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ALUMILOK^{TM} COATINGS:

ENHANCED HIGH TEMPERATURE PERFORMANCE FOR COMMERCIAL STEELS

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ABSTRACT:

For decades, aluminide diffusion coatings have been demonstrated to enhance corrosion protection of iron and nickel based alloys. The controlled diffusion of aluminum into the alloy leads to formation of iron or nickel-aluminides, resulting in excellent resistance to oxidation, sulfidation and carburization. However, such diffusion coatings are typically formed by high-cost pack cementation, vapor-phase or CVD aluminization techniques. These processes are designed for small, high-value parts and are poorly suited for high-volume low-cost manufacturing scenarios. As a result, implementation of these technologies are limited to applications where value imparted are offset the high cost of the techniques.

In contrast, Nexceris offers the *AlumiLok*™ coating technology, which creates aluminization coatings using simple application methods and heat treatment approaches. The technology provides excellent oxidation protection for a wide range of stainless steels and nickel alloys. The process can be tailored to mask off the coating region, and is compatible with a number of pre- and post-coating manufacturing processes. Overall, the approach has broad applicability to components requiring oxidation or corrosion protection in high volume manufacturing scenarios.

THE *ALUMILOK*^{TM} COATING PROCESS:

The *AlumiLok*™ process uses simple slurry coating and heat-treating processes to create coatings with the microstructure and corrosion resistance of costly vapor- and pack-aluminization processes (Figure 1). The coating demonstrates excellent resistance to oxidation, chromium volatilization, and coking on a range of common stainless steels Based on its demonstrated low cost and scalability, *AlumiLok*™ technology could provide a cost break-through for materials engineers, allowing them to replace Inconel components with common stainless steels.

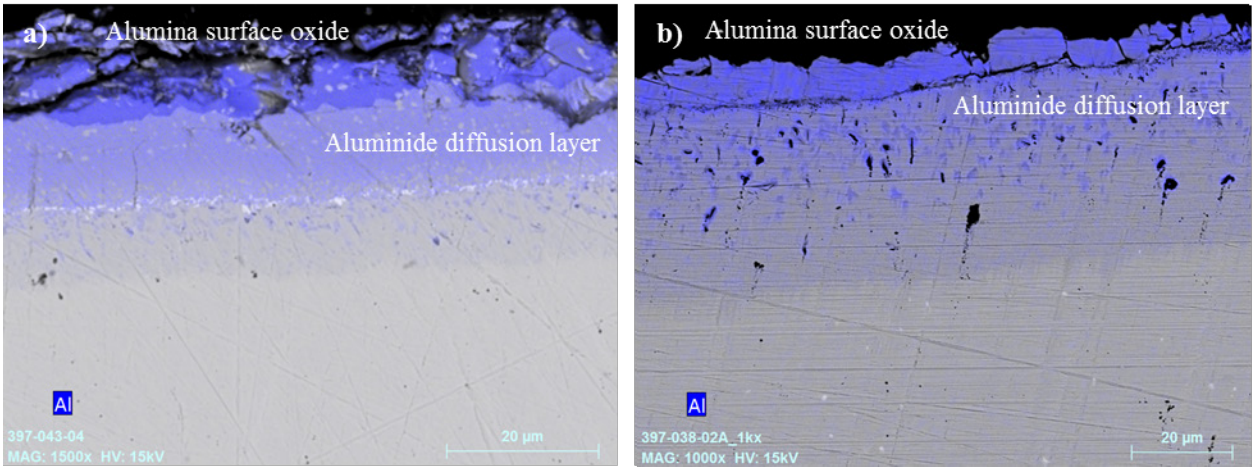

Figure 1. Cross-section SEM with superimposed Al EDS compositional map of coatings formed on 316SS by Nexceris's *AlumiLok*™ technology (a), and vapor-phase aluminization (VPA) (b).

The *AlumiLok*™ process consists of a coating and heat treating step. The coating technology is designed to allow well-defined coating patterns on simple and complex parts, using simple deposition processes. Examples of techniques validated in our lab include roller-painting (Figure 2a), drain casting (2b) and aerosol spray deposition (2c) in addition to simple dip coating processes. We have also successfully scaled the *AlumiLok*™ coating materials to a number of continuous and semi-continuous automated spray systems.

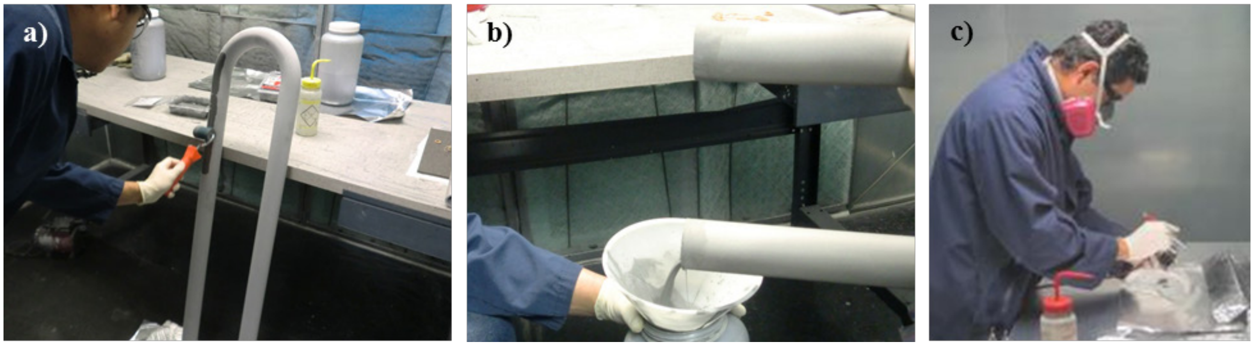

Figure 2. Examples of coating application; roller-coating exterior surfaces (a), slip-coating interior surfaces (b), and hand-spraying (c).

To provide further process flexibility, *AlumiLok*™ suspensions are designed to be easily patterned. An example of the masking flexibility of the *AlumiLok*™ process is shown in Figure 3, where we have applied two different ceramic coatings; the first being a high-temperature electrically conducting coating, the second being *AlumiLok*™. The as deposited coating is easily masked, and can be removed by washing up to the heat treatment stage. The heat-treated coating can be removed post-processing using common abrasive techniques.

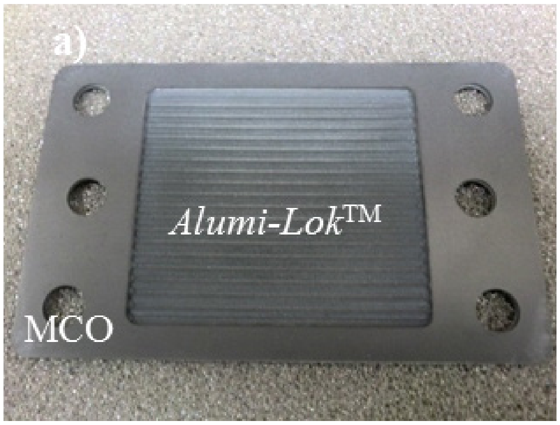

Figure 3. Dual Coated Metal Component, Demonstrating Masking Control of Deposition Area. *AlumiLok*™. coated area is the ribbed central region, while the perimeter is coated with $(Mn,Co)_3O_4$ (MCO)

To further extend the *AlumiLok*™ process flexibility, we have assessed the technology in coordination with common manufacturing processes. There are clear cost advantages in coating sheet metal or tube stock and subsequently form the coated material into the final component. Preliminary experiments have been performed to determine the feasibility of this approach. Figure 4 shows *AlumiLok*™ coated 304 stainless steel sheet that has been successfully rolled into a 5.5" diameter cylinder. Microstructural analysis (Figure 5) indicates that the *AlumiLok*^{TM} coating microstructure is not damaged by the forming operation. The coiled component was further spot welded, using standard processing, to create a thin walled combustion liner.

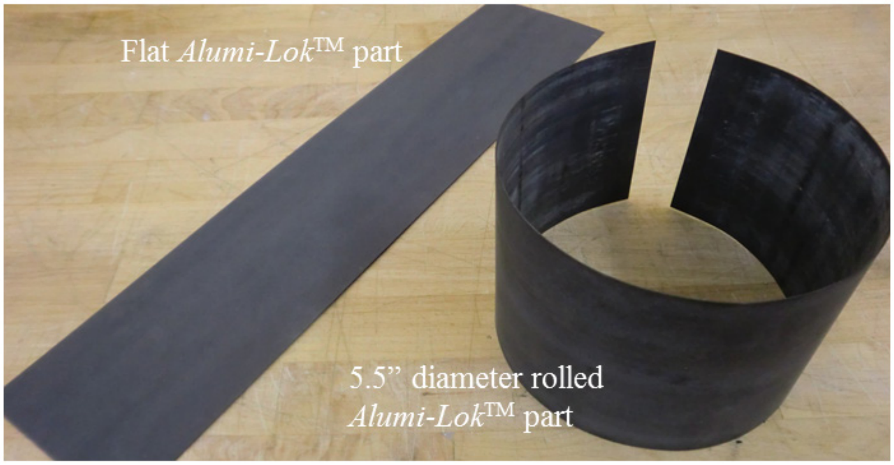

Figure 4. Flat and formed (rolled into 5.5" diameter cylinder) *AlumiLok*^{TM} coated 304SS sheet.

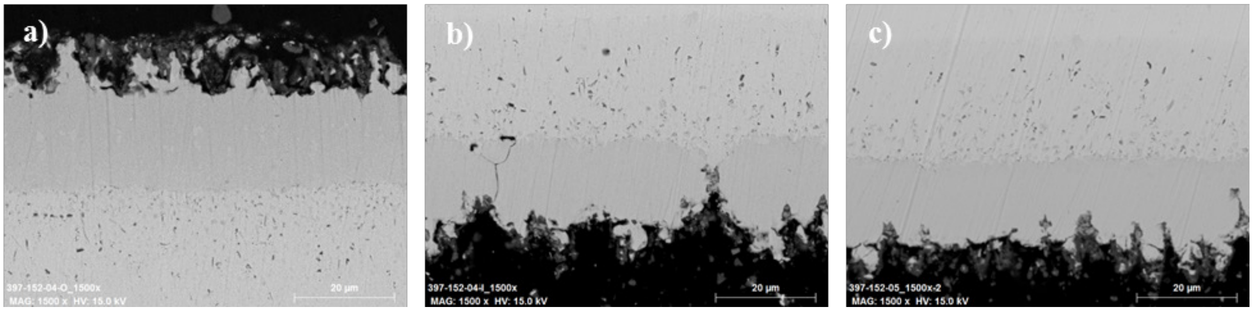

Figure 5. Cross-section SEM micrographs of *AlumiLok*^{TM} coating microstructure on formed (rolled) inside surface (a), and outside surface (b) and flat non-formed surface of 304SS sheet.

ALUMILOK^{TM} COATING PERFORMANCE

High Temperature Oxidation Resistance

Figure 6 shows the long-term isothermal oxidation performance of *AlumiLok*^{TM} coated 316 stainless steel compared to uncoated, and vapor-phase aluminized 316 stainless steel. The inserted photographs show the appearance of the samples after 4000 hours exposure to humidified air at 900 °C. Uncoated 316 stainless steel is unable to survive in this environment, with weight loss – indicative of spallation of oxidation products occurring within 500 hours. Vapor-phase aluminization (VPA) improves the oxidation resistance of 316 stainless steel, with stable oxidation behavior demonstrated up to 3000 hours. However, beyond 3000 hours VPA 316 stainless steel samples display rapid weight-loss and degradation. The *AlumiLok*^{TM} coating displays excellent oxidation resistance, with stable oxidation behavior demonstrated to 4000 hours.

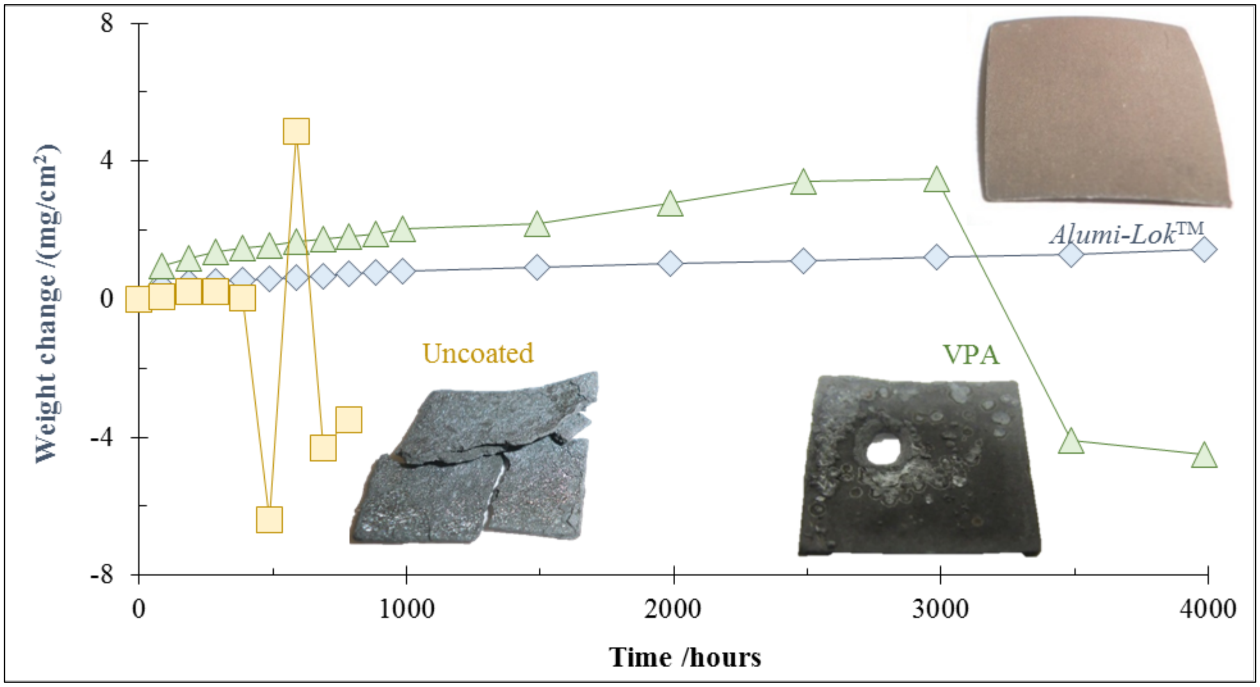

Figure 6. Isothermal oxidation weight change for uncoated 316, *AlumiLok*^{TM} coated and vapor-phase aluminized 316SS at 900 °C for 1000 hours in humidified air.

Resistance of Active Corrosion (Combustion Environments)

A second environment investigated is a high chloride environment, representative of biomass combustion environments, where the principal corrosion mechanisms are chlorine-catalyzed active oxidation and hot corrosion due to molten salt deposits. Figure 7 shows the corrosion resistance of *AlumiLok*^{TM} coated 430 and 304 stainless steels versus uncoated stainless steel, aluminized steel, and FeCrAl samples on exposure to a potassium chloride (KCl deposit) containing air atmosphere at 650 °C.

Uncoated 430 and 304 stainless steels are readily attacked in this corrosive environment, forming a thick, non-protective dual-oxide scale, with rapid exfoliation within 200 hours. The *AlumiLok*^{TM} coating successfully prevents this corrosion and exfoliation on both stainless steel grades through the formation of a stable aluminide/alumina surface microstructure that prevent non-protective oxide formation. *AlumiLok*^{TM} coated stainless steel (both grades 430 and 304) demonstrates superior corrosion resistance than both aluminized steel and FeCrAl in this combustion environment.

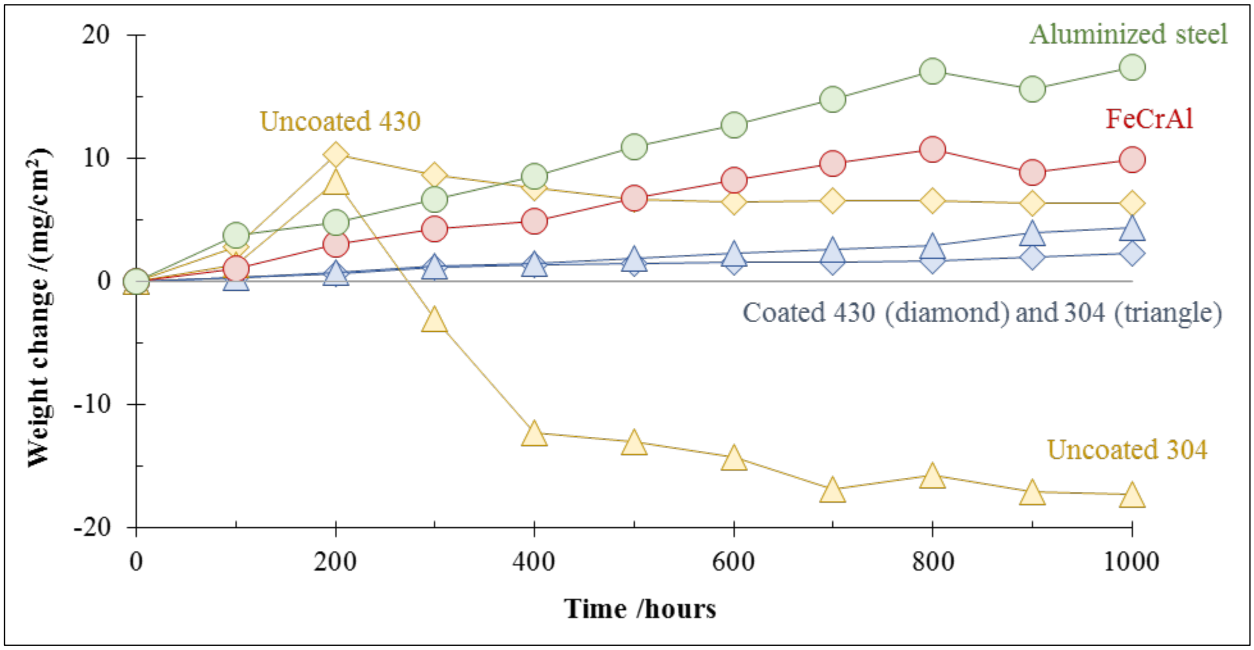

Figure 6. Corrosion behavior of uncoated and *AlumiLok*™ coated 430SS and 304SS, aluminized steel and FeCrAl samples under biomass combustion conditions, temperature 650 °C, potassium chloride containing air atmosphere. The chloride rich atmosphere as achieved by resting the samples over a deposit of potassium chloride crystals.

COMMERCIAL IMPLICATIONS:

The materials requirements in high-temperature industries are severe; components must be tolerant to long-term, high temperature exposure in harsh, corrosive environments. The cost-effective, and scalable high temperature, oxidation, coking, and corrosion protection, enabled by Nexceris's *AlumiLok*™ technology is therefore highly attractive, enabling the opportunity to substitute lower-cost stainless steels for expensive nickel-based alloys.

The coating protection provided by *AlumiLok*™ is unique, creating matte oxide coatings for corrosion protection and coking resistance (the subject of a forthcoming white paper). The process also imbues the underlying alloy with a reservoir of self-repairing aluminum to heal micro-scale defects.

Our product development anticipates the need for scalability and simplicty of manufacture. Current applications include the protection of high-temperature electrical components, burner components, and heat transfer devices, where the coating provides the corrosion protection described above in parallel with enhanced emissivity.