SRI International

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Diffusion Coatings for Corrosion-Resistant Components in Coal Gasification Systems

Quarterly Technical Progress Report 13

Covering the period July 1, 2006 through September 30, 2006

SRI Project P13063

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ABSTRACT

Heat-exchangers, particle filters, turbines, and other components in integrated coal gasification combined cycle system must withstand the highly sulfiding conditions of the high-temperature coal gas over an extended period of time. The performance of components degrades significantly with time unless expensive high alloy materials are used. Deposition of a suitable coating on a low-cost alloy may improve its resistance to such sulfidation attack, and decrease capital and operating costs. The alloys used in the gasifier service include austenitic and ferritic stainless steels, nickel-chromium-iron alloys, and expensive nickel-cobalt alloys.

The primary activity this period was preparation and presentation of the findings on this project at the Twenty-Third annual Pittsburgh Coal Conference. Dr. Malhotra attended this conference and presented a paper. A copy of his presentation constitutes this quarterly report.

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EXECUTIVE SUMMARY

Advanced coal gasification systems such as integrated coal gasification combined cycle (IGCC) processes offer many advantages over conventional pulverized coal combustors. Heat-exchangers, filters, turbines, and other components in IGCC plants often must withstand the highly sulfiding conditions at high temperatures. In collaboration with U.S. Department of Energy and ConocoPhillips, we are developing corrosion-resistant coatings for high-temperature components in IGCC systems.

SG Solution's coal gasification power plant in Terre Haute, IN, uses ConocoPhillips' E-Gas technology. The need for corrosion-resistant coatings exists in two areas: (1) the tube sheet of a heat exchanger at ~1000°C that is immediately downstream of the gasifier, and (2) porous metal particulate filter at 370°C, which is downstream of the heat exchanger. These components operate at gas streams containing as much as 2% H_2S. A protective metal or ceramic coating that can resist sulfidation corrosion will extend the life-time of these components and reduce maintenance.

The primary activity this period was preparation and presentation of the findings on this project at the Twenty-Third annual Pittsburgh Coal Conference. Dr. Malhotra attended this conference and presented a paper. A copy of his presentation constitutes this quarterly report.

INTRODUCTION

Heat-exchangers, filters, turbines, and other components in coal-fired power plants must withstand demanding conditions of high temperatures and pressure differentials. Further, the components are exposed to corrosive gases and particulates that can erode the material and degrade their performance. In collaboration with U.S. Department of Energy and ConocoPhillips, SRI International recently embarked on a project to develop corrosion-resistant coatings for coal-fired power plant applications. Specifically, we are seeking to develop coatings that would prevent the corrosion in the tube-sheet of the high-temperature heat recovery unit of a coal gasification power plant of SG Solution's plant in Terre Haute, IN, which uses ConocoPhillips' E-Gas technology. This corrosion is the leading cause of the unscheduled downtime at the plant and hence success in this project will directly impact the plant availability and its operating costs. Coatings that are successfully developed for this application will find use in similar situation in other coal-fired power plants.

WORK PERFORMED

The primary activity this period was preparation and presentation of the findings on this project at the Twenty-Third annual Pittsburgh Coal Conference. Dr. Malhotra attended this conference and presented a paper. A copy of his presentation constitutes this quarterly report.

DIFFUSION COATINGS FOR CORROSION-RESISTANT COMPONENTS IN COAL GASIFICATION SYSTEMS

- SRI International:
  - Gopala Krishnan, Ripudaman Malhotra, Angel Sanjurjo, Esperanza Alvarez, Kai-Hung Lau, Marc Hornbostel, and Jordi Perez
- ConocoPhillips:
  - Albert Tsang, Cliff Keeler, Michael Hickey, and Gary Young

THE PROBLEM, *aka the pain*

- Corrosion of gasifier components is the dominant cause of unscheduled downtime
- Gas stream leaving a gasifier contains corrosive components such as H_2S, HCl, and H_2O, at temperatures exceeding 900°C
- High levels of H_2S require the use of specialty alloys such as Hastelloy, Haynes alloy or Inconel
- These alloys are expensive, difficult to fabricate, and have low thermal conductivity

COATINGS

- Pros
  - Impart resistance to corrosion, Cr (25%) and Al (15%)
  - Allow use of less expensive and more easily machined components
- Cons
  - Thermal mismatch, spalling off
  - Migration of Fe and Ni along grain boundaries

COATINGS TECHNOLOGY

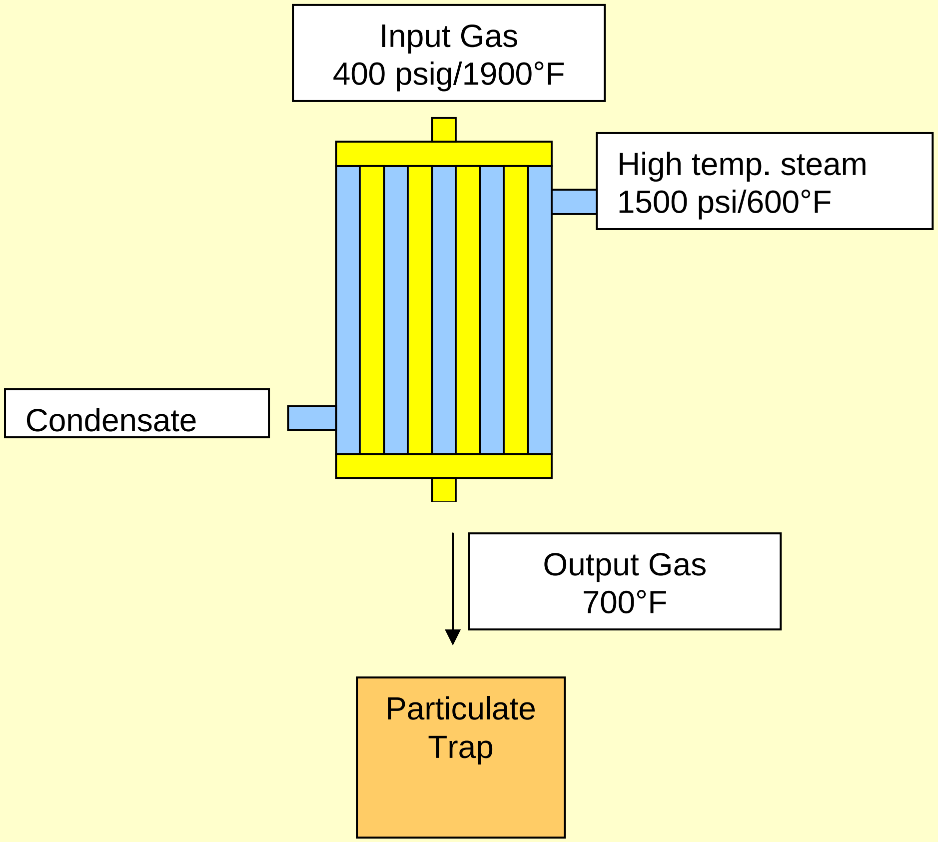
- SRI's fluidized-bed chemical vapor deposition (FBR-CVD) technology allows:
  - Both internal and external surfaces to be coated
  - Allows diffusion bonding of the coating to the substrate
  - Operates at relatively low temperature (600° to 900°C)
  - Allows coatings with multiple elements: Cr, Al, Si, Ti, Ta, Zr, W

COATINGS TECHNOLOGY (continued)

- SRI's FBR-CVD technology uses:
  - Inexpensive precursors
  - Rapid heating, deposition, and cooling that are inherent in fluidized beds
- Coated parts can be bent or welded to form desired shapes

TARGET COMPONENTS

1. Tube sheet in the high-temperature heat-recovery unit (HTHRU)
2. Porous metal filters in the particulates trap downstream of HTHRU

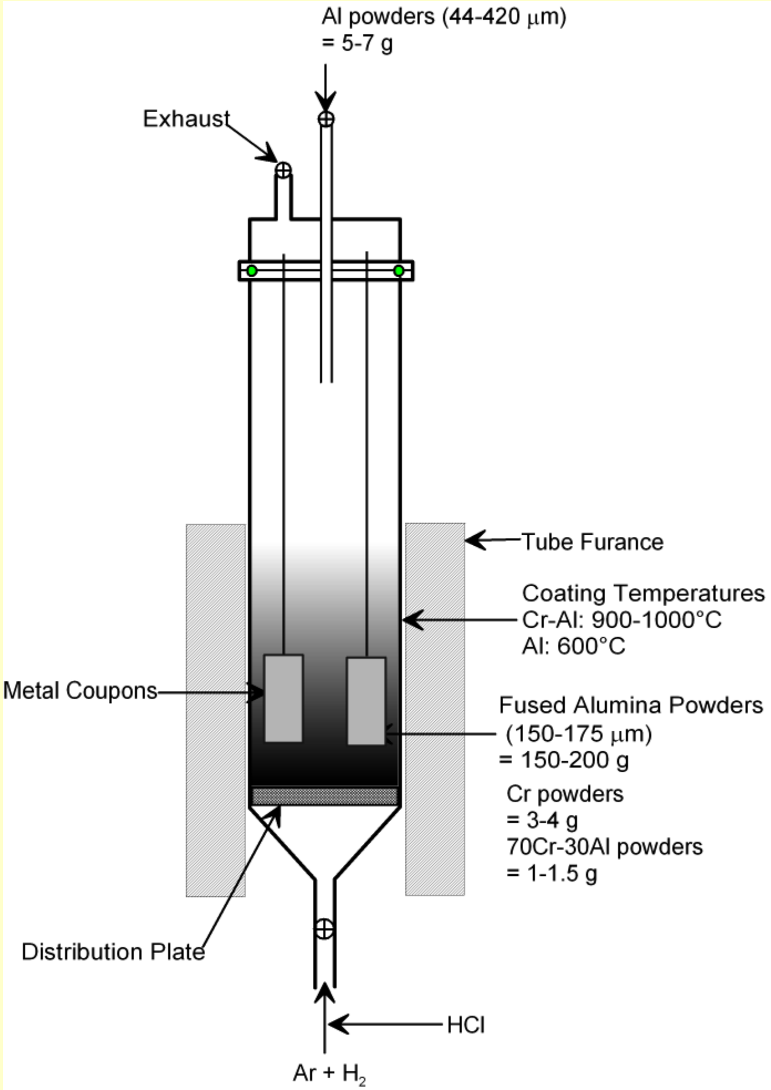


RELEVANCE/BENEFITS

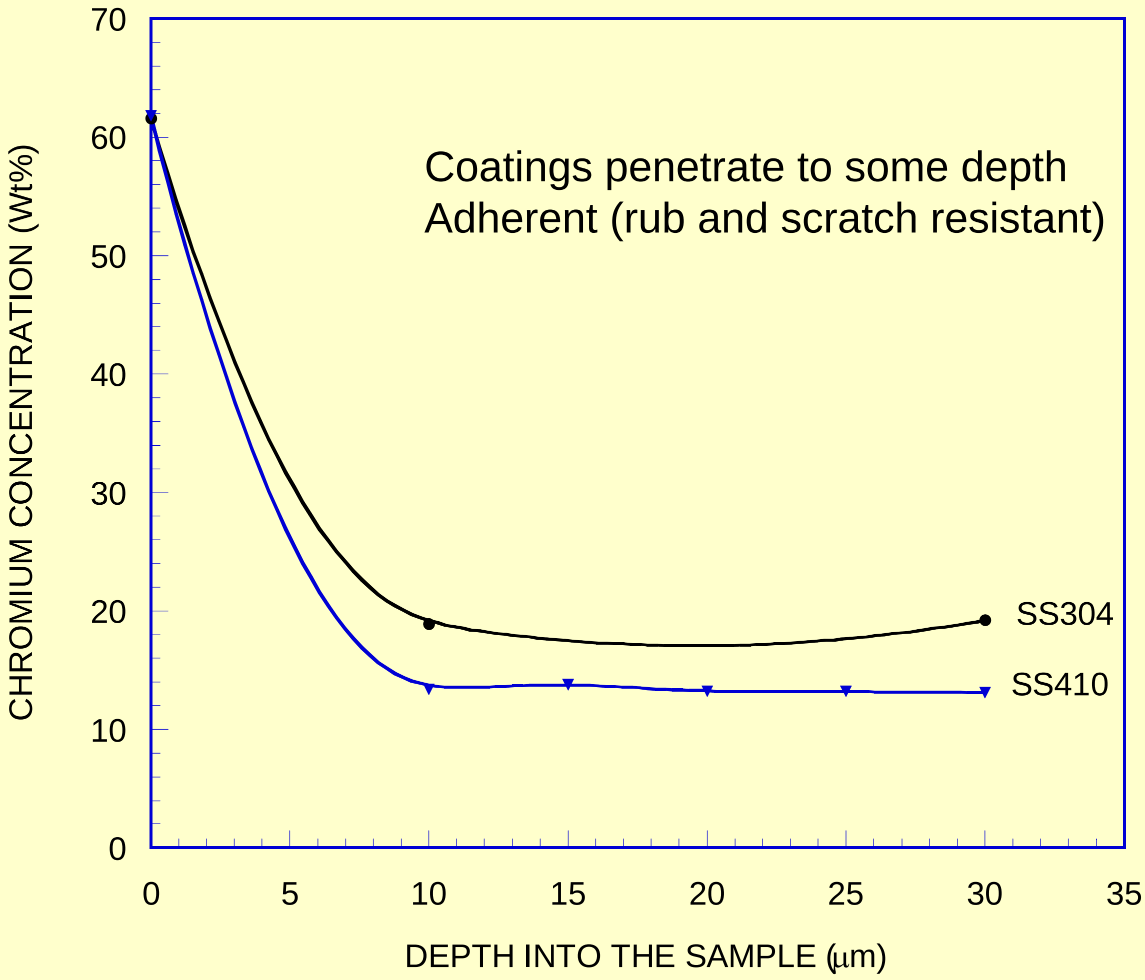
- Flexibility in the selection of component materials for advanced gasifiers
- Minimize downtime and maintenance costs
- Allow environmentally superior IGCC technology to be competitive

FBR-CVD REACTOR

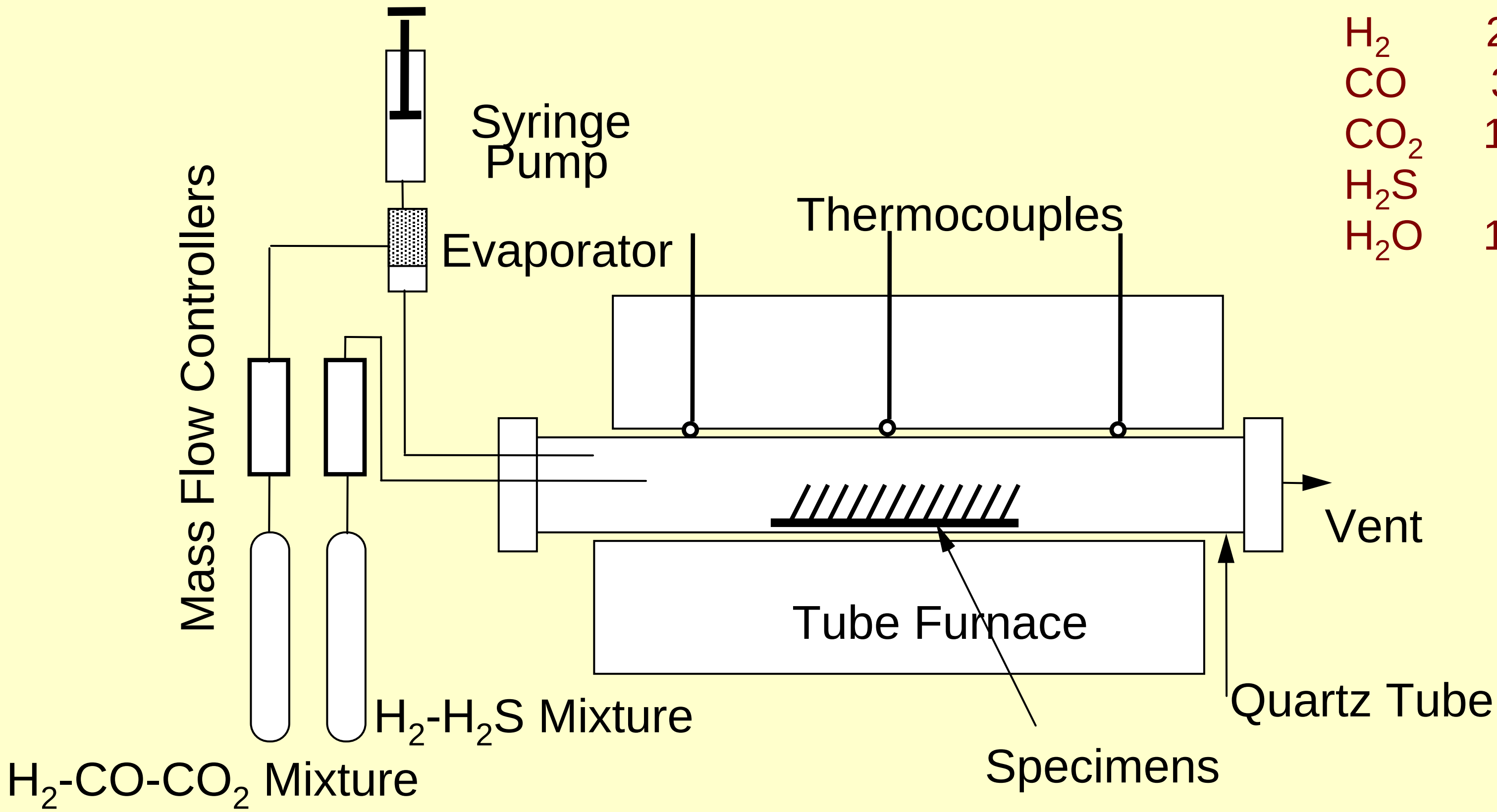
- Form precursors by reaction of a gas such as HCl gas with the selected alloying element
- These precursors are often unstable and reactive
- Due to changes in the local chemical environment, precursors decompose depositing a coating on the substrate
- The fresh metal coating can be converted to oxides or nitrides for additional protection.
- It is applicable to complex shaped objects



PROFILE OF Cr-COATED STEELS

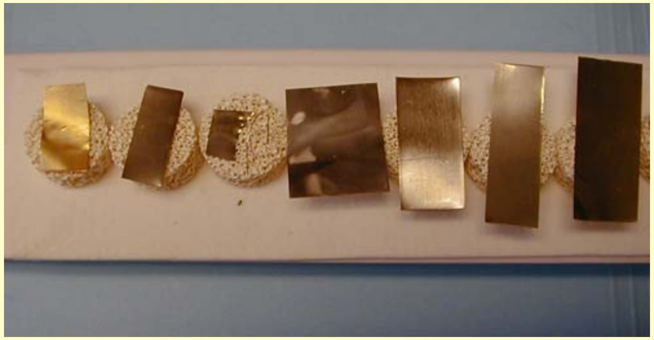


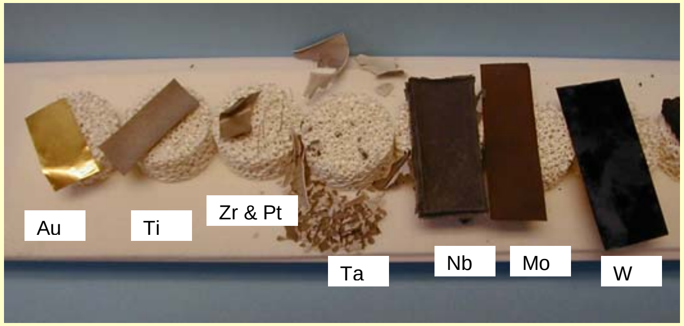
Schematic Diagram of the Bench-Scale Exposure Test System

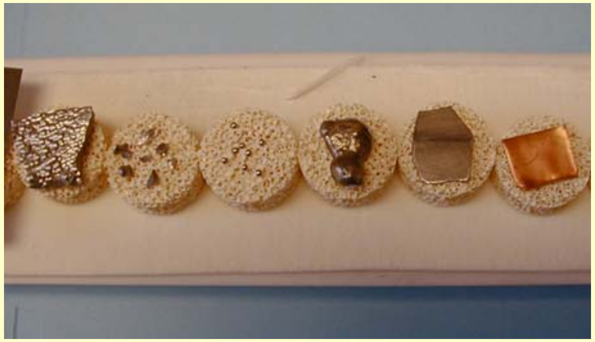


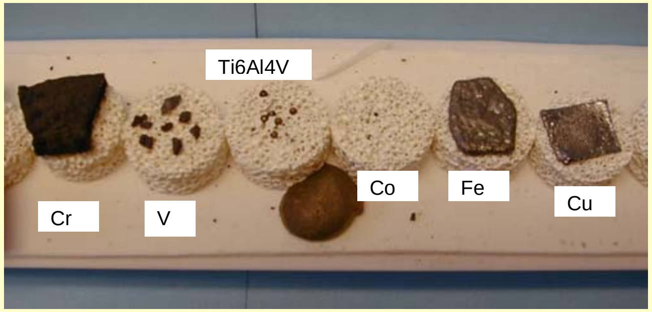
H_2	25.7
CO	38.9
CO_2	17.3
H_2S	1.4
H_2O	16.7

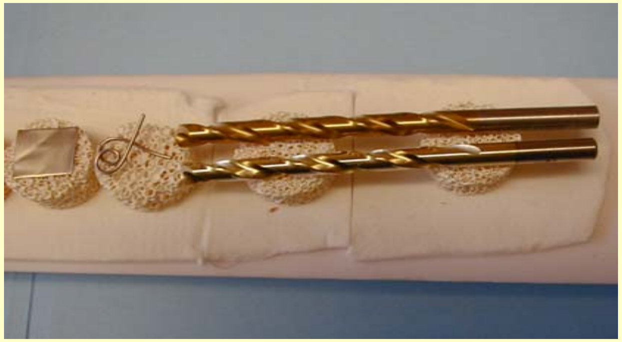
Appearance of Metals and Alloys before and after Exposure to Simulated Coal Gas at 900°C for 112 h

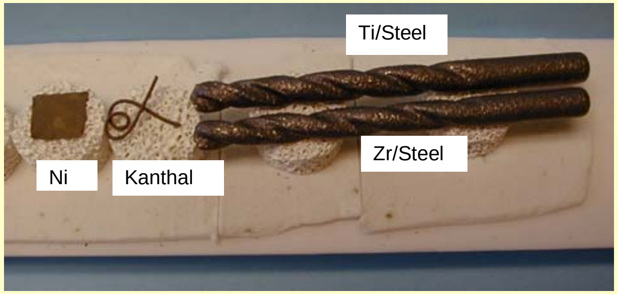




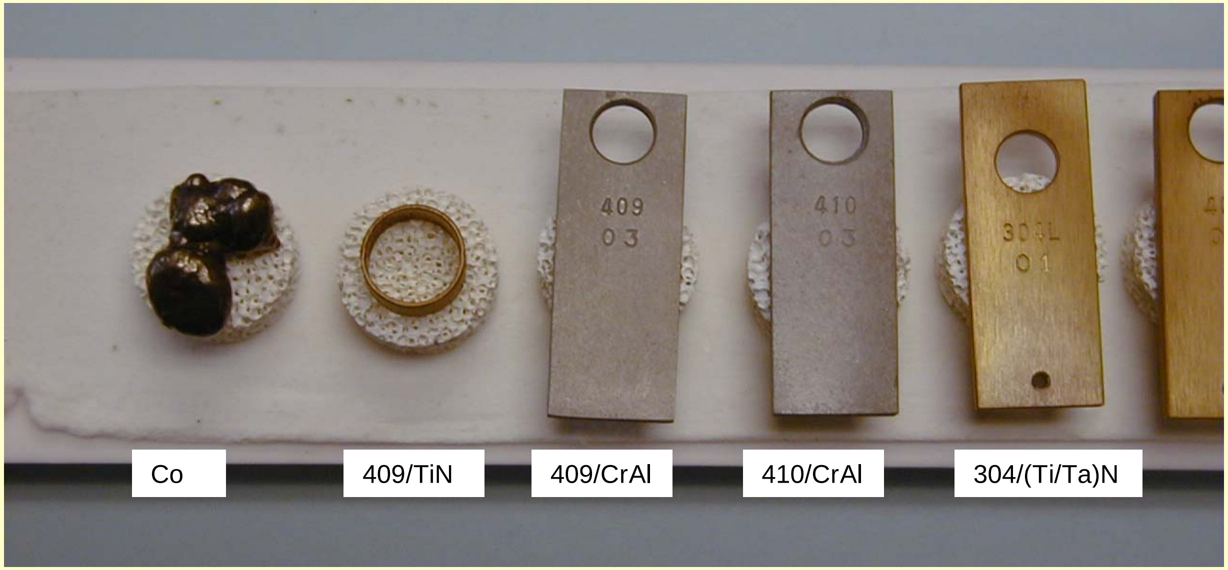


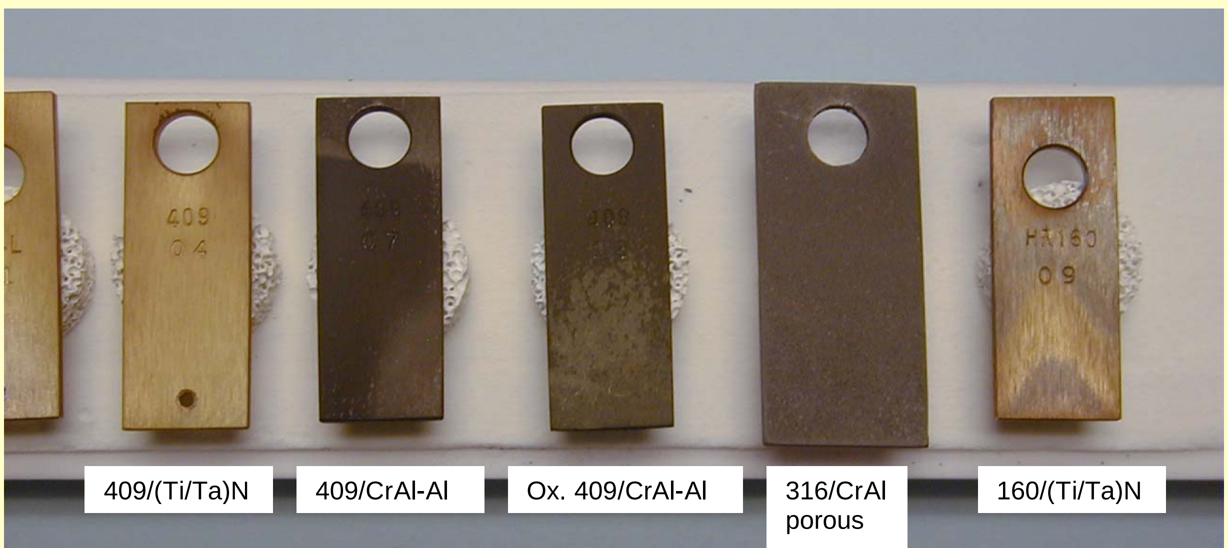




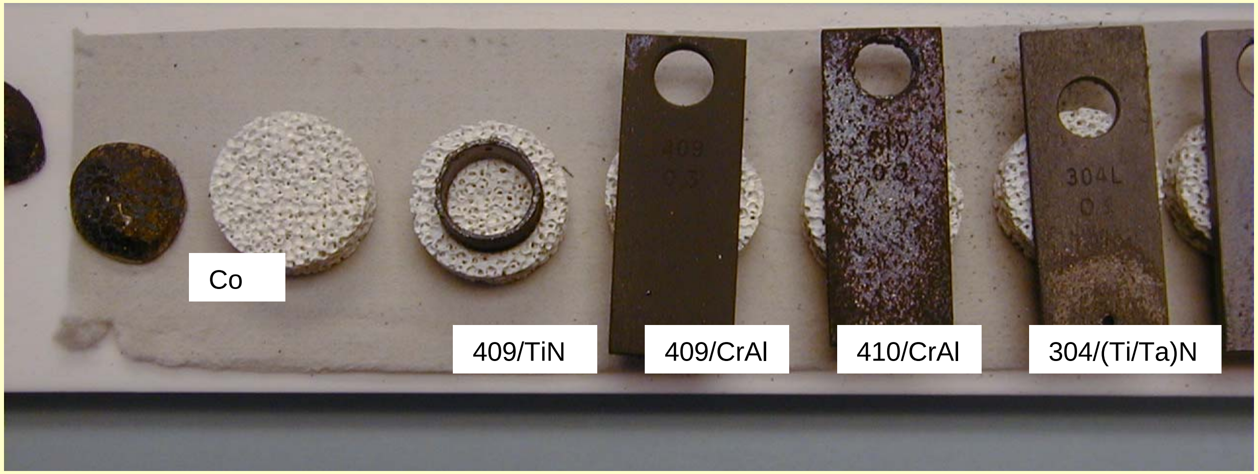


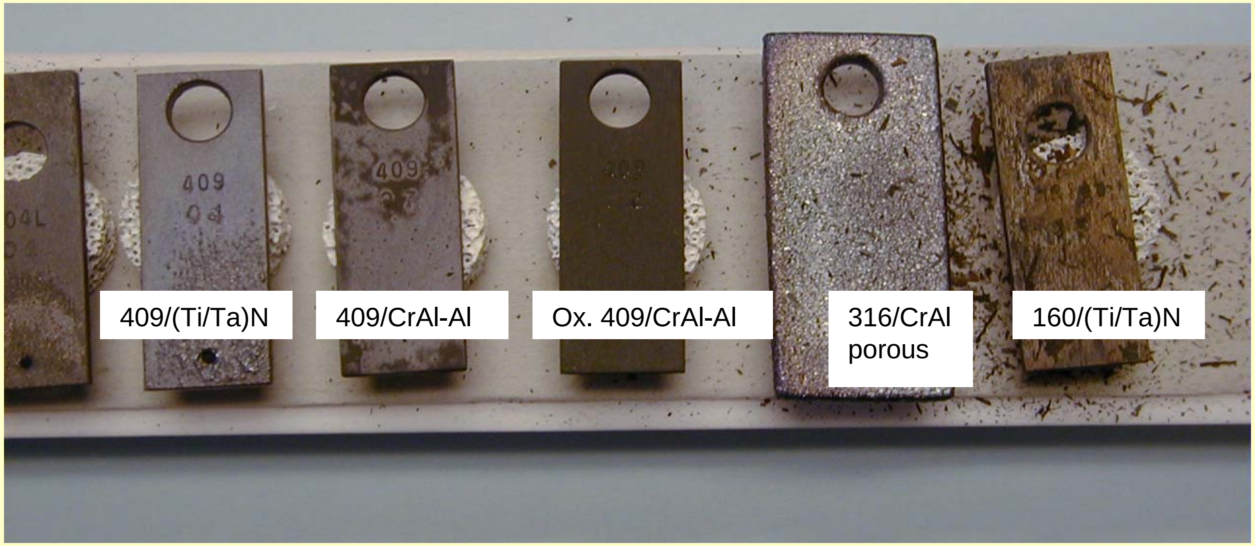
Test 6: Appearance of Metals and Alloys Prior to Exposure



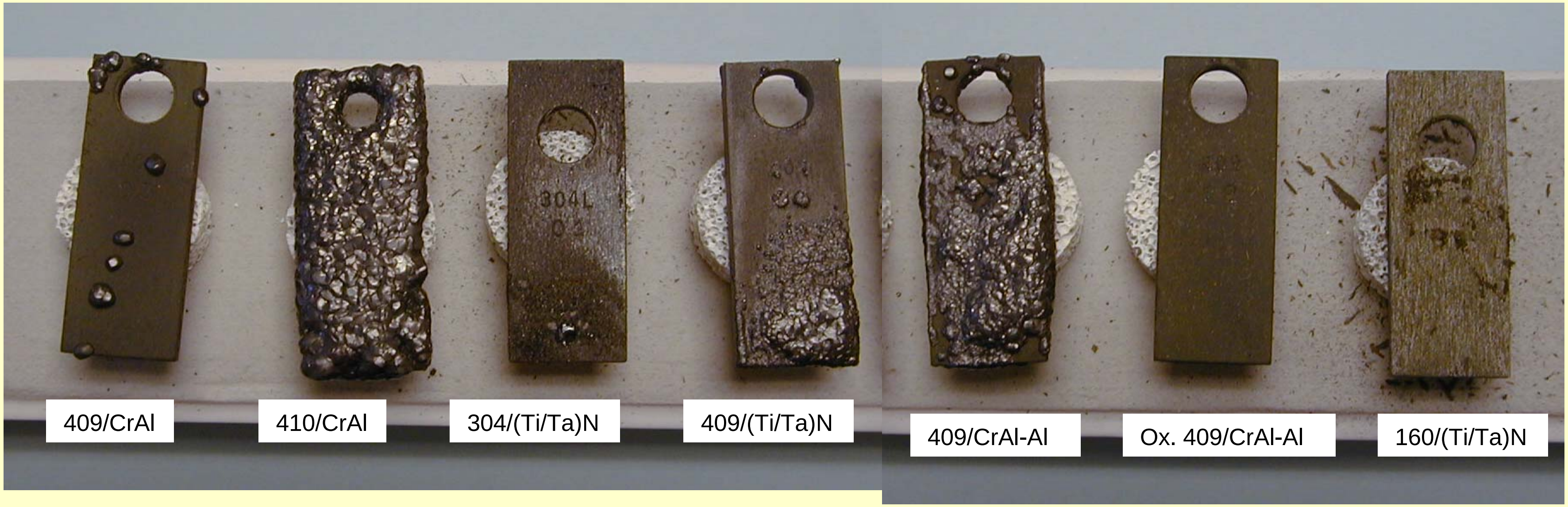


Appearance of Metals and Alloys After Exposure to Simulated Coal Gas at 900°C for 120 h



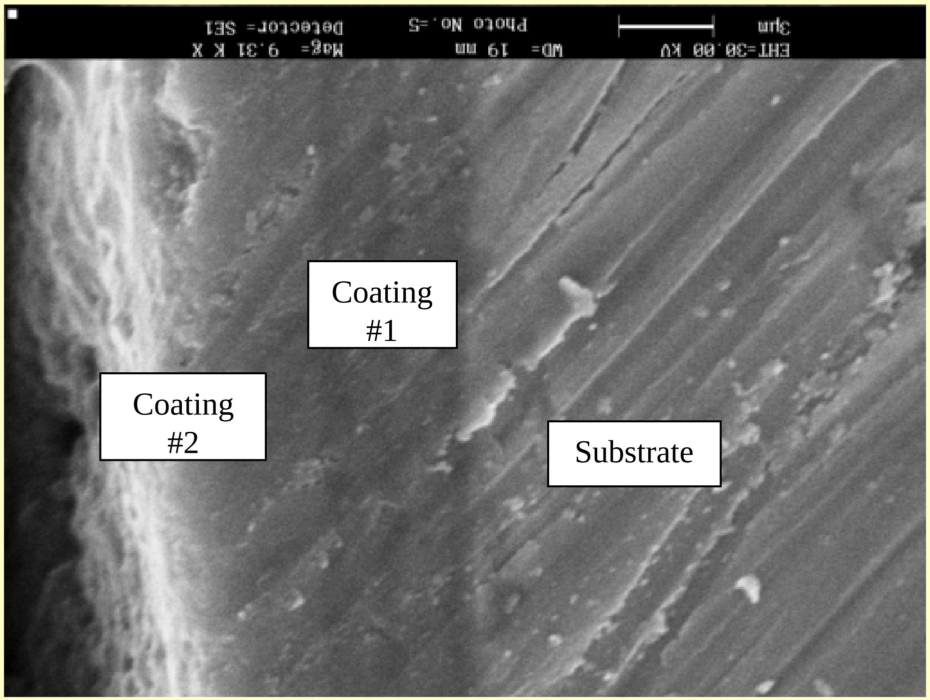


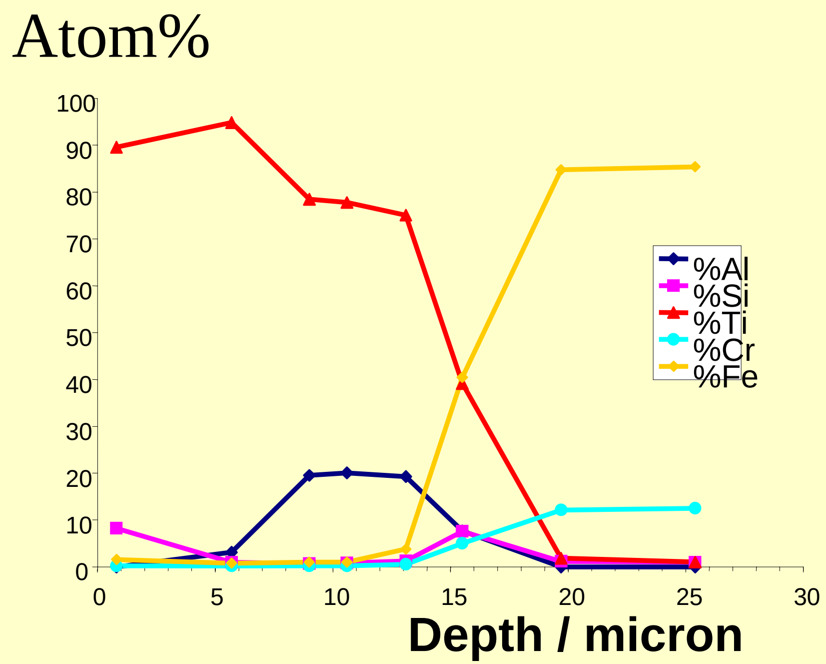
Test 6: Appearance of Selected Samples After Additional 360 h Exposure



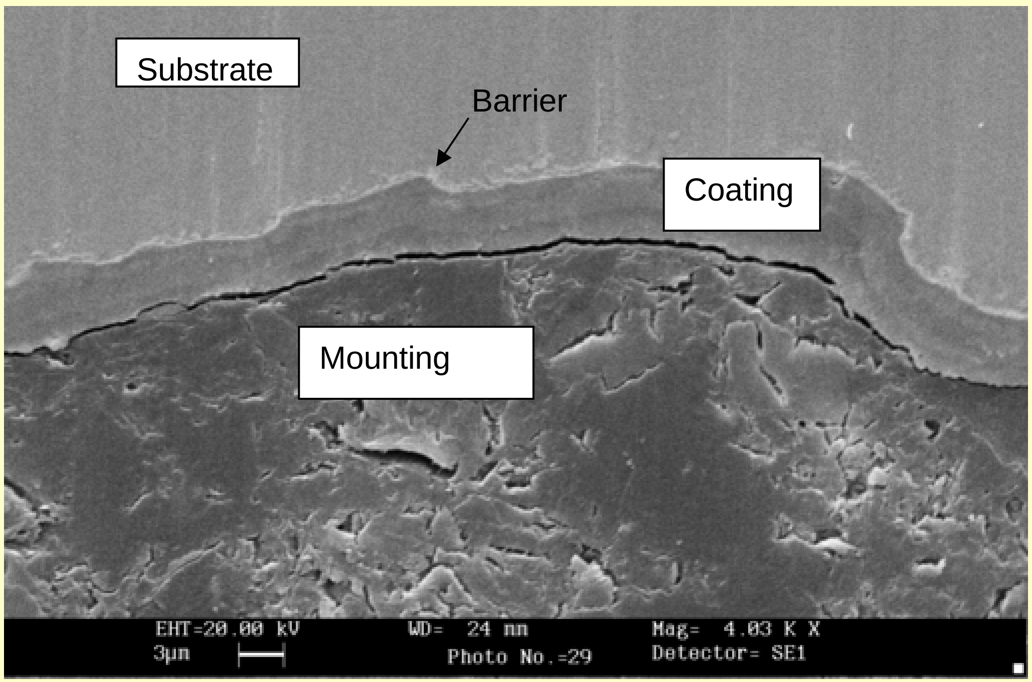
- Coatings inhomogeneity
- C and Ni in metal interfere with the coatings process
- Oxidized Al on Cr/Al survives, but not Cr/Al
- Ti/Ta nitride coatings survive
- Corrosion, once started, appears to accelerate

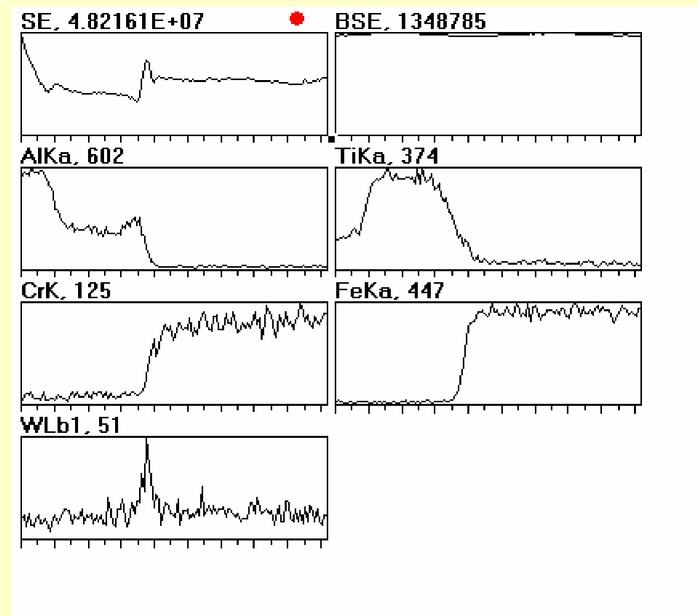
Cross section of a (Ti, Al, Si) nitride coating on SS 409 alloy steel





SEM Photograph of a Nitride Coating on SS409 Alloy with W Diffusion Barrier





Magnified Image of a Porous SS 409 Alloy Coupon

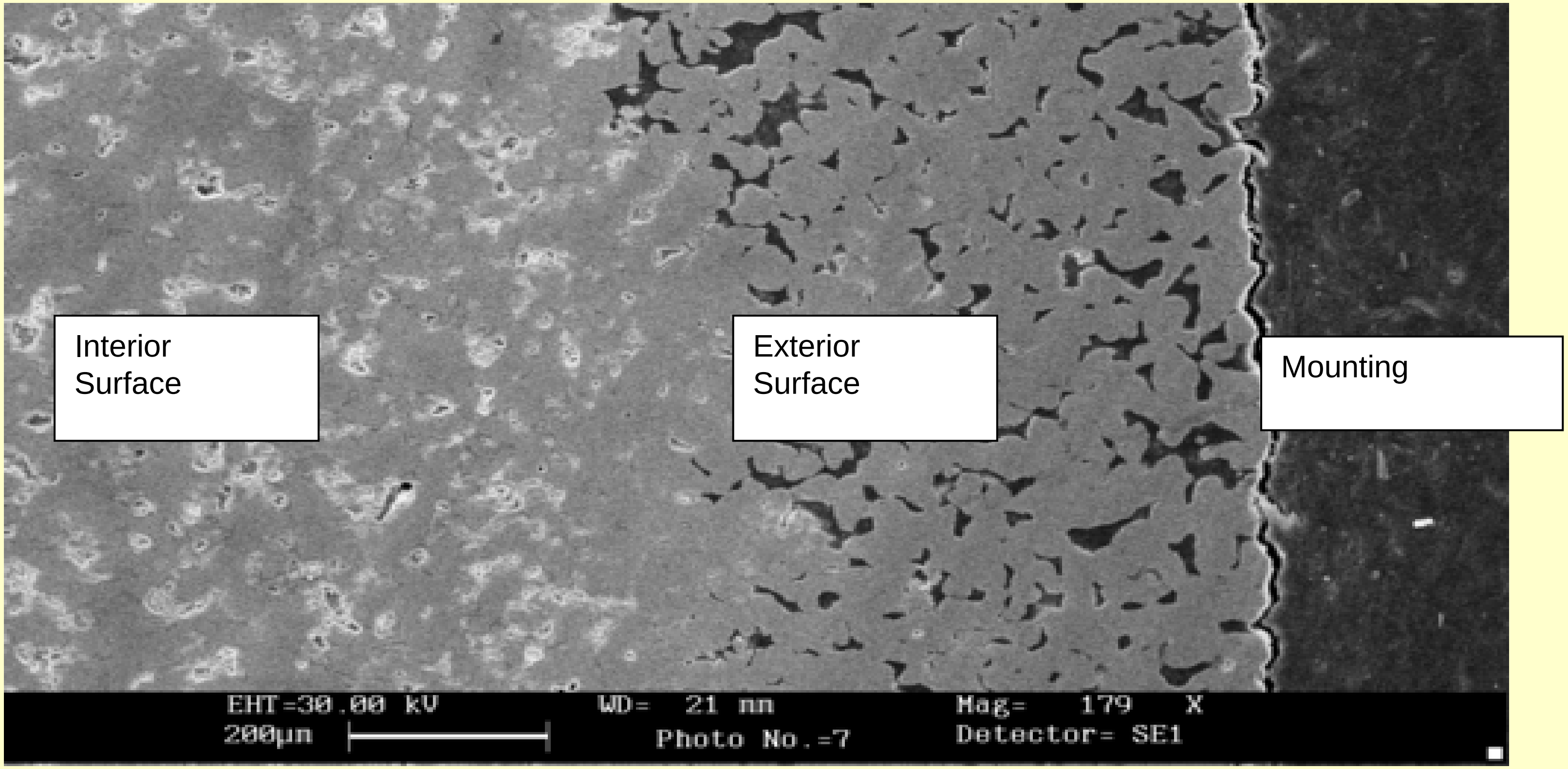
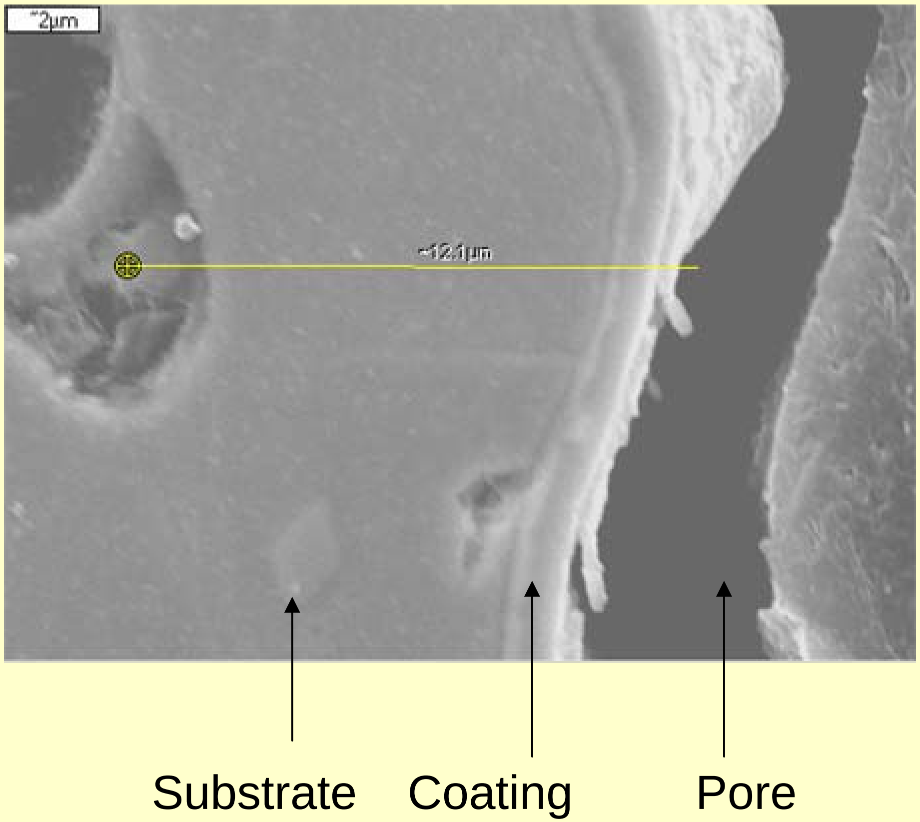
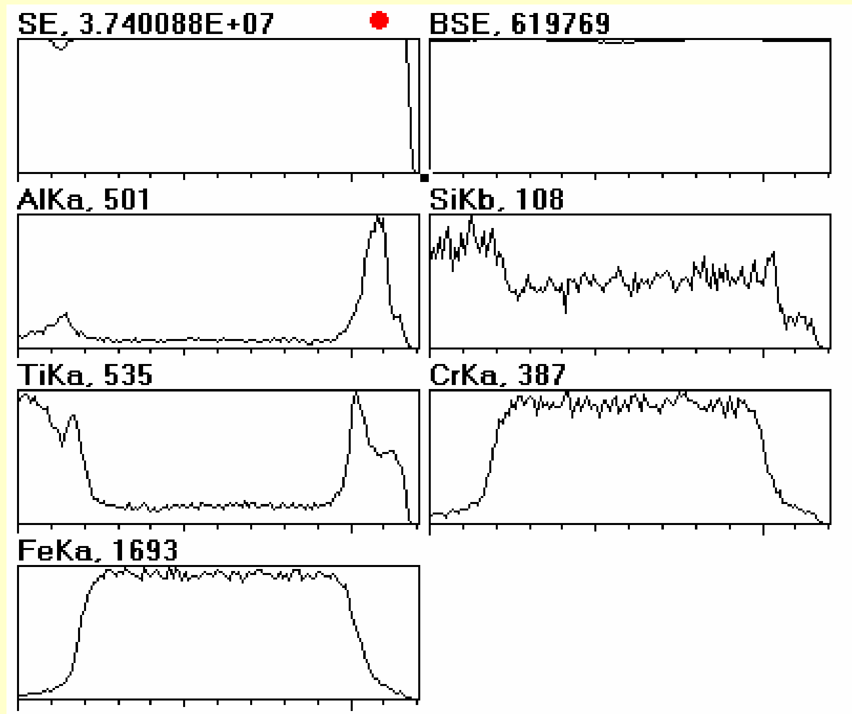


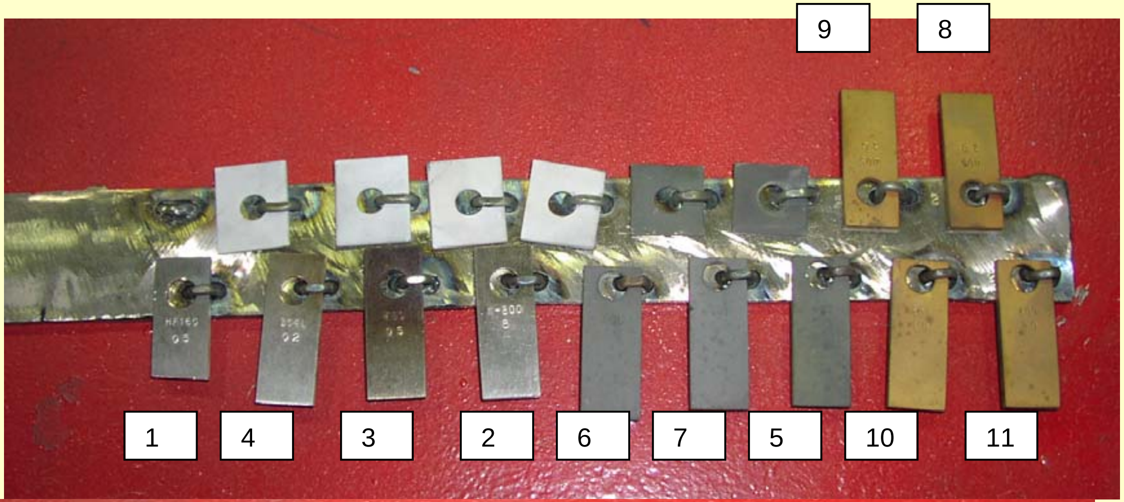
Image and Element Profile inside a Coated Porous SS409 Alloy





Test 11: 300 h at 370°C

Early Samples Recovered from the Gasifier



- Test coupon tree located in a very abrasive environment
- Perhaps, not representative of tube-sheet environment

SUMMARY

- We have an improved procedure for preparing uniform diffusions coatings
- Can coat porous metal filters
- Nitrided Ti, Ta, and Si and oxidized Al on Cr/Al coatings appear most resilient in lab tests
- Await results from exposure of
  - Samples with improved coatings
  - Porous coupons from the filter unit

ACKNOWLEDGMENT

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  Richard Read, Gary Stiegel