Aluminization of Cobalt and a Cobalt-based Superalloy

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Kellogg Honors College Capstone Project

Objective

To successfully coat pure cobalt and HAYNES NS-163 superalloy; investigate the coating thickness, morphology and the role of various elements in the aluminized coupons.

Background

Metallic materials are known to undergo various types of degradation at high temperatures (i.e hot corrosion, oxidation, etc.). One way to extend the lifetime of these industrial materials is to apply protective coatings. Industrial examples of high temperature corrosive environments include power plants, aircraft engines, and waste incineration processes.[1] In this study, the Halide Activated Pack Cementation (HAPC) method was used. This is an economical diffusional process that can coat metals of varying geometries.[2] Coatings produced by this method are diffusional coatings, and are an effective way to achieve protection because they are cost-effective and adhere better to the metal than an overlay coating.

Haynes NS-163 is a cobalt based superalloy with a high temperature alloy performance up to 1204 °C. It possesses a stress-rupture strength approaching that of oxide dispersion strengthened alloys and the highest strength of any other wrought alloy product, developed through a strengthening patented nitriding technique. The alloy consists of Co-28Cr-21Fe-9Ni-1.25Ti-1Nb.[3] The alloy's properties can be further enhanced by aluminizing the sample.

Materials and Methods

Cobalt, and Haynes NS-163 superalloy samples were ground to a 600 grit surface finish and degreased ultrasonically in acetone. Coupon mass and dimensions were measured before coating. A "pack", consisting of a master alloy (aluminum) an inert filler (alumina), and varying chemical activators were poured in specific ratios into a crucible. The metal substrate was buried in these powders and the crucible was sealed. Coating took place in a furnace at various temperatures for 9 hours in an inert environment.

The coated substrates were extracted, cleaned, cross sectioned, mounted, then ground and polished for analysis. Optical microscopy and scanning electron microscopy (SEM) in combination with energy dispersive spectroscopy (EDS) were the primary methods used to examine coating characteristics.

Results and Discussion

In order to better understand the relationship between individual elements composing the superalloy and aluminum, pure elements were also examined. In previous projects, nickel aluminides were thoroughly studied. Since the alloy is cobalt based, pure cobalt was also studied.

Unlike iron and nickel, cobalt has an HCP crystal structure. For various activators and temperatures, the aluminized layer on cobalt substrates was porous, thick, and cracked. An example of this is seen in Figure 1; a backscattered electron image of a cobalt coupon coated with AlF_3 activator at 850°C is shown. Three distinctive layers are seen. Electron dot maps were used to identify the composition of each layer. The darker the color in the image, the greater the abundance of that element. The top layer consisted primarily of aluminum, with some cobalt. The midlayer contained pores, as well as aluminum and cobalt. Finally, the inner layer of the coating consisted of cobalt and a decreasing amount of aluminum. In the HAPC process, aluminum diffuses inward and cobalt diffuses outward, resulting in gradients of the elements through the coating.

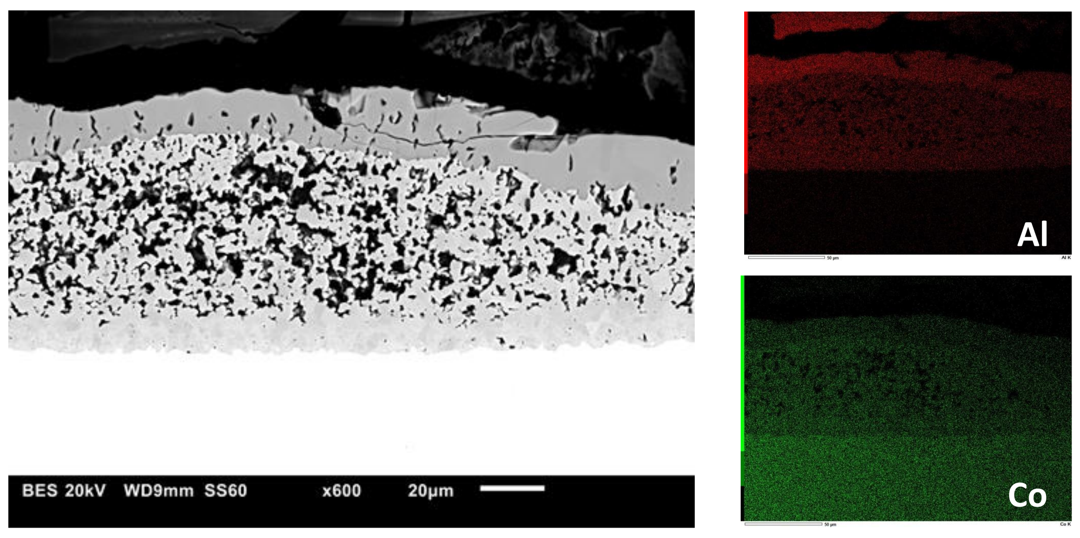

Figure 1 : SEM and elemental map Co/ AlF_3/ 850 °C

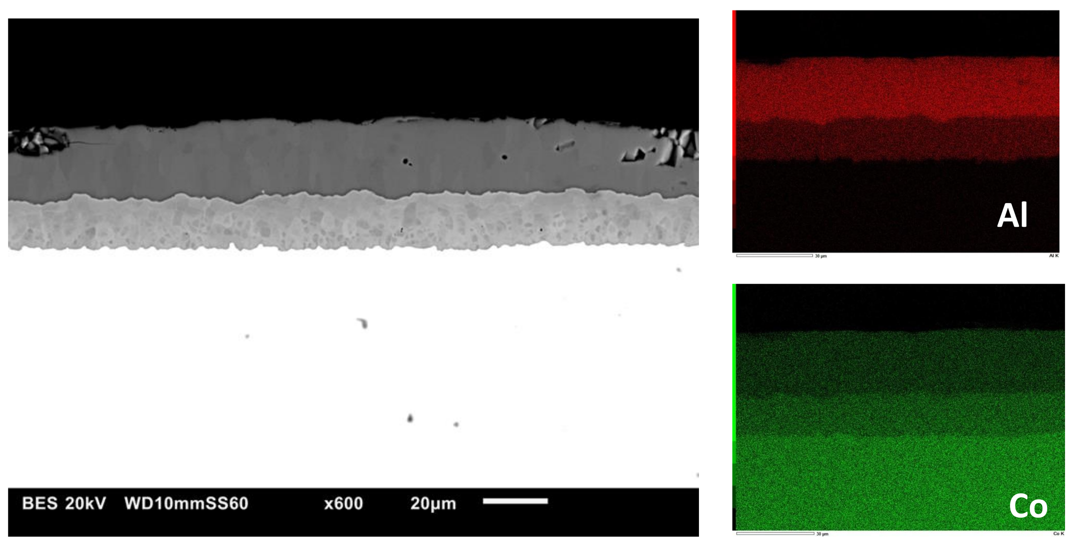

Figure 2: SEM and elemental map Co/ NH_4Cl/ 850 °C

When coated using a different activator, a thinner, more consistent coating is achieved. Figure 2 shows similar phases form; however the cracked midsection is absent. After the coating parameters were optimized, the cobalt superalloy was coated.

Figure 3 shows a backscattered image and dot maps of the main constituents in the aluminide coating: aluminum, chromium, nickel, iron, and cobalt. Chromium-rich fingers are seen throughout the mid layer of the coating. A chromium rich inner diffusion zone is also seen. Such results were also seen in previous studies involving nickel-chromium substrates, indicating that chromium does not readily form phases with aluminum as nickel does. Chromium rich zones are depleted in nickel; as in the previous study. Nickel is shown to diffuse outward more quickly than other elements. Finally, Figure 4 shows an NS-163 alloy coated with a comparatively reactive activator and at a higher temperature. This results in a thicker coating and exaggerated details in grain size and phases. Point analysis was conducted in various areas of the coated coupon, identifying chromium-rich areas , as well as cobalt and niobium rich areas of the coating in concentrated areas, allowing for multifaceted defenses against degradation.

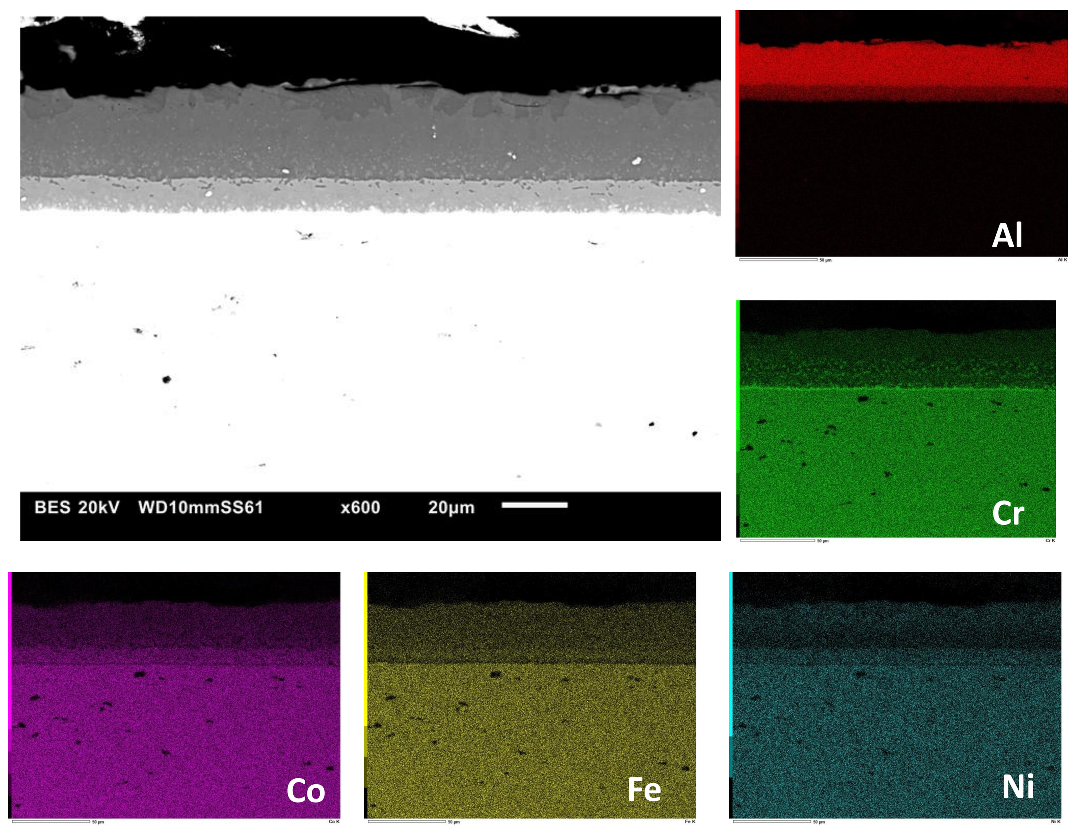

Figure 3: SEM and elemental map NS 163/ NH_4Cl/ 850 °C

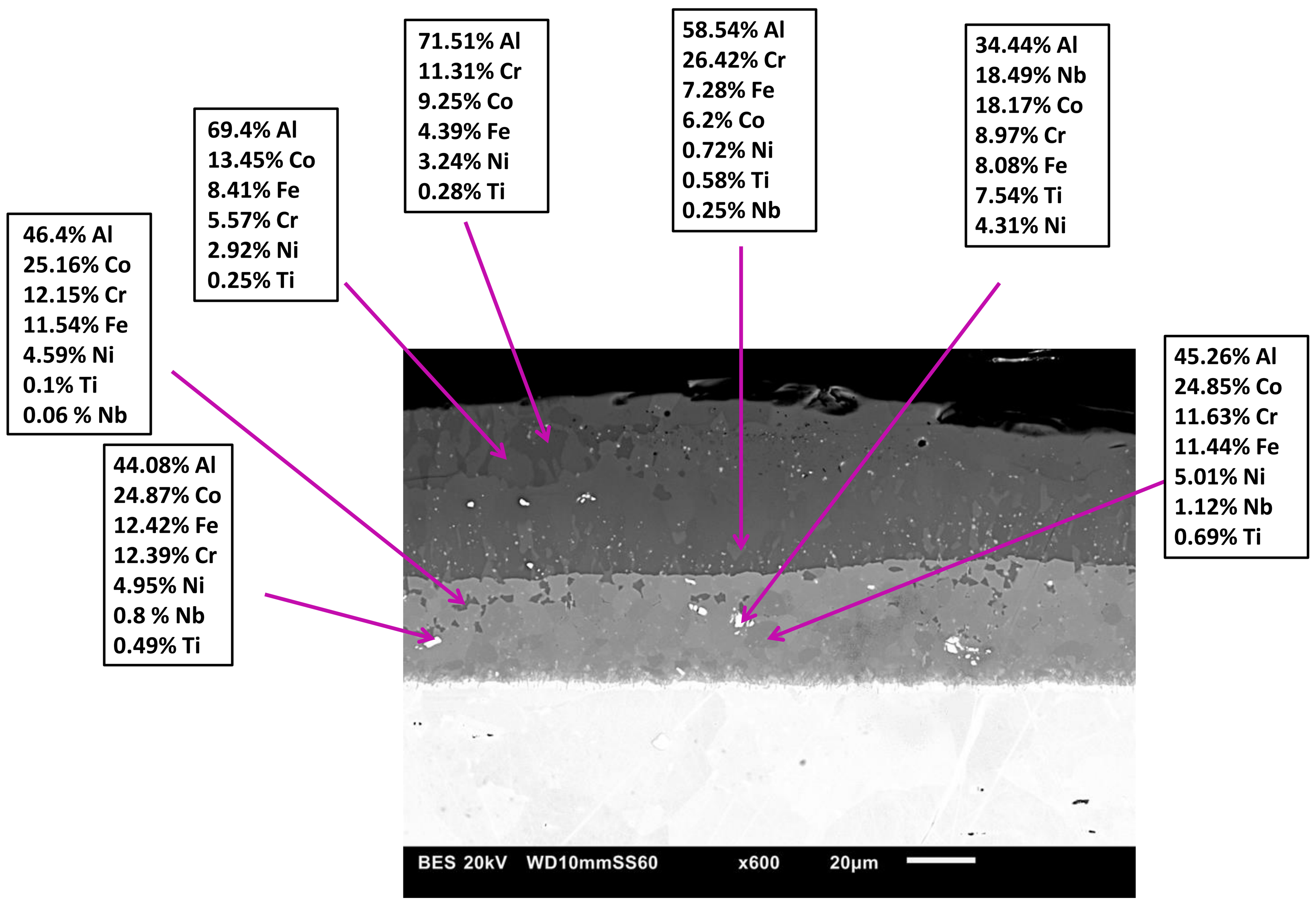

Figure 4: SEM point analysis NS 163/ NaF/ 950 °C

Conclusions

Pure cobalt and NS-163 alloy coupons were successfully coated at various temperatures and using various activators. Coating pure cobalt was more challenging, as conducting the procedure at a higher temperature produced a thick, porous coating that had cracks throughout the middle layer. Using a different activator at lower temperatures– produced a more consistent coating that contained different phases and remained intact.

Aluminizing Haynes NS 163 resulted in a complex, multilayer, multiphase coating with promise for effective high temperature corrosion protection.

References

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Acknowledgements

I'd like to thank my advisor, Dr. Vilupanur Ravi for his patience and support, as well as the Kellogg Honors College this wonderful opportunity. I'd also like to thank Obed Villalpando, Anan Hamdan, Ulus Ekerman, Armando Coronado, and Shahan Kasnakjian for their assistance in this project. Financial support from the LA Section of NACE International, Western States Corrosion Seminar, Western Area of NACE International, NACE Foundation, California Steel Industries, and Southern California Chapter of AIST is gratefully acknowledged.