# *High Performance Corrosion Protection for Commercial Stainless Steels*

**Presented to:**


***Matthew M. Seabaugh, Ph.D***
***Director***
**June 2, 2015**

YOUR MATERIALS INNOVATION TEAM

# Overview of Presentation

- Nexceris Introduction
- Potential of Coating Technology
- Overlay Coatings
- Diffusion Coatings
- Emerging Technologies

# COMPANY OVERVIEW

# What We Do

Power Generation

Refining

Natural Gas Appliances

Near Term Products

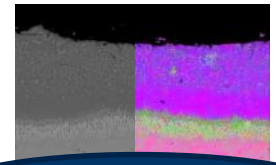
Assess Technology Fit to Existing Markets

Cutting Edge Materials Research

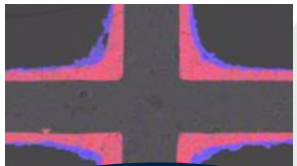
Natural Gas Appliances

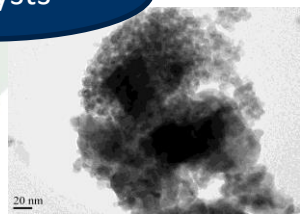
Exhaust Cleanup

Natural Gas Compression



Corrosion Protection

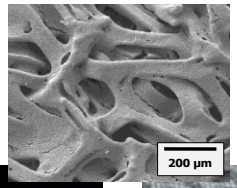


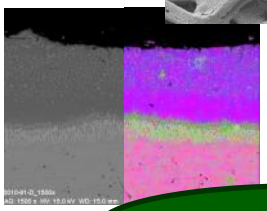


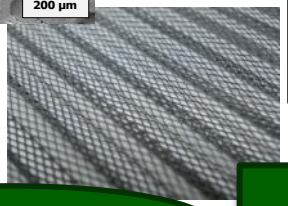

Catalysts

# How We Work with Customers

**We Are Seeking:**
- Partners to Develop New Products
- Partners to Reach Target Markets
- Collaborative Solution Development for Specific Markets or Customers

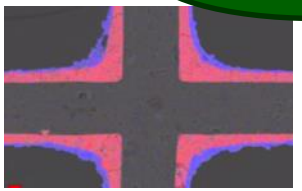


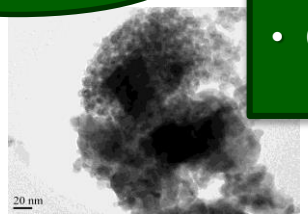





Corrosion Protection

Catalysts





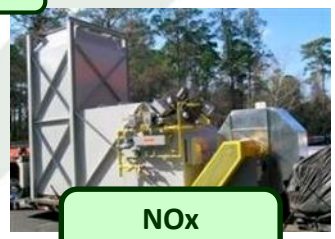

**We Provide Unique and Proprietary:**
- Coating Capability
- Coating Technology & Know-How
- Catalyst Designs
- Catalyst Formulation & Mfg.

Power Generation

Natural Gas Appliances

Refining

VOC Abatement



NOx Abatement

# Need for Coating Technologies

## Coatings Allow Better Materials Design:

- Alloy Selection to Meet Application-Critical Criteria
  - Mechanical Strength
  - Electrical Conductivity
  - Thermal Conductivity
  - Cost
- Surfaces are Tailored to Create Additional Value:
  - Corrosion Resistance
  - Catalytic Function
  - Electrical Function
  - Appearance

# Coating Technologies

## We Divide High Temp Coatings into Two Categories:

- Overlay Coatings
  - Metal or Ceramic Coating on Top of Substrate
    - Examples:  Catalytic Reactors, Electrical Components
  - Plasma Spray
  - Physical or Chemical Vapor Phase Growth
  - *Spray and Heat Treat*
- Diffusion Coatings
  - Metal or Ceramic Coating Evolves From Support Alloy
    - Examples Aluminides, Carbides, Nitride Coatings
  - Vapor Phase/Vacuum Treatments
  - Plating and Heat Treat in Controlled Atmosphere
  - *Atmospheric Spray and Heat Treat*

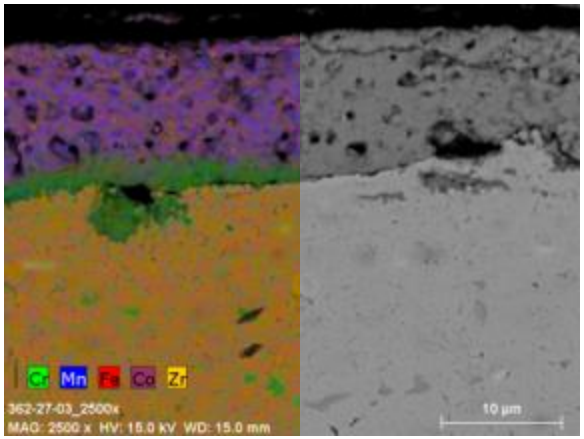
# TECHNOLOGY OVERVIEW

# Overlay Protective Coatings

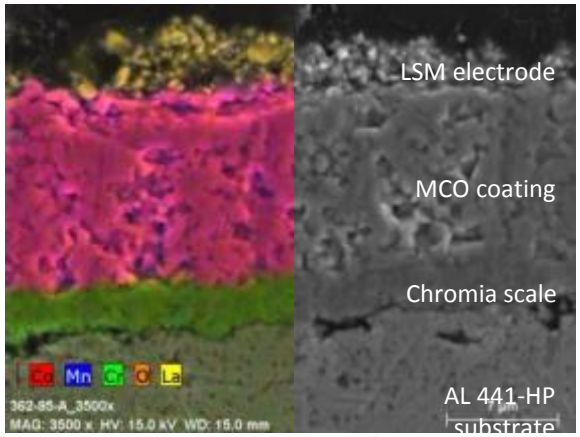
Process Characteristics

- Designed for ferritic stainless steel
- Reduces Cr volatility
- Electrical conductivity can be tailored
- Coatings for oxidizing and reducing atmospheres

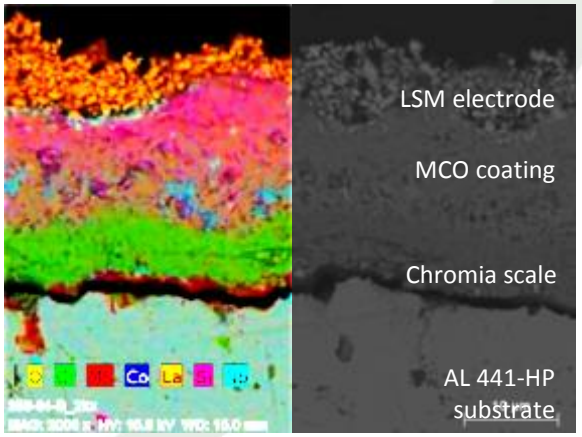
**After Deposition**



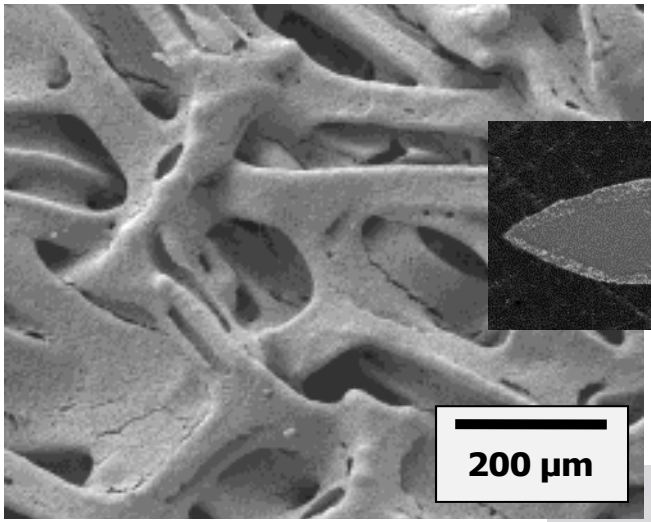

**800 hrs 800 °C**

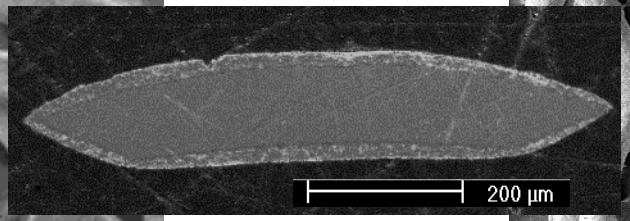


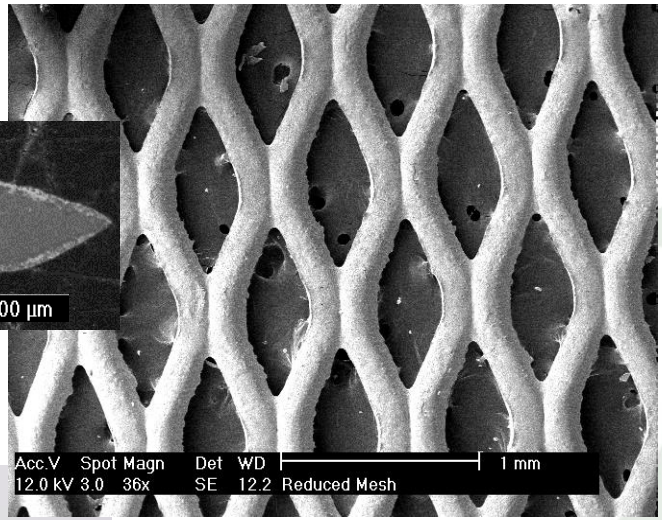

**> 7000 hrs 800 °C/900 °C**

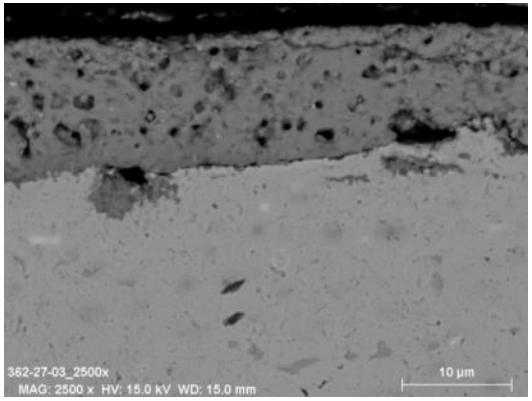


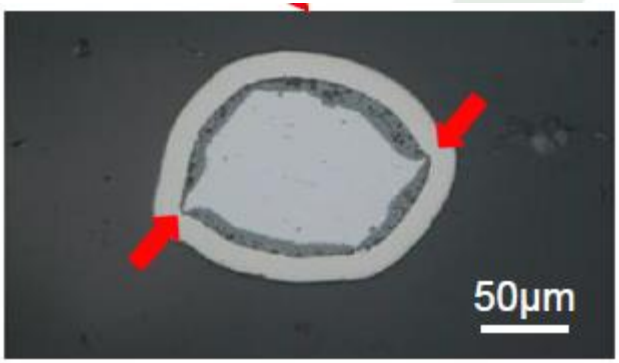
# Overlay Coatings on Complex Metal Surfaces



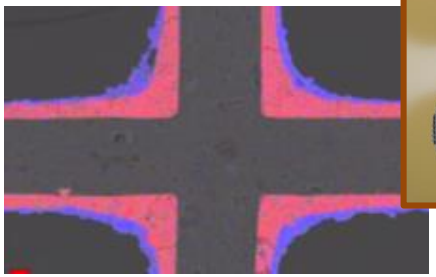



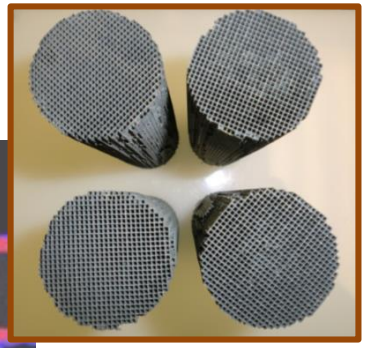



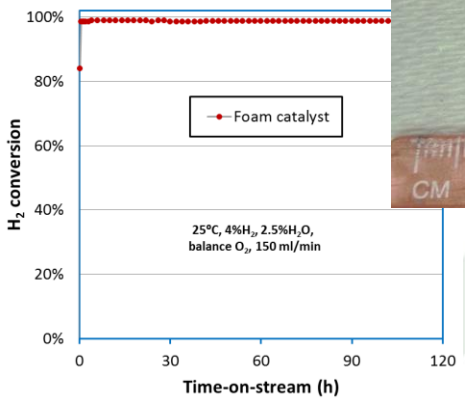



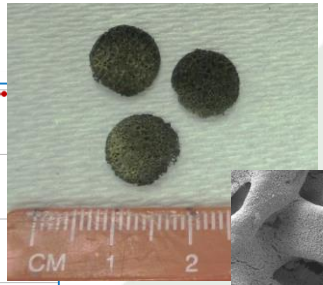
# Overlap and Integration with Heterogeneous Catalysis

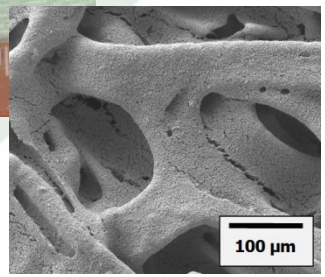
- High Temperature Chemical Reactors
- VOC Oxidation for Stationary Industrial Systems and $H_2$ abatement systems for advanced Batteries
- Fuel Reforming and SMR Reactors







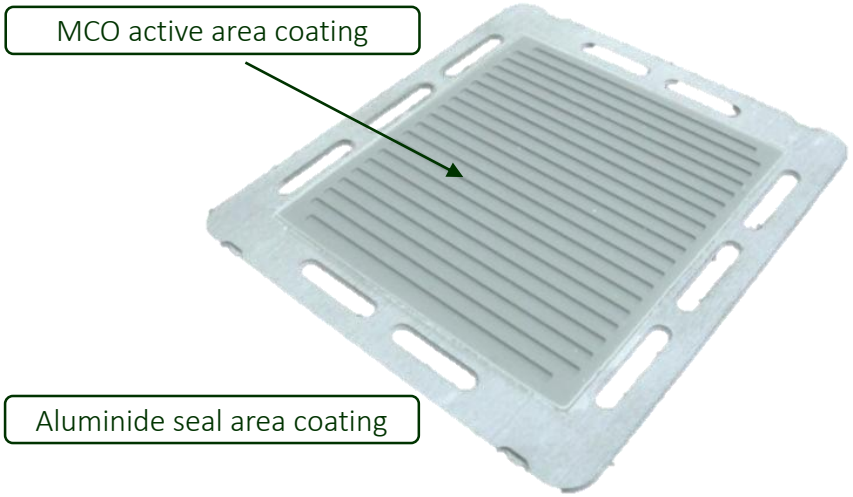



# How Are Overlay Coatings Applied?

- Non-Protective Coatings
  - Dip Coating
  - Wash Coating
- Protective Coats
  - Spray Deposition
  - Screen Printing

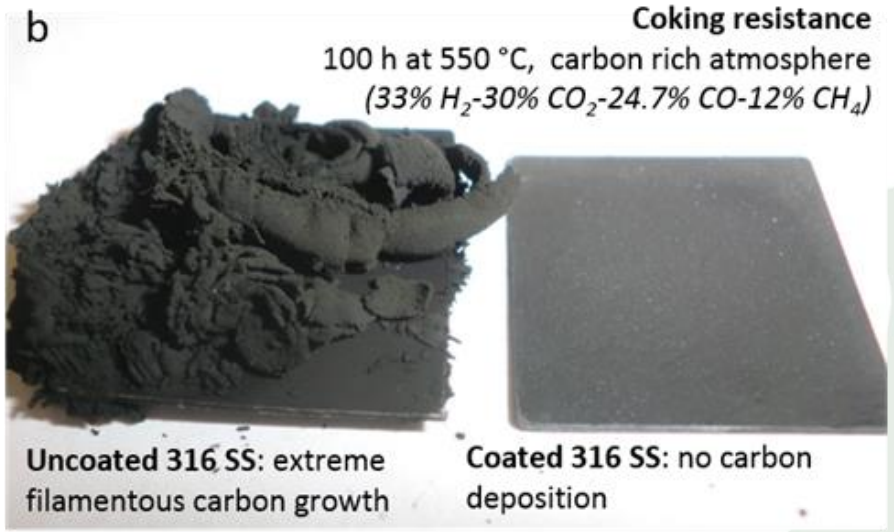
# Overlay Protective Coatings

Dual MCO/Aluminide Coated Metallic Interconnect




Coated Balance of Plant Components

# Diffusion Coating Value Proposition


Oxidation Resistance

Coking Resistance

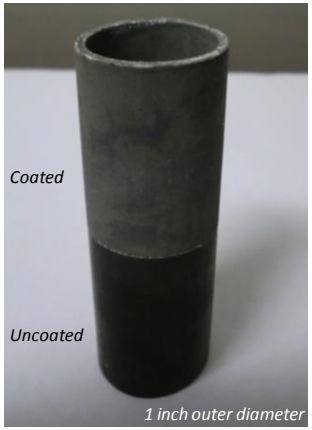
Other Features of Aluminide Technology:

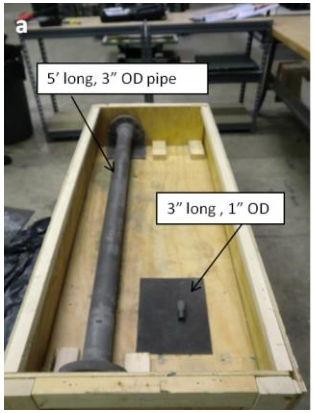
- Increased Thermal Conductivity
- Enhanced Emissivity
- Improved Wear Resistance
- Simple, Low Cost Application

Lower Cost Austenitic Alloys in

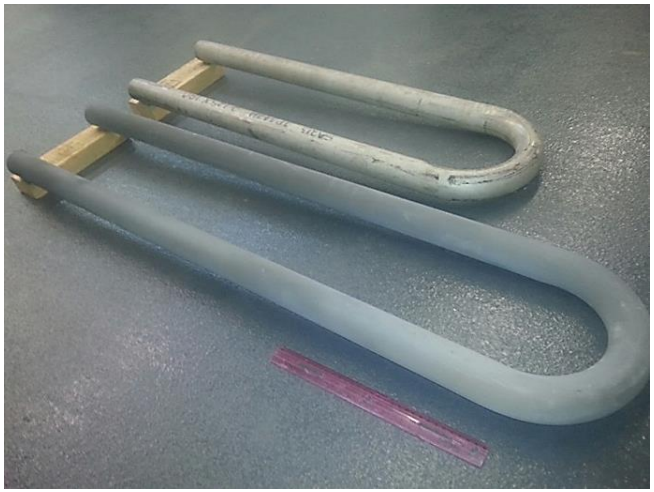
- Heat Transfer
- Corrosion Resistance
- Carburization Resistance
- Sulfidation Resistance

# Diffusion Protective Coatings



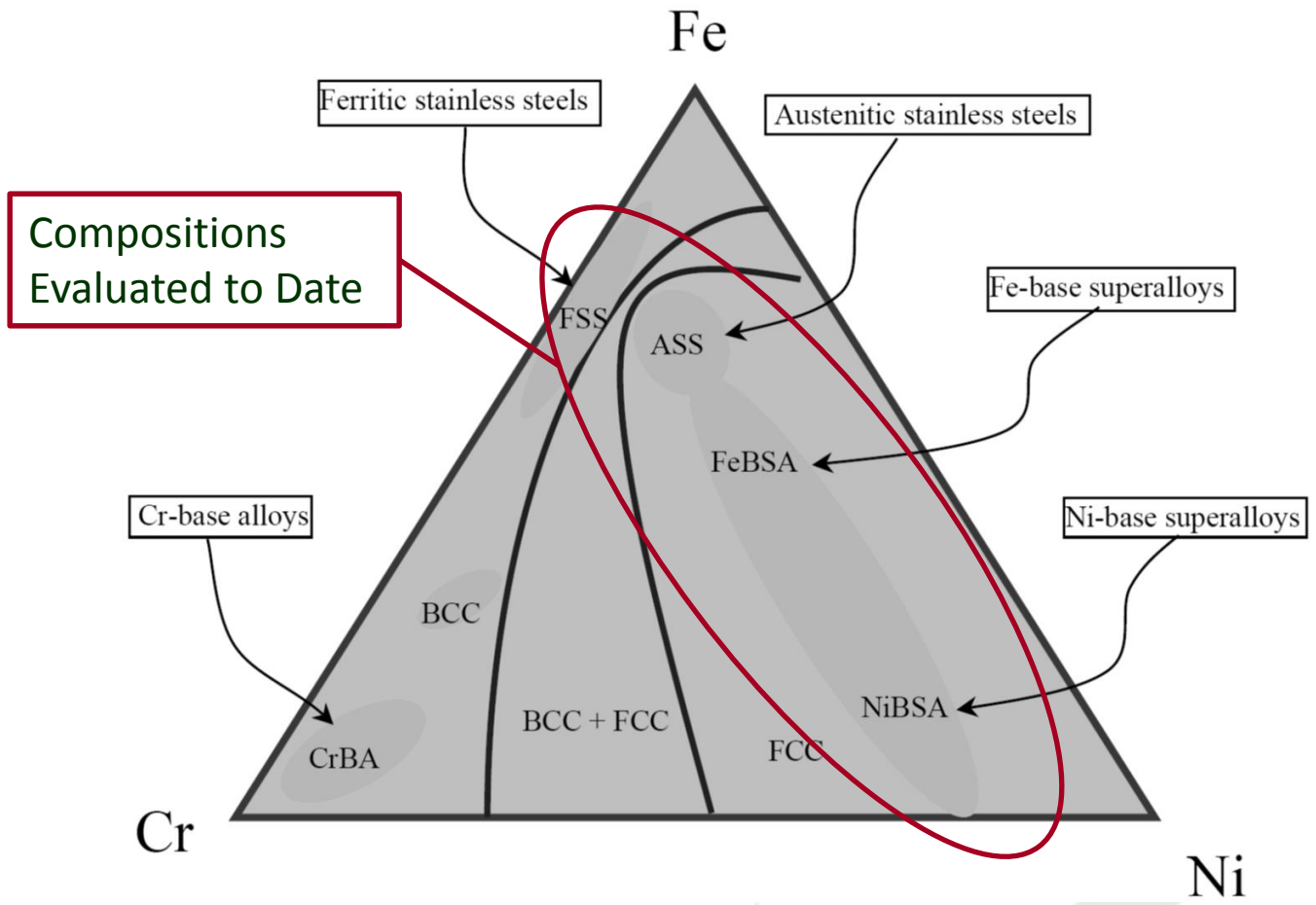







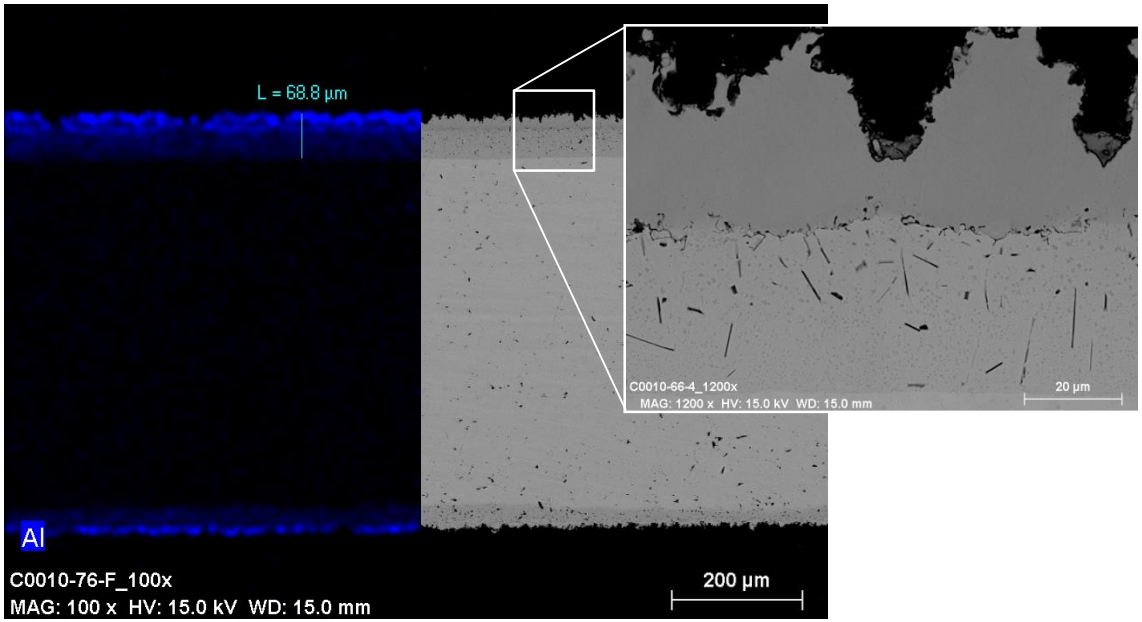
- Ferritic (441, 446, Crofer 22APU)
- Austenitic (316, 347H)
- Inconel (600, 601, 617)
- Nickel Alloy 200
- Copper Alloys

# Phase Diagram of Alloys

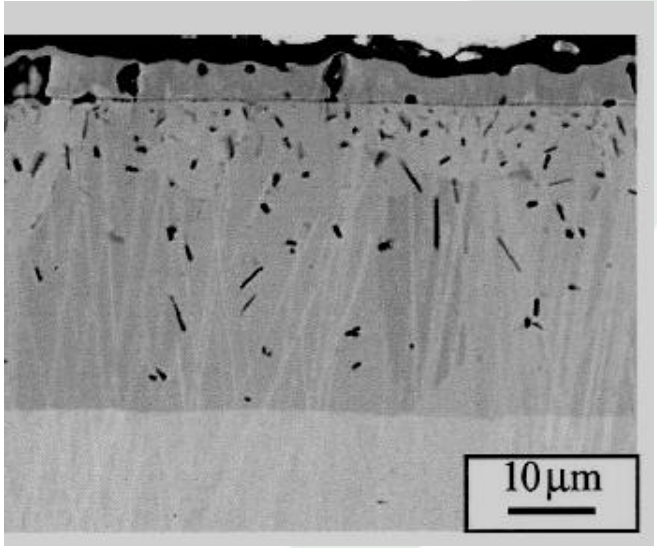


# Diffusion Coating on Stainless Steels

**Cross-section SEM and Al compositional EDS map for Nexceris aluminide coating on Grade 304 stainless steel**



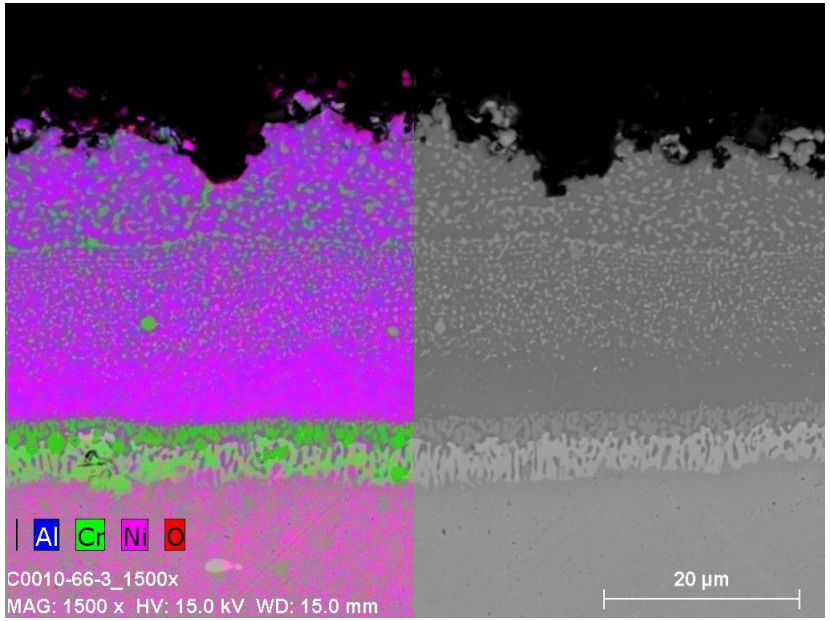

**Cross-section SEM of aluminide coating produced by CVD on Grade 304**



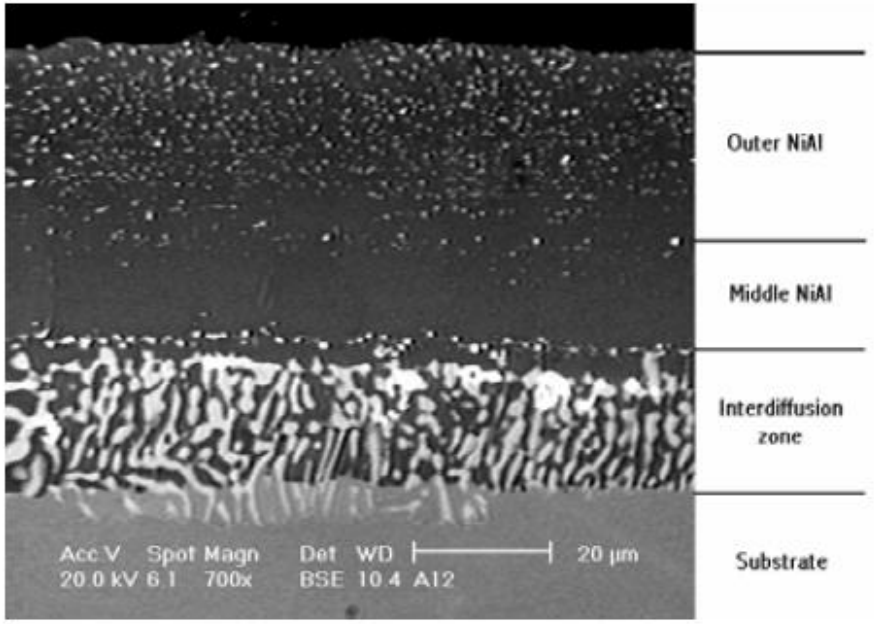

*B. A. Pint et al., Evaluation of Iron-Aluminide CVD Coatings for High Temperature Corrosion Protection, Materials at High Temperature 18(3) (2001) 1.*

# Diffusion Coatings on Superalloys

**Cross-section SEM for Nexceris aluminide coating on Inconel 617**



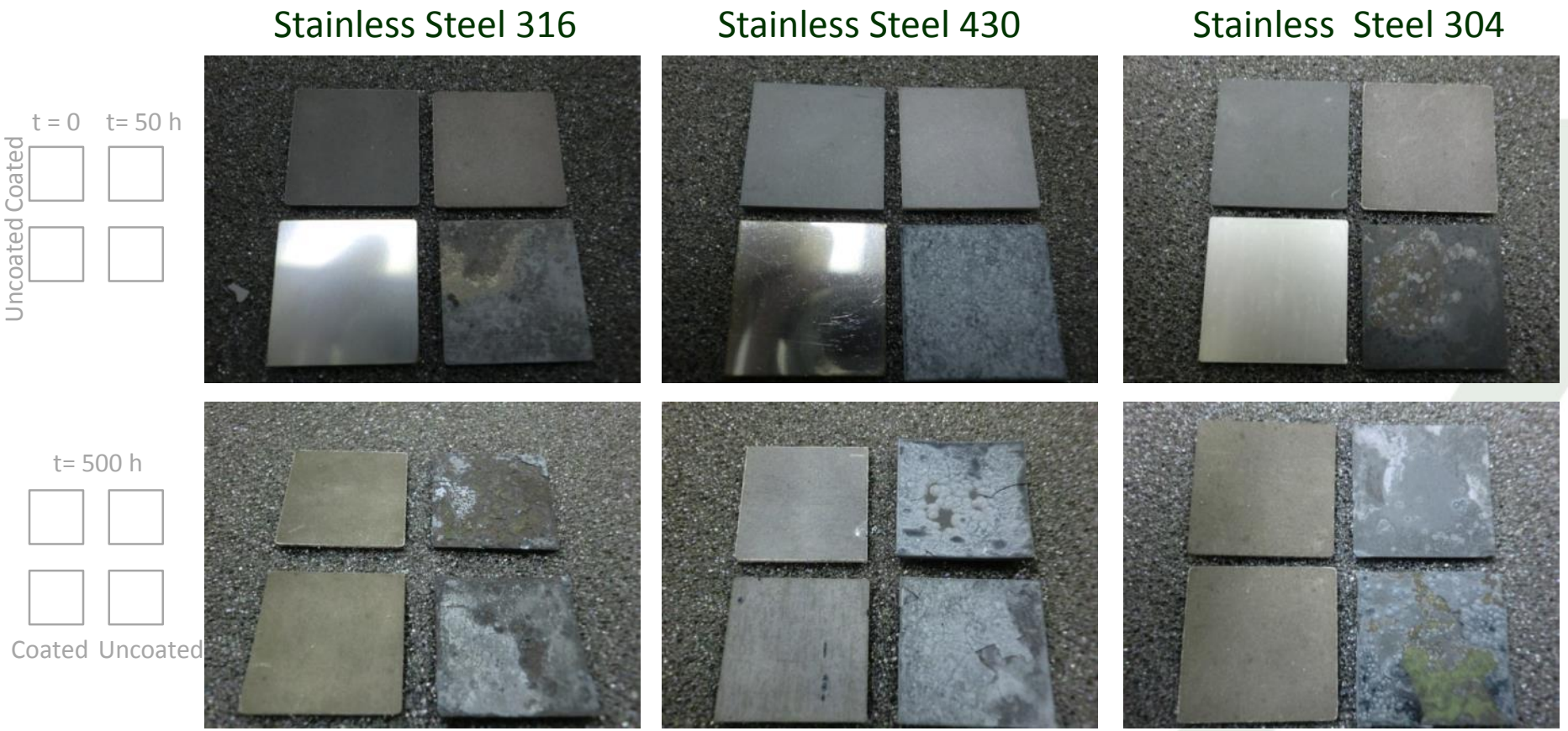

**Cross-section SEM of Si modified aluminide coating produced by pack cementation on IN-738 LC**




*H. Arabi et al., Formation Mechanism of Silicon Modified Aluminide Coating on a Ni-Base Superalloy, Int. J. Eng. Sci., 19(5-1) (2008) 39.*

# Oxidation of Common Alloys

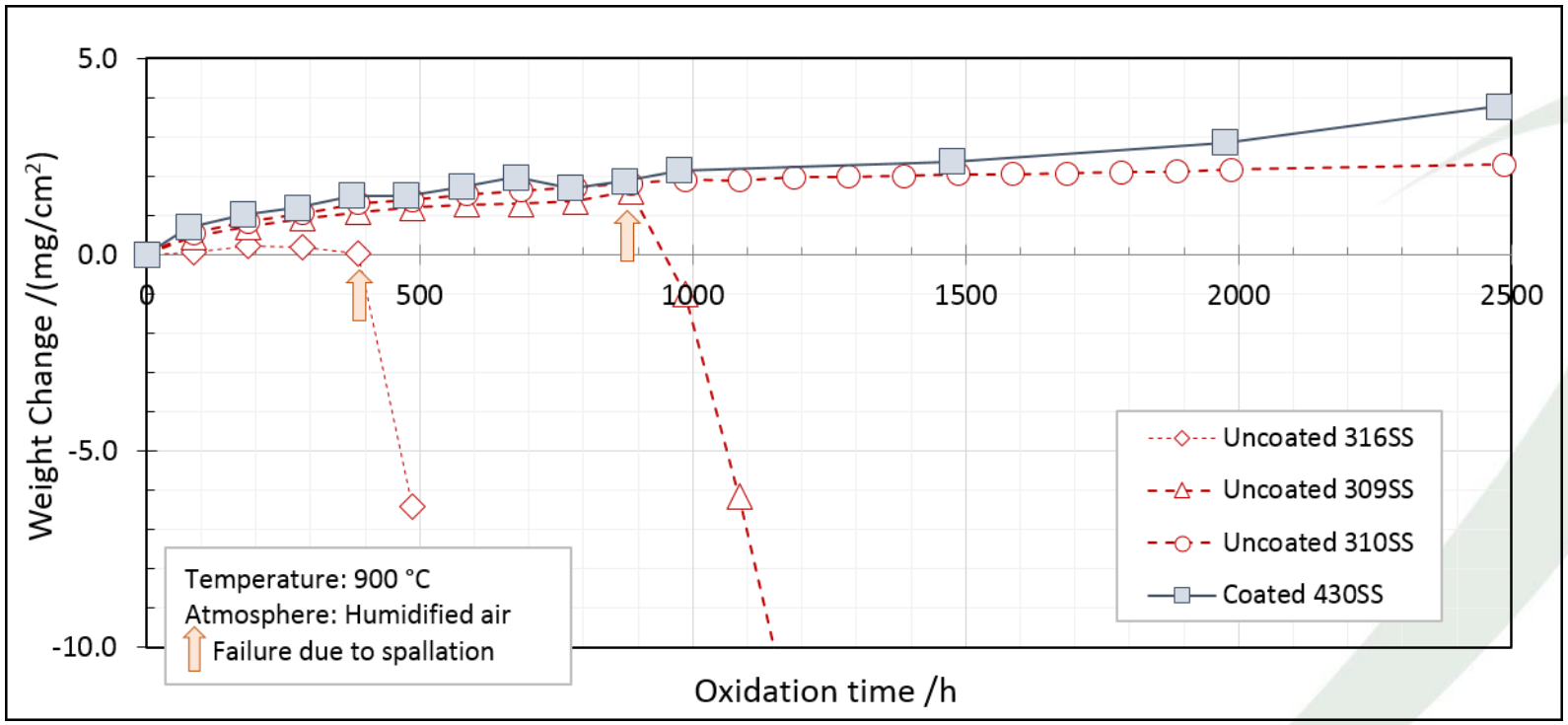
*Aluminide coating successfully prevents spallation alloy scale during oxidation*




Substrate: Alloy 304, 316 and 430; Aluminide coating: 20 μm fired
Test Conditions: 900 °C, Humidified Air, Isothermal oxidation testing

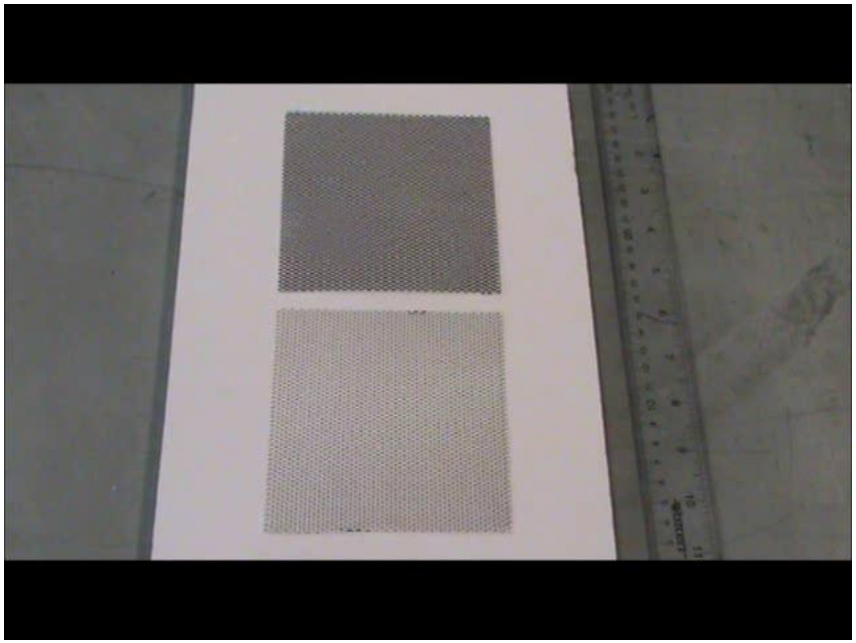
# Comparative Performance of Coated 430 vs Various Austenitic Steels

430 Alloy Achieving Corrosion Performance of 4X more expensive 310 Alloy

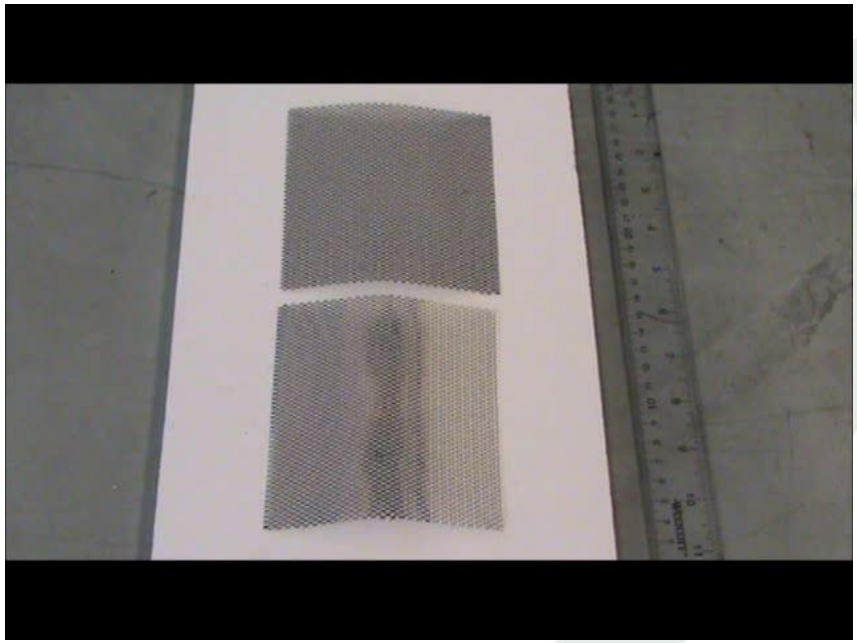


# Propane Torch Stress Tests

## Pass 1

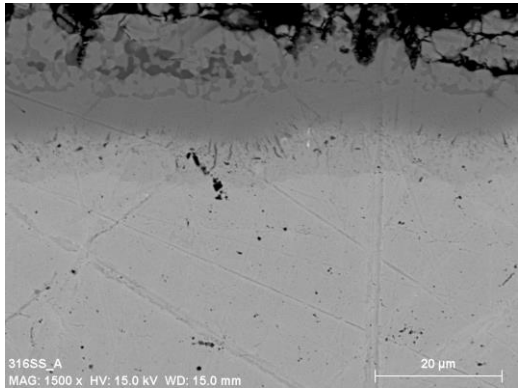


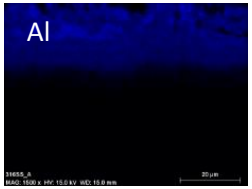
## Pass 7-10

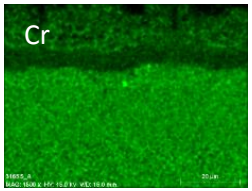


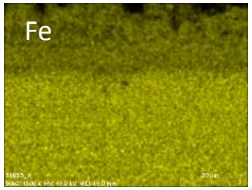
# Modifying Oxidation Behavior

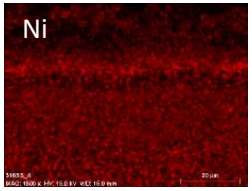
t = 0

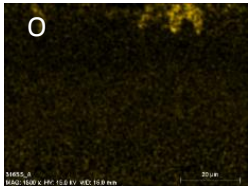


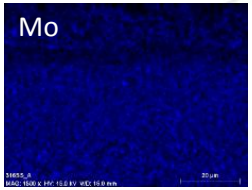

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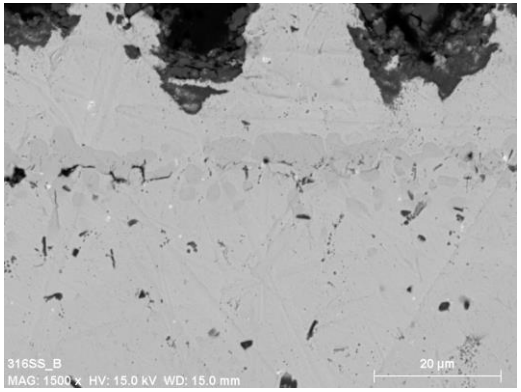
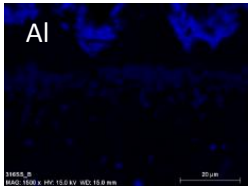
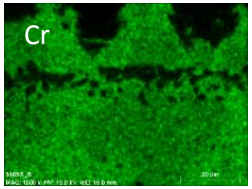
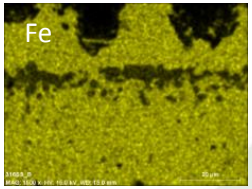
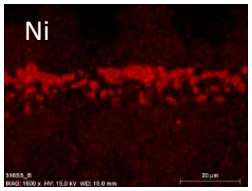
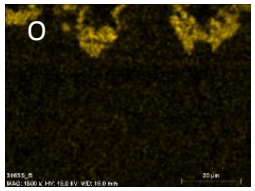


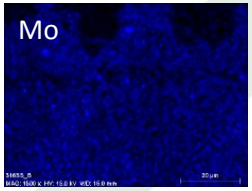



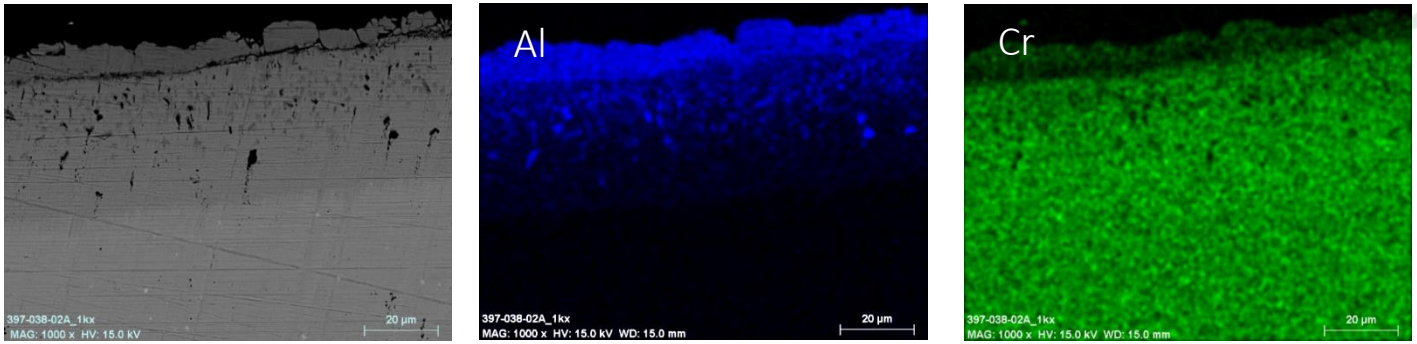




- SS316 with Aluminide coating
- 500 hours in humidified air at 900 °C

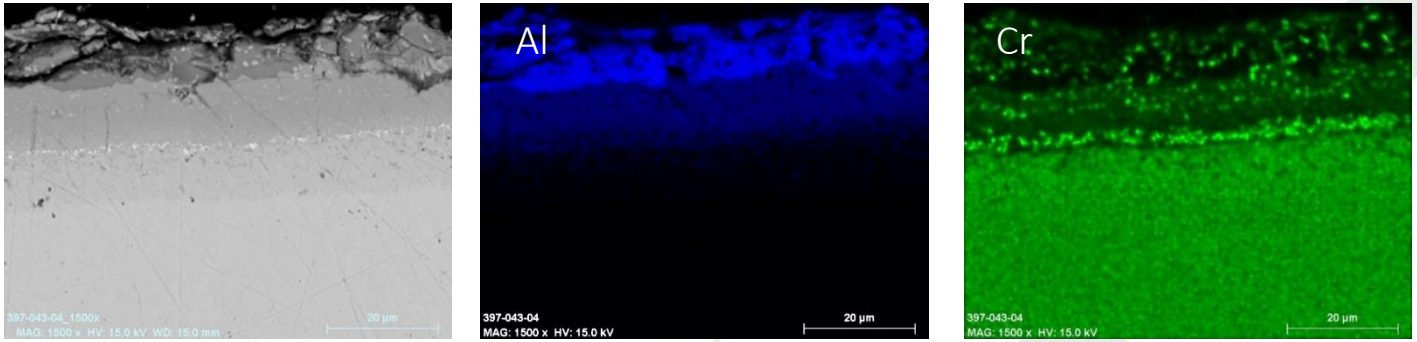
# Performance Comparison to Vapor Phase Coatings

NexTech's coating process successfully reproduces the diffusion based surface microstructure produced by more conventional aluminization processes

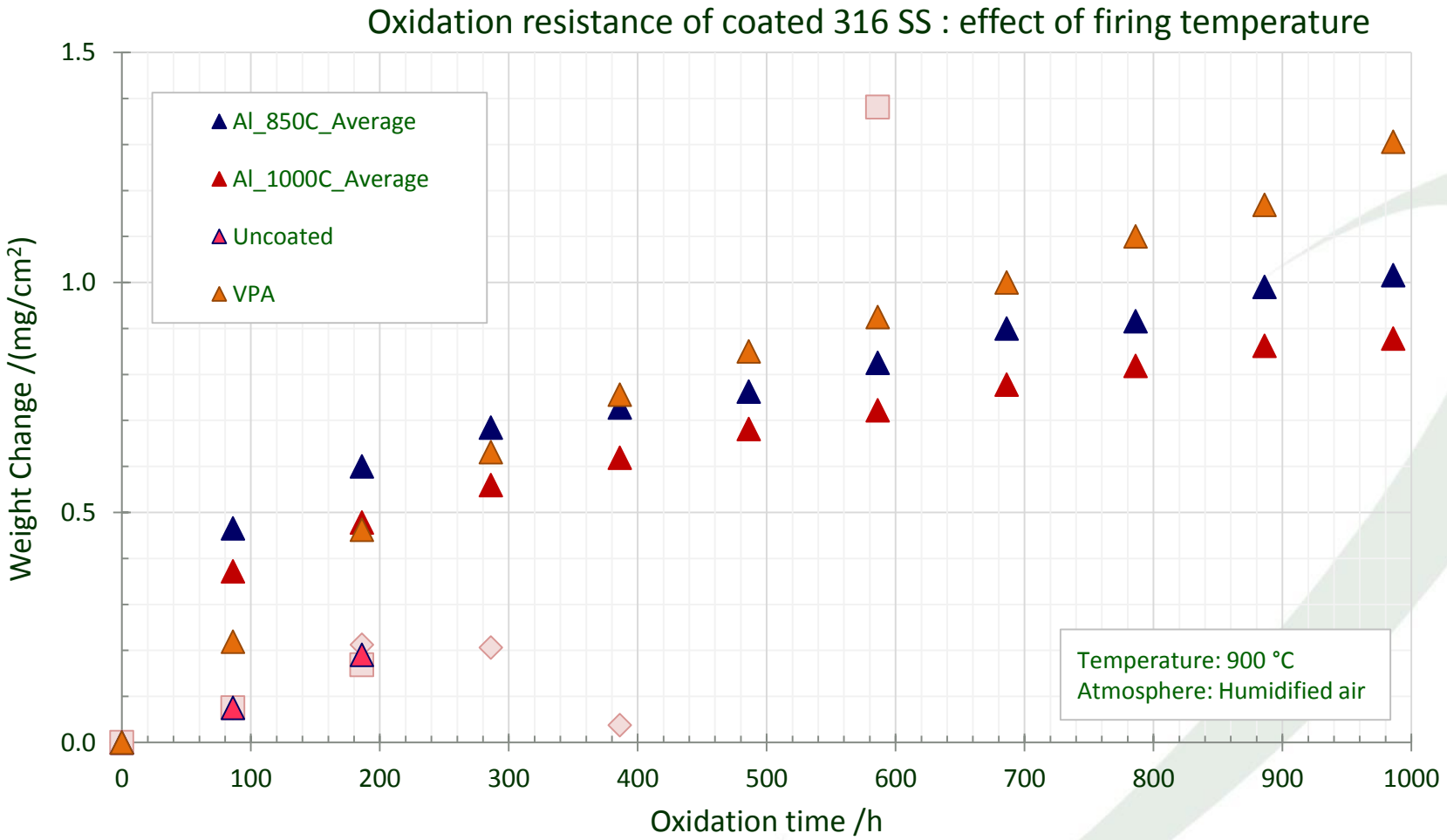
Vapor Phase Aluminization (VPA) Coating Microstructure on SS316



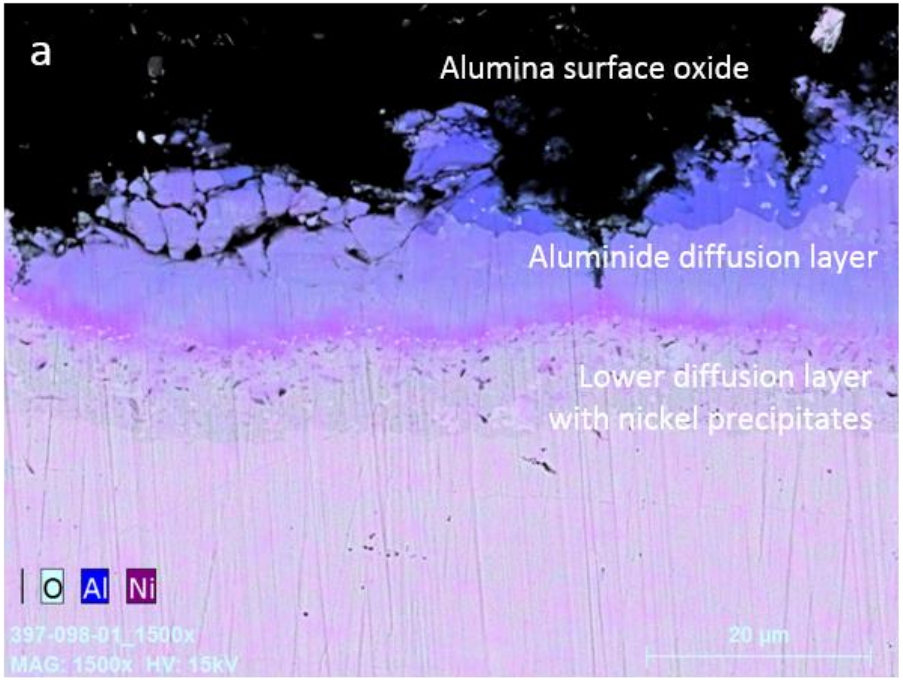

NexTech's Aluminide Coating Microstructure on SS316

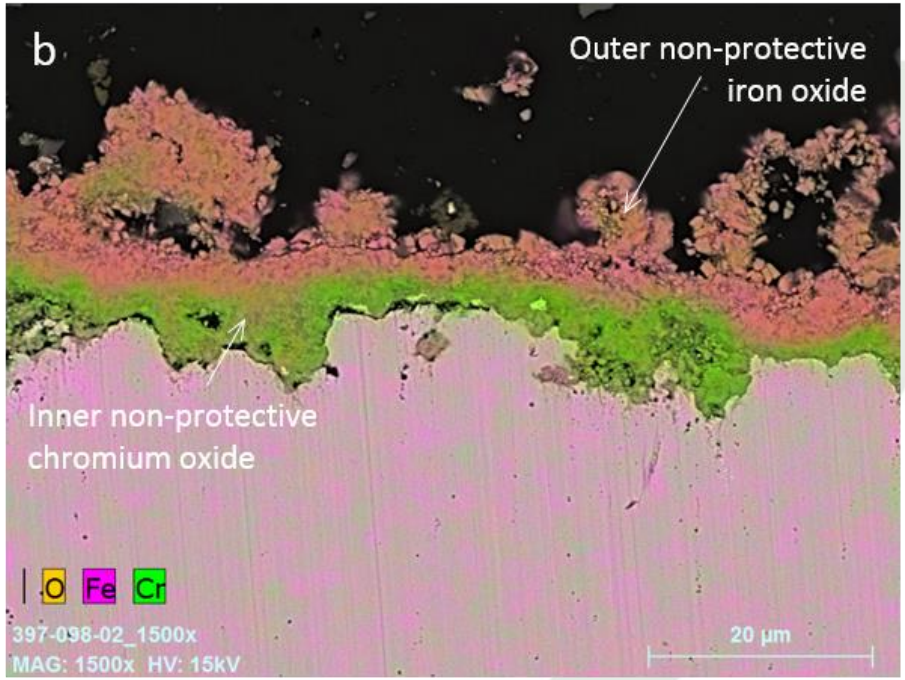


# Performance Comparison to Vapor Phase Coatings



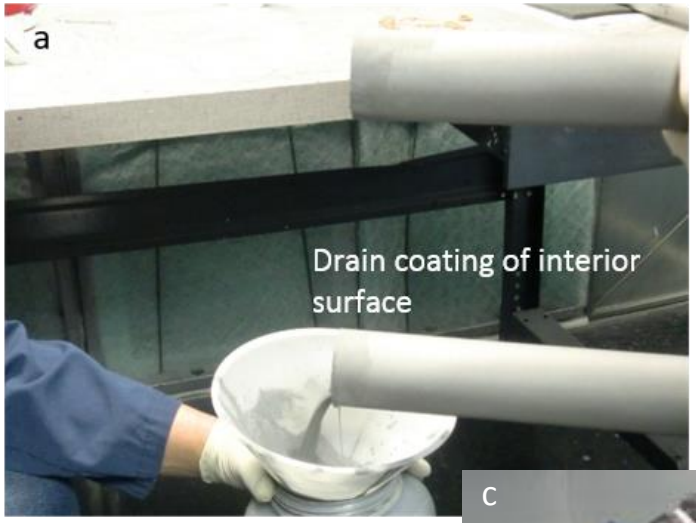
# Addressing Biomass Derived Contaminants
# 50h Exposure KCl containing air, 650 °C



# How Does it Work?

# Coating Application Methods

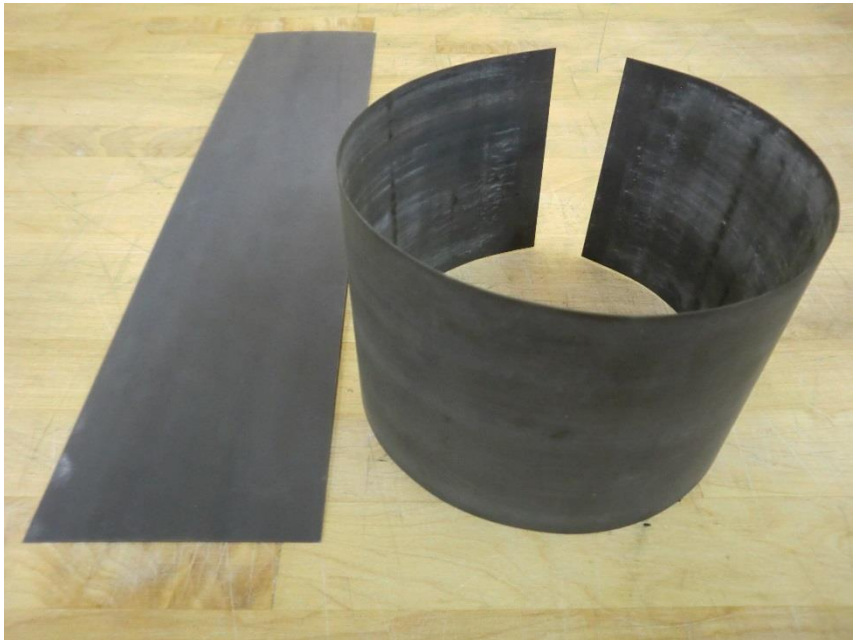





Also:

- Dip Coating
- Curtain Coating
- Brush Painting
- Transfer Printing

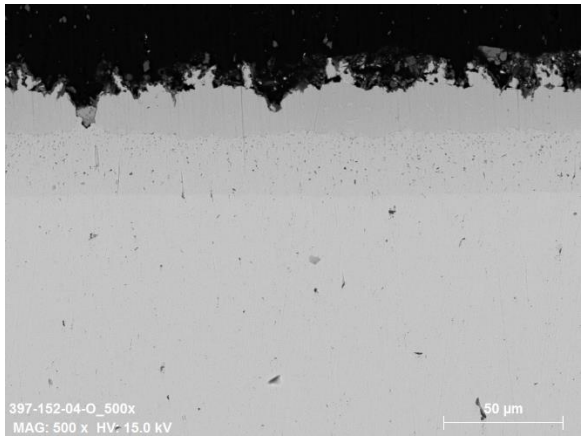
# Post Coating Rolling Operation (304 Stainless Steel)

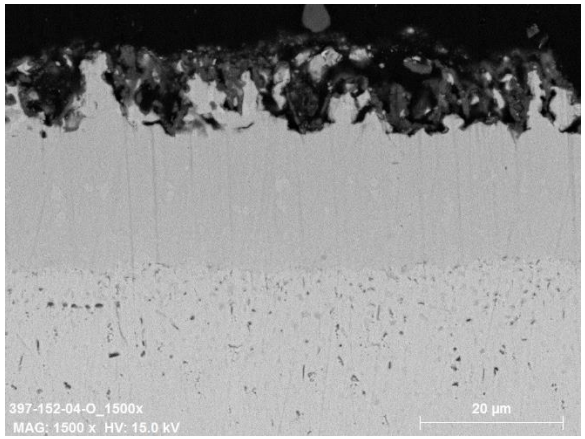


# SEM analysis (Rolled 304 Stainless Steel)

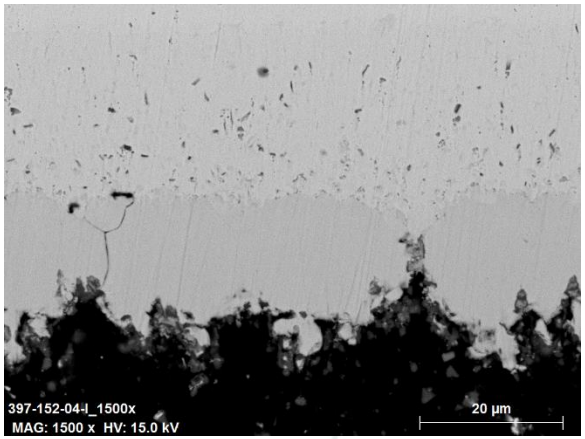
Rolling operation does not damage the aluminide coating

Rolled component: outside

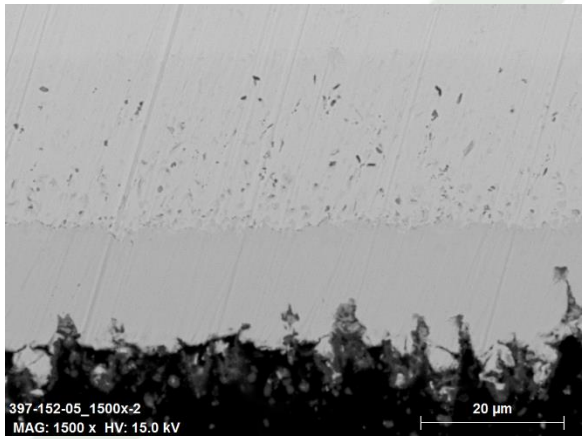



Rolled component: inside

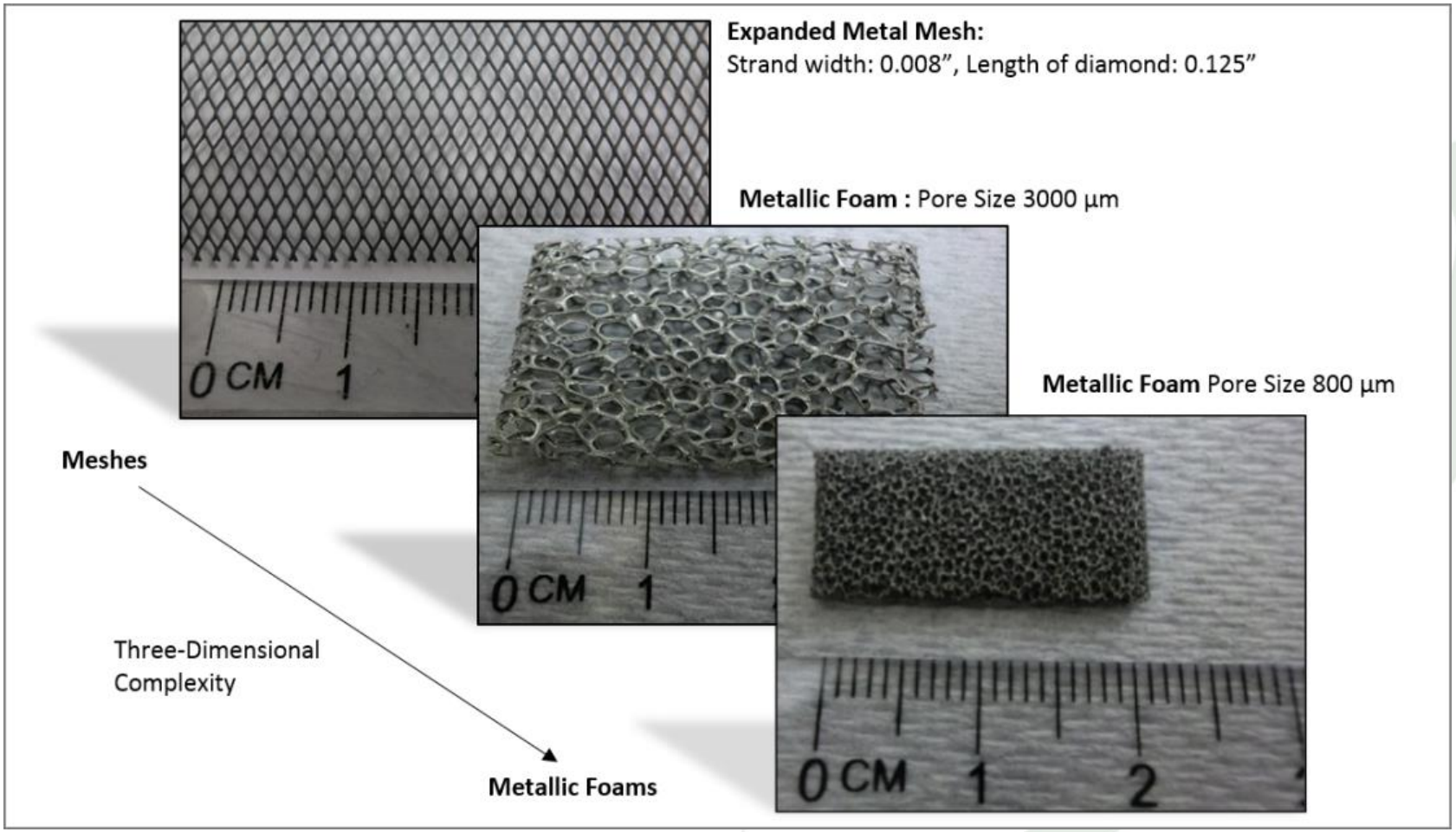

Flat component (no forming)

# EMERGING APPLICATIONS

# Stratalyst™ Product

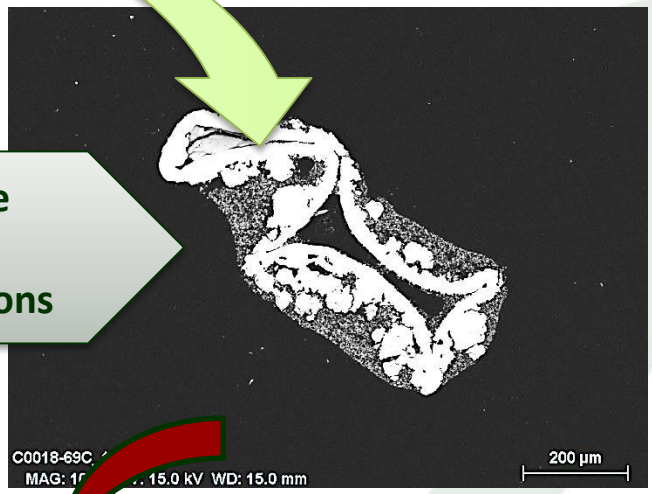
## *Thermal Management and Catalyst Support*



# Extending the Design Space

Single Dip Coating in Aluminum & Air Firing


**Increased Corrosion Resistance**
**Increased Surface Area**
**Passivation to Chemical Interactions**




- Creates New Catalyst Support Product Platform
- Creates Immediate Opportunities in Burner Markets

# The product:

## *Strata-Lyst* Nickel Aluminide Catalyst Supports

**Porous $\alpha$-$Al_2O_3$ Topcoat**

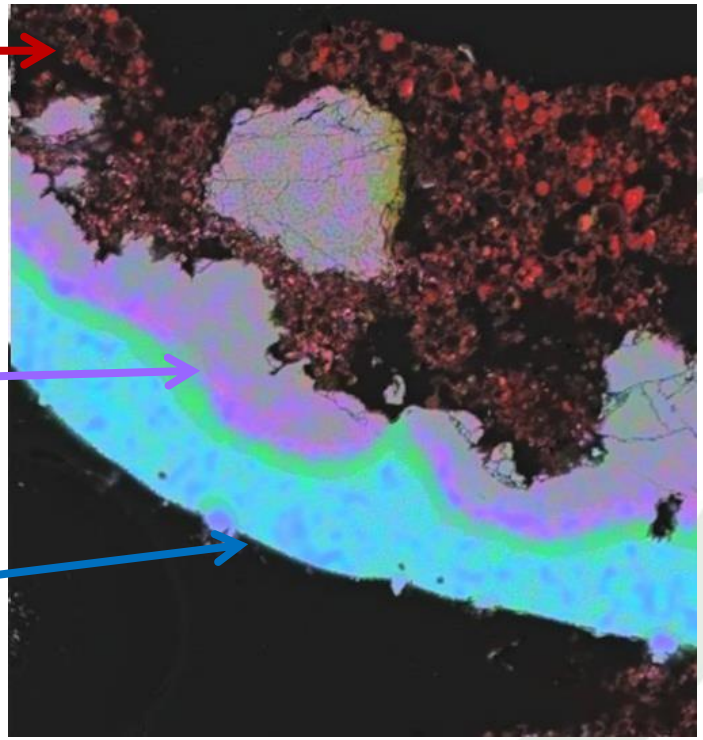
- Open, Interconnected Porosity for Infiltration
- Catalysts Infiltrated to Allow Lower Temp Combustion

**Aluminide diffusion coating**

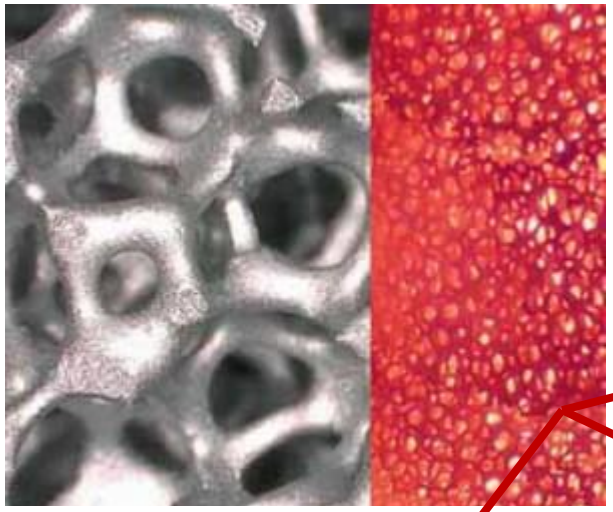
- Oxidation resistance
- Enhanced IR Emssivity
- Good Thermal Conductivity

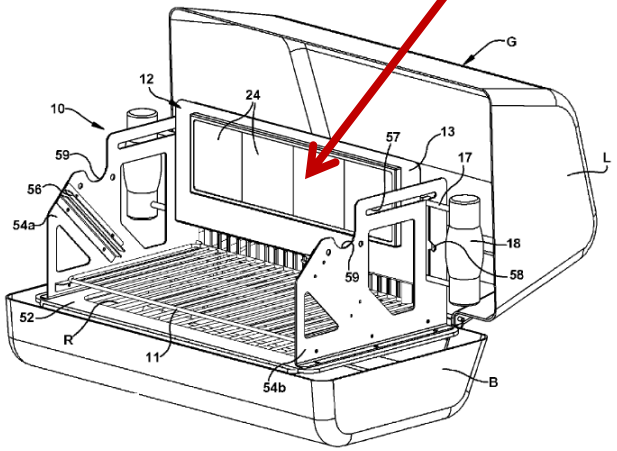
**Nickel Skeleton**

- Deformability
- Mechanical Robustness
- Lower Cost than Alloys (Mfg. Scale—NiMH Batteries)



# Applications in Burners for Corrosion Resistant Foams




# Conclusions

- Coatings can protect low-cost alloys in high temperature environments.
- Overlay coatings approaches offer broad chemical compositions and tailorable electrical and catalytic properties.
- Diffusion coatings offer excellent thermal stability, corrosion resistance and damage tolerance.
- Coatings can be applied by low-tech, easily scaled and adopted technologies with wide process tolerances.
- Technologies in development to create unique coated composites from a range of iron and nickel alloys.
- We are exploring other alloys for heat exchange applications.

# For Further Information

Matthew M. Seabaugh, Ph.D.
Director
Nexceris
404 Enterprise Drive
Lewis Center, OH 43035
Phone:  (614) 842-6606 extension 107
Email:  matt@nexceris.com