WestVirginiaUniversity
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DoE Award No. DE- FE0005717

Self-Powered Wireless-Ready Electrochemical Sensor For In-Situ Corrosion Monitoring of Coal-Fired A-USC Boiler Tubes

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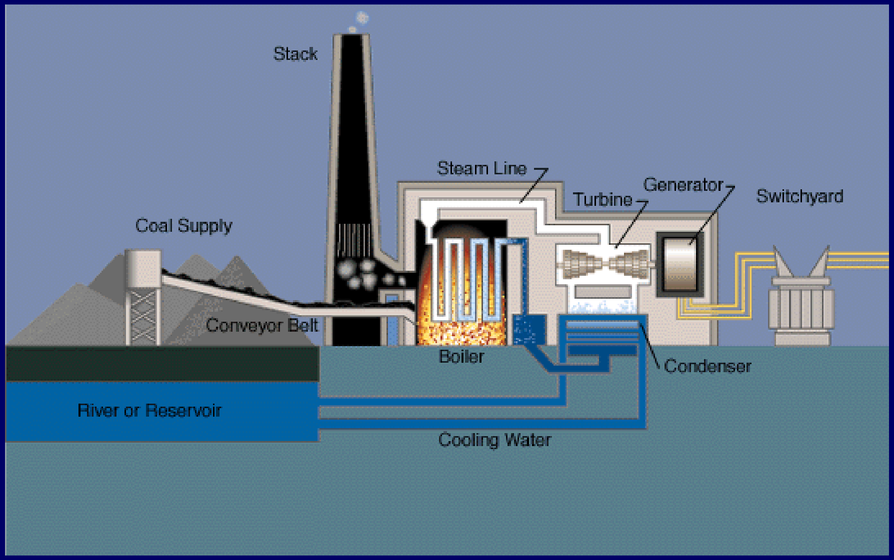
April 29, 2015

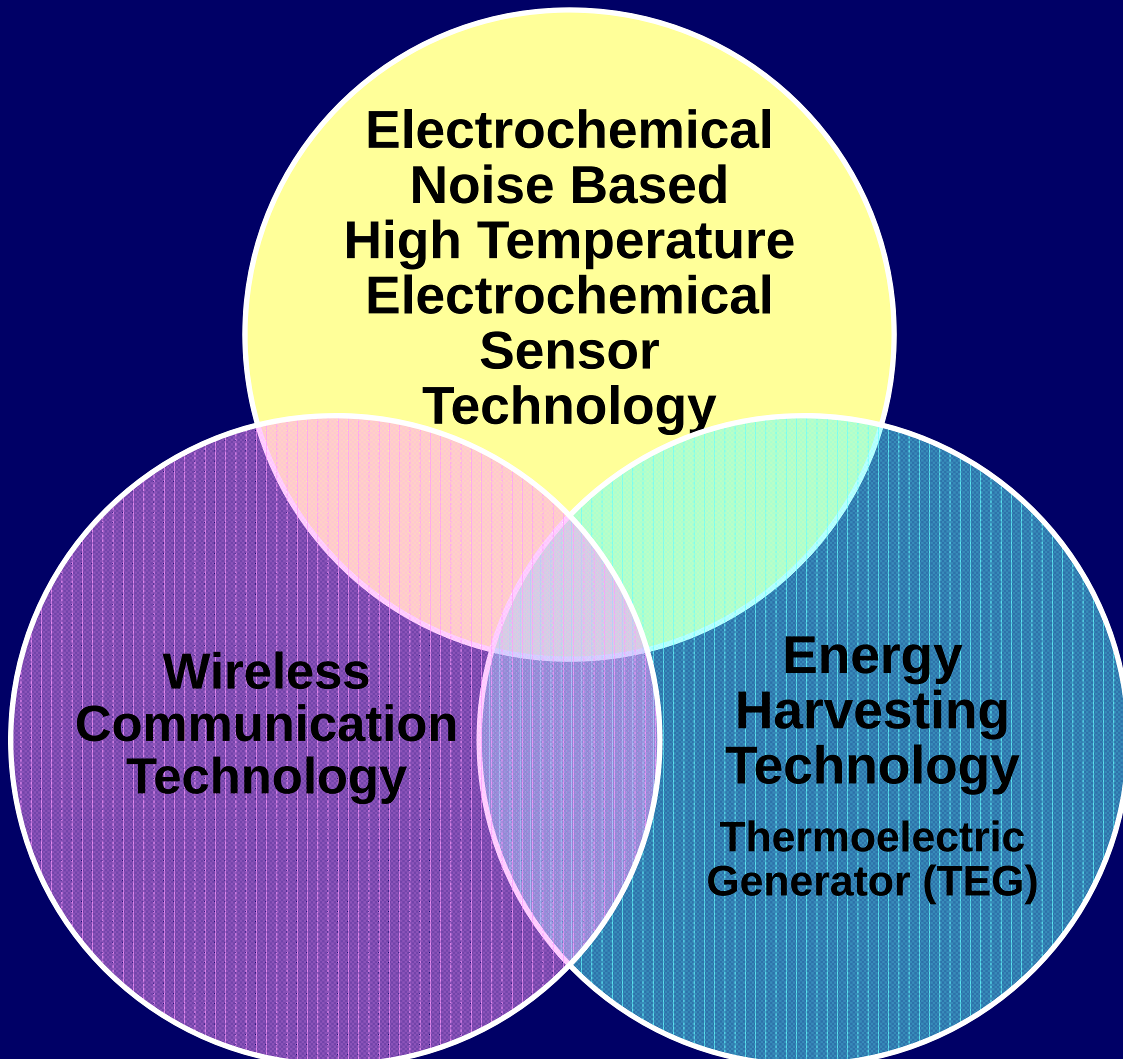
Project Objectives

- To develop a self-powered wireless high temperature electrochemical sensor for in situ monitoring hot corrosion under the harsh conditions present in coal-based power generation system

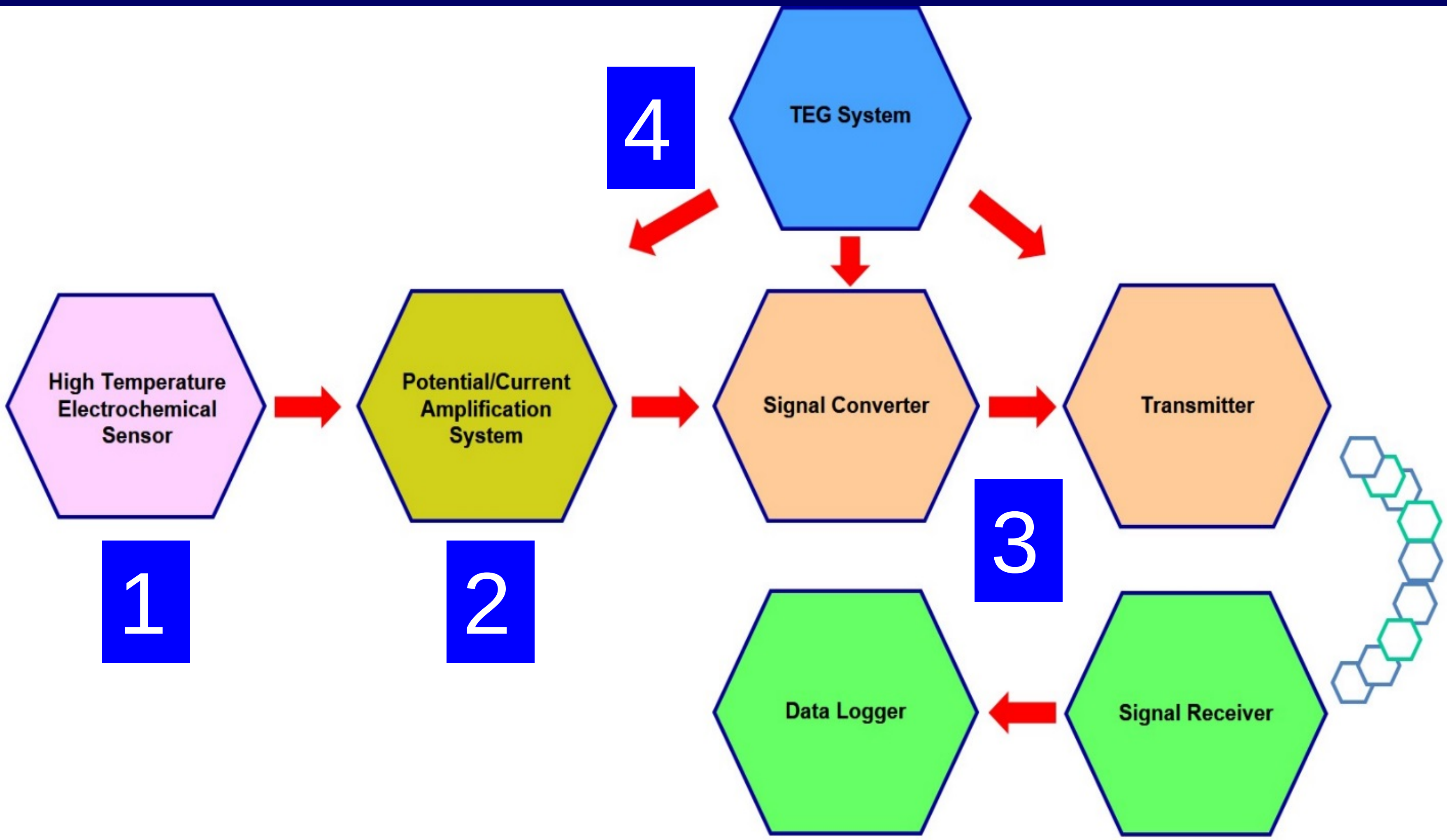


- To develop thermal-electric based energy harvesting and telecommunication devices for the self-powered wireless ready sensor system

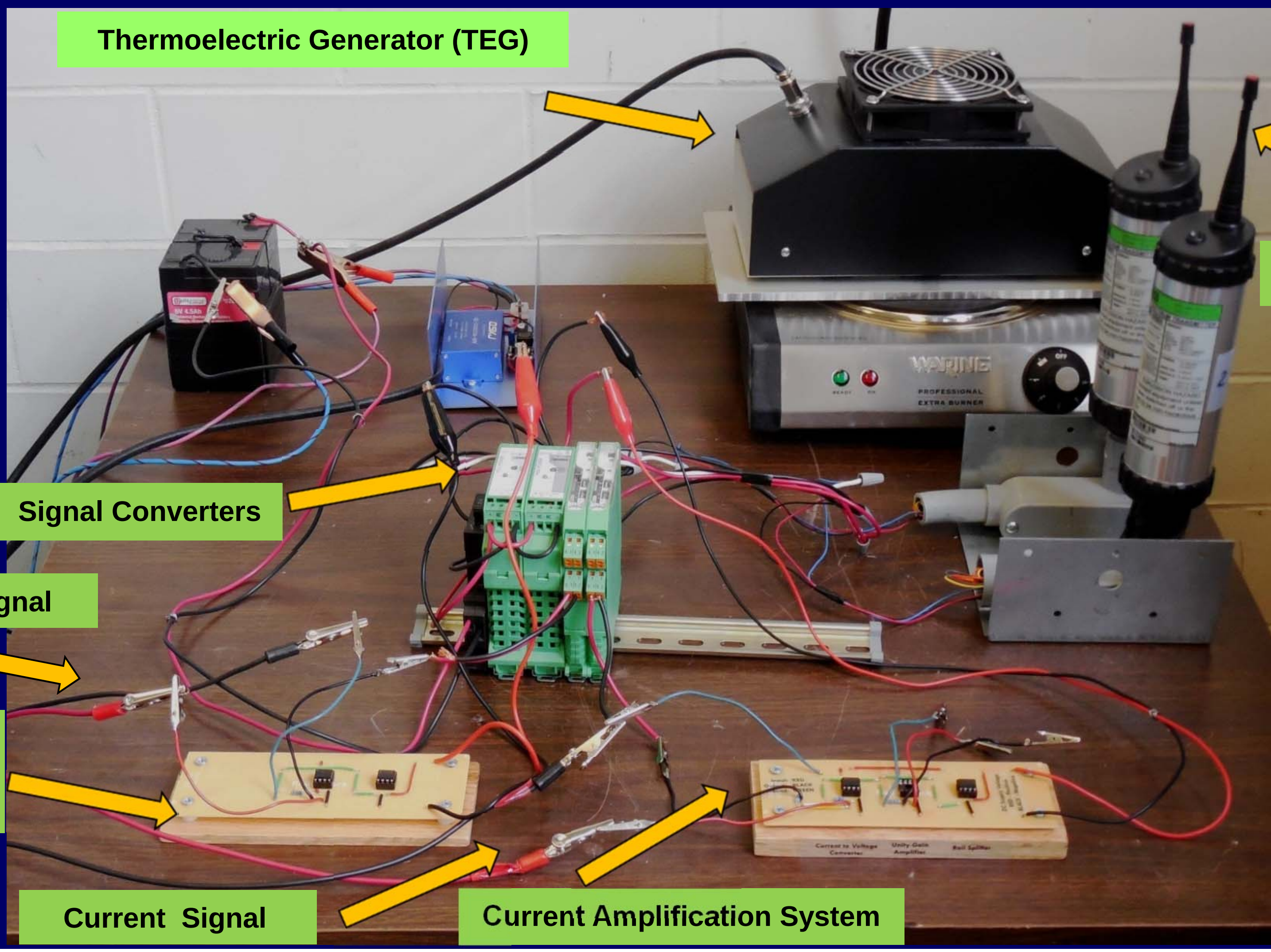
Key Innovations of the Project



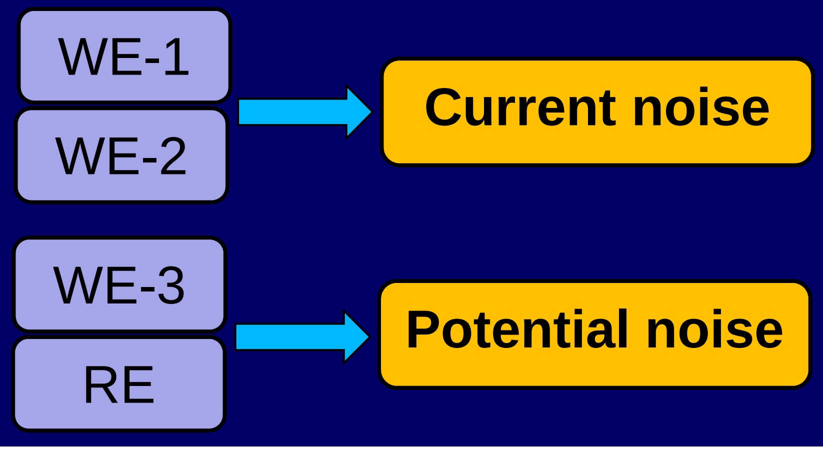
Conceptual Design of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor



Self-Powered Wireless Sensing System for Concurrent Potential and Current Signals Measurement



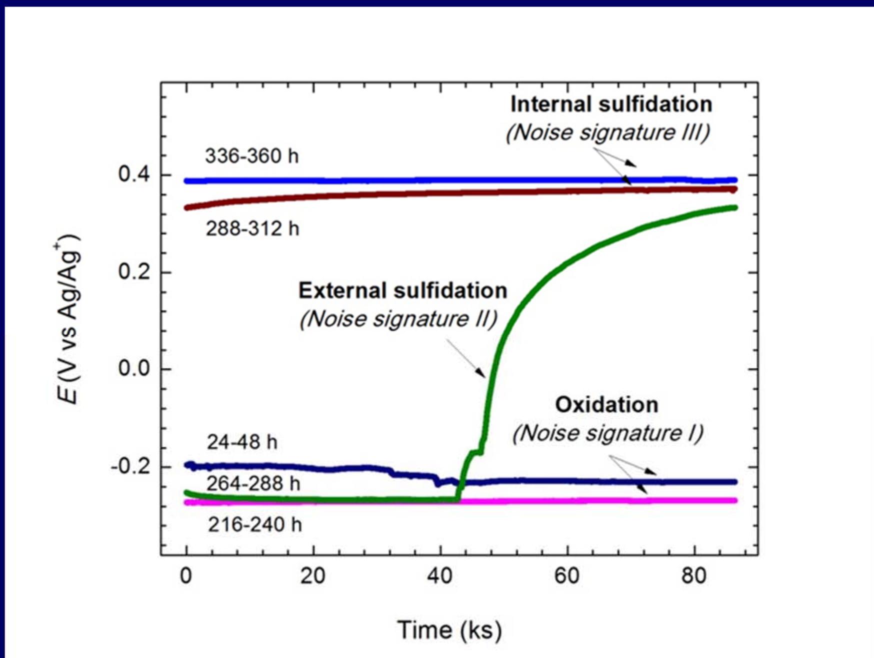
High Temperature Corrosion Sensor Design for Concurrent Potential and Current Signals Measurement

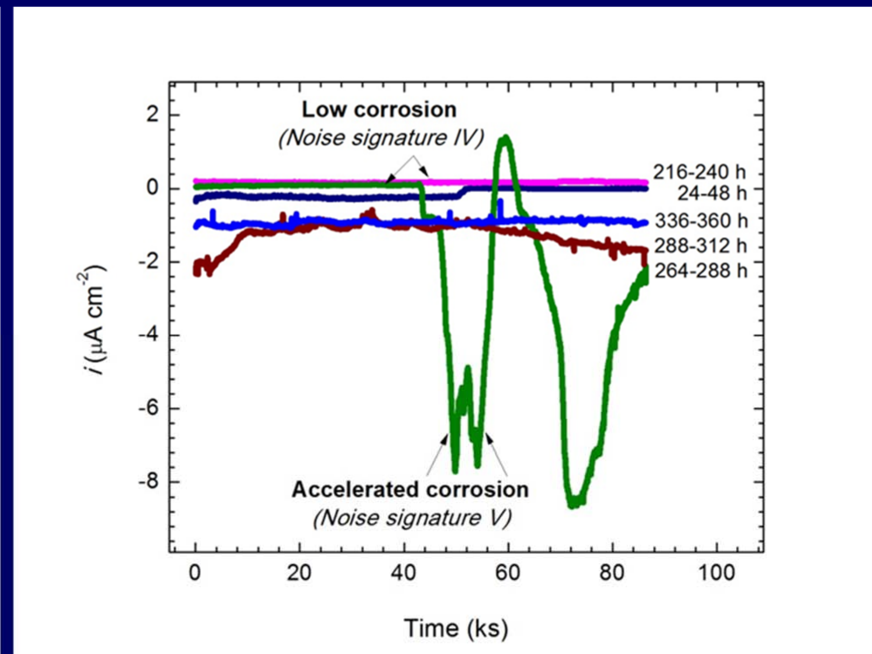


Experimental Conditions

Corrosion condition	
Materials	IN 740-1
Temperature	650-850°C
The Flue Gas Composition	With/without SO_2 15 CO_2 + 4 O_2 + 80 N_2 + 1 SO_2
Coal ash thickness	Uniform /Localized Thin film 89 % Ash +10% Alkali +1% NaCl
Exposure time	20 days

THREE Different Stages of Coal Ash Hot Corrosion Process





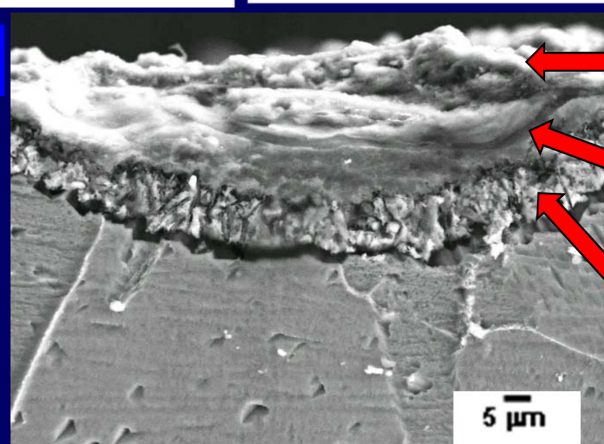
Coal Ash Hot Corrosion Process

Oxidation Stage

Sulfidation Stage

External

Internal

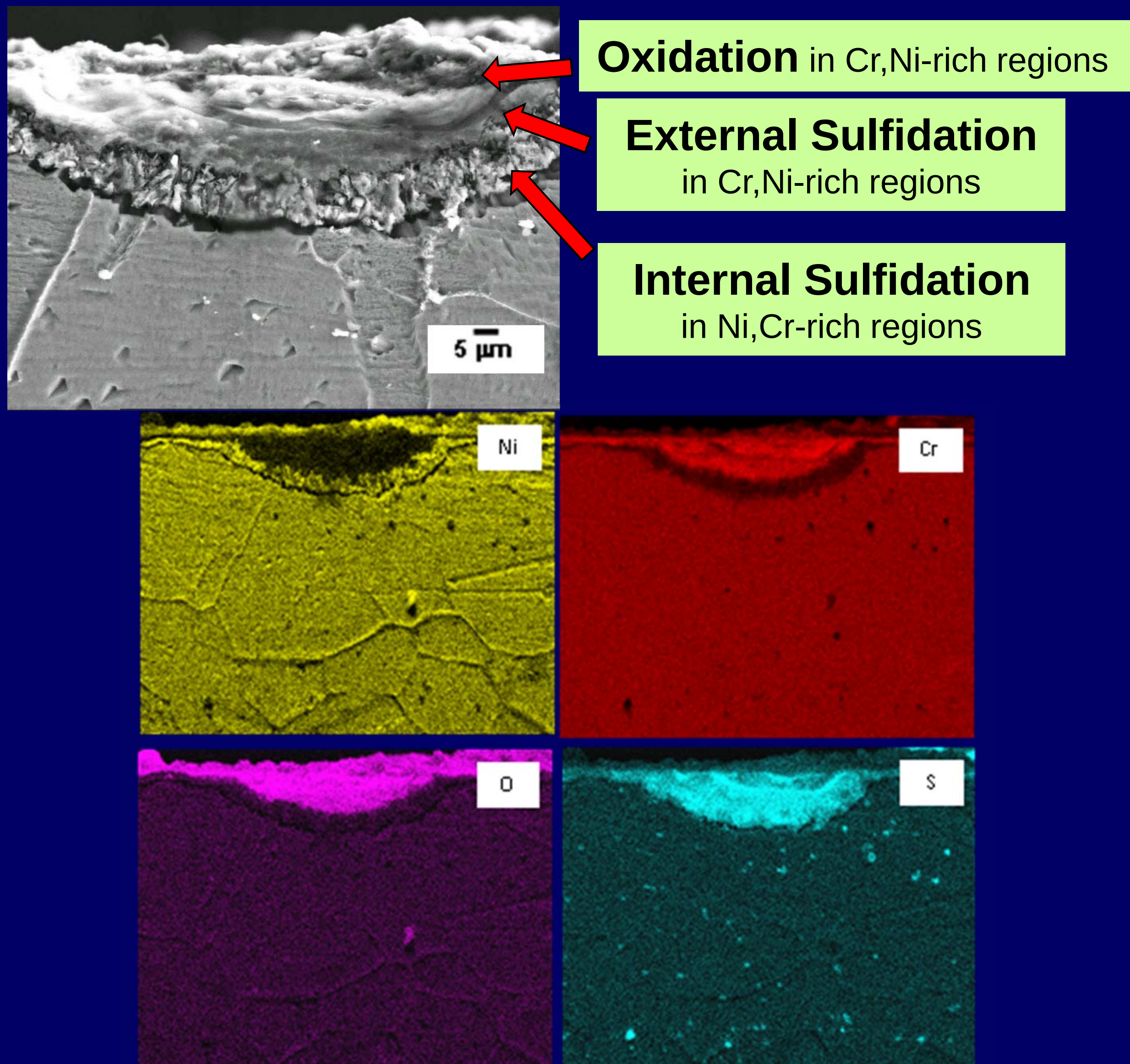


Oxidation in Cr,Ni-rich regions

External Sulfidation in Cr,Ni-rich regions

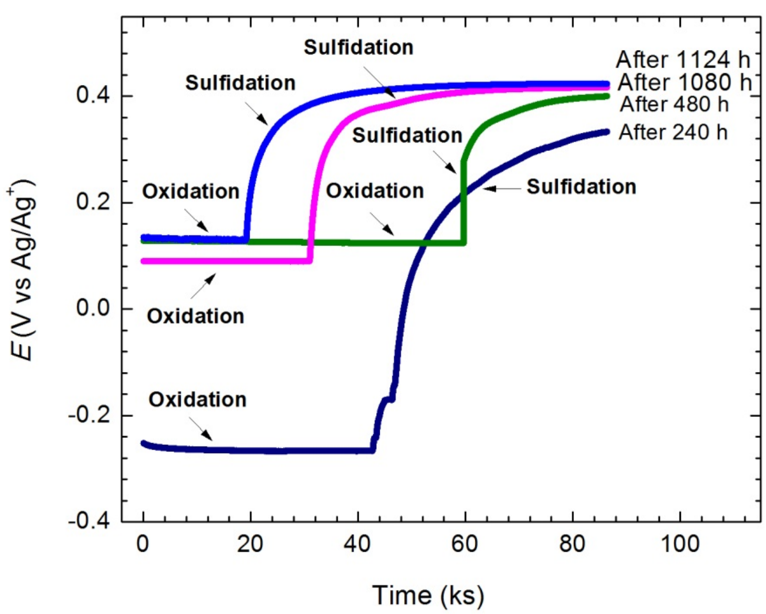
Internal Sulfidation in Ni,Cr-rich regions

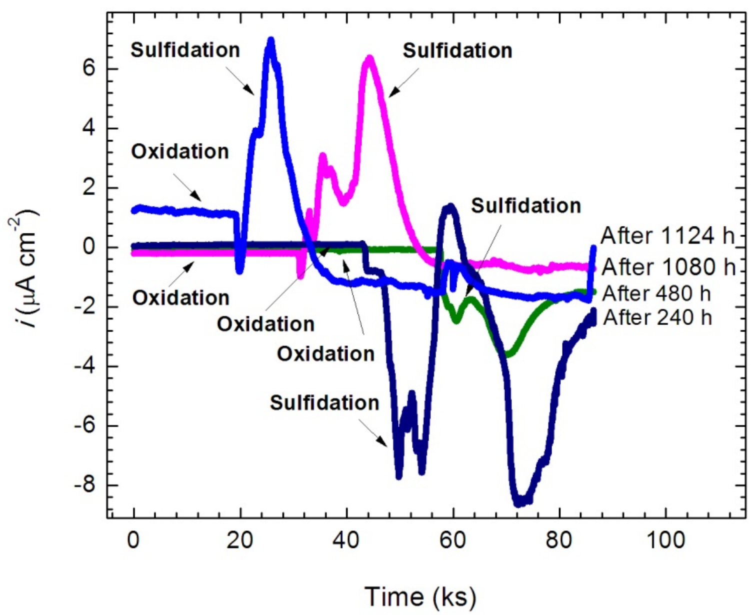
Oxygen and Sulfur Diffusion During Oxidation & Sulfidation Stages



Reproducibility of Potential and Current Signals During Oxidation and Sulfidation

IN 740-1 alloy + 850 °C + Thin coal ash + without /with SO_2





FIVE Typical Noise Signals Measured in the Coal Ash Hot Corrosion Process

Electrochemical Potential Noise Signals

- The noise signature of a gradual potential continuously changing in the negative region ***(Noise Signature I)*** corresponded with the Oxidation Stage
- The noise signature of quick potential continuously approaching more positive values ***(Noise Signature II)*** correlated to the External Sulfidation Stage.
- The noise signature of positive potential fluctuating randomly in a narrow range ***(Noise Signature III)*** corresponded with the Internal Sulfidation Stage

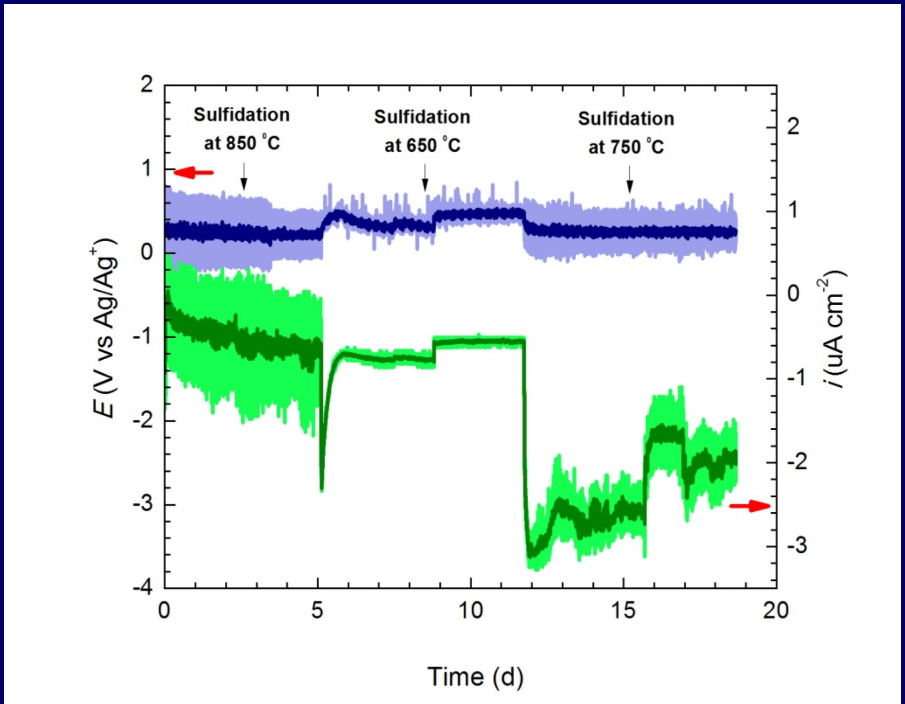
Electrochemical Current Noise Signals

signature of current fluctuating with no sudden spike correlated to the Low Extent of Oxidation/Sulfidation ***(Noise Signature IV)***.

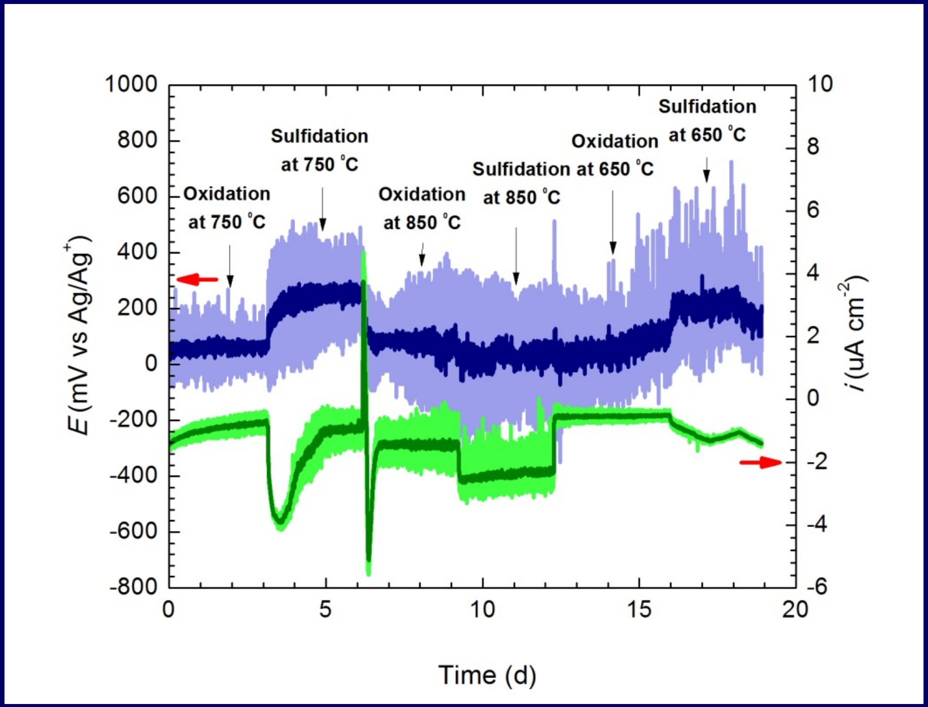
- The noise pattern of sudden change in current values followed by slow or no recovery corresponded with the Accelerated Oxidation/Sulfidation ***(Noise Signature V)***. These signatures can be seen clearly at 750 °C, in the flue gas without SO_2 as well as deep coal ash.

Concurrent Transmission of Corrosion Potential and Current Signals

Under Uniform Thin Coal Ash Film

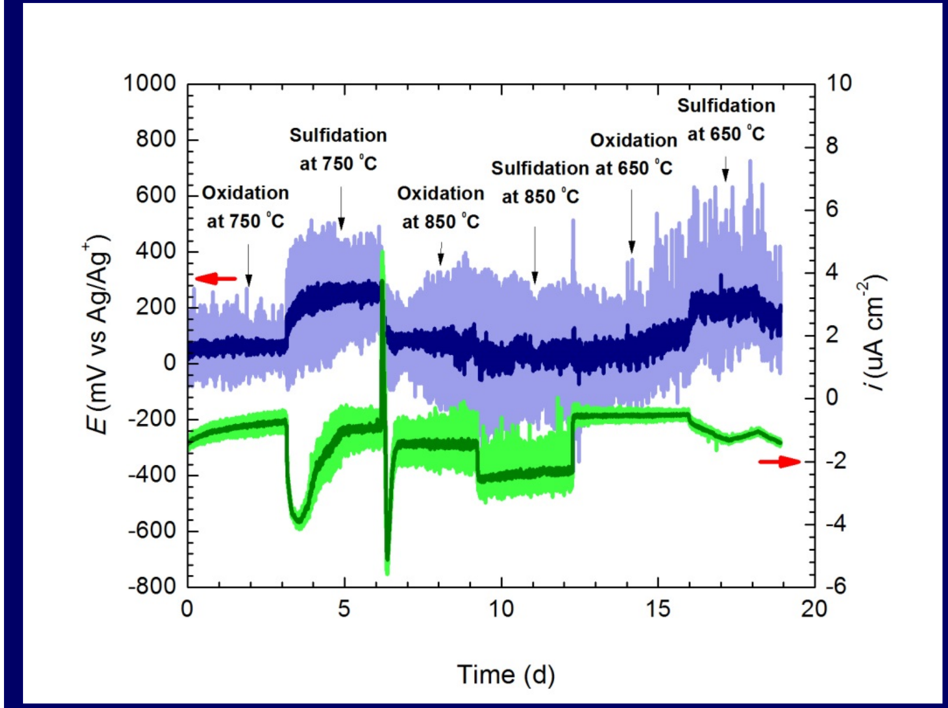


Under Localized Thin Coal Ash Film

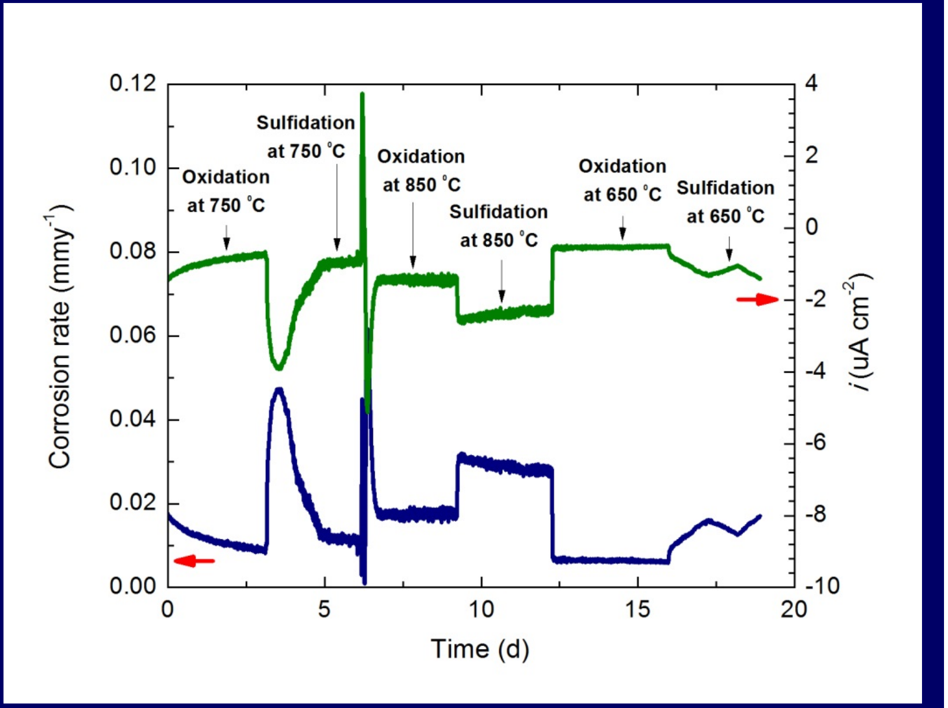


Calculation of Corrosion Rate from Current Noise Signals

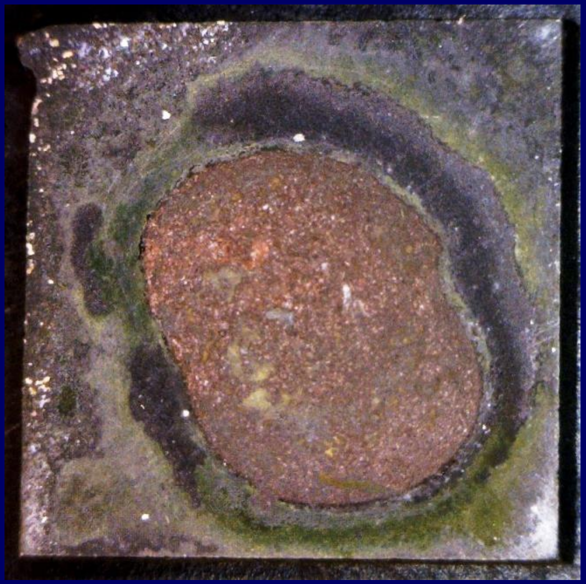
Corrosion Potential and Current



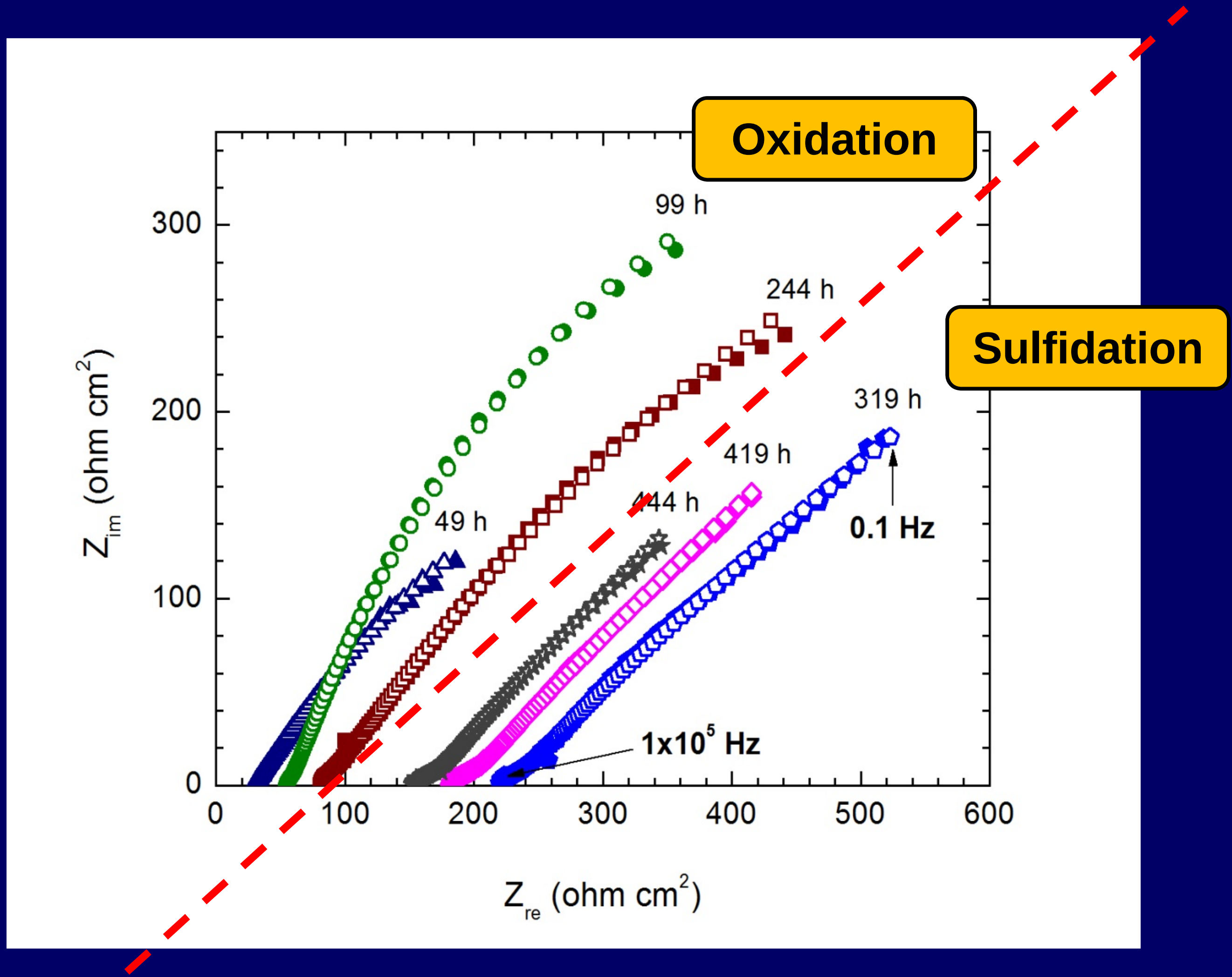
Corrosion Current and Corrosion Rate



Study of Localized Under-Coal Ash Deposit Corrosion (LUAC) using High Temperature Electrochemical Sensor

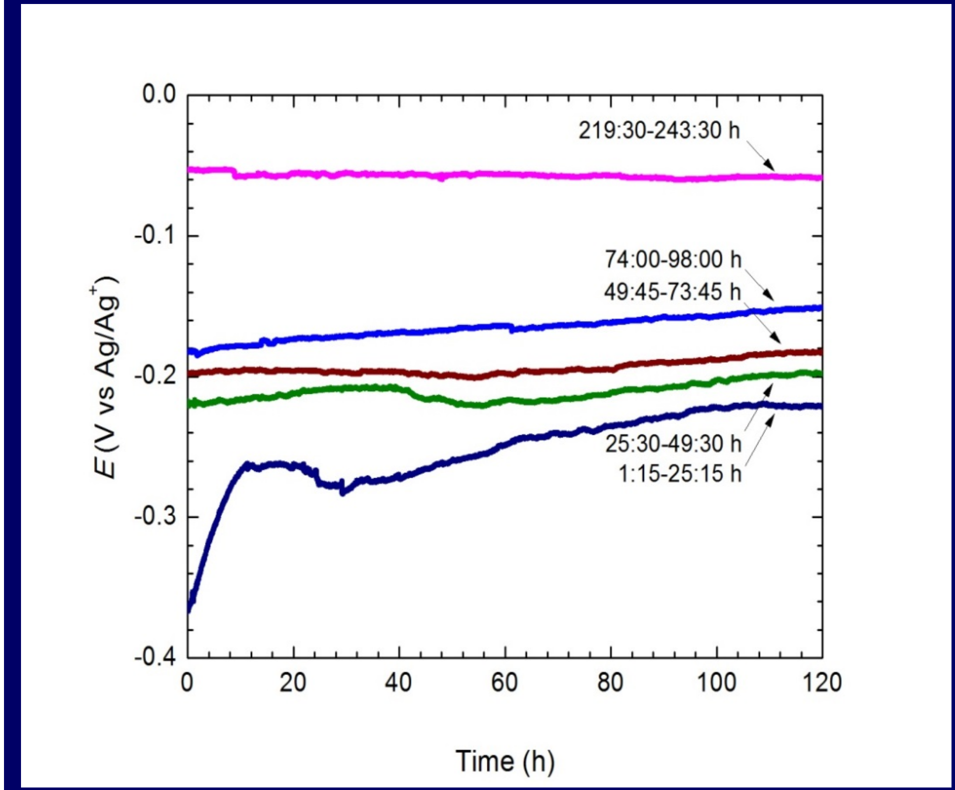


EIS Showing Oxidation and Sulfidation Stages During LUAC

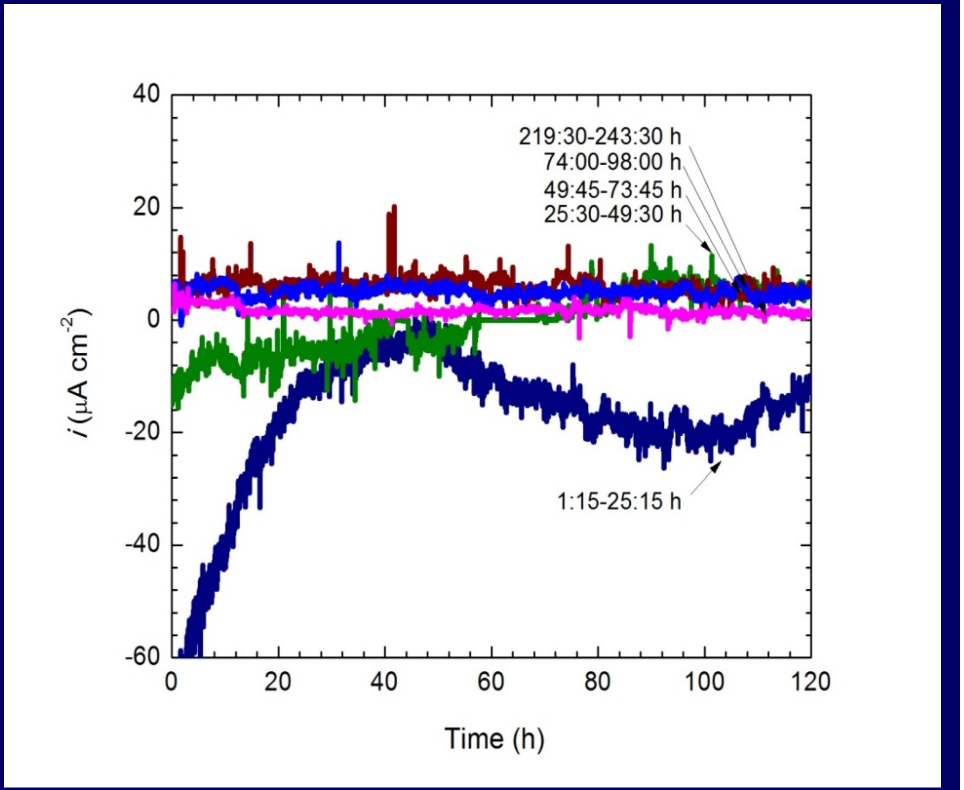


EN Data Showing Oxidation Stage During LUAC

Potential Noise Signal

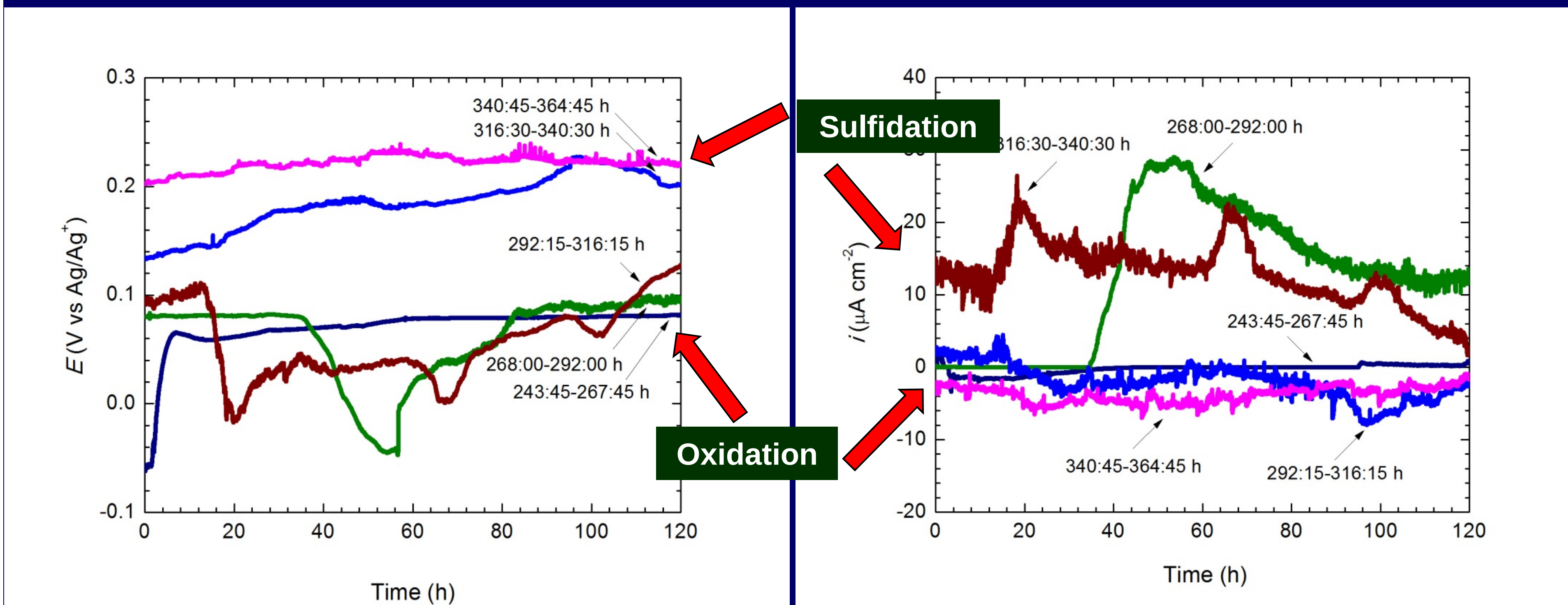


Current Noise Signal



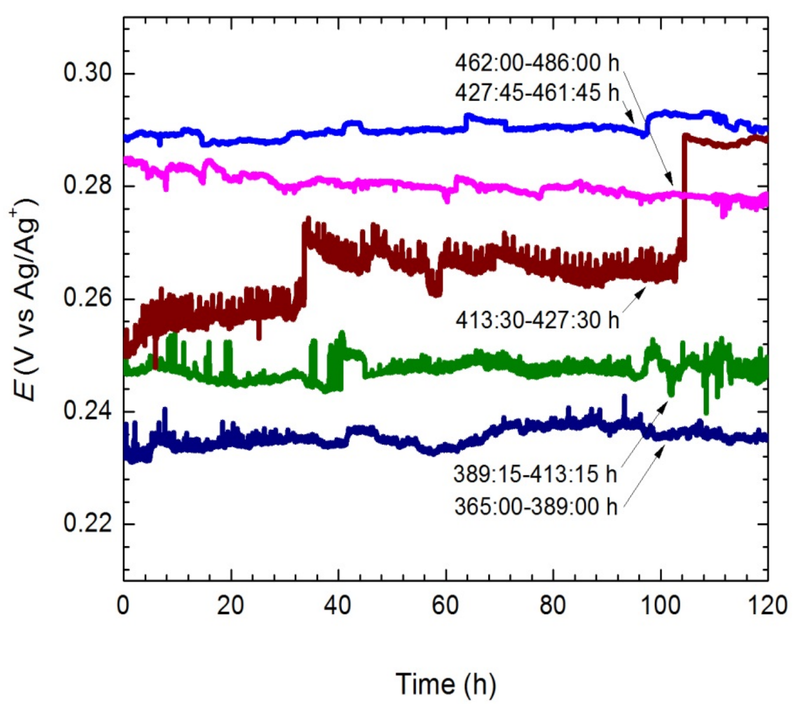
EN Data Showing Transition from Oxidation to Sulfidation Stages During LUAC

Potential Noise Signal | **Current Noise Signal**

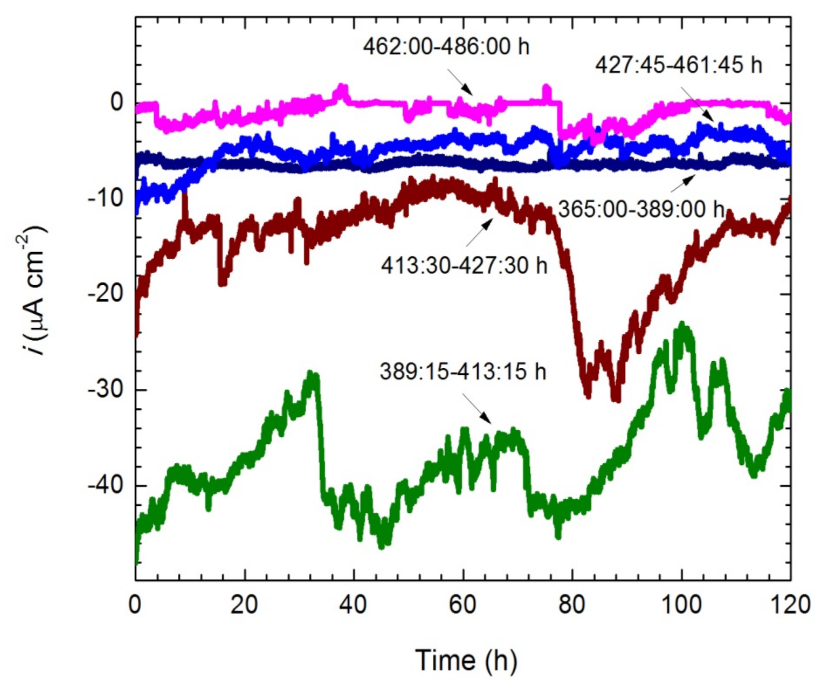


EN Data Showing Sulfidation Stage During LUAC

Potential Noise Signal



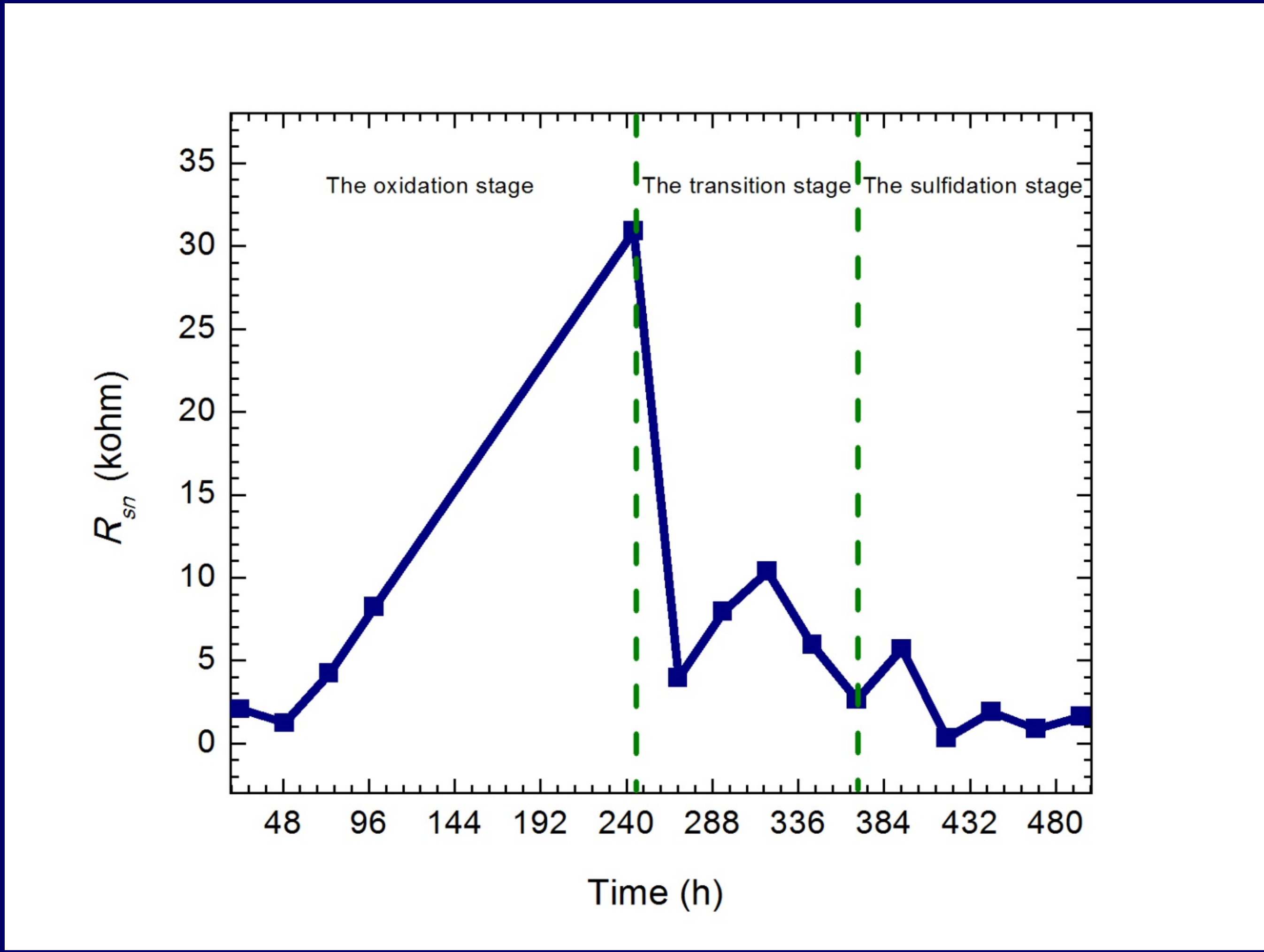
Current Noise Signal



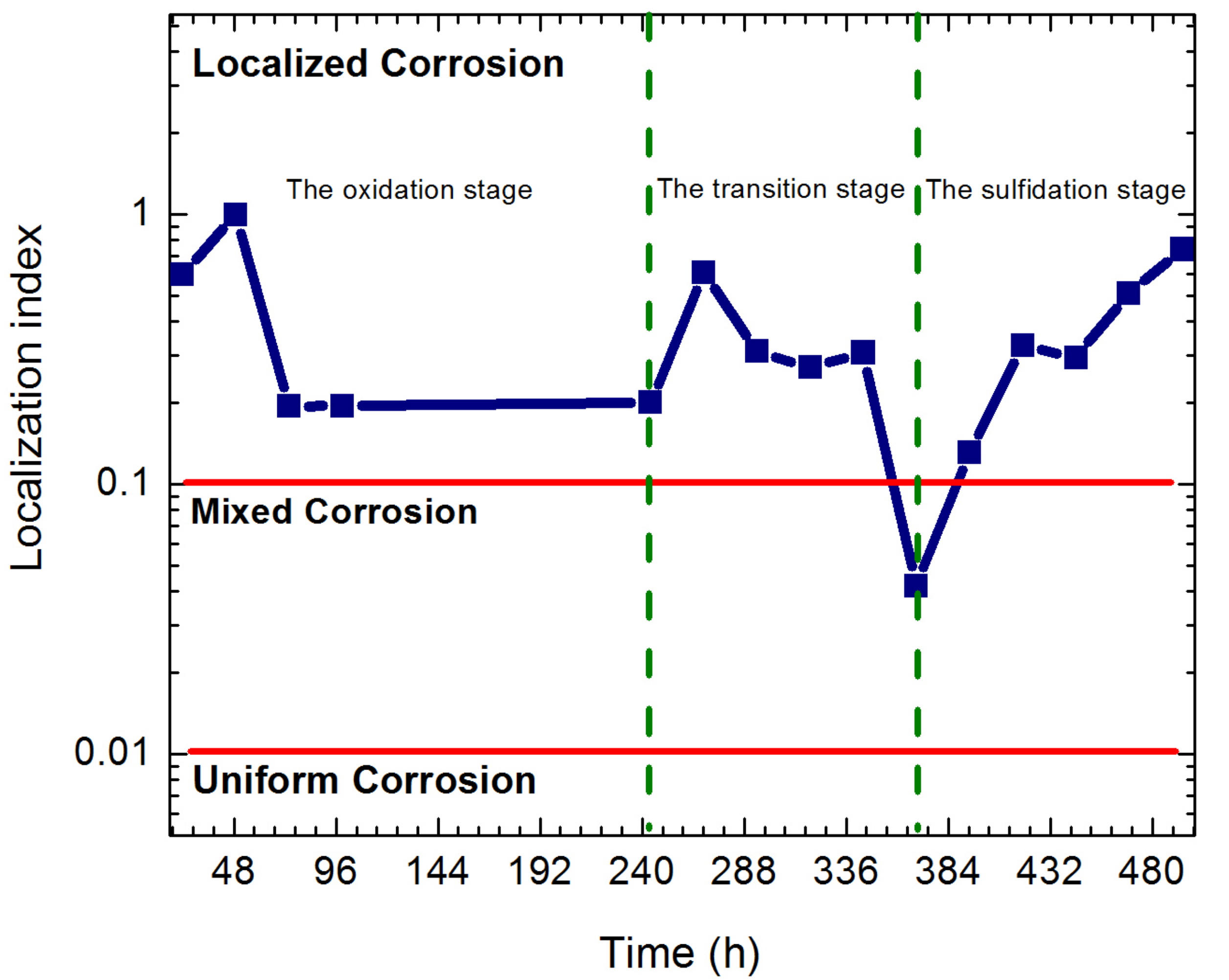
Three Different Stages of LUAC

- **The oxidation stage** was featured with the noise pattern of continuously changing potential approaching less negative values. The noise signature of current fluctuating with no sudden spike during oxidation indicates the low extent of corrosion.
- **The transition stage from the oxidation to sulfidation** was featured with the characteristic potential noise pattern of the continuous cyclic oscillations. In this stage, sulfidation initiated with significant increase of current.
- **The sulfidation stage** correlated to a characteristic noise signature of quick potential continuously approaching more positive values. The accelerated sulfidation can be evaluated with the noise signature of sudden change in current values followed by slow or no recovery.

Noise Resistance Values During LUAC



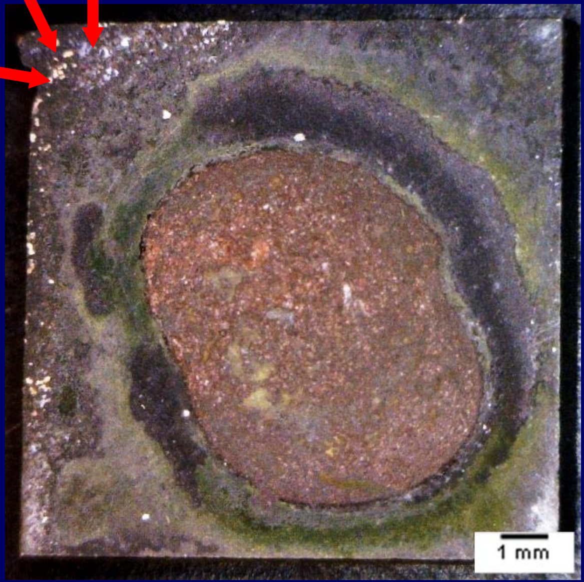
Localization Index During LUAC

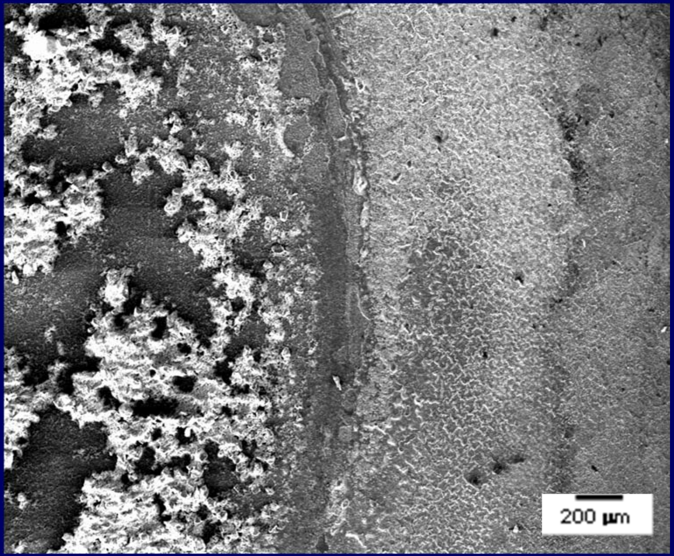


Corroded Surfaces of LUAC after 20 days

Oxidation

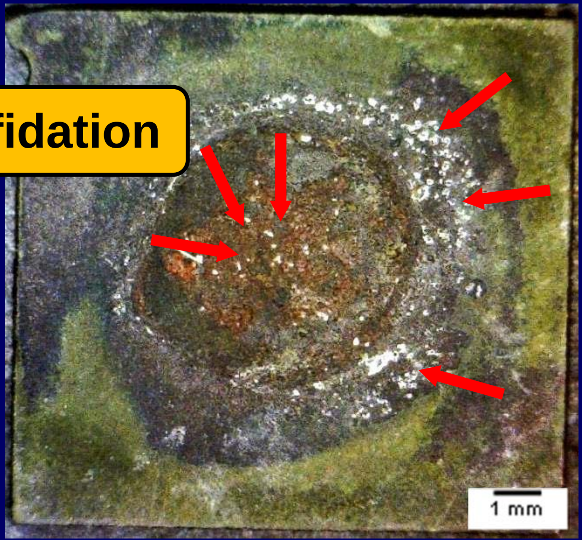
After 10 days

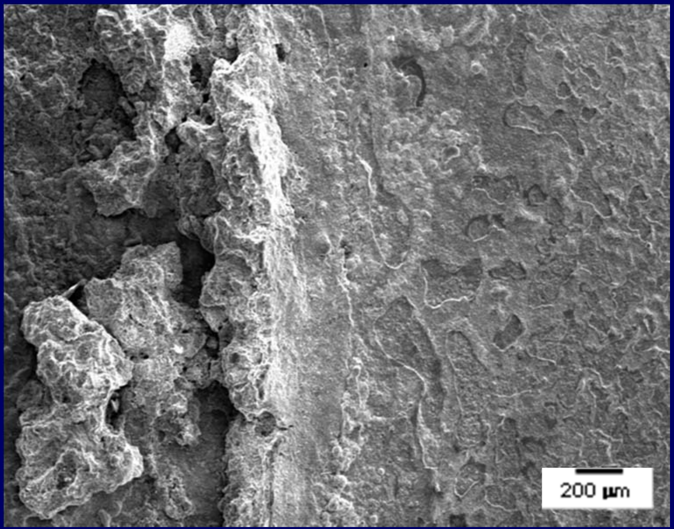




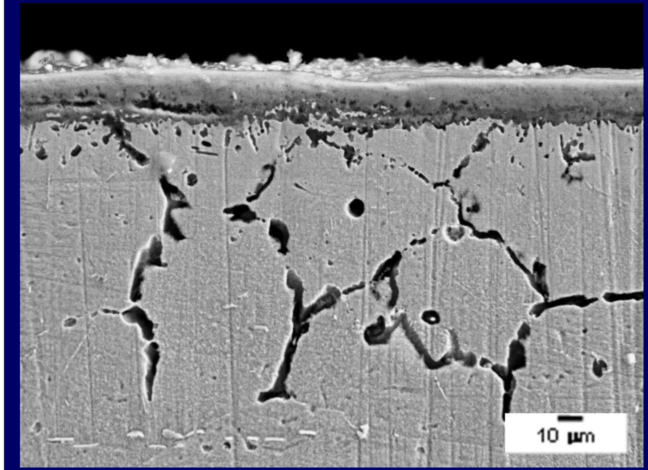
Sulfidation

After 20 days

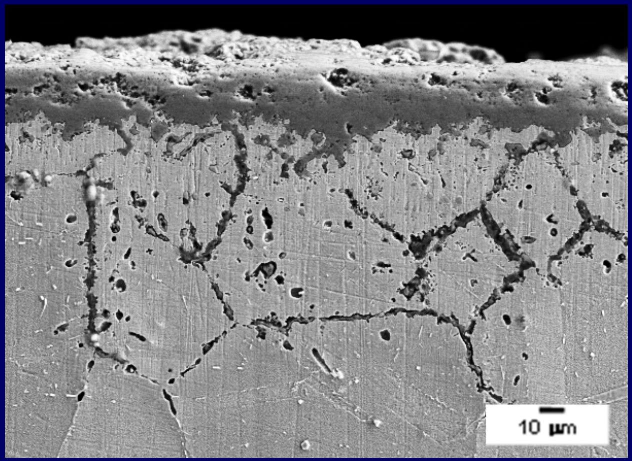




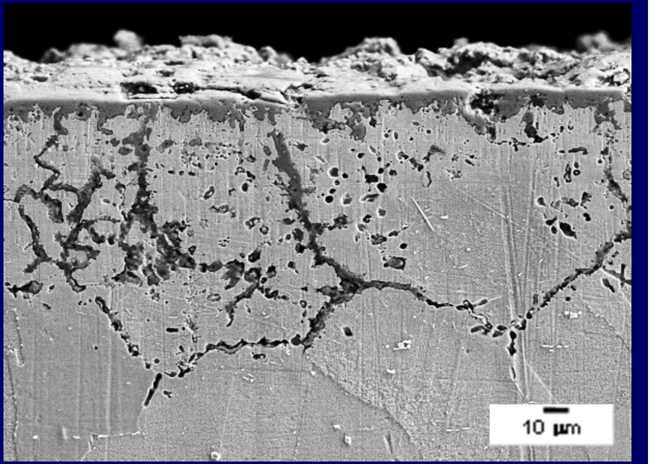
Cross Sectional Corroded Surfaces of LUAC after 20 days



Oxidation
under coal ash
uncovered area

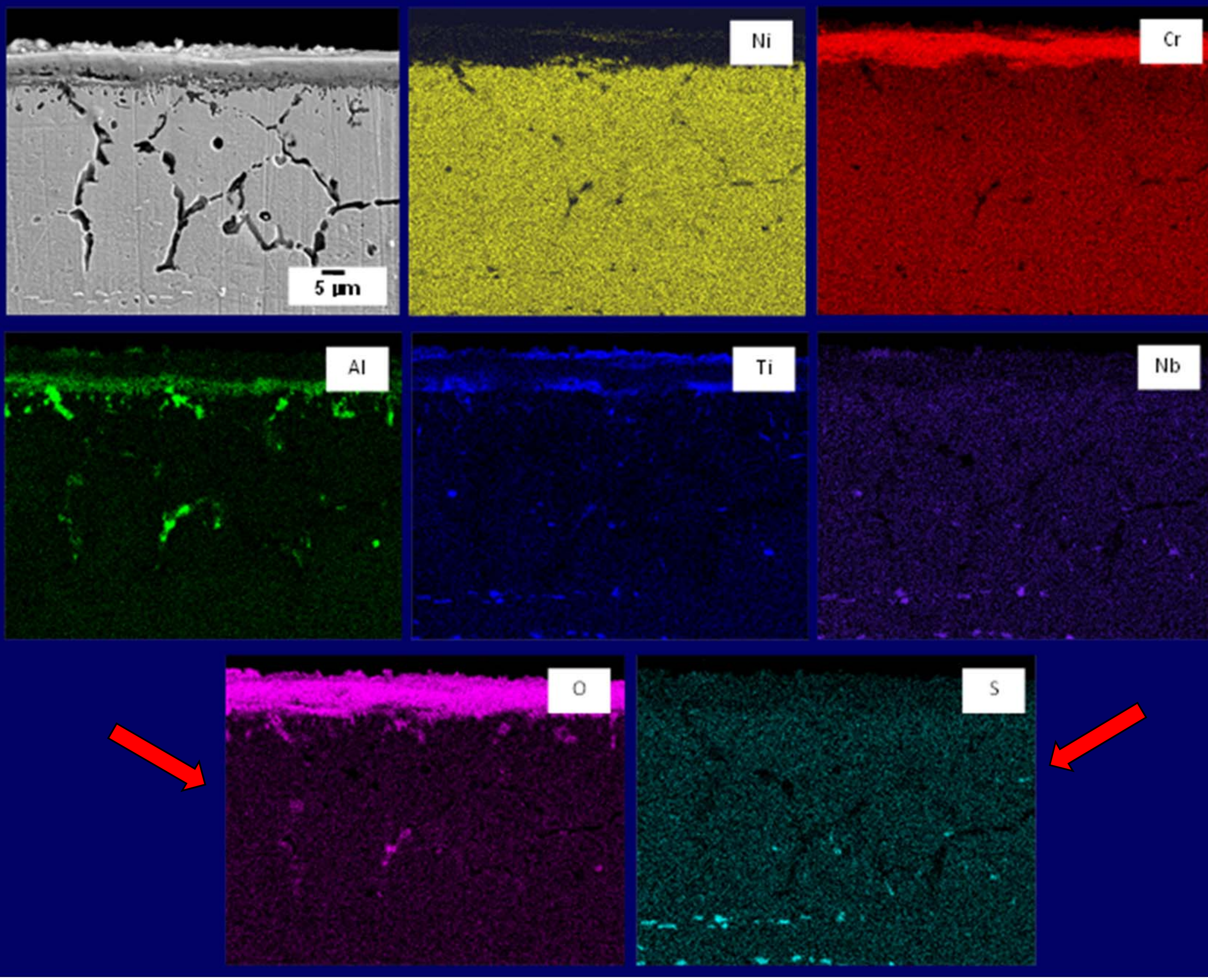


Sulfidation
under area between coal ash
uncovered and covered areas

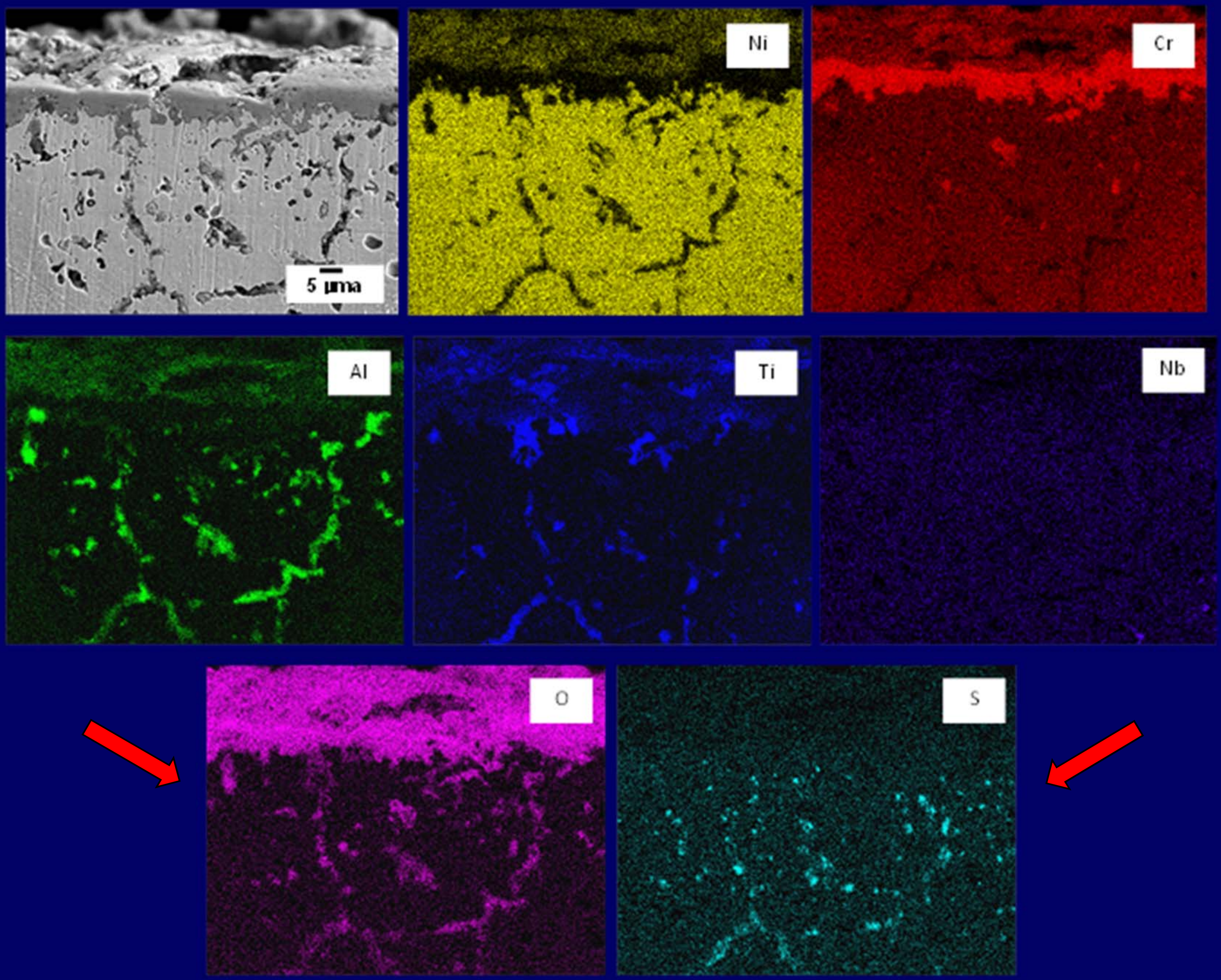


Sulfidation
under coal ash
covered area

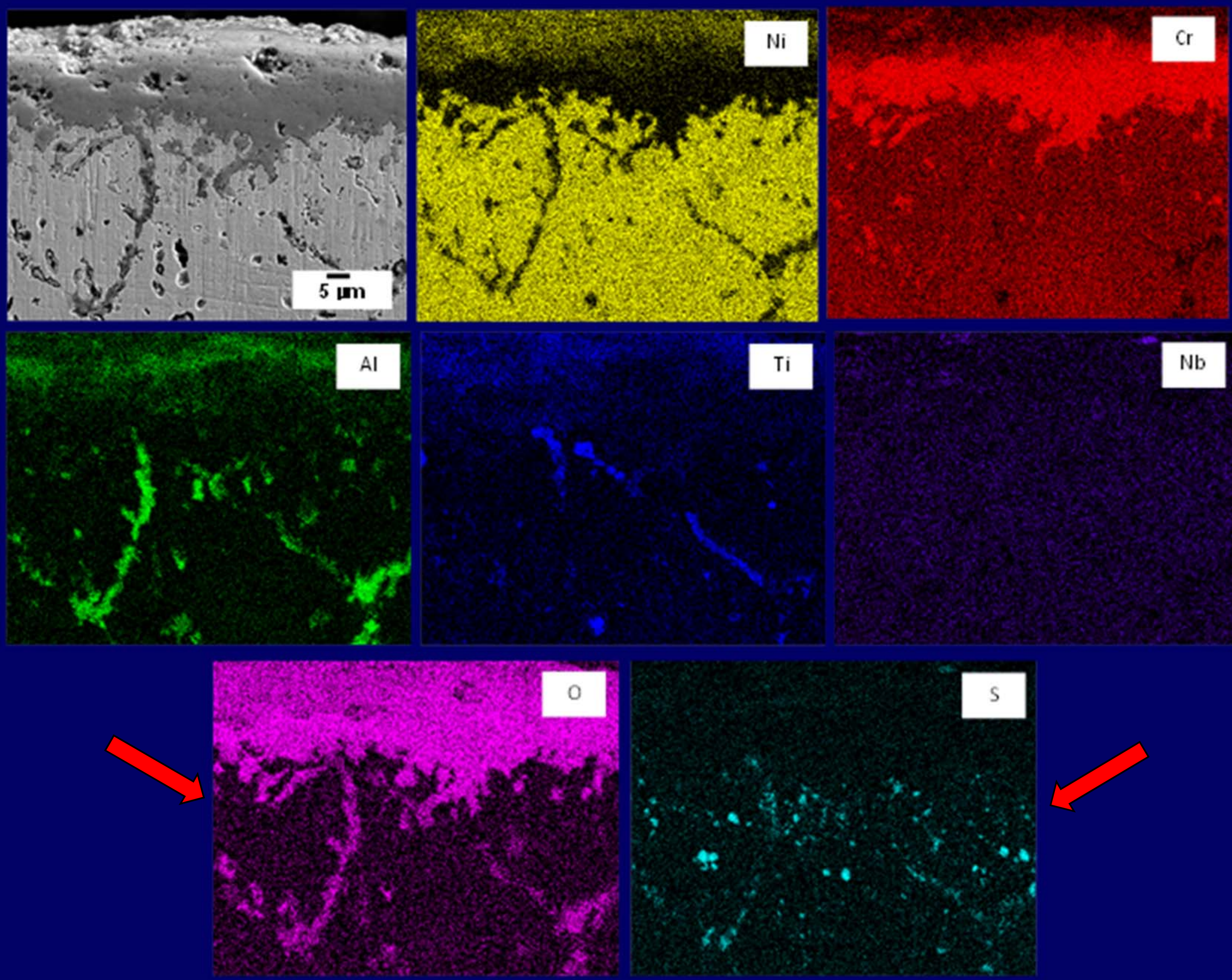
Oxygen and Sulfur Diffusion At Coal Ash-Uncovered Corroded Area



Oxygen and Sulfur Diffusion Near Coal Ash Covered Corroded Area



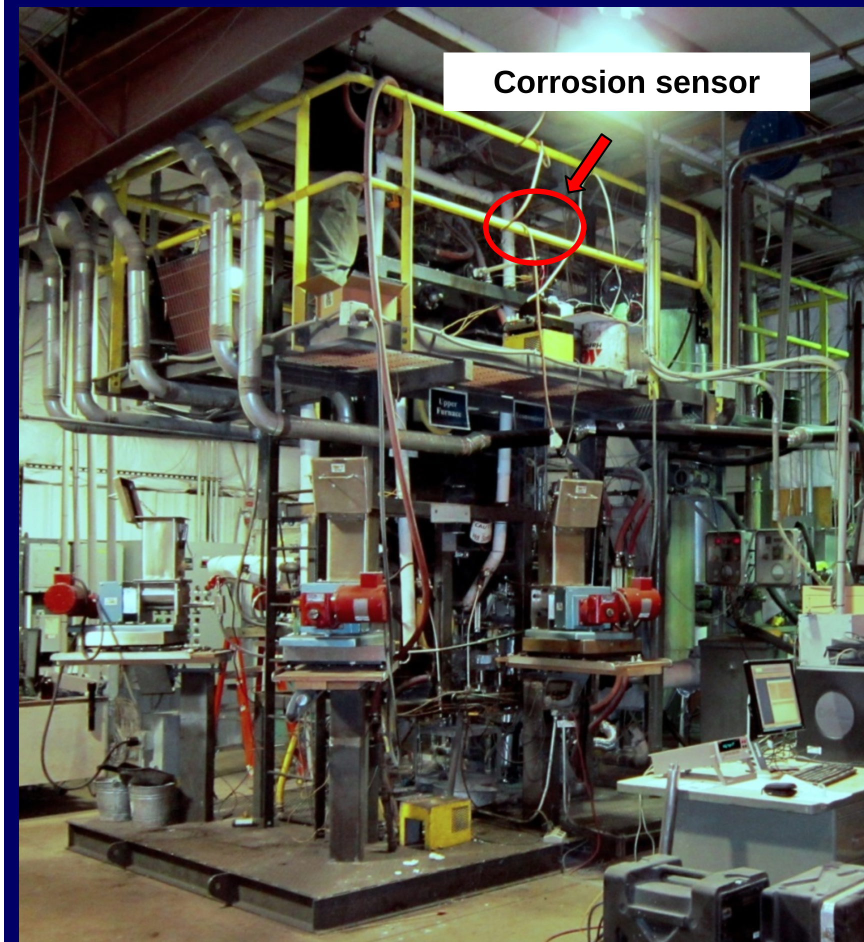
Oxygen and Sulfur Diffusion Inside Coal Ash-Covered Corroded Area



Testing Sensor in Industrial USC Boiler Setting

(Western Research Institute, Laramie WY)

Sensor Setting
Inside and Outside USC Boiler System
22 April 2015



Wireless Sensing System
for Concurrent Potential and Current Signals Measurement

Conclusions

- A self-powered wireless sensing system has been successfully developed for concurrent transmission of potential and current signals from coal ash hot corrosion.
- Characteristic patterns in the wireless concurrent potential and current noise signals can clearly identify the oxidation and sulfidation stages of coal ash hot corrosion process after data smoothing.
- Localized under- coal ash deposit corrosion behaviour of Inconel 740 superalloy was studied using the sensor. The predominant stages during the LUDC process can be identified with three typical potential noise patterns and their extents of the corrosion can be evaluated with two characteristic current noise patterns.
- Analysis of electrochemical noise signals by power spectral density (PSD) was applied to coal ash hot corrosion study. PSD plots using coefficient 1000 of MEM show more reasonable information for mechanism of the oxidation and sulfidation processes.

Journal Publications

1. Naing Naing Aung, Xingbo. Liu, High temperature electrochemical sensor for in situ monitoring of hot corrosion, Corros. Sci. 65 (2012) 1-4.

2. Naing Naing Aung, Xingbo Liu, Effect of SO_2 in flue gas on coal ash hot corrosion of inconel 740 alloy-a high temperature electrochemical sensor study, Corros. Sci. 76 (2013) 390-402.

3. Naing Naing Aung, Xingbo Liu, Effect of temperature on coal ash hot corrosion resistance of inconel 740 superalloy, Corros. Sci. 82 (2014) 227-238.

4. Naing Naing Aung, Edward Crowe, Xingbo Liu, Development of Self-Powered Wireless-Ready High Temperature Electrochemical Sensor for In Situ Corrosion Monitoring in Coal-Fired Power Plant, ISA Trans. 55 (2015) 188-194.

5. Naing Naing Aung, Xingbo Liu, In situ monitoring coal ash hot corrosion using the combined high temperature electrochemical sensor with ENA method, Corros. Sci (Under review).

6. Naing Naing Aung, Xingbo Liu: Study of local under-coal ash deposit corrosion of Inconel 740 alloy using high temperature electrochemical sensor, Corrosion (Under review)

Acknowledgements

DoE-NETL: Bob Romanosky, Susan Maley, Chuck Miller, Paul Jablonski

WRI: Don Collins, Vijay Sethi

Special Metals Corp.: John J. deBarbadillo

ILZRO: Frank Goodwin

Thank You