Iron or Nickel Aluminide Coatings by an In-situ Reaction Process for Metal Alloys in Coal-fired Environments

Zhigang Z. Fang, H.Y. Sohn, Peng Fan and Eric Riddle, University of Utah, Department of Metallurgical Engineering
Marshal D. Clark, Structural Integrity Associates, Inc.

A novel in-situ reaction process for depositing high temperature corrosion resistant coatings, including iron aluminide coatings on steel substrates or nickel aluminide coating on Ni-alloy substrates, was developed. In this process, aluminum powder is fed through a plasma transferred arc (PTA) torch onto the steel or Ni-alloy substrate surface. Experimental results demonstrated that the iron aluminide or nickel aluminide coating was formed by an in-situ reaction between the aluminum powder and the steel or Ni-alloy substrate. Aluminide coatings prepared under optimum conditions were porosity-free and metallurgically bonded to the steel or Ni-alloy substrate. It is expected that the principle demonstrated in this process can be applied to the deposition of other intermetallic and alloy coatings.

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: low thermal expansion,
(used at < 620°C) high thermal conductivity;
low corrosion resistance;

Austenitic steels: good corrosion resistance;
(used at < 675°C) 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: Intermetallics — Iron or Nickel Aluminides

- 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.

Very attractive, but not suitable for fabrication as large components due to its low ductility at ambient temperature.

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; 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.

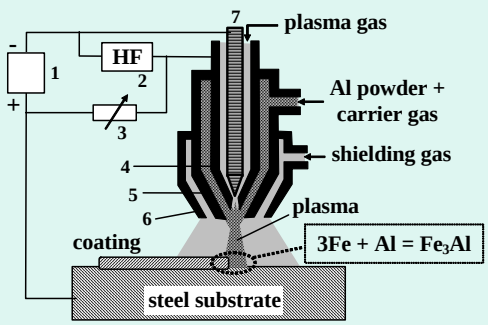
Objective of this work:

Develop a new reaction coating process that:

- Coating to be formed via in-situ chemical reactions
- Metallurgical bonding similar to weld-on
- No/minimum porosity
- Sufficient and controllable thickness
- Corrosion resistance with controlled composition and grain microstructure

The New Reaction Coating Process

based on PTA (plasma transferred arc) process



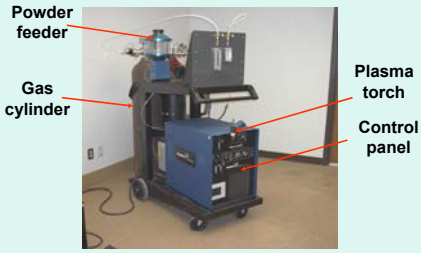
1. Power source
2. Oscillation unit
3. Ballast resistance
4. Plasma nozzle
5. Focusing nozzle
6. Shielding nozzle
7. Electrode

Aluminide coating are formed by in-situ reaction

- Element Al powder react with substrate while forming coating on substrate during the PTA process;
- Reaction w/ substrate plays a role that assures good bonding.

Advantages of this process:

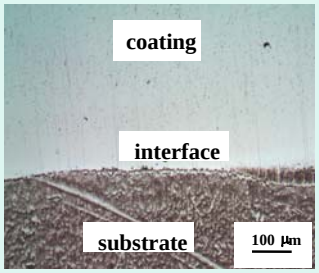
- Reaction bond coating;
- Thicker coating than CVD;
- No or very low porosity;
- Composition and grain size control.



Coating equipment

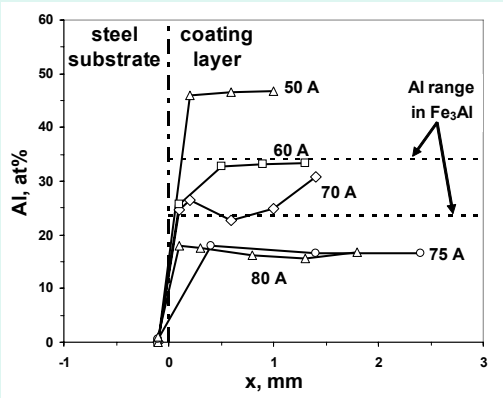
Results

Porosity-free Coating Formed

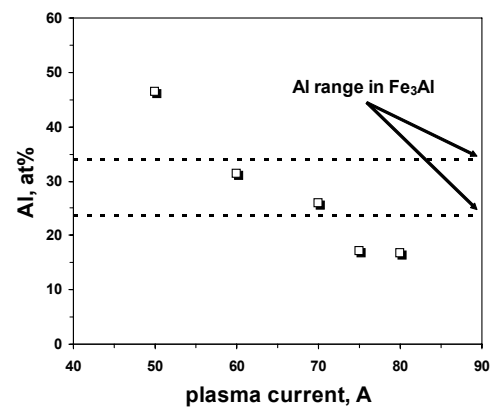


Cross-sectional view of the Fe_3Al-coated steel sample, indicating the coating is porosity-free and metallurgically-bonded to the substrate

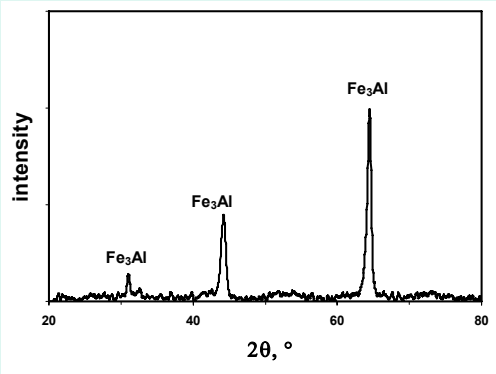
Composition across Coating-Substrate Interface



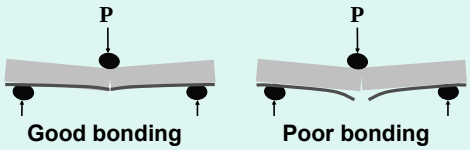
Composition in Coating vs Plasma Current

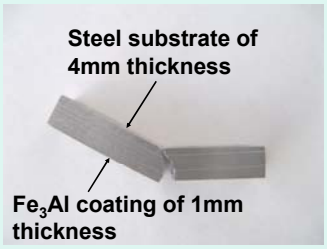


Identification of phases in the coating layer by XRD analysis



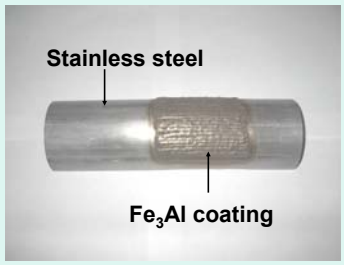
Evaluation of Coating-Substrate Bonding Strength by 3-point bending test

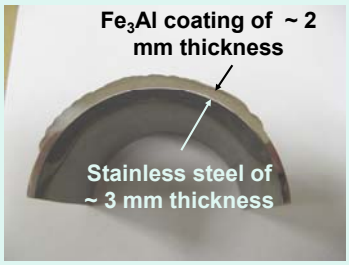




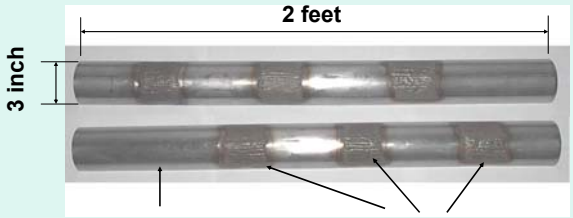
Front-view of the coated sample after 3-point bending test, indicating good bonding between the coating and the substrate

Coating on Half-Circle-Shaped Stainless Steel Pipes





Industrial Use Field Test



Coated Pipes are now under Field-Testing in Power Plant

Summary

- Iron aluminide coating can be formed by feeding Al powder on steel substrate through PTA torch, via an in-situ reaction coating process.
- Similarly, nickel aluminide coating can be formed on Ni-base alloys.
- This in-situ reaction coating principle is expected to be applicable to prepare other intermetallic and alloy coatings.
- Excellent metallurgical bonding forms between the coating and the substrate.
- Iron aluminide coated stainless steel pipes is under field-testing in power plant.

Acknowledgement

This study is financially supported by the US Department of Energy under contract number DE-FG26-05NT42529.