

The Effect Of Process Parameters On Pack Aluminizing Of UNS S30400 Stainless Steel

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ABSTRACT

Aluminide coatings were applied to UNS 30400 stainless steel coupons using the halide activated pack cementation process. The aluminizing process was studied at two different temperatures with two different activator salts - aluminum fluoride and aluminum chloride. The effect of process conditions, i.e., pack composition, pack size, process temperature, and activator salt type, on the coating characteristics (microstructure, thickness, hardness, etc.) was investigated using different metrics, including mass and thickness changes, microhardness, microscopy, and surface topography. Mass gain per unit area and coating thicknesses were plotted as a function of temperature. The coating microstructure was evaluated using optical microscopy, optical surface profilometry, and scanning electron microscopy coupled with energy dispersive spectroscopy. In addition, X-ray diffraction was used to identify phases present in the coating. Coated coupons were further characterized using Vickers microhardness. The surface topography of the coated coupons was quantified.

Key words: aluminizing, pack cementation, stainless steel, halide activated pack cementation, coatings

INTRODUCTION

UNS S30400 is an austenitic stainless steel that has been employed in a wide range of applications. The combination of formability, weldability and corrosion resistance¹ make this alloy amenable for wide-ranging applications including home appliances, food and chemical processing, pharmaceuticals, etc. For applications that require high temperatures, the lifetime of this material can be extended through the use of protective coatings. Aluminide coatings are one approach to protect the underlying substrate and allow for extended operation.²⁻⁶ The aluminide coating serves as a source of aluminum that subsequently forms a protective slow growing scale of aluminum oxide in oxygen-containing atmospheres, thereby providing an effective defense against oxidation⁷⁻⁸.

Application of such a coating to UNS S30400 could prove to be a beneficial treatment to prolong the service life of the material at high temperatures. Halide-activated pack cementation (HAPC) is a common process used to fabricate protective diffusion coatings that are both wear and corrosion resistant. Packs generally consist of a master alloy, halide salt, and an inert filler^{9,10}. The master alloy typically contains

the metal that is to be deposited on the surface of the substrate. The thermodynamic stability of the halide salt plays a crucial role in the resulting coating. Chloride activator salts are thermodynamically unstable at typical coating temperatures due to a higher standard Gibbs free energy of formation per mole of chlorine, and typically result in thicker, uniform coatings. In comparison, fluoride activator salts are more thermodynamically stable and tend to produce thin, irregular coatings under similar coating conditions¹¹. Both activator salts were used to further understand the impact of varying pack constituents in the coating process. The process is typically carried out in a high temperature furnace under an inert atmosphere. The resulting modification of the alloy surface improves the oxidation resistance and the service life of these materials in high temperature applications. The resulting coating microstructure is dependent on various process parameters such as process time, activator salt, coating temperature, and pack composition.

EXPERIMENTAL PROCEDURE

UNS S30400 stainless steel coupons were prepared by cutting approximately 3 - 4 mm thick coupons from a 12.7 mm diameter rod. Each face of the coupon was ground manually using a series of silicon carbide grit papers from 240 grit to 600 grit. Packs were prepared by thoroughly blending a powder mix comprised of a filler, master alloy, and activator salt. The powder blend along with the alloy coupon to be coated were placed in ceramic crucibles sealed with a ceramic cement, and heated to the temperature of interest for the desired time. The effect on coating characteristics (microstructure, thickness, hardness, etc.) due to changes in pack composition and activator salt type was investigated. The coating microstructure was evaluated using optical microscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS). In addition, coated coupons were characterized by measuring coating thickness, hardness, and surface profilometry.

RESULTS

UNS S30400 was successfully aluminized at two different temperatures using two different activator salts and two levels of pack aluminum content. The ratio of activator salt to master alloy was used to differentiate between sets of data, e.g. 1:3 or 2:25. Similarities and differences were found between coatings generated using varying pack compositions as well as temperatures, as shown using various characterization techniques. At the higher temperature, both activators produced nominally thicker coatings as compared to the coatings produced at lower temperatures; however the aluminum fluoride activated packs revealed a noticeably different morphology, as shown using SEM and EDS analysis. At 650°C, the aluminum fluoride-activated packs generated a thicker coating as compared to those generated in the aluminum chloride-activated packs. At 850°C, both activators produced similar coatings with a nominally 3-layer morphology. Higher coating thicknesses were observed for coupons coated in packs with increased aluminum content. Coatings obtained using aluminum chloride-activated packs had similar surface roughness at both temperatures; however, aluminum fluoride-activated packs resulted in increased mean surface roughness for the coupons coated at higher temperatures. The microhardness measurements indicated that the coatings were harder than the substrate in all cases.

Coating Characterization

Microscopy

Aluminized coupons displayed distinct coating morphologies depending upon on the process variables. At 650°C, the resulting coatings consisted of a single layer, approximately 13-22 μm thick, with a minimal interdiffusion zone. Figure 1 shows cross-sectional images of coatings fabricated at 650°C with varying pack constituents. The single layer coatings were rich in aluminum with a small concentration of nickel on the outermost edge. Packs using AlCl_3 as the activator salt produced coatings with a more uniform thickness than packs activated using AlF_3 . The AlF_3 activated pack containing increased aluminum

content produced the thickest coatings but also the ones with higher variability (higher coefficient of variation) as opposed to the lower aluminum content packs for both activator salts. At 850°C, the resulting coatings were nominally thicker (61 - 88 μm) than coatings produced at 650°C, as shown in Figures 1 and 2. Coatings fabricated at 850°C consistently produced three distinctive layers, typically with a large interdiffusion zone and a varying outer layer.

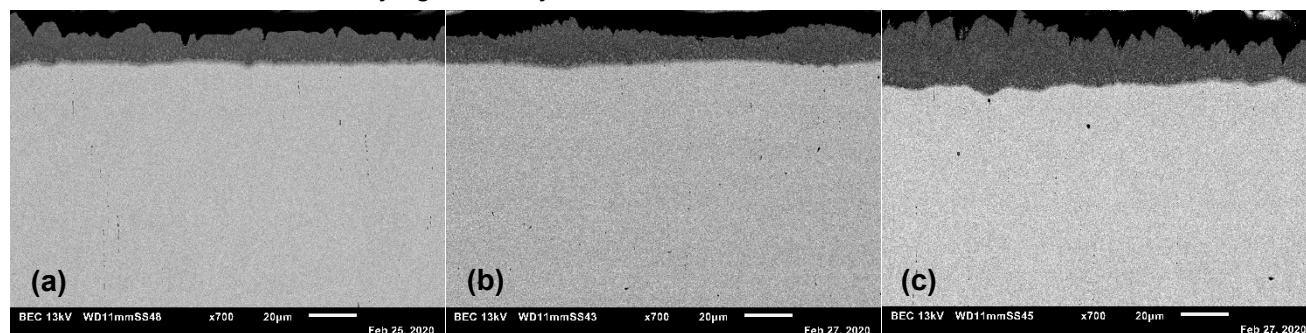


Figure 1: Backscattered electron images of coatings on UNS S30400 stainless steel treated at 650°C for 9 hours using (a) AlCl_3 1:3 (b) AlF_3 1:3 (c) AlF_3 2:25

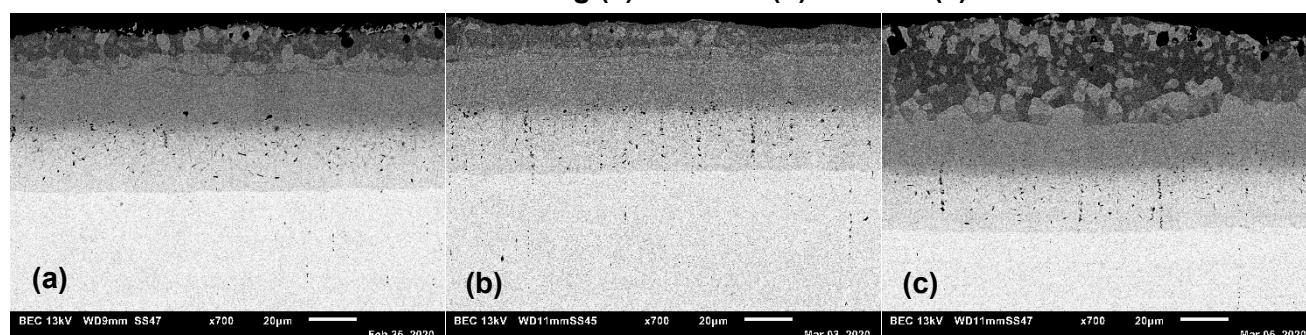


Figure 2: Backscattered electron images of coatings on UNS S30400 stainless steel treated at 850°C for 9 hours using (a) AlCl_3 1:3 (b) AlF_3 1:3 (c) AlF_3 2:25

The aluminum content within the coatings decreased as a function of depth into the substrate, leaving the outer layer with the greatest concentration of aluminum. Nickel and chromium precipitates were found in the outer layer of the coatings with subsequent depletion zones within the interdiffusion zone (Figure 3 shows an illustrative example). The coatings produced using AlF_3 as the activator with increased aluminum content (2:25) generated the largest outer layer with a distinct morphology.

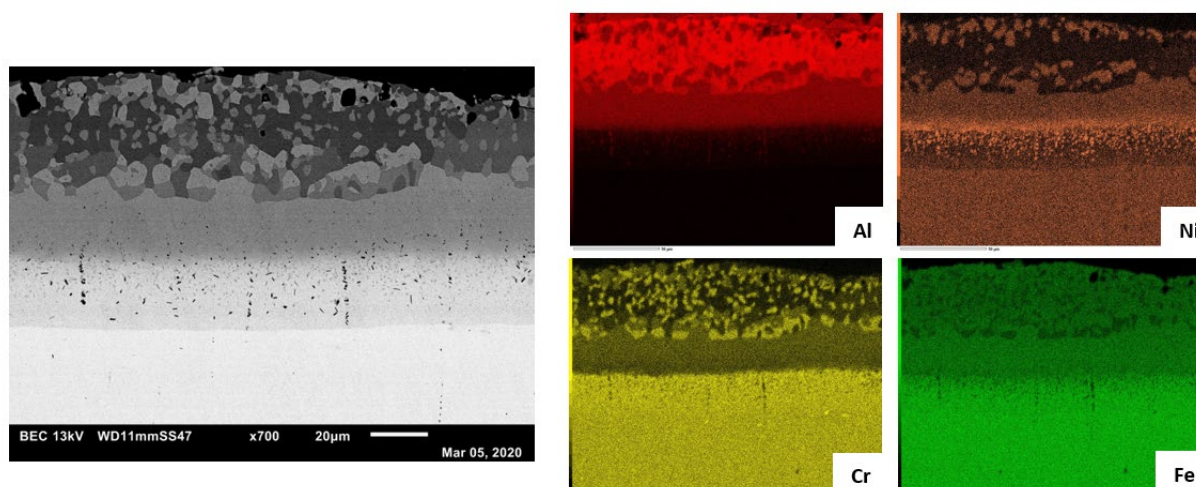


Figure 3: Backscattered electron image and elemental maps (EDS) of coatings on UNS S30400 stainless steel coated at 850°C for 9 hours using AlF_3 2:25