NEXTECH MATERIALS

Aluminide Based Coatings for the Protection of Metallic Components in SOFC Systems

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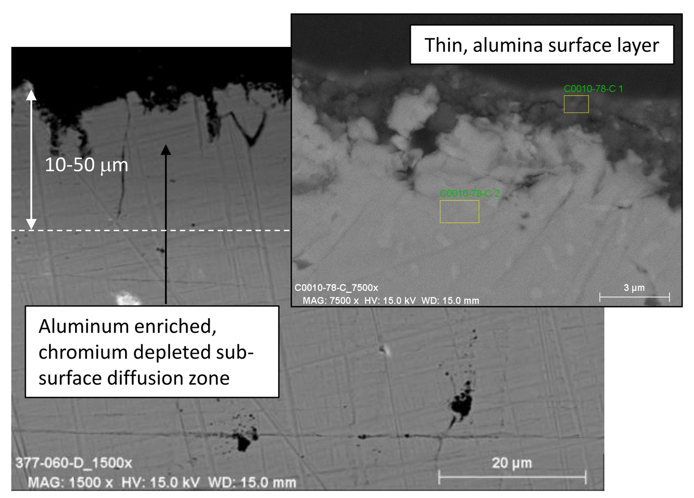
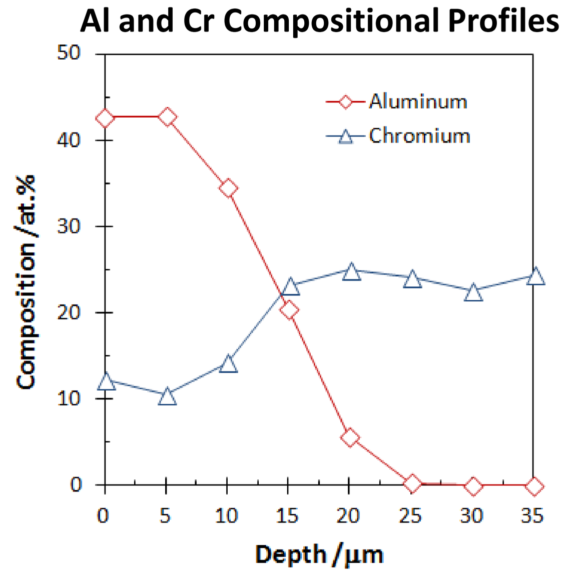
Protective Aluminide Based Coating

NexTech has demonstrated the feasibility of a spray-based, low-cost aluminization process for applying aluminum/aluminide coatings to metallic components. For the non-active (sealing surfaces) areas of metallic interconnects, a modified firing process has been developed compatible with the processing of the manganese cobaltite (MCO) active area coating. This has enabled the aluminide coating and MCO coating to be co-deposited, allowing significant cost reductions to be realized. Interconnects have been successfully dual-coated with MCO/aluminide coatings using an Aerosol Spray Deposition (ASD) process.

Cross-Section Aluminide Coating



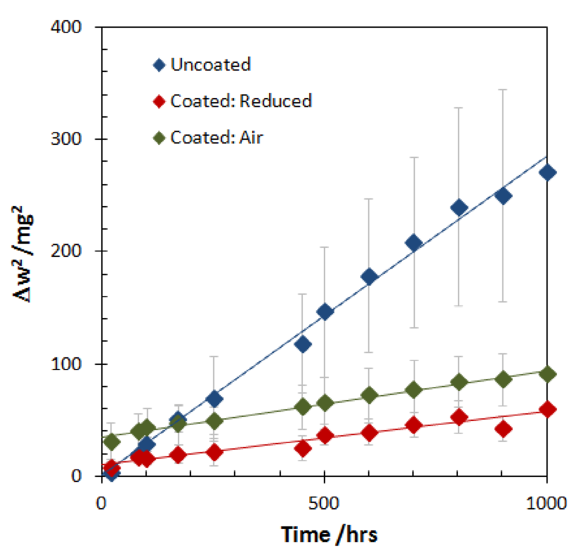
Al and Cr Compositional Profiles



Substrate: Ferritic stainless steel AL 441HP
Aluminide coating: 20 µm fired| Standard Processing Conditions

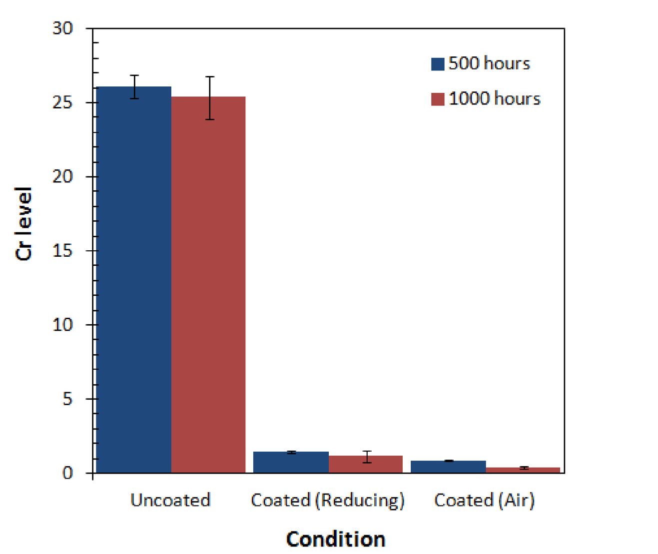
Significantly enhanced oxidation and chromium volatility resistance has been demonstrated for aluminide coated (fired both in air and with the MCO coating compatible firing process) versus uncoated ferritic stainless steel.

Isothermal Oxidation | Weight Gain



Substrate: Ferritic stainless steel AL 441HP
Aluminide coating: 20 µm | Standard Processing
Oxidation: 1000 hr | Air | 900 °C

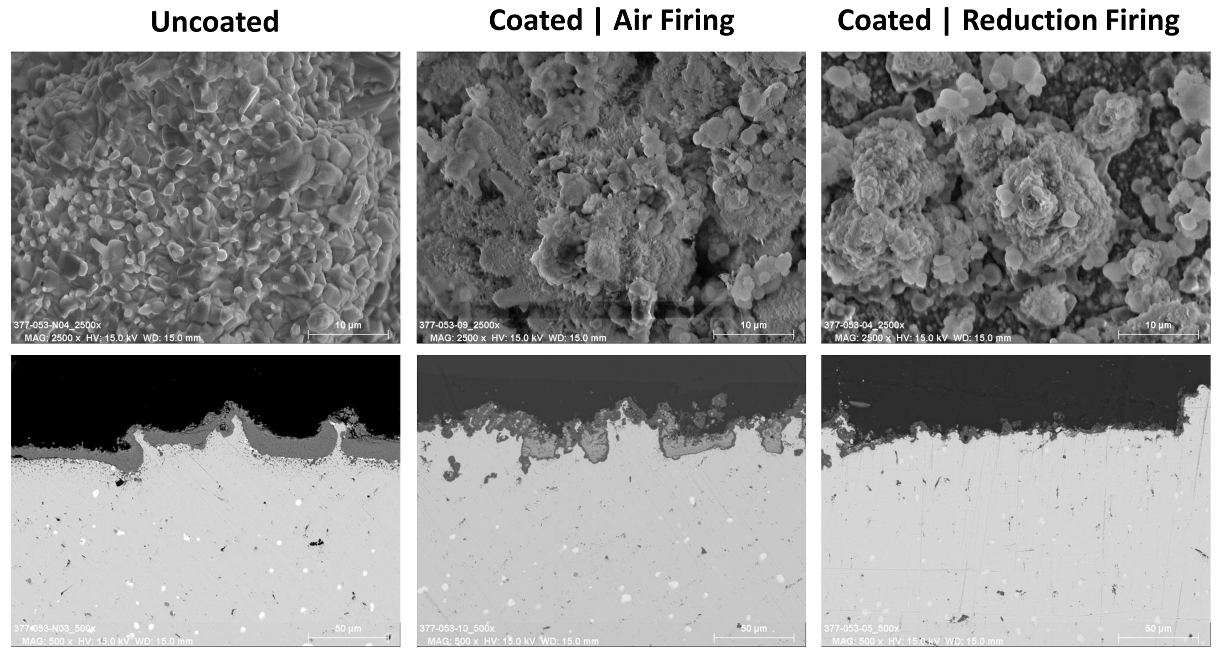
Chromium Volatility Resistance



Substrate: Ferritic stainless steel AL 441HP
Aluminide coating: 20 µm | Standard Processing
Cr volatility: 1000 hr | air | 900 °C
Cr volatility: EDS of Cr capturing material

Post-mortem microstructural analysis after 1000 hours at 900 °C confirms that the aluminide coating is effective at preventing the thick chromia scale present on uncoated stainless steel from forming. Instead a thin alumina scale forms, reducing chromium volatility and improving oxidation resistance. The coating can be fired in either oxidizing or reducing environments, offering flexibility to combine the aluminization process with other coating operations.

Long-Tem Microstructural Analysis



Substrate: Ferritic stainless steel AL 441HP
Aluminide coating: 20 µm fired | Standard Processing
Test Conditions: 900 °C | Air | 1000 hours

Introduction and Motivation

High temperature steel corrosion is common in today's power generation systems, causing the failure of heat exchangers, heat recovery systems, boilers and turbine blades. Corrosion costs US industries ~$250 B per year [1]. ***Further, the impact of high temperature corrosion spans the field of new power generation technologies, and is only increasing in next-generation power systems.***

In the case of solid oxide fuel cells (SOFCs), the key barrier to technology commercialization is the high system cost, which is driven by materials selection. The U.S. DOE cost goal of $700/kW for SOFC power generation systems requires the selection of common grade stainless steel wherever possible. However, without protective coatings, the air-facing surfaces of steel components oxidize and volatize chromium species that poison the stack. Similarly, air/exhaust heat exchangers must be designed to prevent chromium volatilization; on the fuel side, oxidation (due to high steam content gas streams), carburization and coking are all catastrophic failure mechanisms for metals facing high carbon fuel streams.

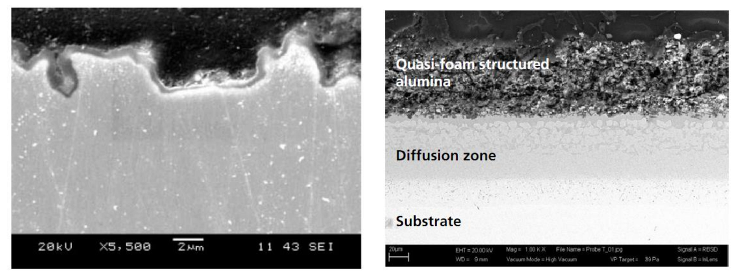
Metallic Interconnects: Ferritic stainless steel interconnects (ICs) are used in SOFCs because they offer lower cost and simpler manufacturability than alternatives. However, these alloys cannot achieve the target service lifetimes without protective coatings to prevent oxidation and chromium volatilization.

Balance of Plant: In addition to metal interconnects and the conductive stack gasket, there are numerous electrically insulating metallic components which require oxidation protection and chrome containment. These sub-systems include fuel stream conditioning, thermal management equipment, residual fuel recirculation/consumption systems, as well as piping and control systems.

Aluminide coatings oxidize to form self-repairing alumina scales that enhance alloy corrosion resistance in high temperature applications. Conventionally, aluminide coatings are produced by vapor deposition or pack-cementation approaches -- batch processes that require controlled atmospheres [2].

For aluminide diffusion coatings to be commercially viable for SOFC applications, lower cost coating processes are required. Researchers at Pacific Northwest National Laboratory (PNNL) have recently demonstrated a reactive air aluminization (RAA) process which does not require a controlled atmosphere heat treatment [3,4]. Outside SOFCs, similar air-fired spray/slurry aluminization processes have been reported by the PARTICOAT consortium in Europe to deposit complete thermal barrier coatings (TBC) systems on nickel-based superalloys [5,6].

Low-cost aluminization approaches



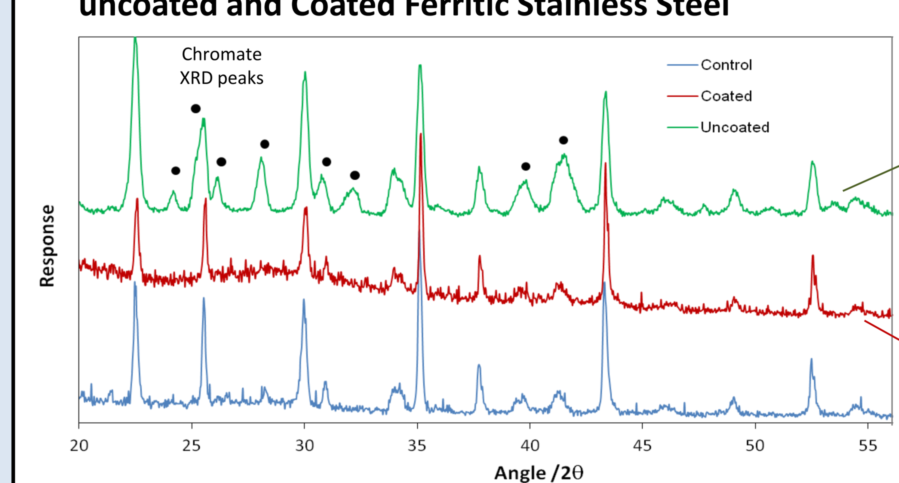
PNNL Reactive-Air Aluminization (RAA) [3]
PARTICOAT multifunctional aluminide based TBC [5]

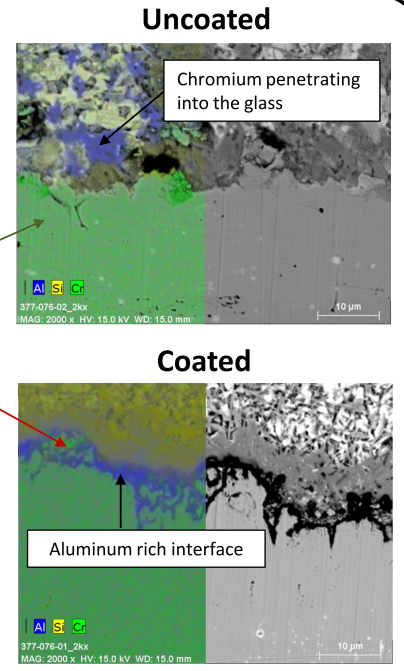
NexTech is developing a low-cost alternative process to conventional aluminization to provide a protective coating to improve high temperature oxidation/corrosion and chromium volatility resistance of metallic components used in SOFC systems.

Coating/Seal Interactions

The aluminide coating reduces interactions between the seal material (alkaline aluminosilicate glasses) and chromium, present in chromia forming stainless steels. These interactions form low thermal expansion chromates (i.e., $SrCrO_4$ and $BaCrO_4$) that cause failure during thermal cycling.

XRD Spectra of Composite Glass Seals in contact with uncoated and Coated Ferritic Stainless Steel

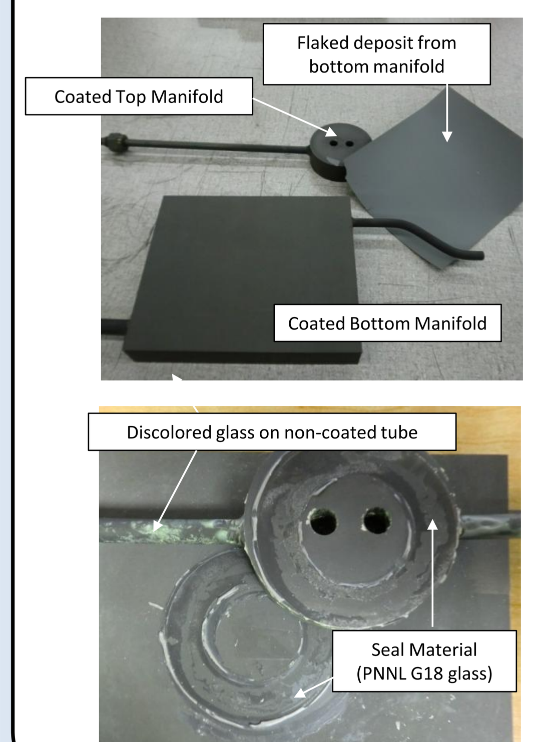


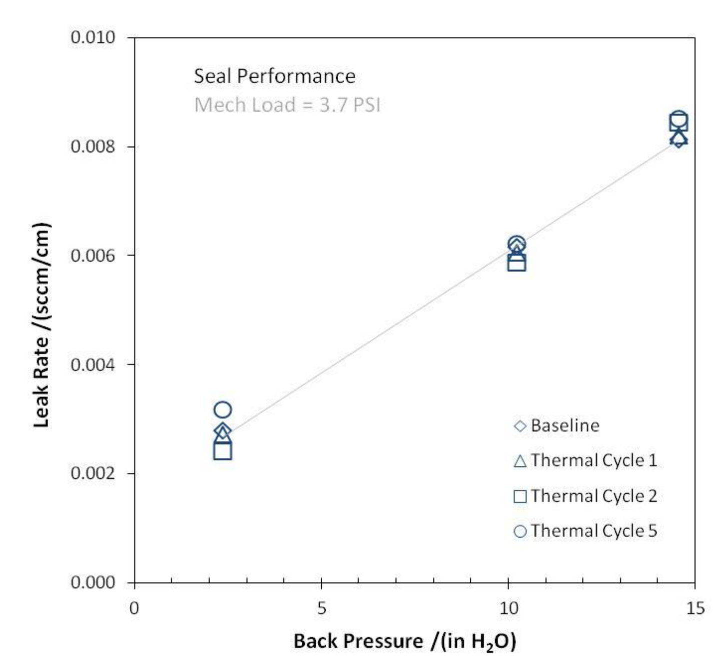


Substrate: Ferritic stainless steel AL 441HP
Aluminide coating: 20 µm fired | Standard Processing Conditions
Composite glass seal (80 % alumina, 20 % PNNL G18 glass)
Ageing | 4 hours | 850 °C

By reducing chromate formation, a significant improvement in thermal cycling performance of coated manifolds (glass seal, comprising PNNL G18 glass, binder) was demonstrated using a seal-test stand.

Seal Testing





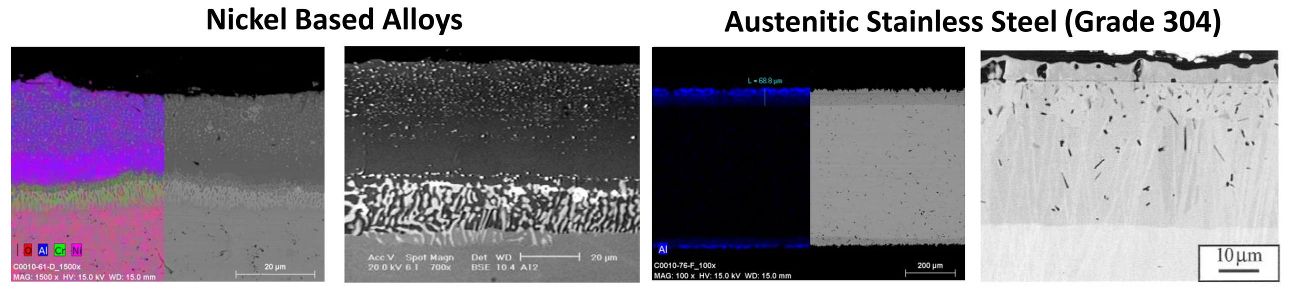
Substrate: Ferritic stainless steel | Glass: PNNL G18 glass with an appropriate binder
Aluminide coating: 20 µm fired | Standard Processing

Extension to Balance of Plant Alloys

The aluminide coating process readily translates to other alloys including ferritic (430), austenitic (304, 316) stainless steel and nickel based alloys. The coating microstructures are similar to those produced by traditional pack-cementation/ vapor deposition techniques.

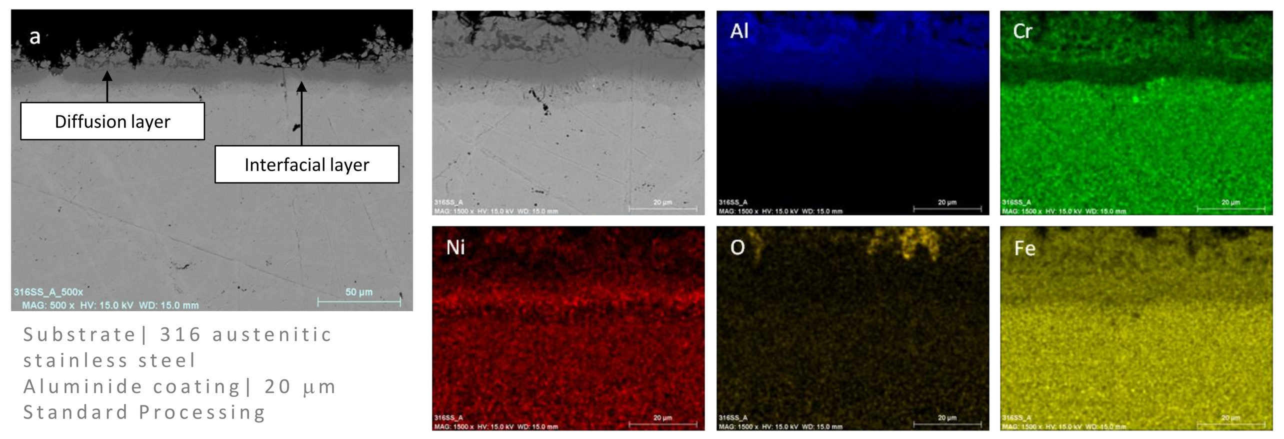
Coating Microstructures versus Traditional Coating Techniques

Nickel Based Alloys | Austenitic Stainless Steel (Grade 304)



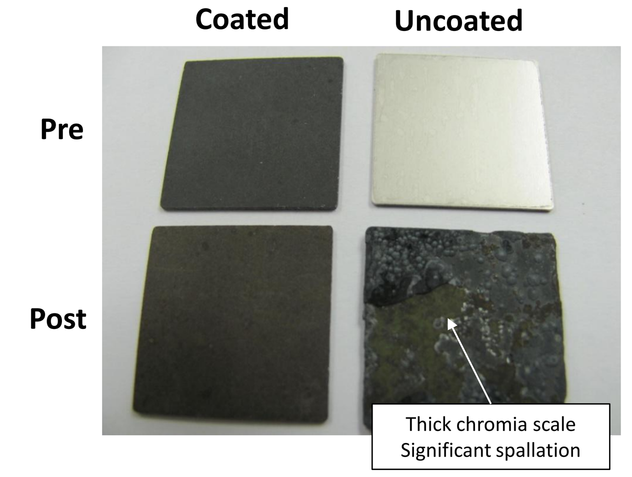
Inconel 617
Ni-based alloy IN738LC Pack Cementation [7]
Grade 304
Grade 304 CVD process [8]

Aluminide Coating Microstructure | Compositional Analysis



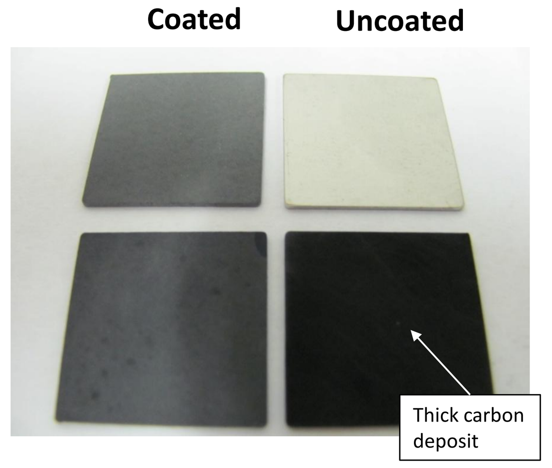
Substrate| 316 austenitic stainless steel
Aluminide coating| 20 µm
Standard Processing

Oxidation Resistance



Substrate| 304 austenitic stainless steel
Aluminide coating| 20 µm Standard Processing
Oxidation Testing | 500 hours, Humidified Air, 900 °C

Coking Resistance

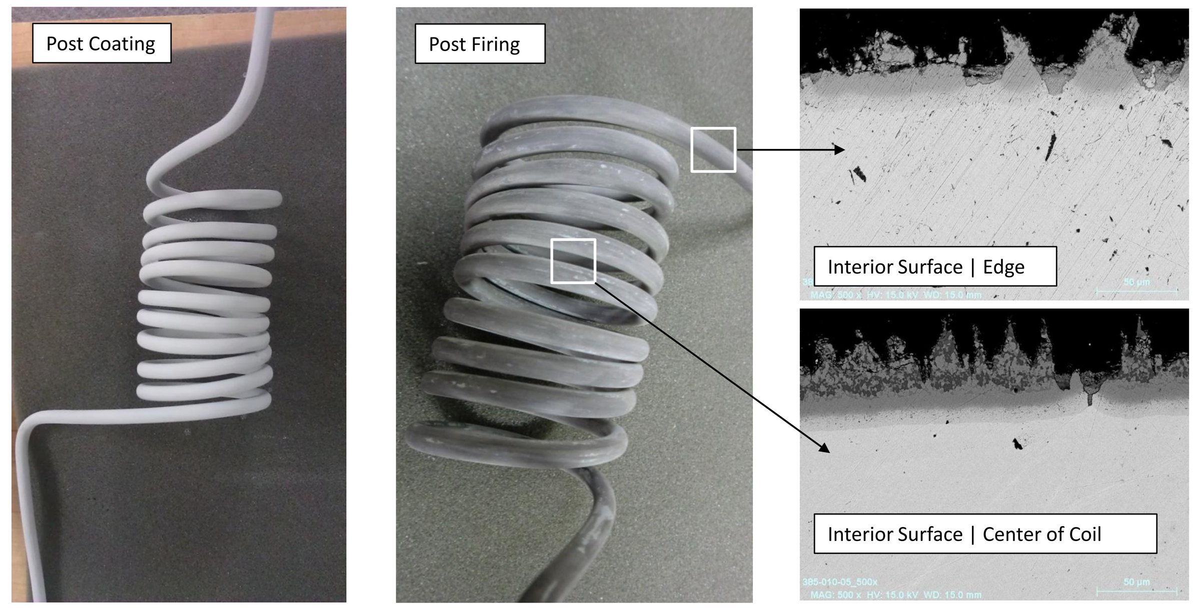


Substrate| 304 austenitic stainless steel
Aluminide coating| 20 µm Standard Processing
Coking Test | 24 hours| Gas Composition: 18% CH_4 45% CO_2 37% CO | 600 °C

Manufacturing Improvements

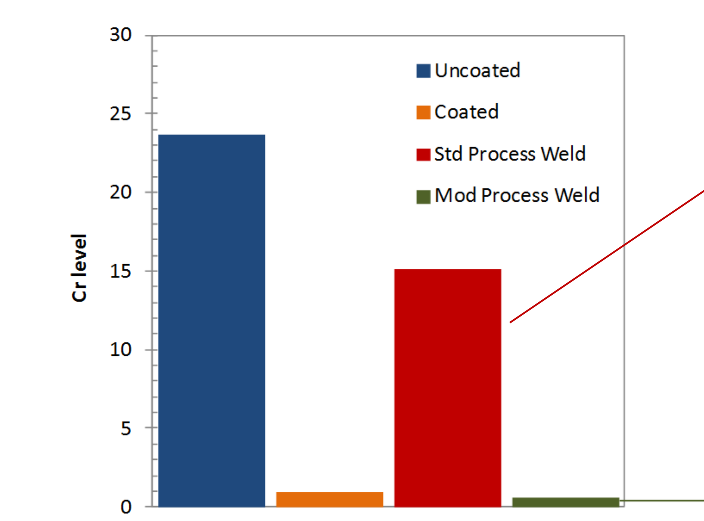
Manufacturing (coating application, firing and post-firing cleaning) strategies have been developed to scale the coating technology to coat large, complicated components including 5 foot long piping. A surface pre-treatment has been developed to allow the coating to be uniformly applied to weldments.

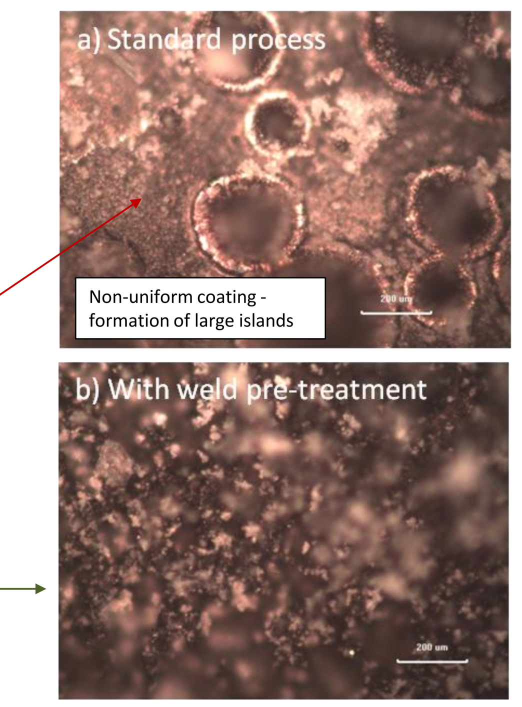
Coating of Complex Component (1/4" 316 Stainless Steel Coil)



Substrate: ¼" 316 stainless steel coil
Aluminide Coating: 20 µm fired |Standard Processing

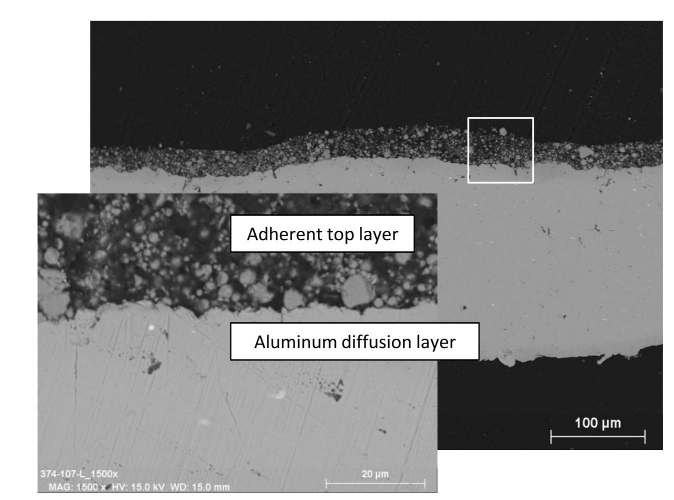
Application of the Coating to Weld Areas



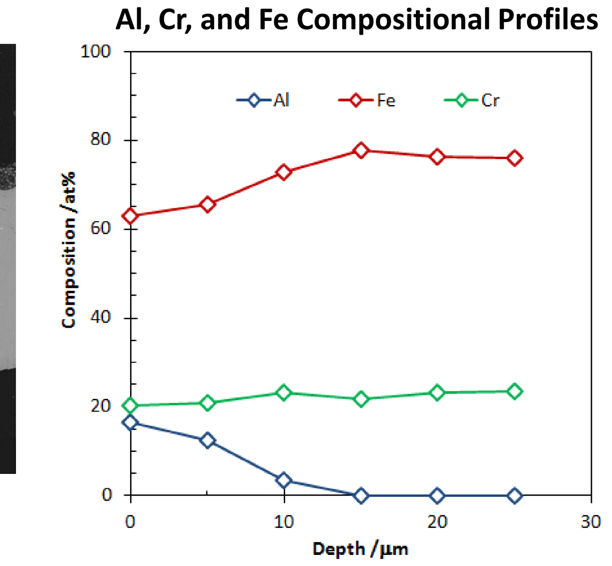


Substrate: Nickel based alloy
Aluminide coating| 20 µm |Standard Processing
Weld pre-treatment

Coating | Localized Heat Treatment



Al, Cr, and Fe Compositional Profiles



Substrate: Ferritic stainless steel
Aluminide coating: 20 µm
Localized Heat Treatment

References

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