Reactive Air Aluminization (RAA) Application Study for High-Temperature Hydrogen Reactor

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Introduction

Reactive Air Aluminization (RAA) was developed for solid oxide fuel cell (SOFC) systems, where they have shown very promising results. SOFC systems use ferritic stainless steel, so RAA was optimized for coating this material. However, the High-Temperature Hydrogen Reactor developed by our partner operates in higher temperature harsh conditions. Therefore, our partner wants to use Inconel 617 instead of ferritic stainless steel. PNNL's patent for RAA does not specifically mention Inconel 617 but it does cover nickel-based alloys, so this effort evaluates RAA coatings applied to Inconel 617. The results presented here include XRD, EDS, and SEM analysis data. The RAA process forms a good alumina protective layer on the surface of Inconel 617 with a chromium-depleted reaction band underneath the alumina layer. This suggests great potential for long-term stable operation.

Objective

To provide a stable, electrically non-conductive, and non-reactive layer for hermetic and strong glass sealing. Moreover, to prevent chromium volatility and maintain stable electrical insulation.

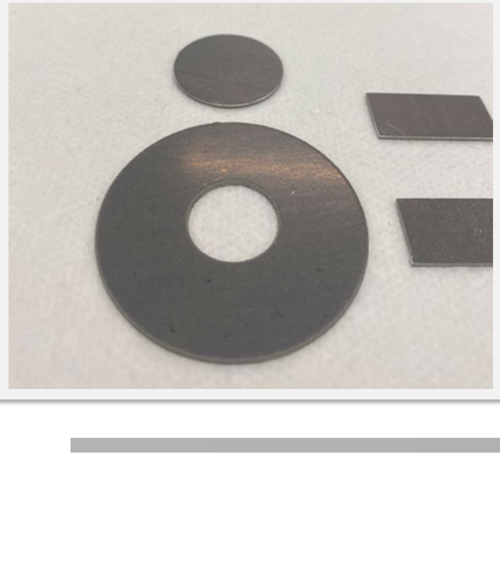
Issue and idea

For a strong and hermetic glass seal that is gas-tight, the substrate should not form a weakly bonded scale or react with the glass seal material. Inconel 617 contains aluminum already, so, it is interesting how the pre-existing aluminum in the alloy reacts with the RAA. The resulting strongly bonded alumina provides an electrically insulative layer that does not react with the glass seal material and is stable during high-temperature reactor operation.

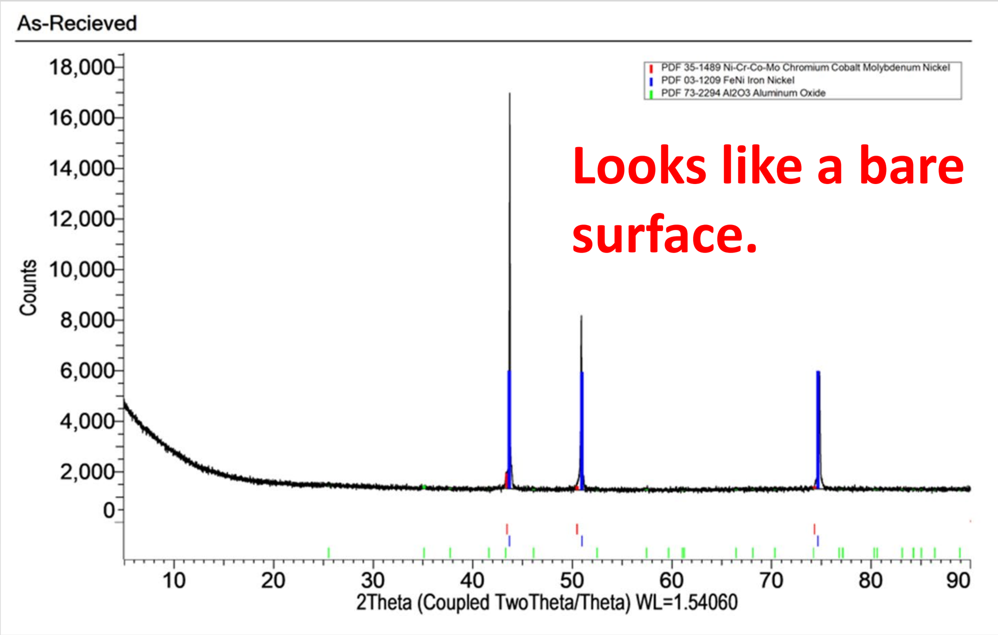
Results

Table 1 - Limiting Chemical Composition, %, of INCONEL alloy 617

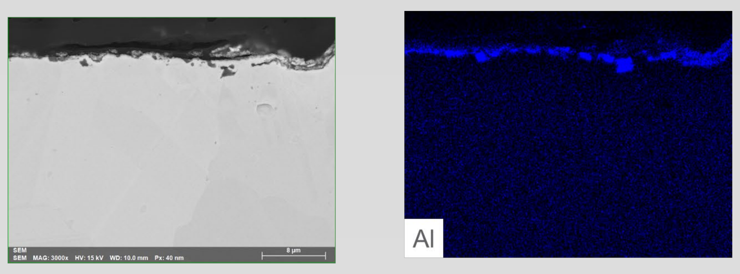
Nickel	44.5 min.
Chromium	20.0-24.0
Cobalt	10.0-15.0
Molybdenum	8.0-10.0
Aluminum	0.8-1.5
Carbon	0.05-0.15
Iron	3.0 max.
Manganese	1.0 max.
Silicon	1.0 max.
Sulfur	0.015 max.
Titanium	0.6 max.
Copper	0.5 max.
Boron	0.006 max.

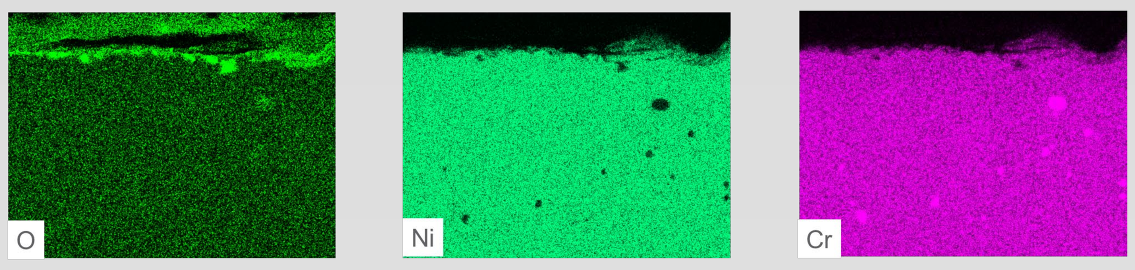


As received Inconel 617 samples



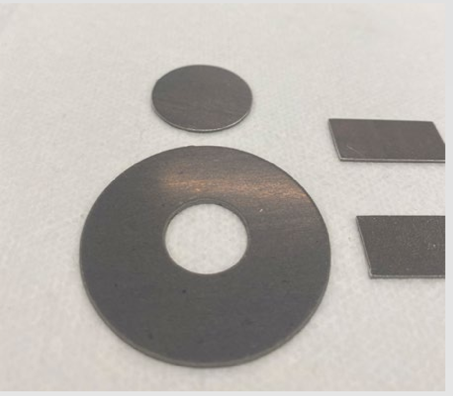
As received Inconel 617 alloy – Cross section



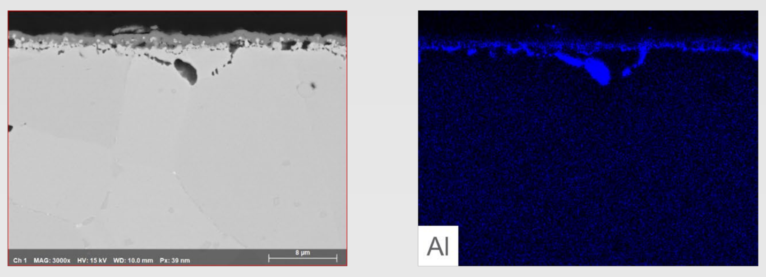


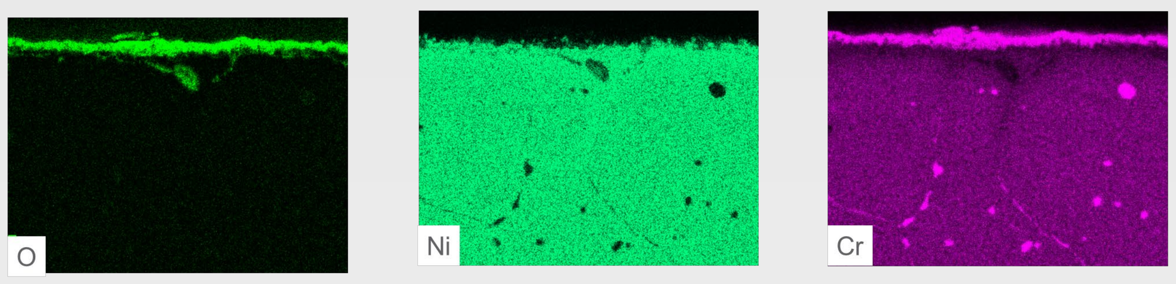
Non-continuous alumina forms under or with chromium and nickel oxide. Why is the oxide on the surface already?

Surface color was different because the manufacturer heat treated it before shipping



Polished and heat treated at 1000°C





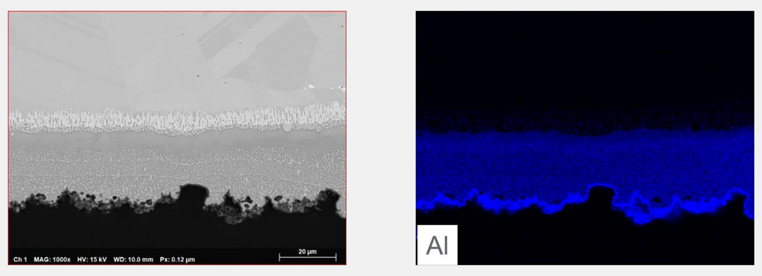
As expected, chromium oxide forms on the surface and alumina forms discontinuously under the chromium oxide layer. This is not good for long-term stability in high-temperature conditions.

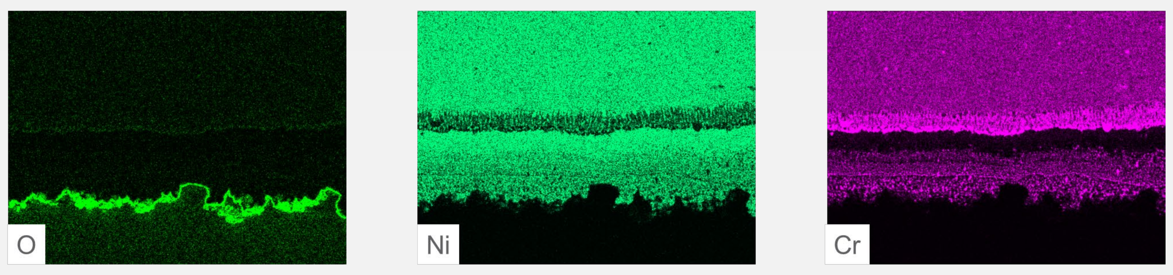
Quick optimization

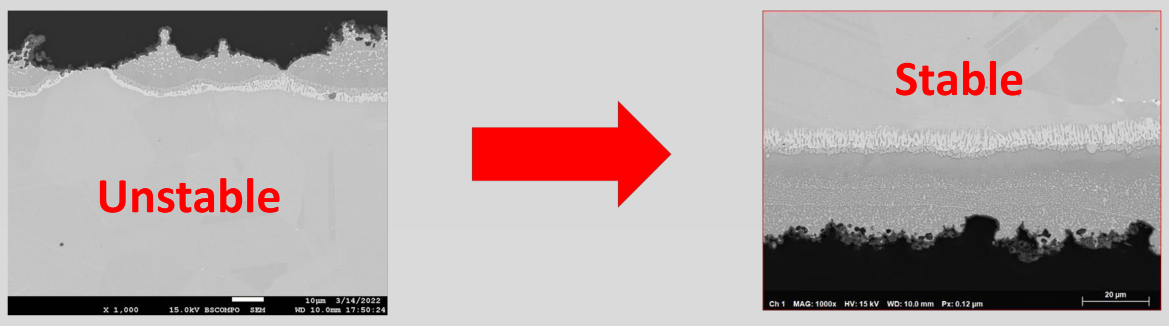
Applied RAA coating with ultrasonic spray coater

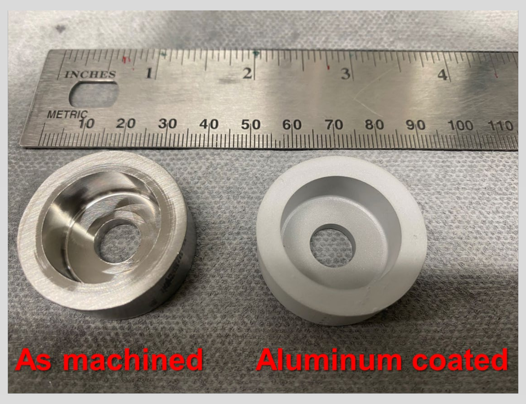
RAA-6

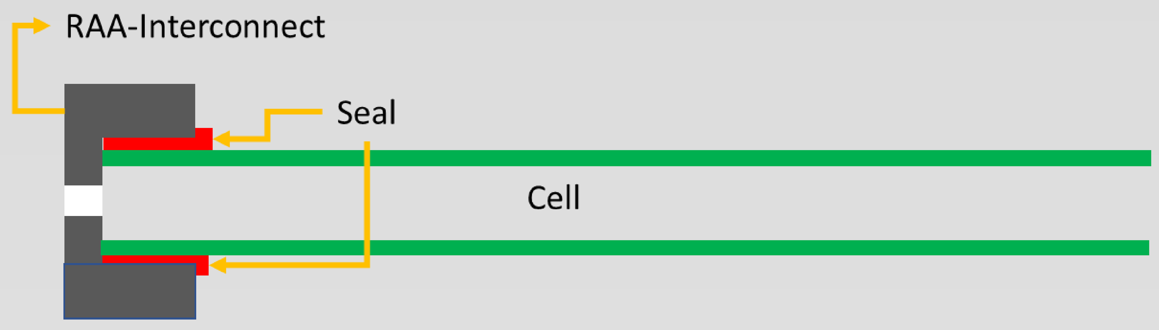
The reaction band is composed of Ni, Cr, Co, Fe and Mo.











Summary

Inconel 617 has 0.8-1.5 wt% aluminum in the alloy. Such a composition would be expected to form alumina on the surface during high-temperature operation. Therefore, a special heat treatment schedule was adopted to form alumina on the surface. However, it did not form a continuous stable alumina layer. The polished and heat-treated sample's EDS map shows that thick chromium oxide forms on the surface with some discontinuous alumina. This is not desirable for long-term operation. Since the Inconel 617 contains aluminum in the alloy, the RAA process parameters were adjusted and reoptimized. The RAA process creates a 20-30 μm reaction barrier and a good 0.5μm alumina coating on the Inconel 617 surface.

ABOUT

Pacific Northwest National Laboratory

The Pacific Northwest National Laboratory, located in southeastern Washington State, is a U.S. Department of Energy Office of Science laboratory that solves complex problems in energy, national security, and the environment, and advances scientific frontiers in the chemical, biological, materials, environmental, and computational sciences. The Laboratory employs nearly 5,000 staff members, has an annual budget in excess of $1 billion, and has been managed by Ohio-based Battelle since 1965.

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