NOVEL NANOCRYSTALLINE INTERMETALLIC COATINGS FOR METAL ALLOYS IN COAL-FIRED ENVIRONMENTS

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Outline

- Background
- Selected materials
- New coating process concept
- Results to date
- Summary & future work

Background

- Challenges for achieving higher plant efficiency:

  Increasing steam temperature and pressure requires combined resistances to creep, thermal fatigue, and corrosion at > 800°C

- Current materials for steam pipes:

Ferritic steels: (used at < 620°C)	low thermal expansion, high thermal conductivity; low corrosion resistance;
Austenitic steels: (used at < 675°C)	good corrosion resistance; low thermal fatigue resistance; low thermal conductivity;

Two Pathways of Solutions to the Challenge

- Develop new super steels or alloys having superior high temperature performance

- Use a high-temperature corrosion-resistant coating on a base alloy with excellent mechanical properties

Selected Material for Coatings

Iron Aluminide: Fe_3Al

- Much higher oxidation & sulfidation resistance than ferritic & austenitic steels;
- Mechanism of its high corrosion resistance:

  Forming a dense and protective Al_2O_3 scale even at very low oxygen potential
- High temperature strength;
- Low density;
- Good wear resistance;
- Low cost.

Selected Material for Coatings

Iron Aluminide: Fe_3Al

- Very attractive, but not suitable for fabrication as large components due to its low ductility at ambient temperatures
- Great candidate as a coating material to provide high-temperature corrosion resistance to substrate alloys

Coating Processes

- ***Thermal spray (e.g. HVOF, APS, etc):***
  - Low cost,
  - Porosity,
  - Thickness limited,
  - Problematic adhesion due to mechanical rather than metallurgical bonding to the substrate

- ***CVD or PVD coatings:***
  - Thickness < 50 microns
  - Cost usually high
  - Substrate T>800°C

Coating Processes

- ***<u>Conventional weld-on overlay:</u>***
  - – Metallurgical bonding
  - – Thickness >1 mm,
  - – Welding defects
  - – Weld-able material selection versus the properties of these materials

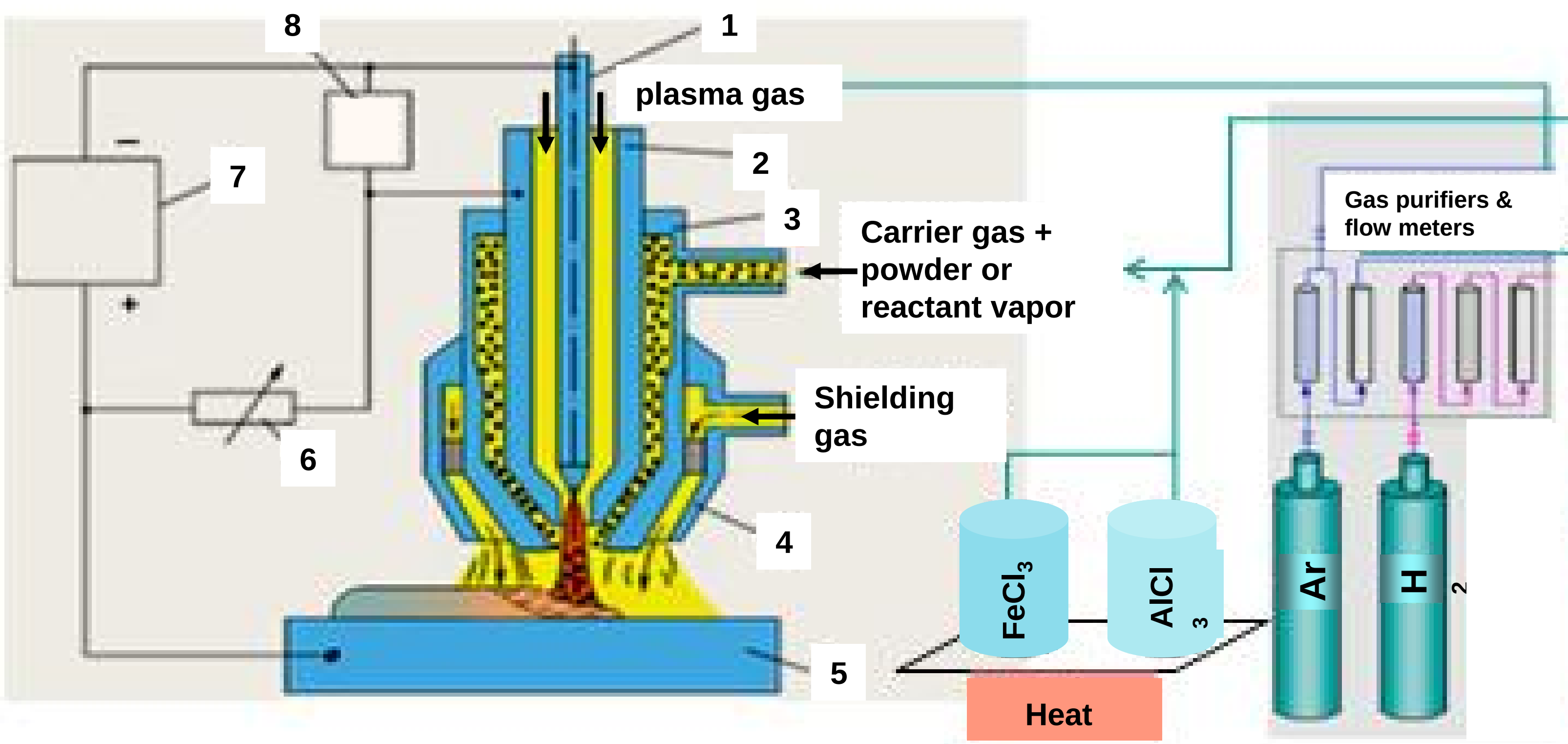
Scope and Objective of this project:

***Develop a new reaction coating process* that:**

- Coating to be formed via in-situ chemical reactions, similar to CVD
- Metallurgical bonding similar to weld-on
- No/minimum porosity overcome the shortcomings of thermal spray
- Sufficient and controllable thickness
- Corrosion resistance with controlled composition and grain microstructure

A New Reaction Coating Process

Based on PTA (plasma transferred arc)



1. Electrode
2. Plasma nozzle
3. Focusing nozzle
4. Shielding nozzle
5. Substrate
6. Balast resistance
7. Power source
8. Oscilation unit

A New Reaction Coating Process
Based on PTA (plasma transferred arc)

Fe_3Al coating are formed by either

- Element Fe and Al in the powder mixture react while forming coating on the substrate during the PTA process
- Elemental Al fed through the plasma react with substrate Fe and form a continuous coating
- Vapor phase reaction of Fe and Al in-flight or while depositing as coating
- In all scenarios, reaction w/ substrate plays a role that assures good bonding

Advantages of this process:

- **Reaction bond coating,**
- **Thicker coating than TS, CVD,**
- **No or very low porosity**
- **Composition and grain size control**

Coating Equipment

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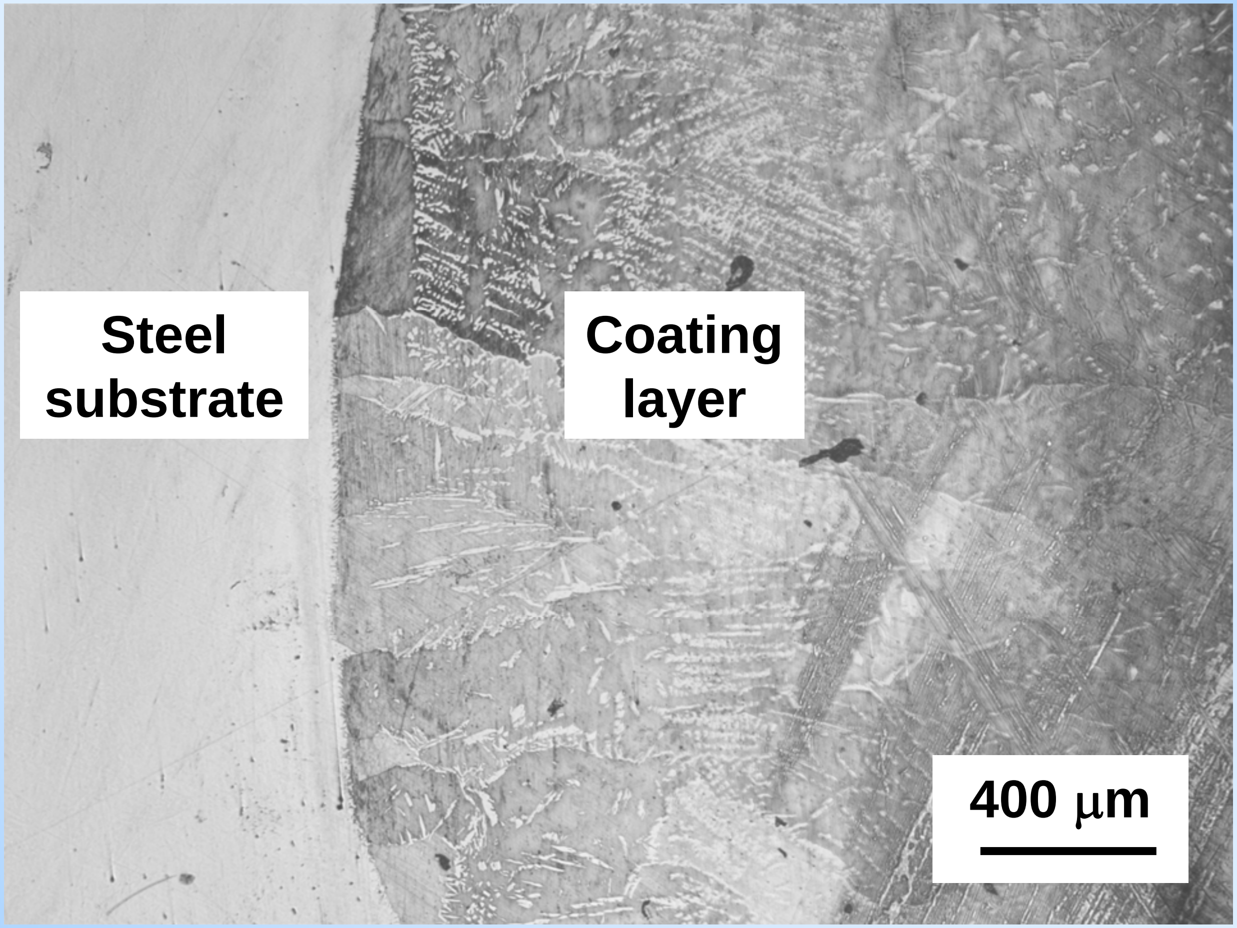
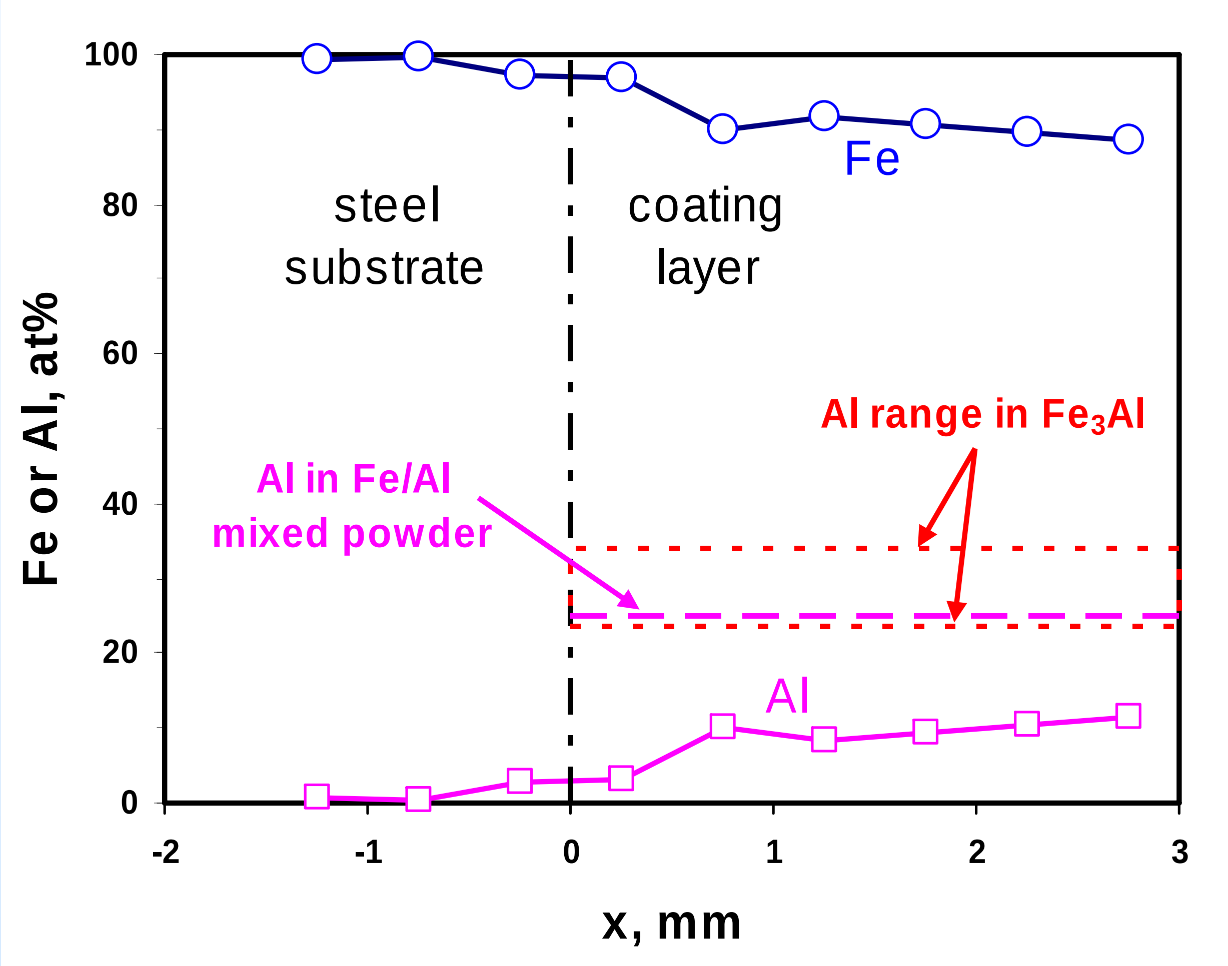
- New coating process concept
- **Results to date**
- Summary & future work

Coating with Elemental Fe/Al Mixed Powder



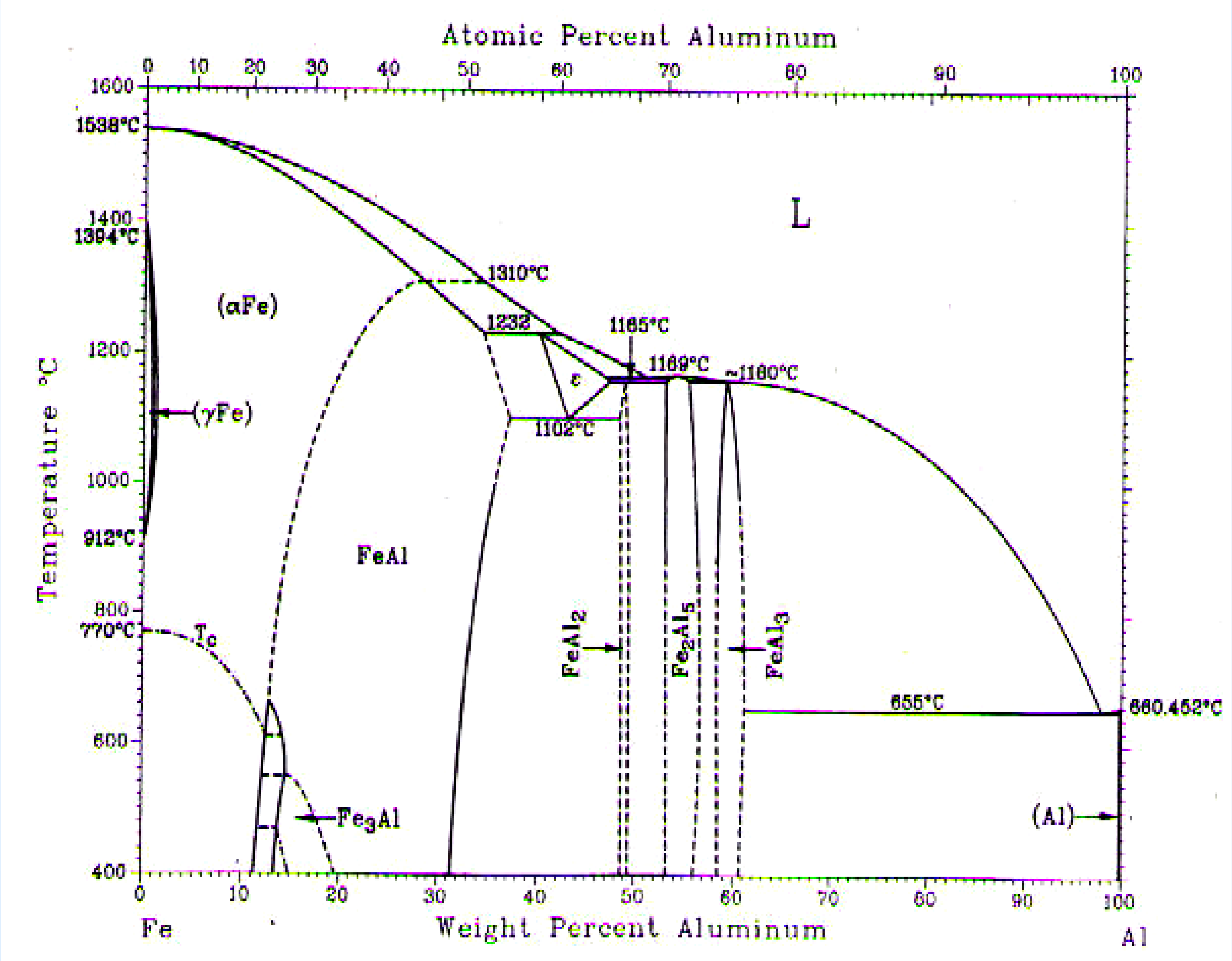
Microscopic view

Coating with Elemental Fe/Al Mixed Powder

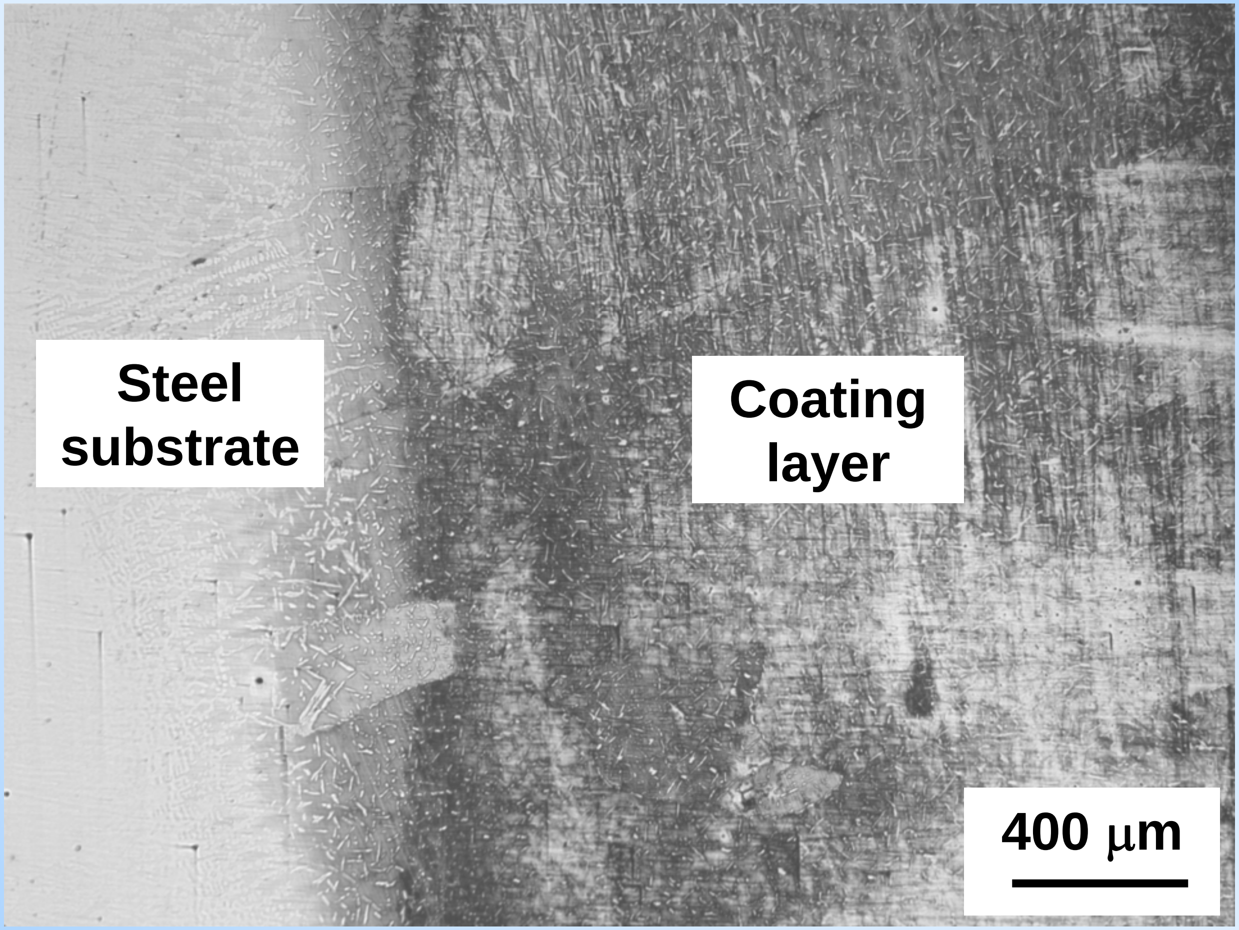


Composition across Coating-Substrate Interface

Fe-Al Phase Diagram

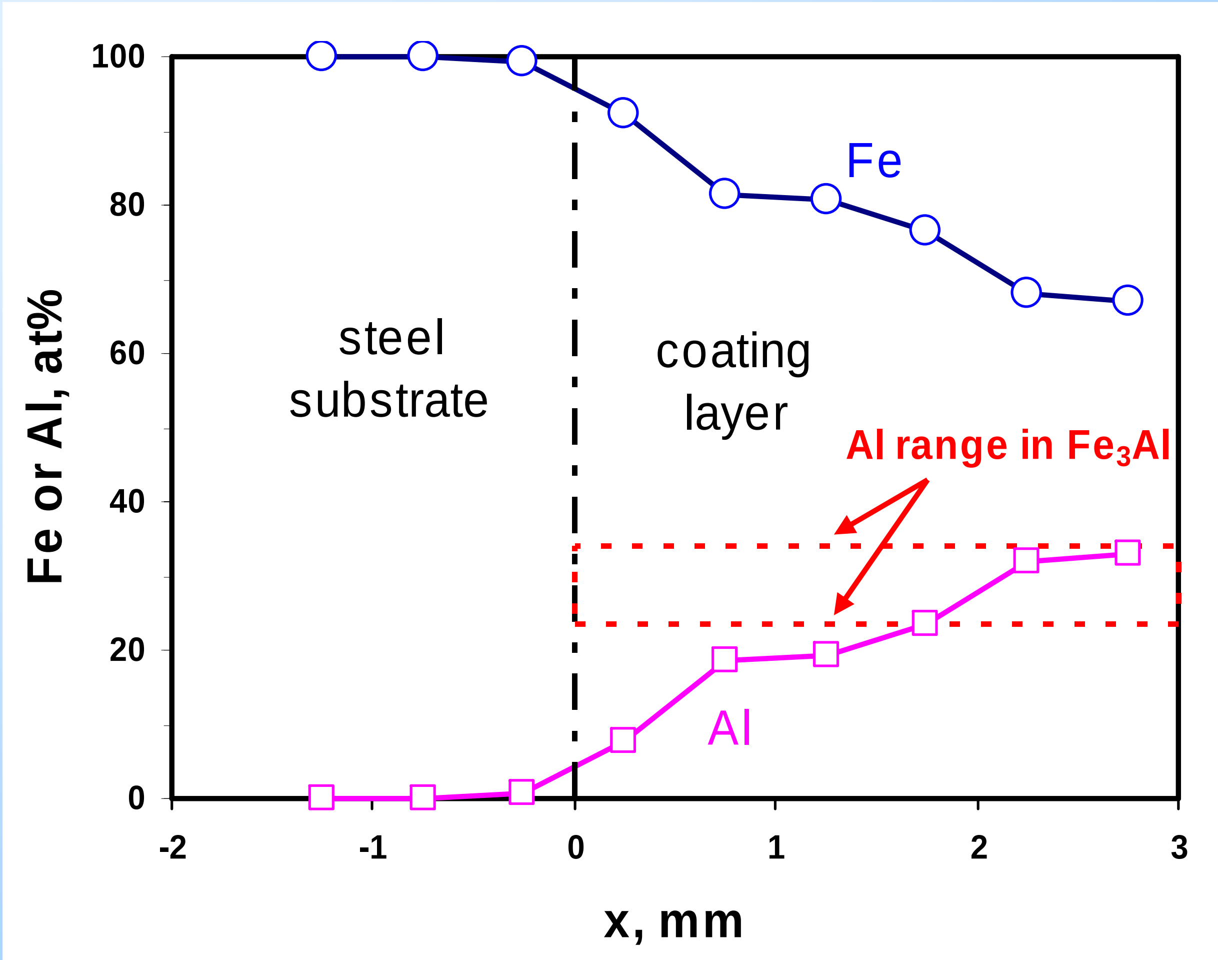


Coating with Al Powder



Microscopic view

Coating with Al Powder

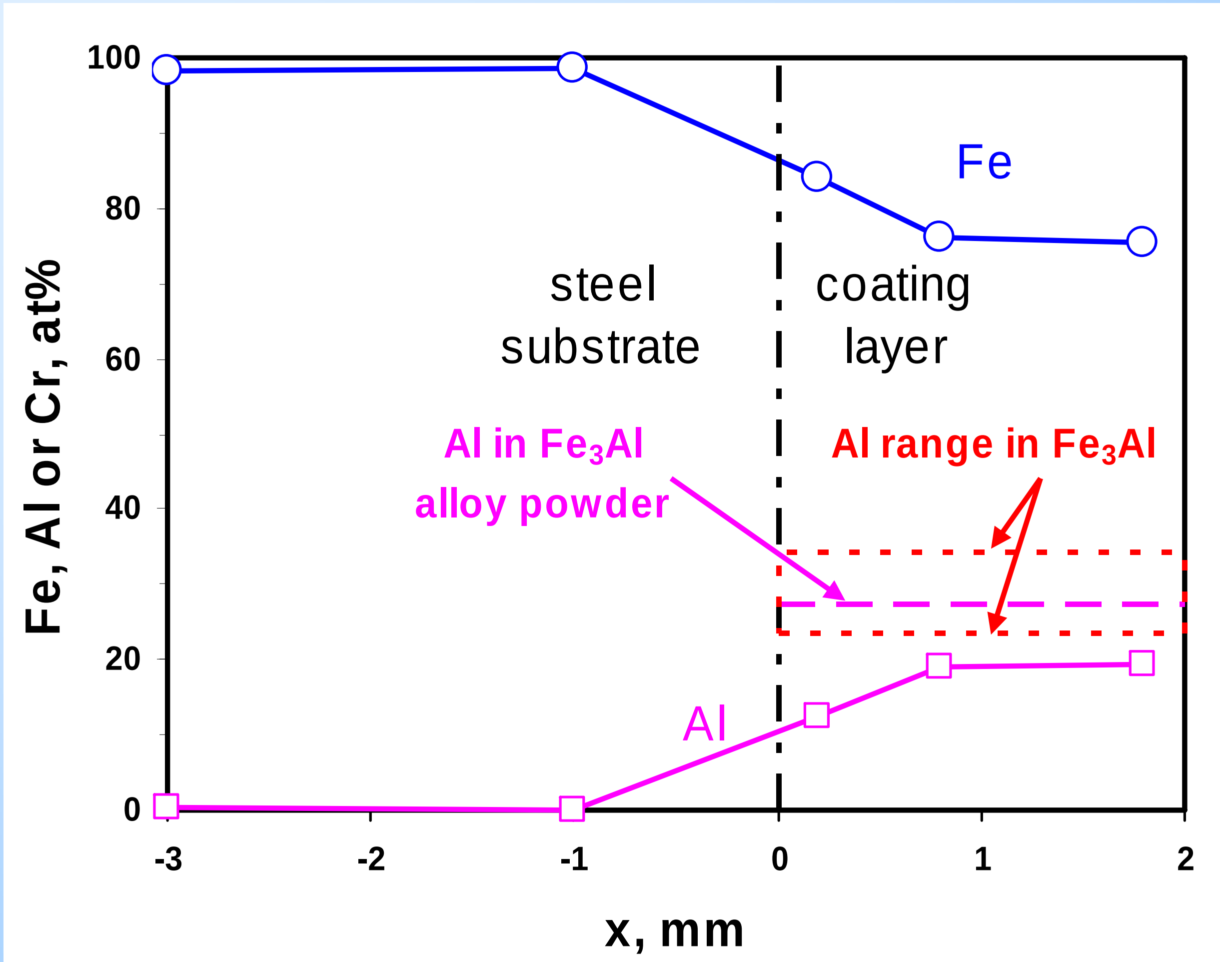


Composition across Coating-Substrate Interface

Coating with Fe_3Al Alloy Powder

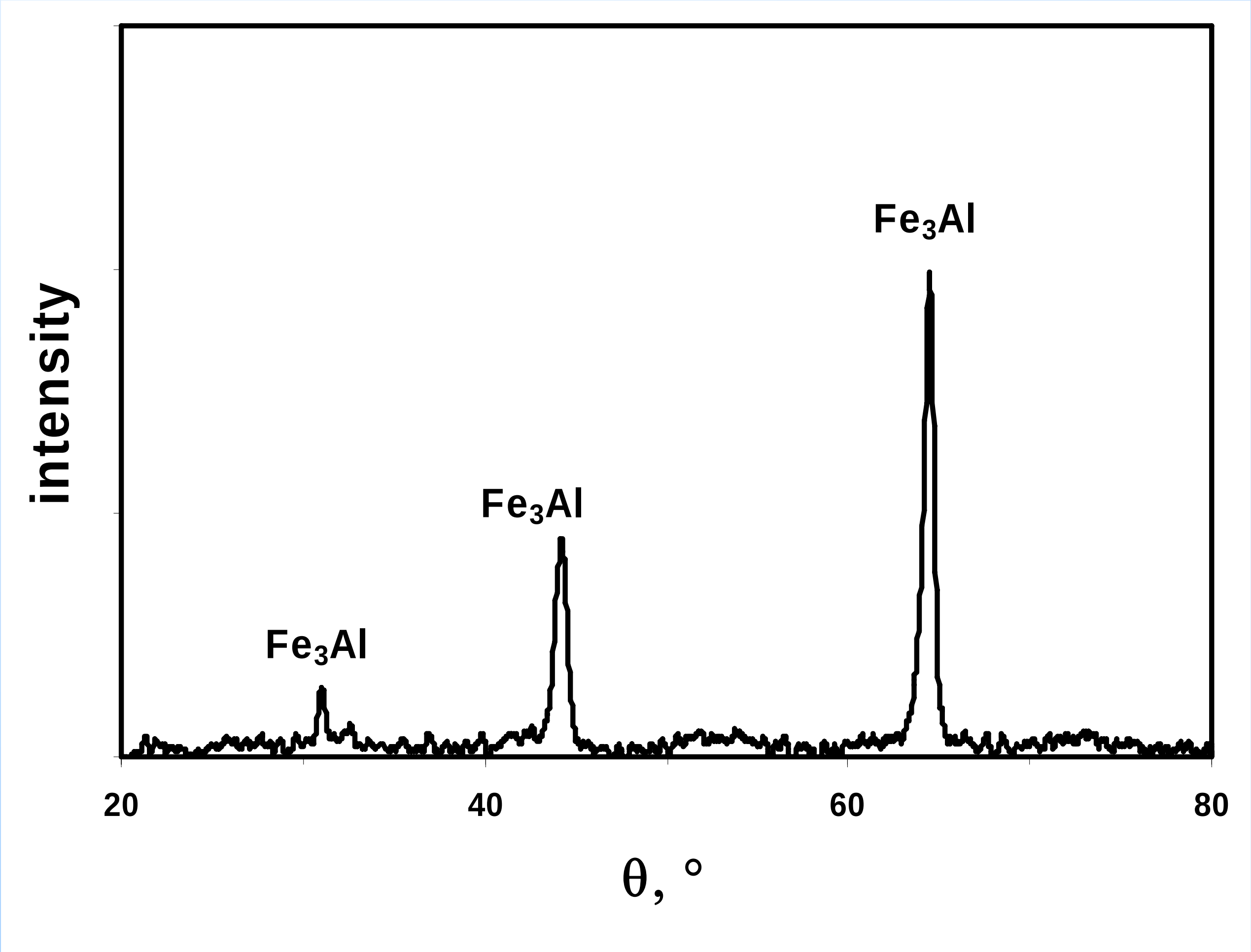
Microscopic view

Coating with Fe_3Al Alloy Powder



Composition across Coating-Substrate Interface

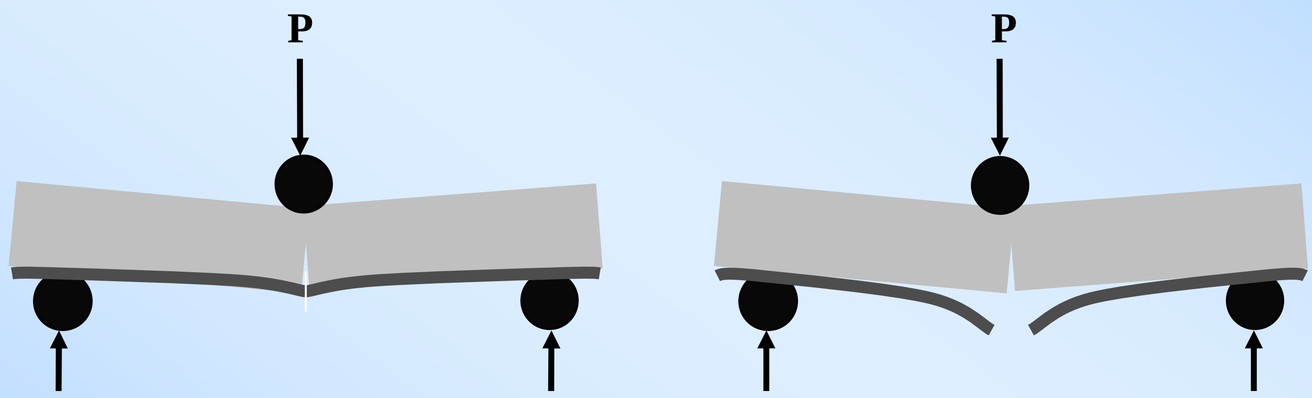
Coating with Fe_3Al Alloy Powder



XRD analysis of coating layer

Evaluation of Coating-Substrate Bonding Strength

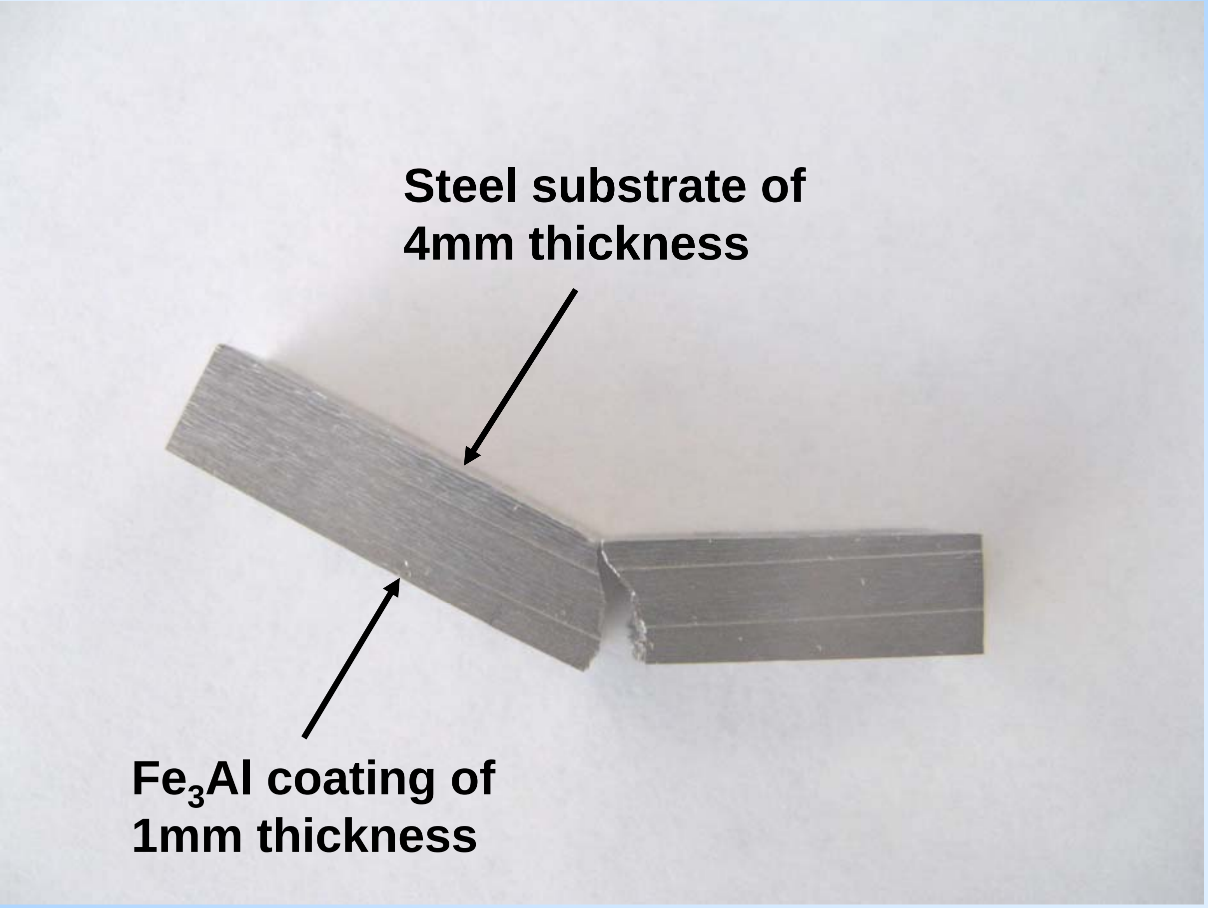
3-point bending test



Good bonding

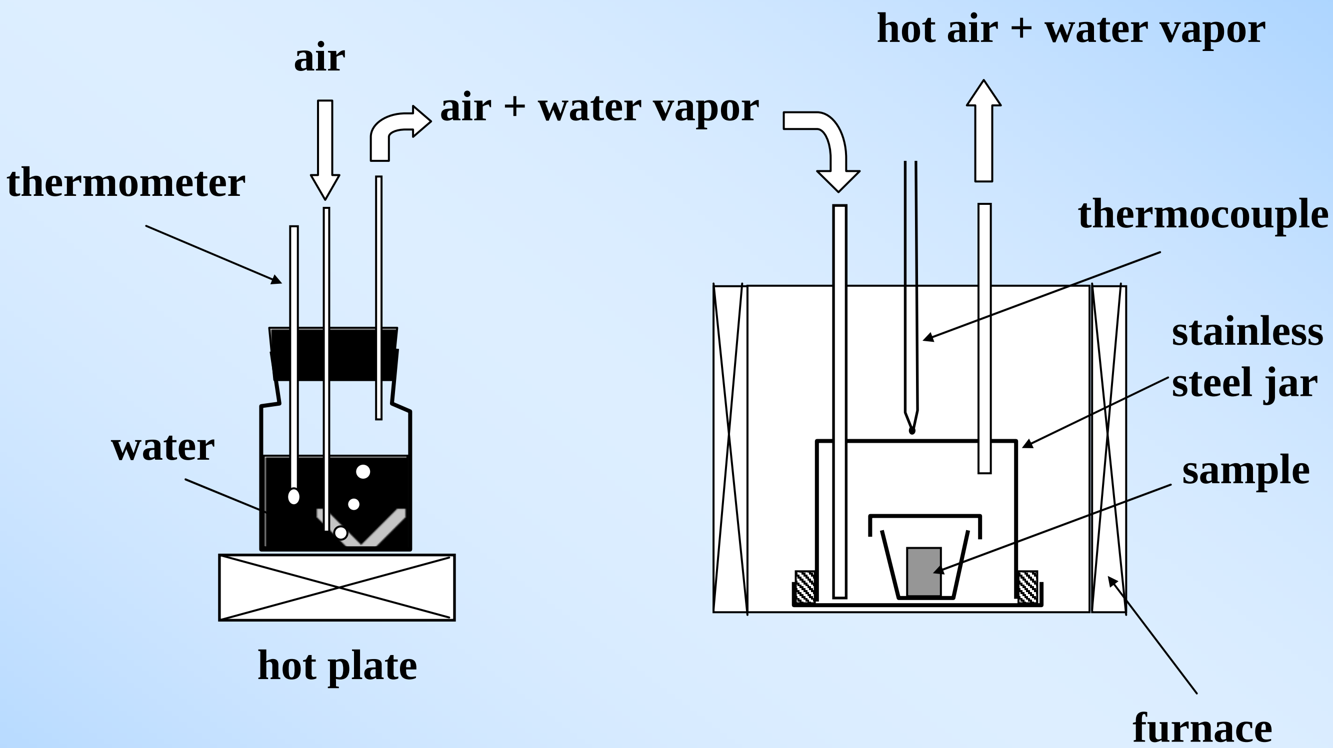
Poor bonding

Good Coating-Substrate Bonding



Metallurgical Bonding at Interface

Steam-side Corrosion Test

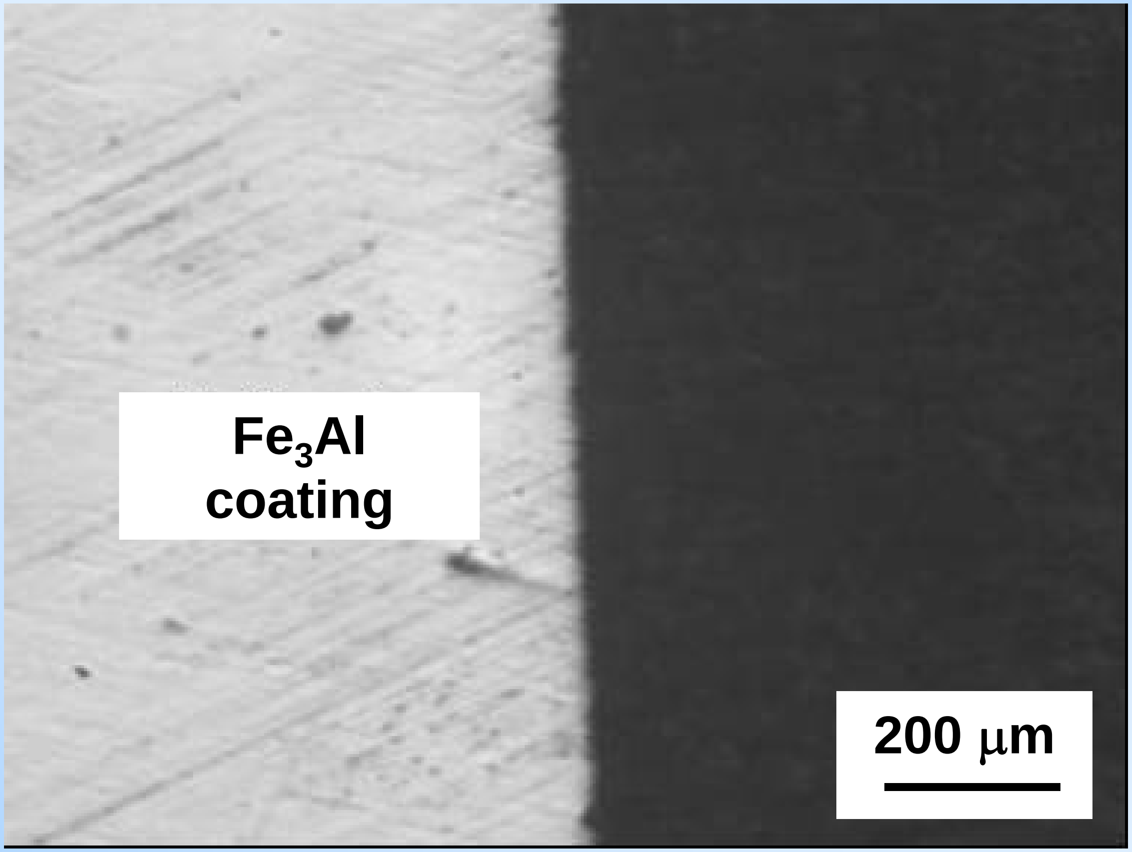


Heating cycle: 20°C/min to 800°C; 20h at 800°C; 10°C/min to 300°C

Atmosphere: air - 10 vol% H_2O

Tested materials: Fe_3Al coating vs Stainless steel (304)

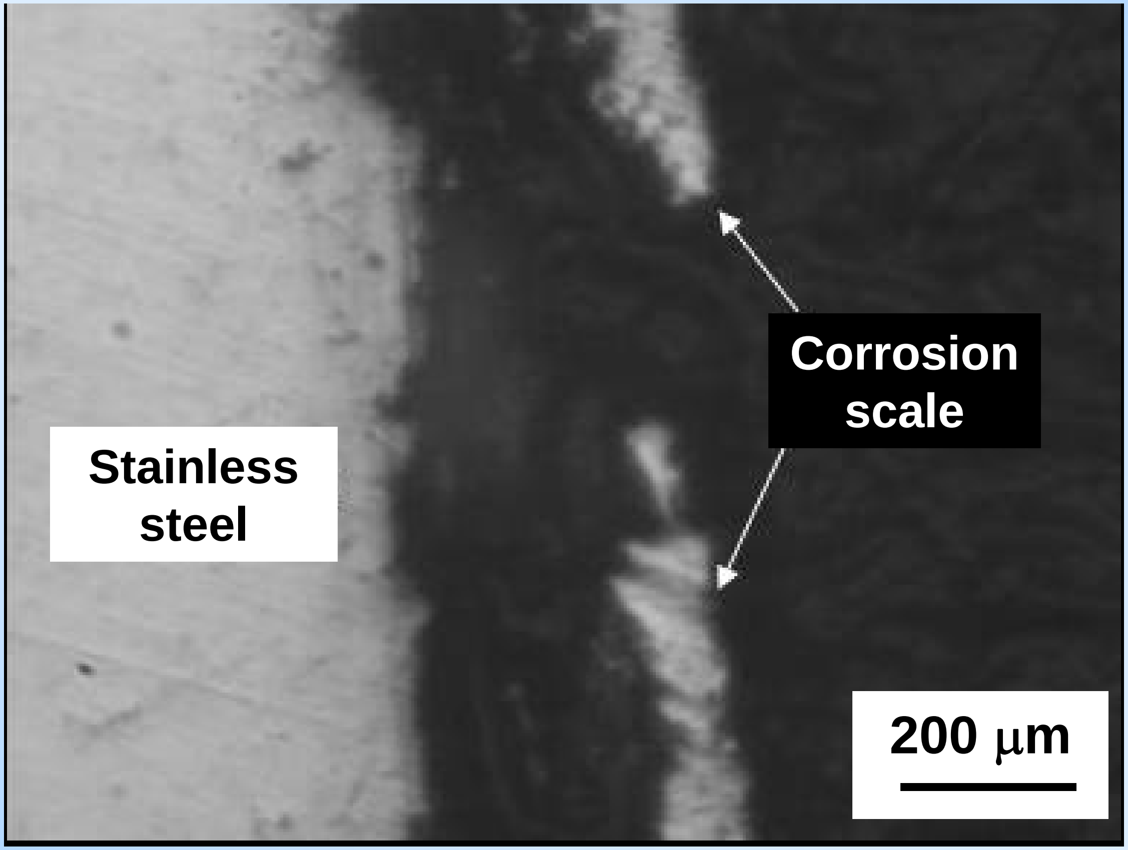
Coating Surface after Steam-side Corrosion



4 cycles of 20°C/min to 800°C; 20h at 800°C; 10°C/min to 300°C

Atmosphere: air - 10 vol% H_2O

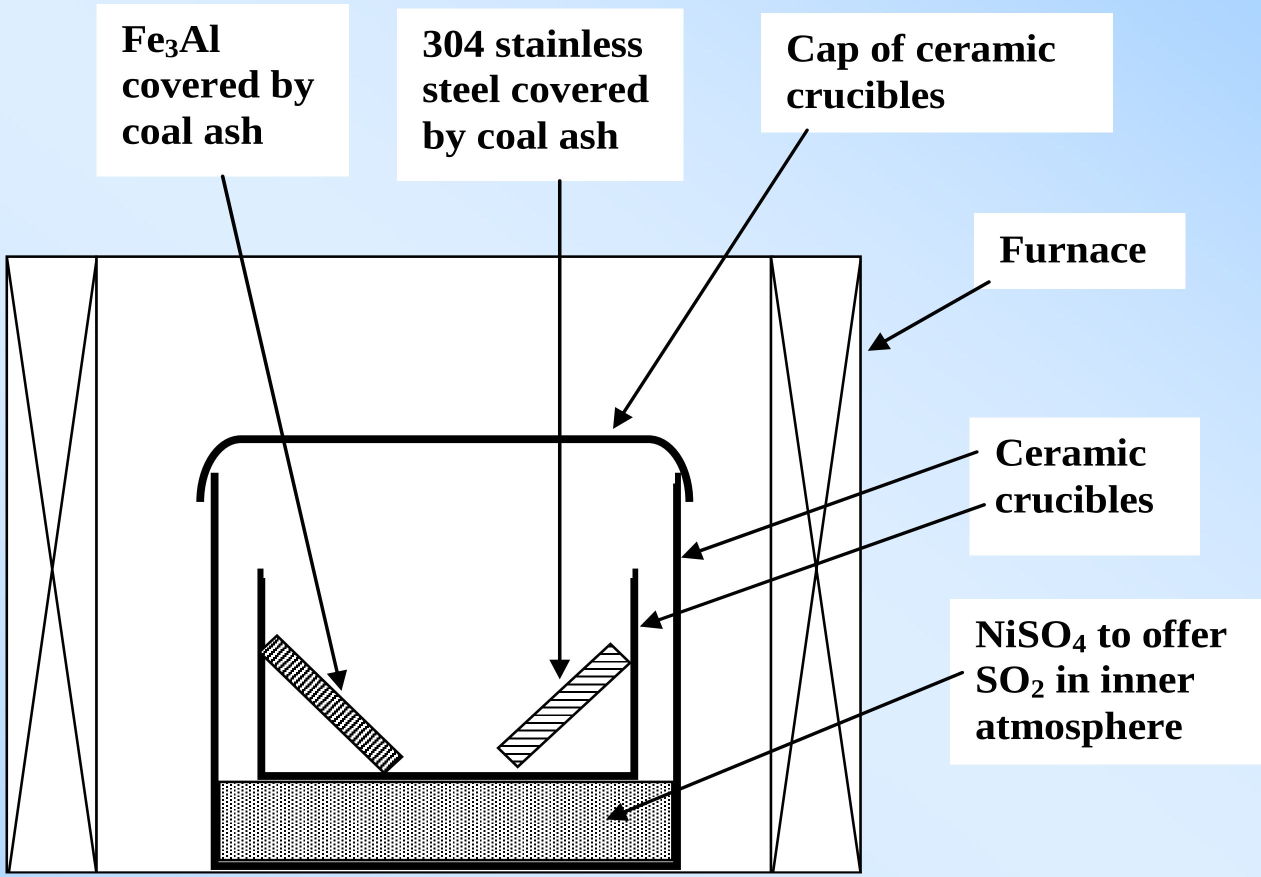
Stainless Steel Surface after Steam-side Corrosion



4 cycles of 20°C/min to 800°C; 20h at 800°C; 10°C/min to 300°C

Atmosphere: air - 10 vol% H_2O

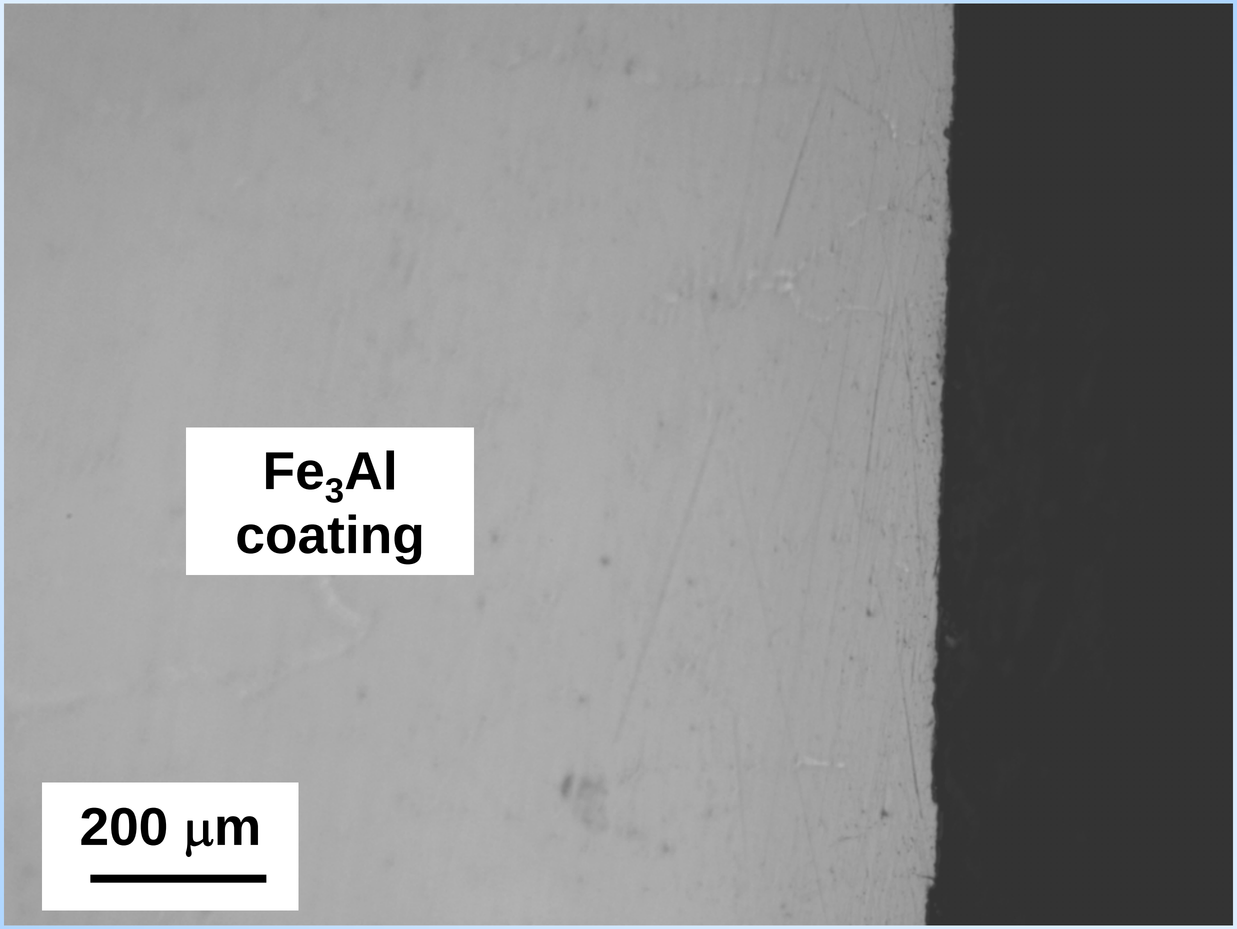
Fire-side Corrosion Test



Conditions: 800°C; air - 5 vol% SO_2

Coal ash (wt%): $5Na_2SO_4$ - $5K_2SO_4$ - $30Al_2O_3$ - $30SiO_2$ - $30Fe_2O_3$

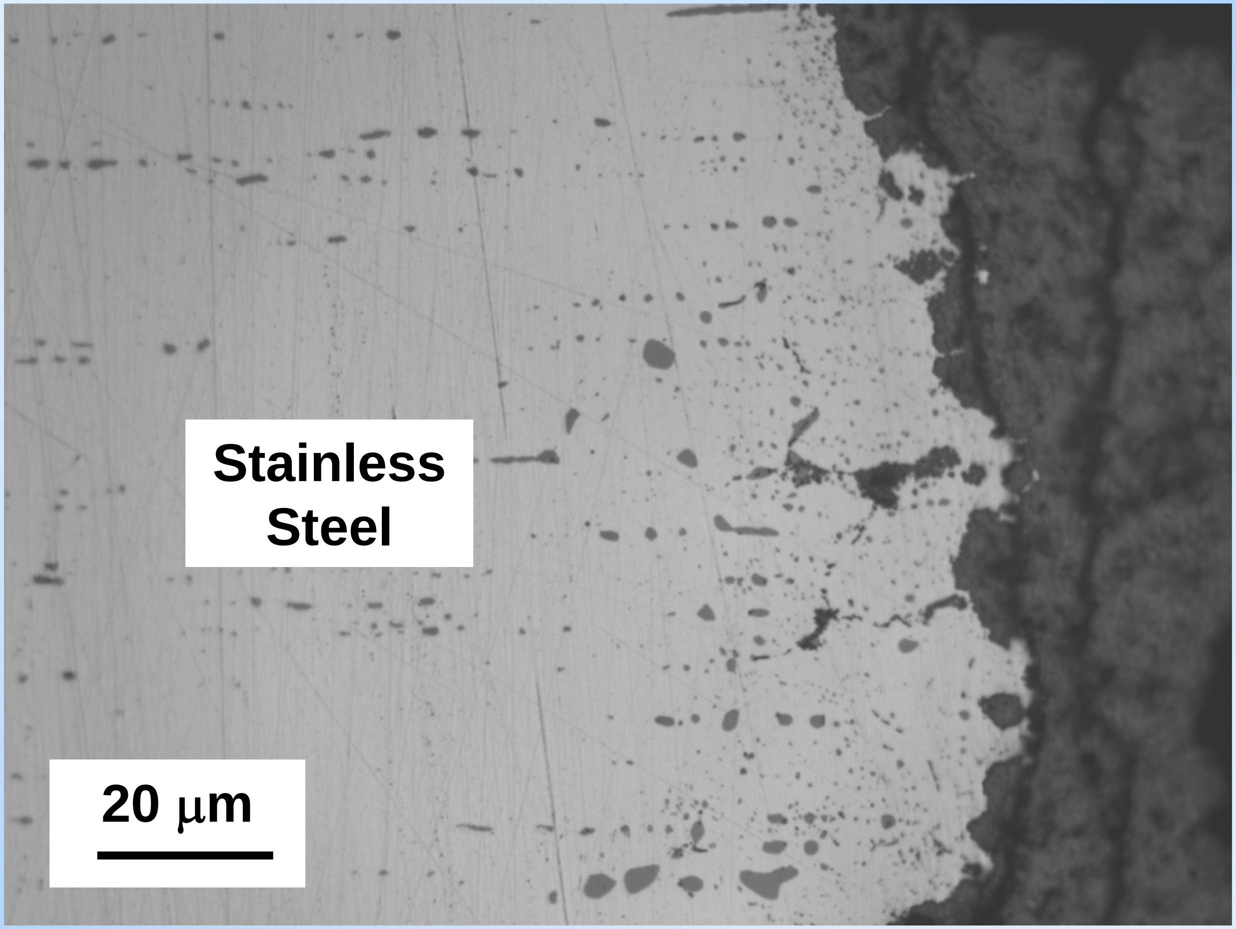
Coating Surface after Fire-side Corrosion



Conditions: 200h at 800°C; air - 5 vol% SO_2

Coal ash (wt%): $5Na_2SO_4$ - $5K_2SO_4$ - $30Al_2O_3$ - $30SiO_2$ - $30Fe_2O_3$

Stainless Steel Surface after Fire-side Corrosion



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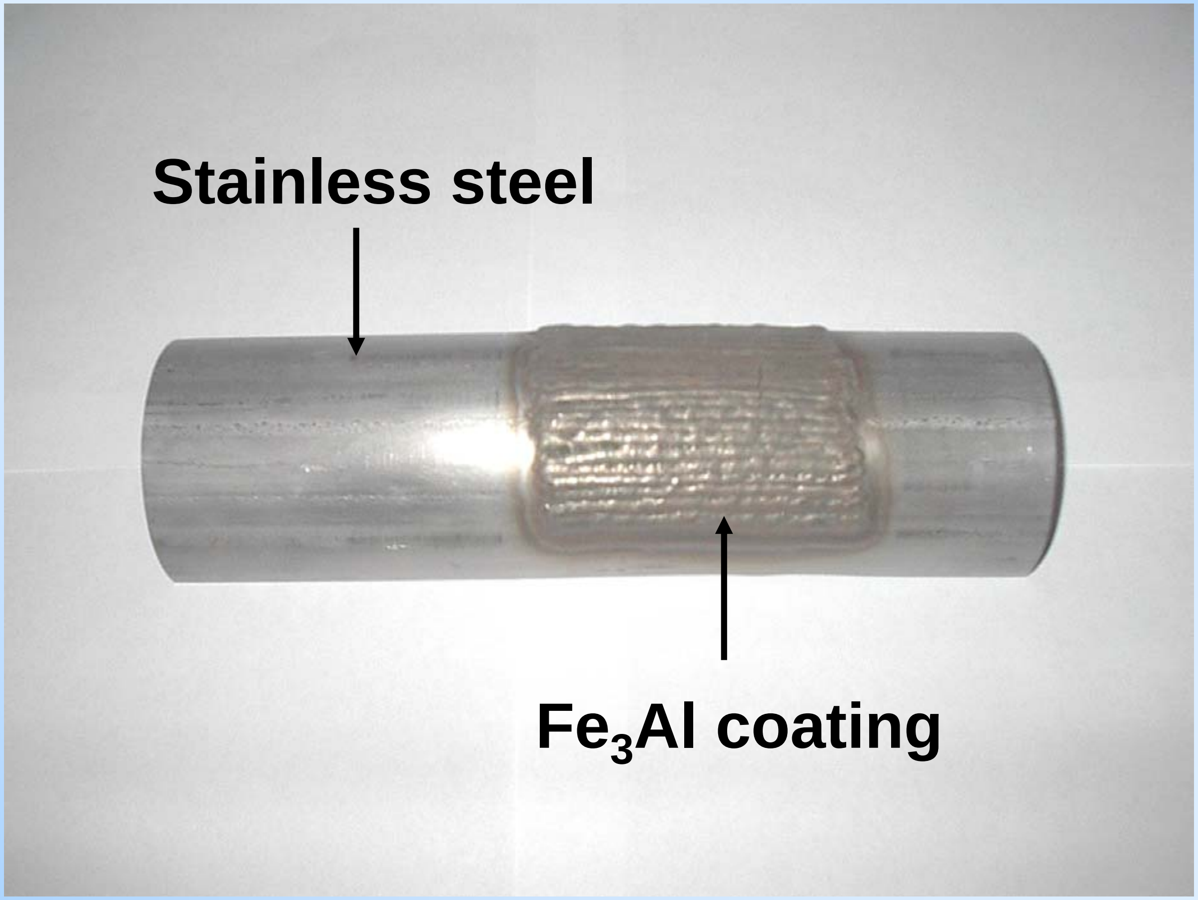
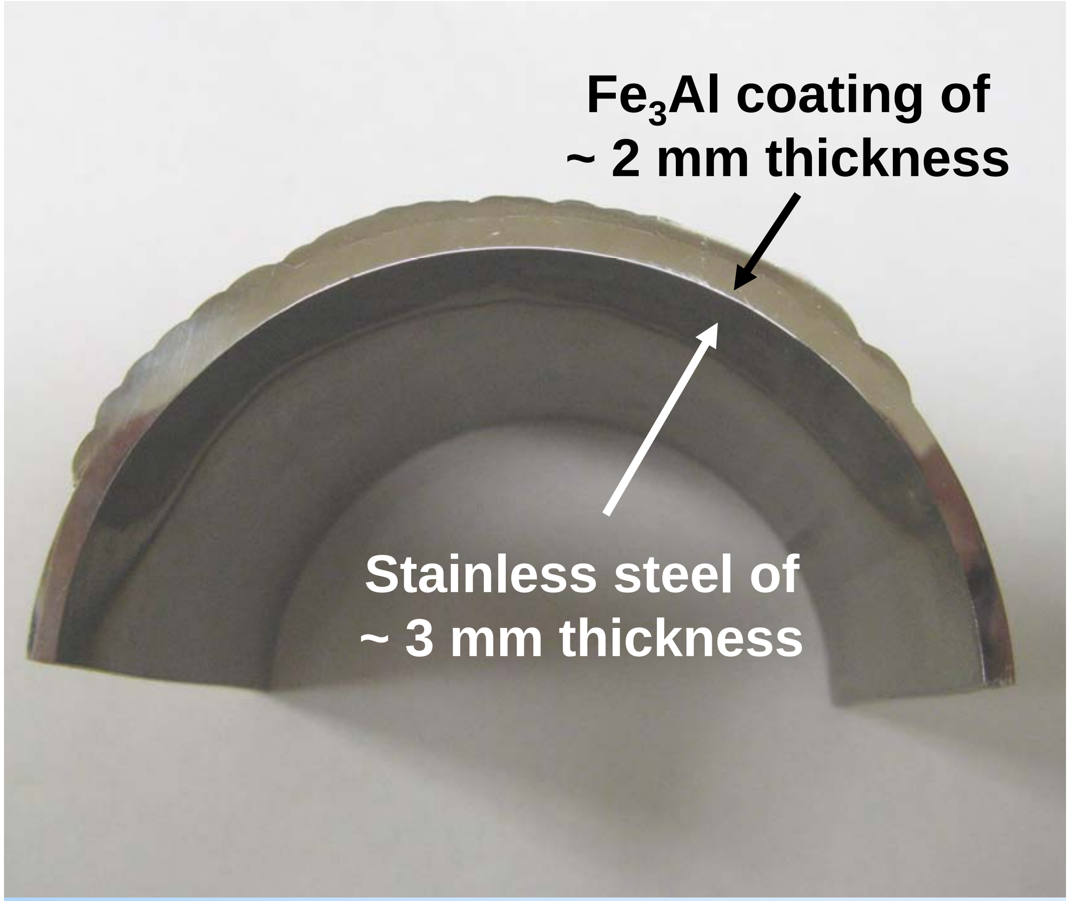
Industrial Use Field Test



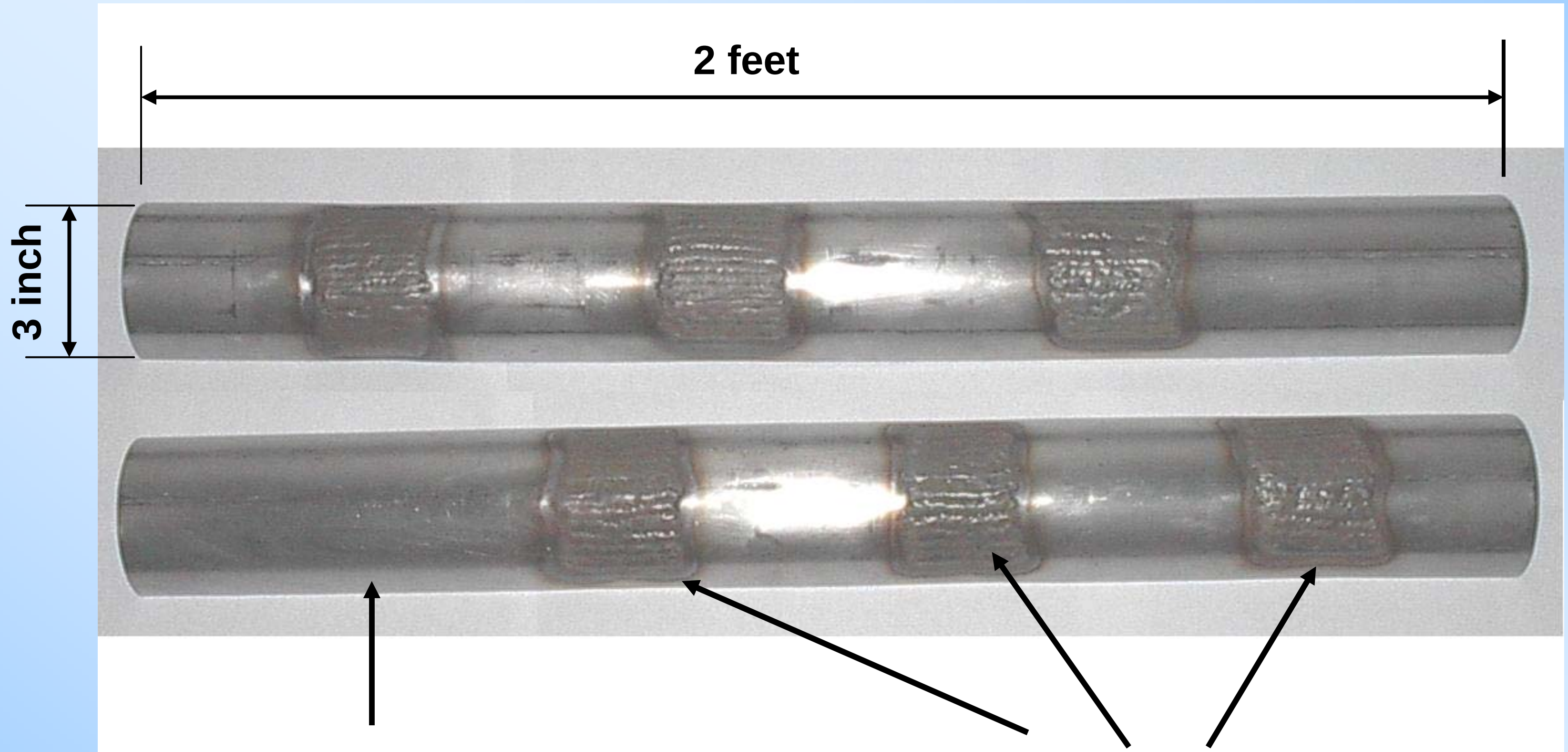
Fe_3Al coated on half-circle-shaped stainless steel

Industrial Use Field Test



Cross-section of Fe_3Al coated on half-circle-shaped stainless steel

Industrial Use Field Test



Half-Circle-Shaped Stainless Steel Pipe

Fe_3Al coatings

Coated Pipes to be Field-Tested in Power Plant

Summary and Future Work

- Fe_3Al coating can be formed by using Fe_3Al alloy powder, Fe/Al mixed powder as well as Al powder.
- Excellent metallurgical bonding forms between Fe_3Al coating and steel substrate.
- The superior corrosion resistance of Fe_3Al coating formed using the PTA process has been confirmed. For both steam-side and fire-side environments.
- Fe_3Al coated stainless steel pipes will be field-tested in power plant.
- Fe_3Al coating by the PTA reaction coating process using either elemental powders or vapor phase reaction of $FeCl_3$ & $AlCl_3$ with H_2 will be investigated
- The dependence of grain size on processing techniques and the effect of grain size on corrosion resistance will also be studied.

Acknowledgement

DOE/NETL/Coal Research Program

Thank you

Questions?