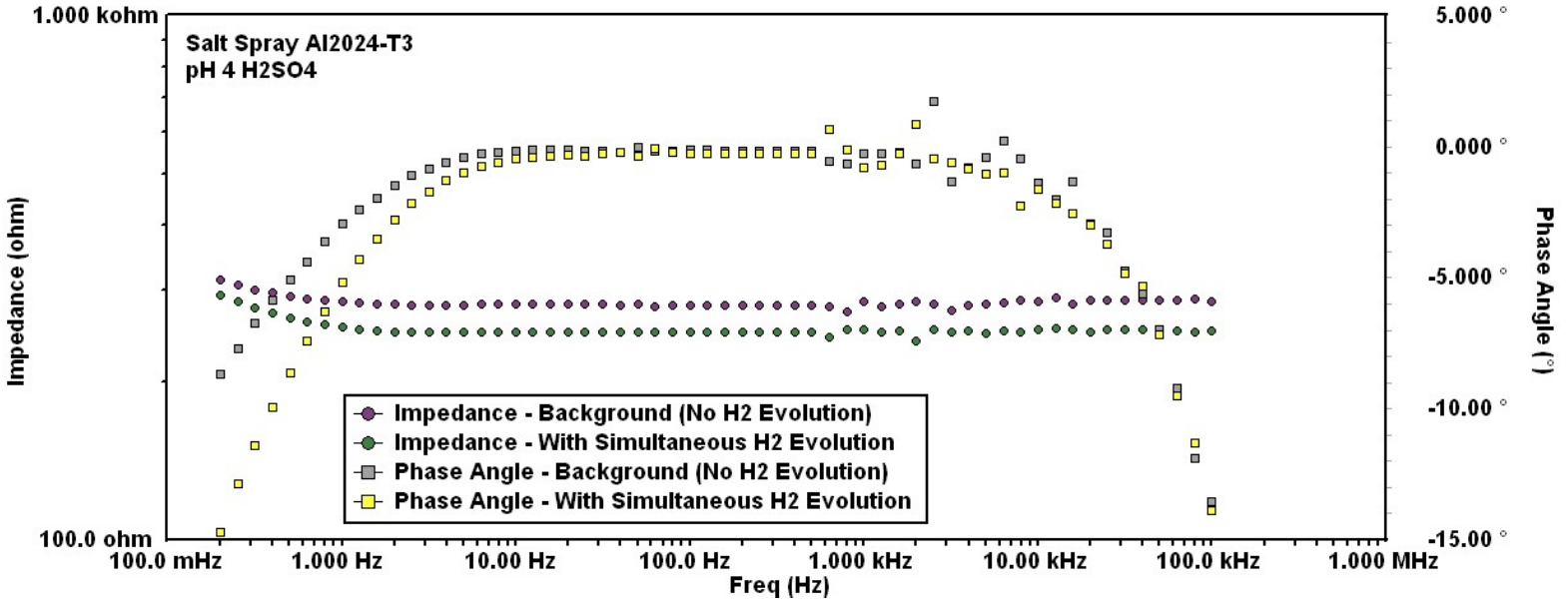
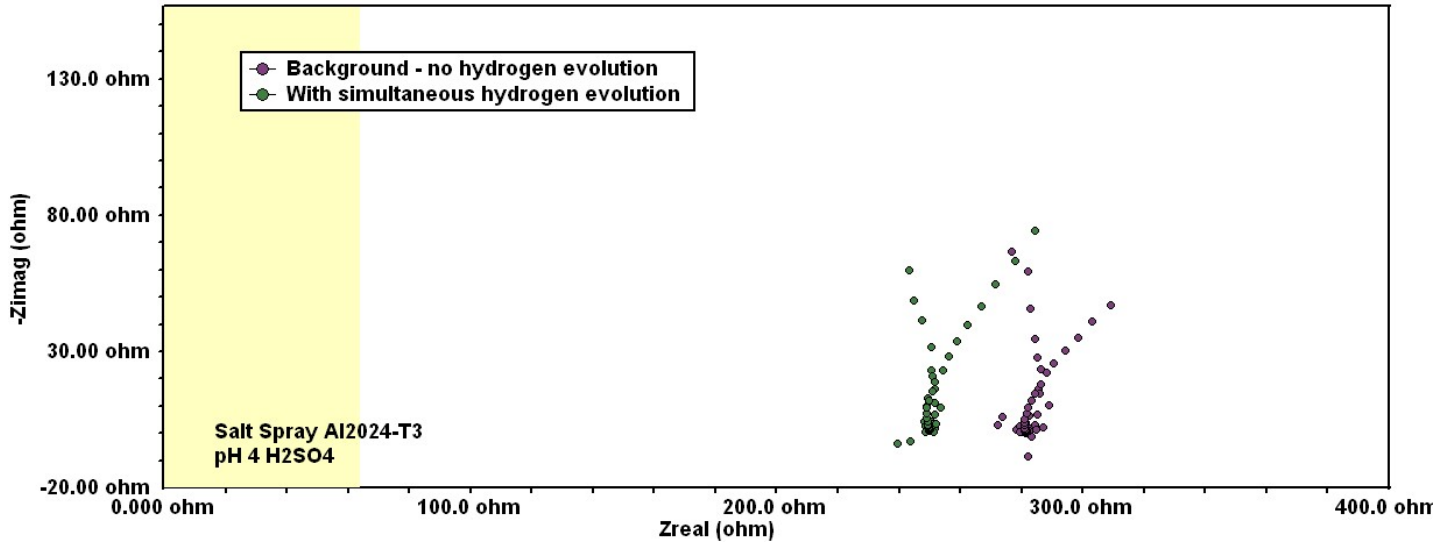
Variation in EIS Response on Al2024-T3 Between Background and Induced Hydrogen Evolution





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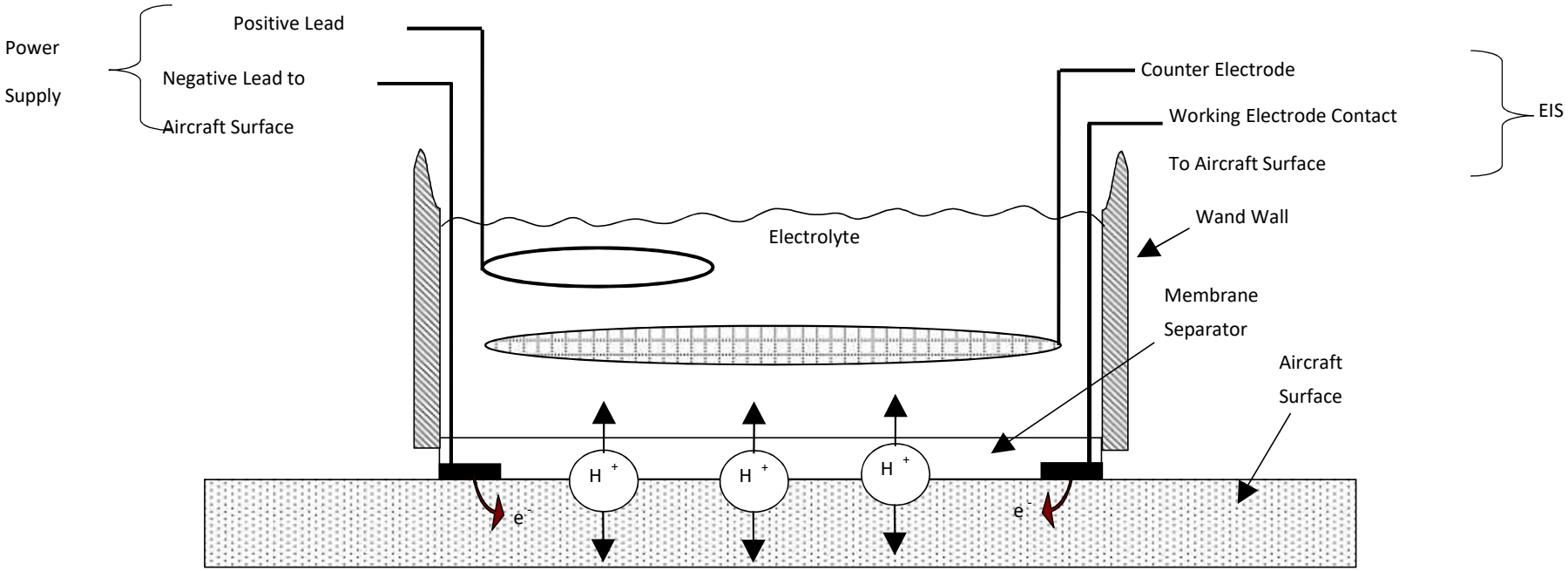
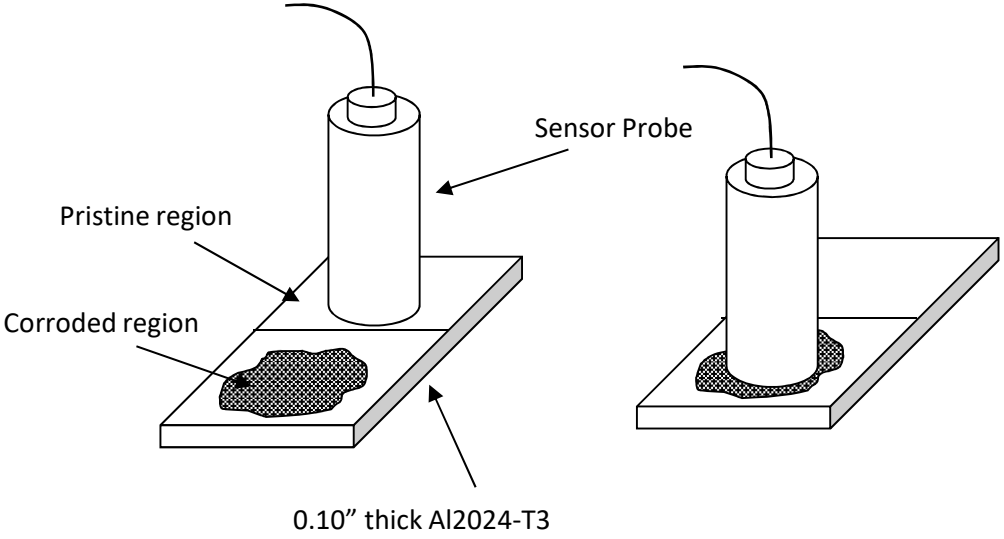
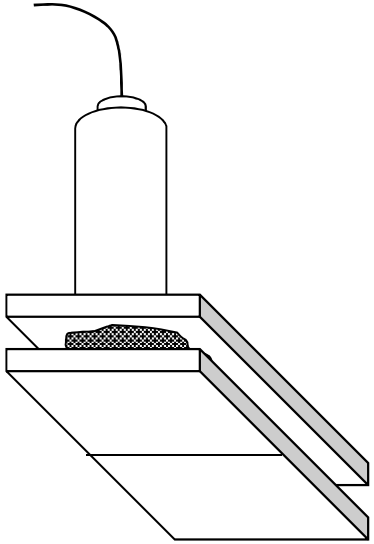
Surface Contact Sensor Operation



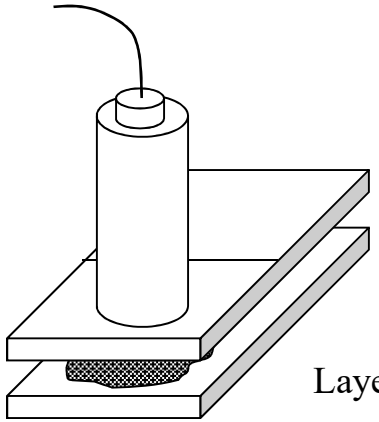
Multi-Layer Corrosion Coupons



Layer 0



Layer 1



Layer2

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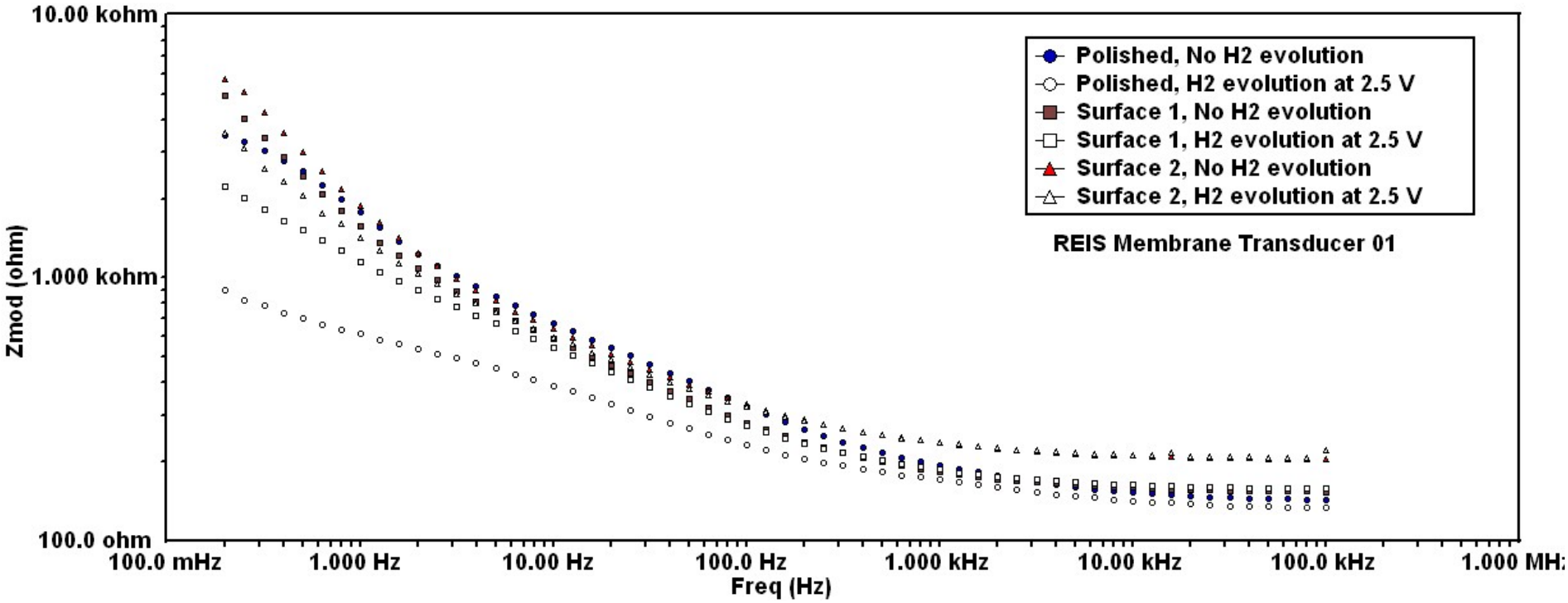
Comparison of Surface Contact Sensor for Hidden Corrosion



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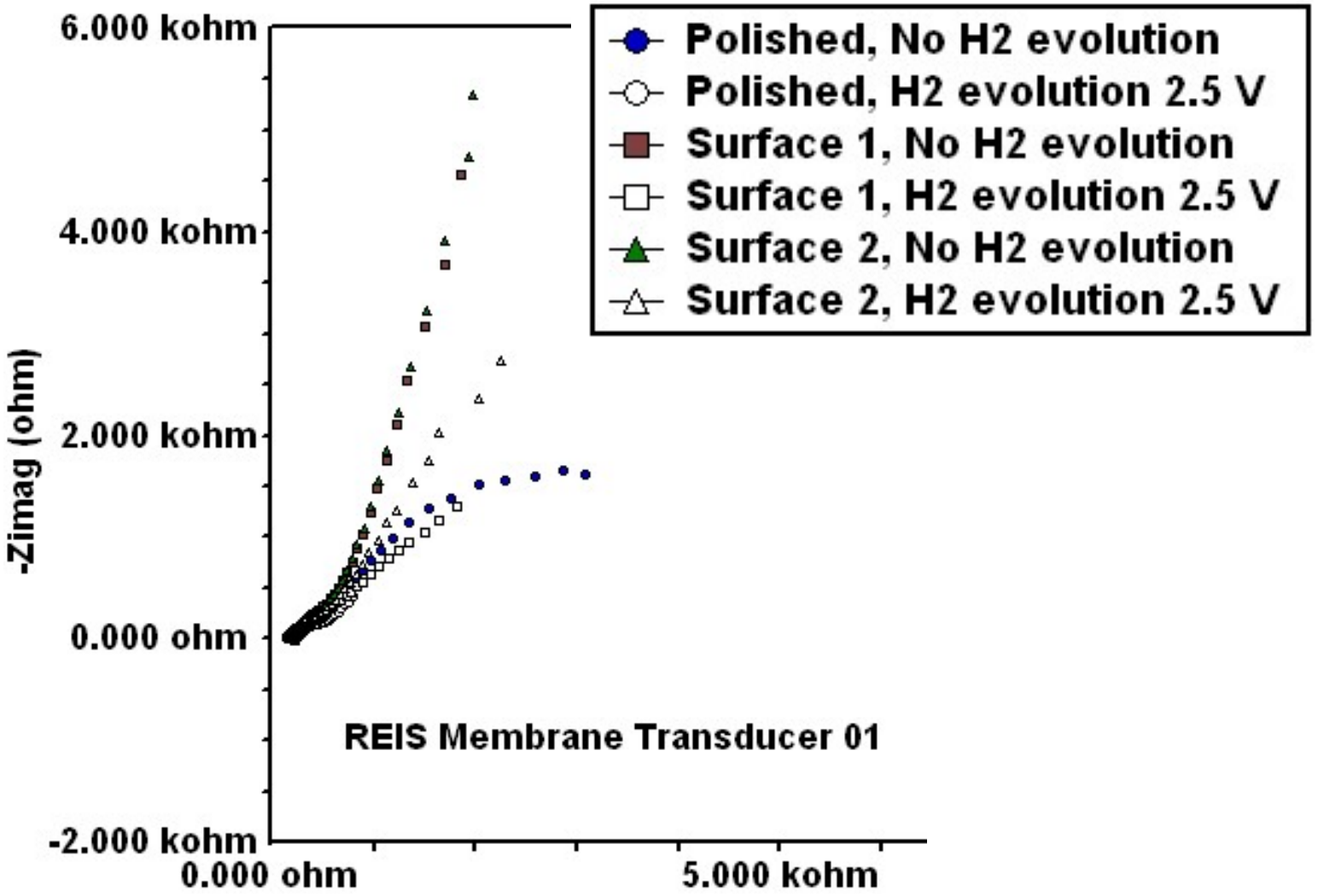
Nyquist Response for Multi-Layer Corrosion



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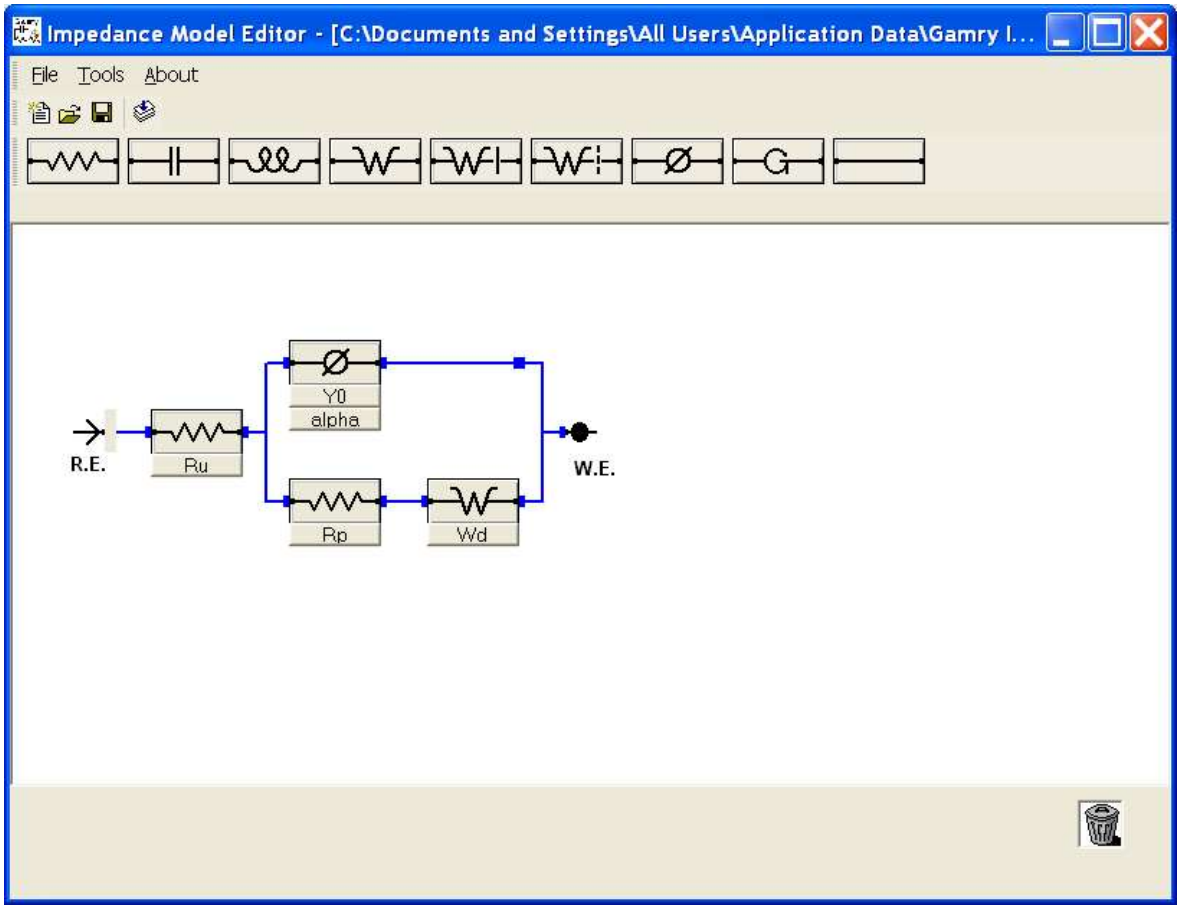
Equivalent Circuit Models to Help Interpret EIS Response for Hidden Corrosion Detection

- Examined a few equivalent circuit models
- Regress circuit parameters and use to correlate hidden corrosion



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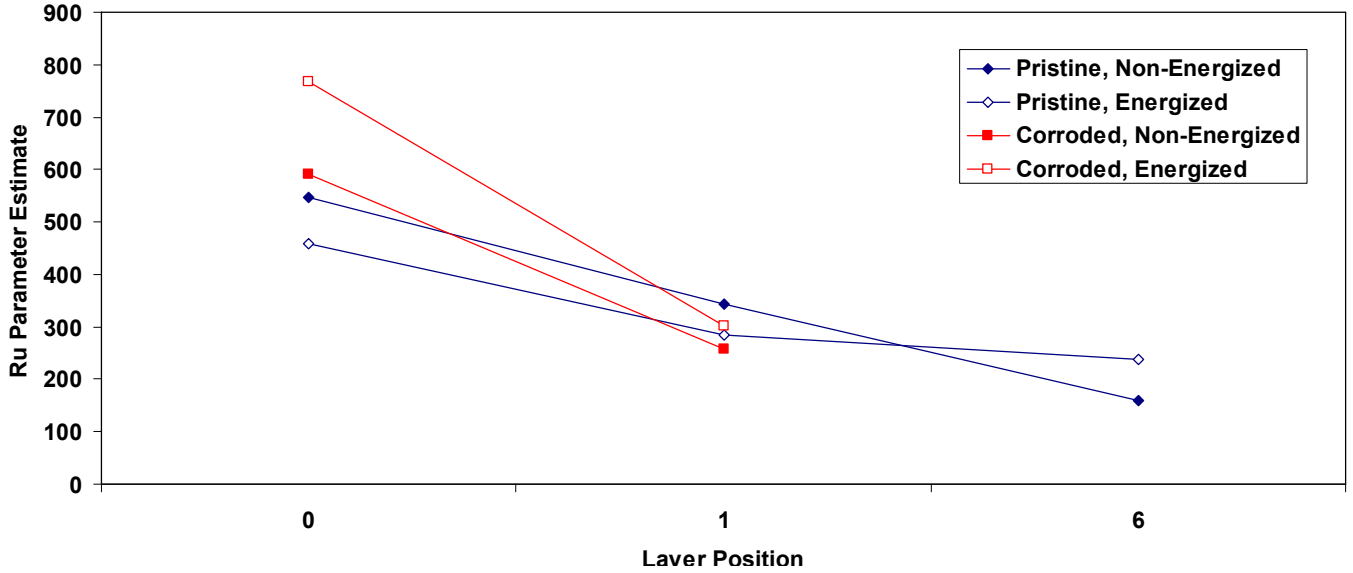
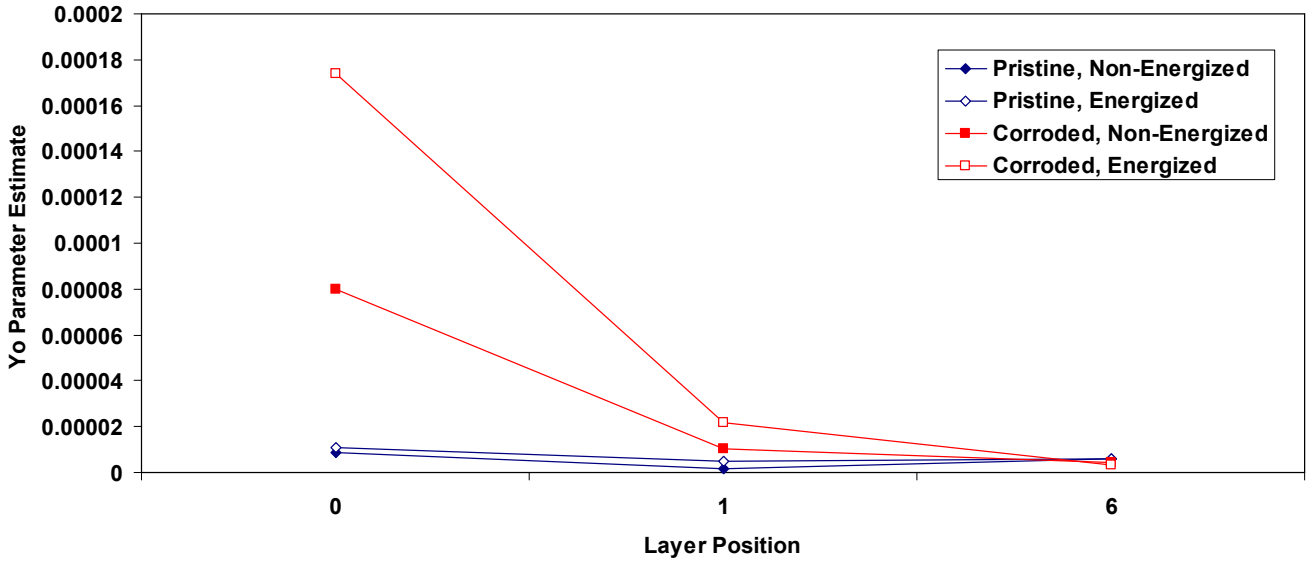
Variation of EIS Parameters with Corrosion Location Between Non-Energized and Energized Modes





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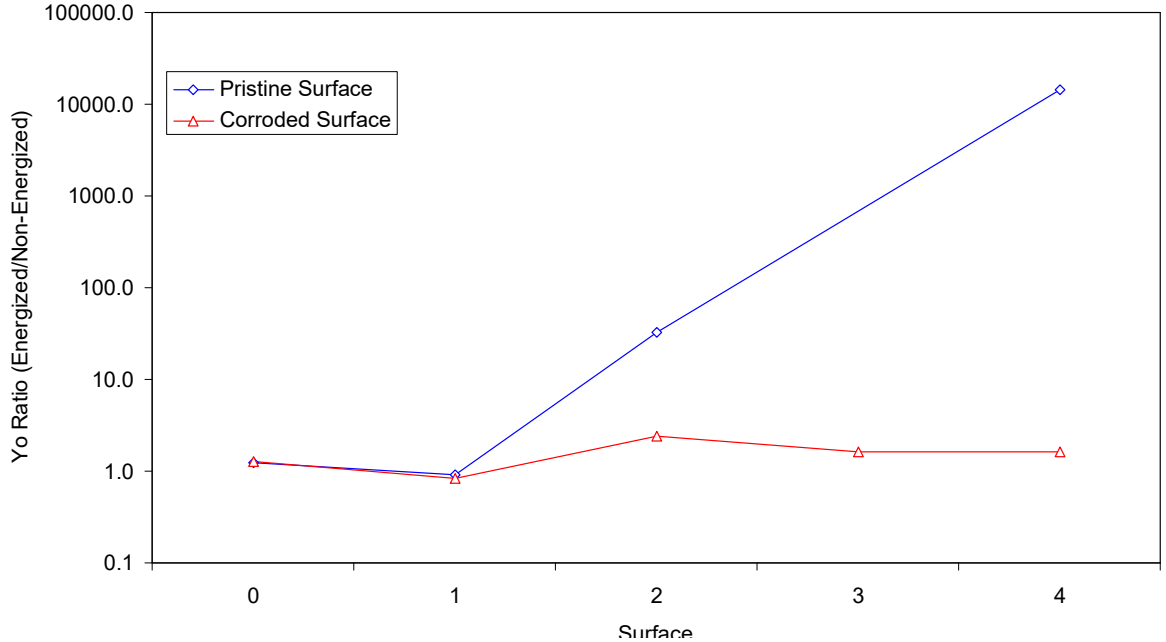
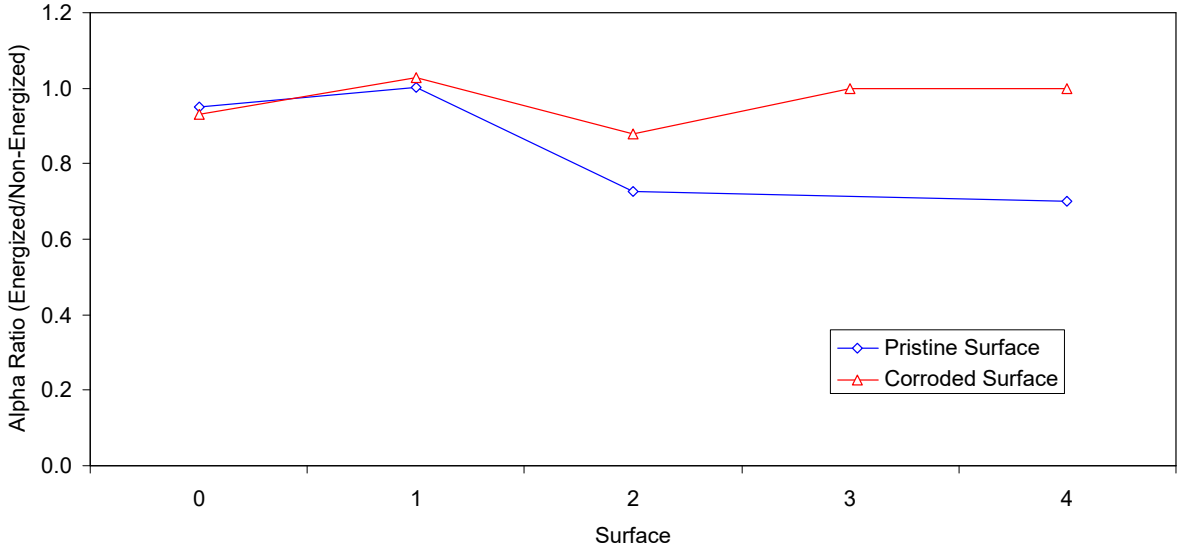
Correlation of Energized to Non-Energized Parameter Estimates Tracks with Corrosion Location





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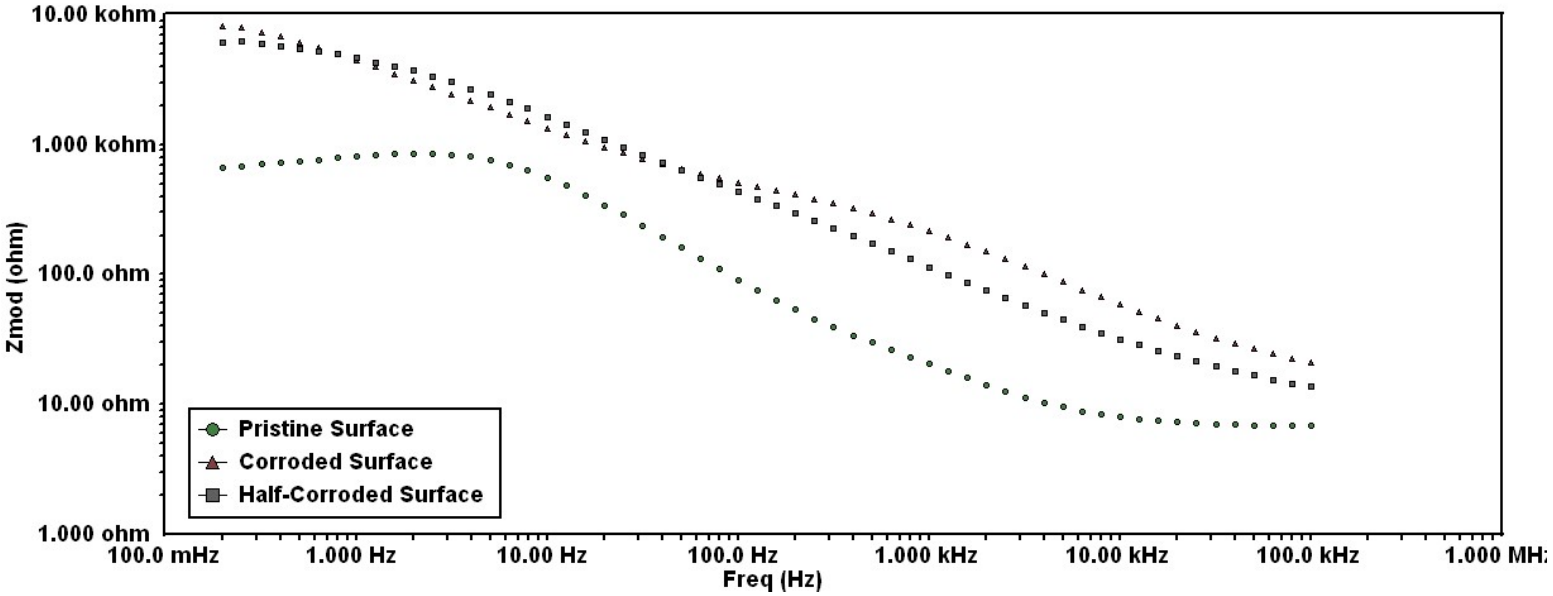
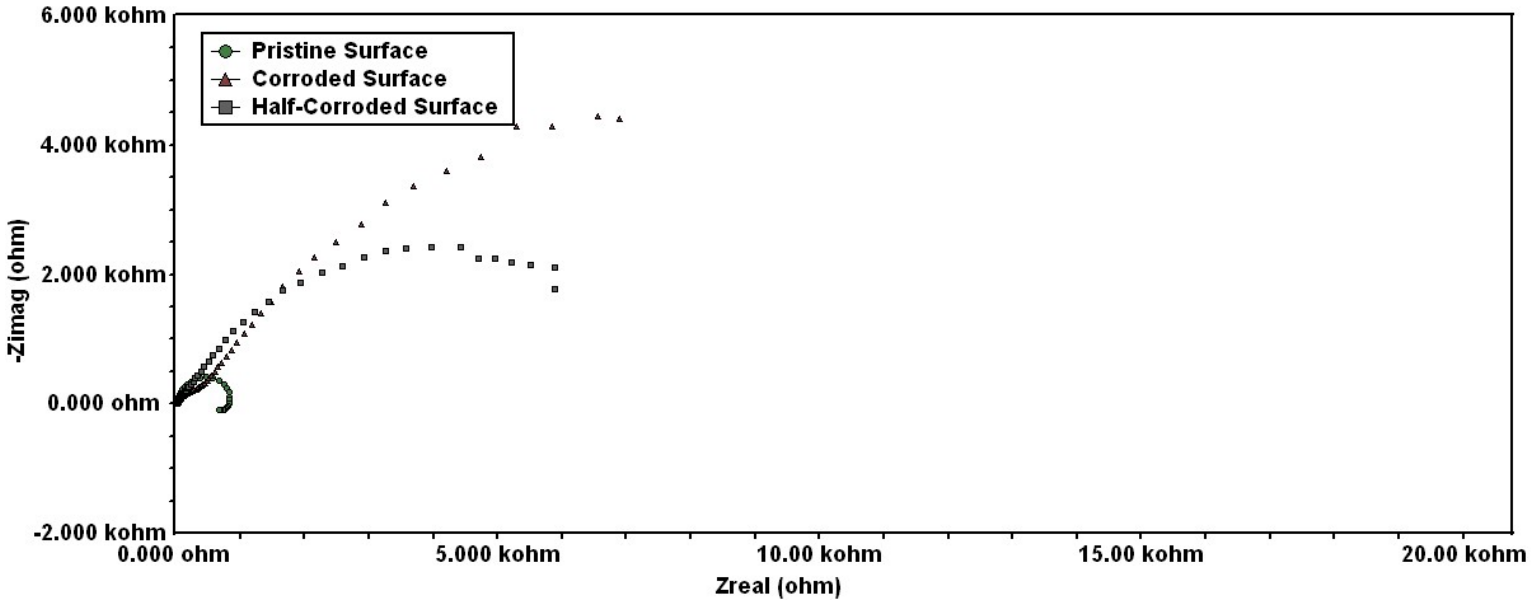
Tap Water Couplant Between the Sensor and Corroded Surface Feasible for Corrosion Severity





Summary

- A sensor and detection method has been shown based on reactive electrochemical impedance spectroscopy to detect hidden corrosion
- Distinct EIS spectrum were obtained on Al2024-T3 coupons between non-energized and energized (induced hydrogen evolution) modes for pristine and corroded samples
- Equivalent circuit models were used to regress parameters that could be used to indicate hidden corrosion on multi-layer samples
- Next steps are to refine the equivalent circuit models and detection algorithms

Acknowledgment

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