

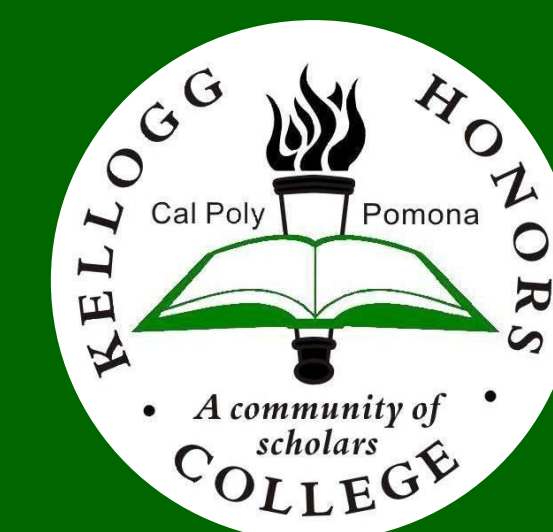
The Effect of Chromium Content on the Aluminization of Nickel-Chromium Alloys – A Microstructural Study



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1. Background

Metallic alloys often degrade when exposed to corrosive, high temperature environments such as in gas turbines or nuclear power plants. To mitigate these effects, an aluminum-rich coating can be applied using the Halide Activated Pack Cementation (HAPC) method [1]. Chromium is a key component in structural alloys that can also form a protective oxide layer [2]. It is important to understand the role of chromium in promoting or inhibiting the diffusion of aluminum into the substrate. Understanding the mechanisms that create these coatings leads to improved design & performance.

2. Objective

To investigate the effect of chromium in the formation of aluminide coatings on nickel-chromium alloys by detailed microstructural characterization.

3. Materials & Methods

Nickel-chromium alloy coupons containing 2.5, 5, 7.5, and 10 wt.% chromium were surface ground to a 600 grit surface finish. The coupons were coated with elemental aluminum through the HAPC method by burying in a pack of powders — aluminum, sodium fluoride, and aluminum oxide — in an alumina crucible. Sealed crucibles were heated at 750-950°C in a furnace for 9 hours. Cross-sectioned specimens were polished to a 0.05 μm surface finish and characterized using Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM/EDS). Chemical compositions were analyzed and quantified using Elemental Composition Mapping and Spot Chemical Analysis.

4. Results & Discussion

SEM images of coated samples (Figure 1) show the original substrate, the aluminide coating, as well as the interface between them. The composition profile of each sample was compared. For all substrates with 2.5 to 10 wt.% Cr aluminized at 750 to 950°C, aluminum and nickel were the major components of the outer regions of the coating. The chromium content became significant at a distance of about 100 to 150 μm from the outer surface of the coupon (a “chromium-rich” zone).

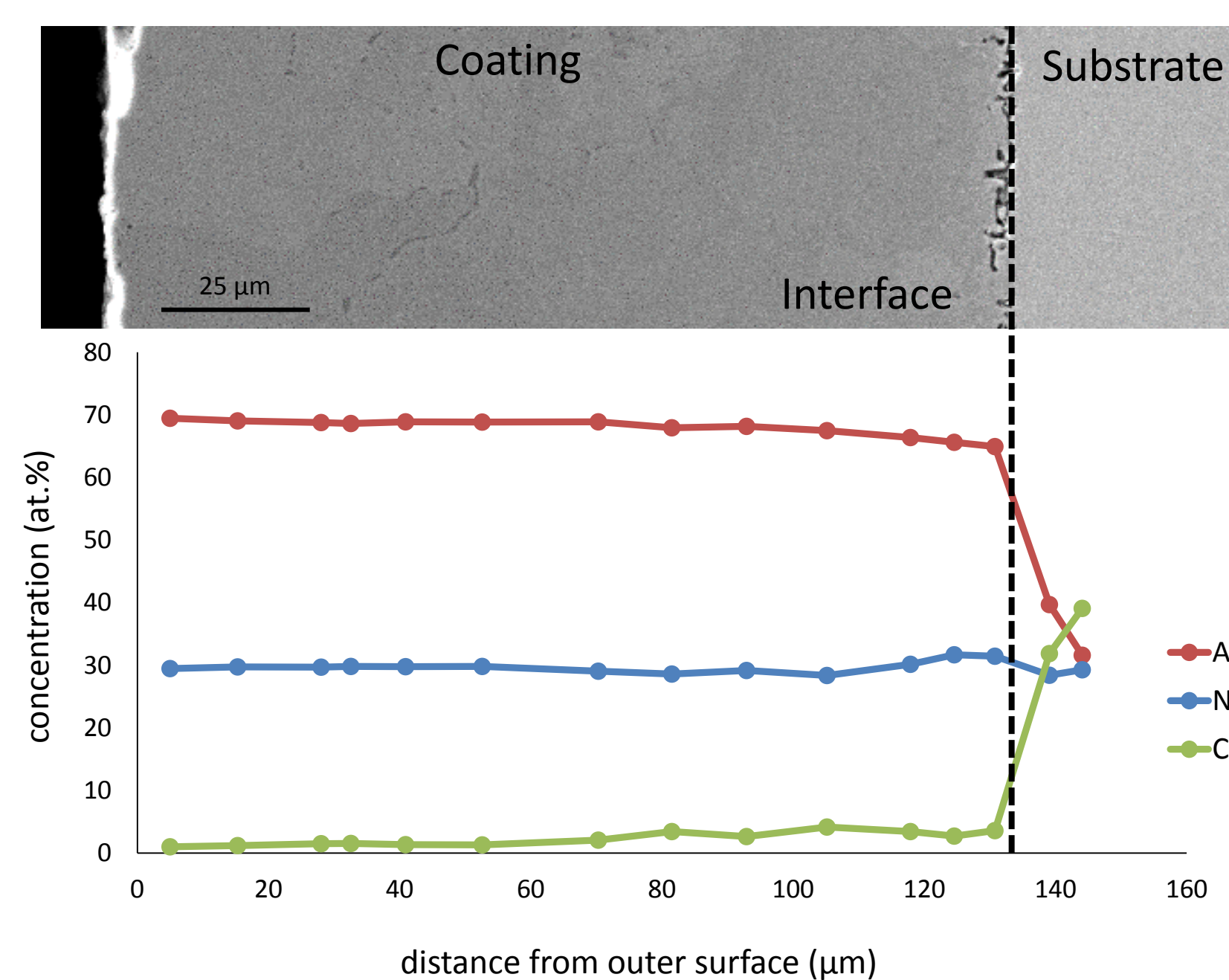


Figure 1: Composition profile of Ni-10Cr aluminized at 950°C using NaF as the activator.

These chromium-rich particles can be seen more clearly in an elemental dot map (Figure 2), which illustrated the distribution of the relevant elements. Aluminum and nickel are seen throughout the coating; nickel is seen in the substrate, and chromium accumulates at the interface.

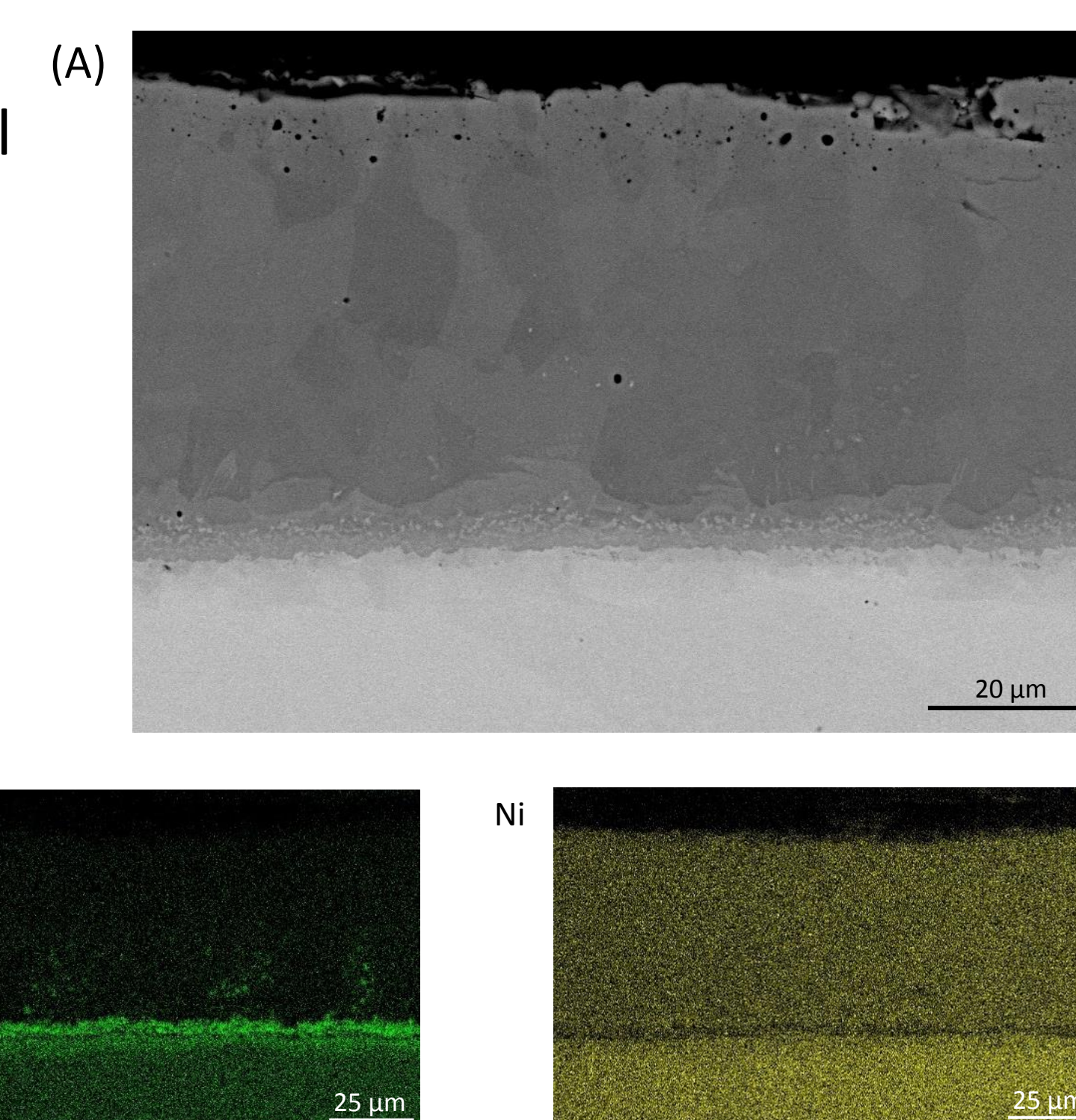


Figure 2: (A) SEM backscattered electron image of Ni-10Cr aluminized at 850°C using the NaF activator and (B) its elemental composition maps.

The chromium-rich zone became thicker as the chromium content in the substrate increased from 2.5 to 10 wt.% Cr (Figure 3). Thus as the substrate chromium content increases, the chromium diffuses further outward.

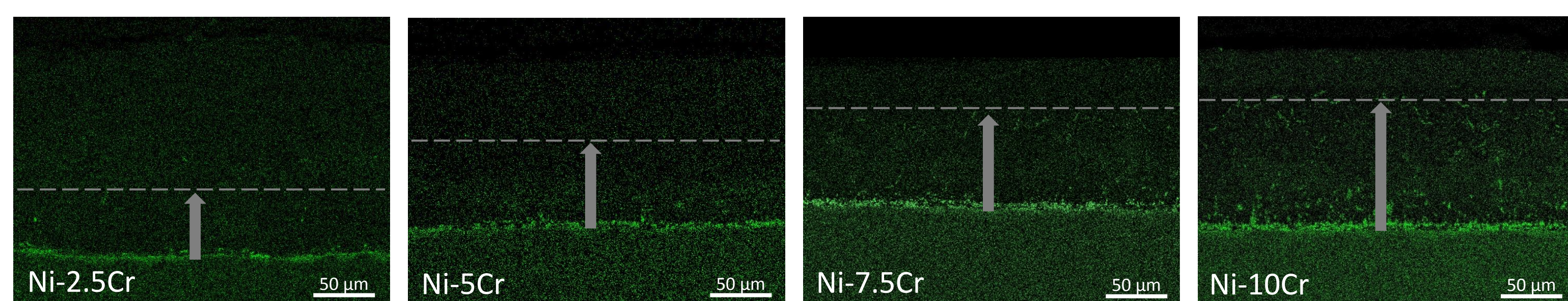


Figure 3: Chromium elemental compositions maps for nickel with 2.5, 5, 7.5, and 10 wt.% Cr from left to right, aluminized at 950°C using the NaF activator.

The general growth of the chromium-rich zone (Figure 4) can be described by the maximum solid solubility of chromium at ~2 at.% [3] in the nickel-aluminum matrix of the coating. Additional amounts of chromium in the substrate would not be further soluble in the nickel-aluminide layer, and remain as chromium-rich precipitates.

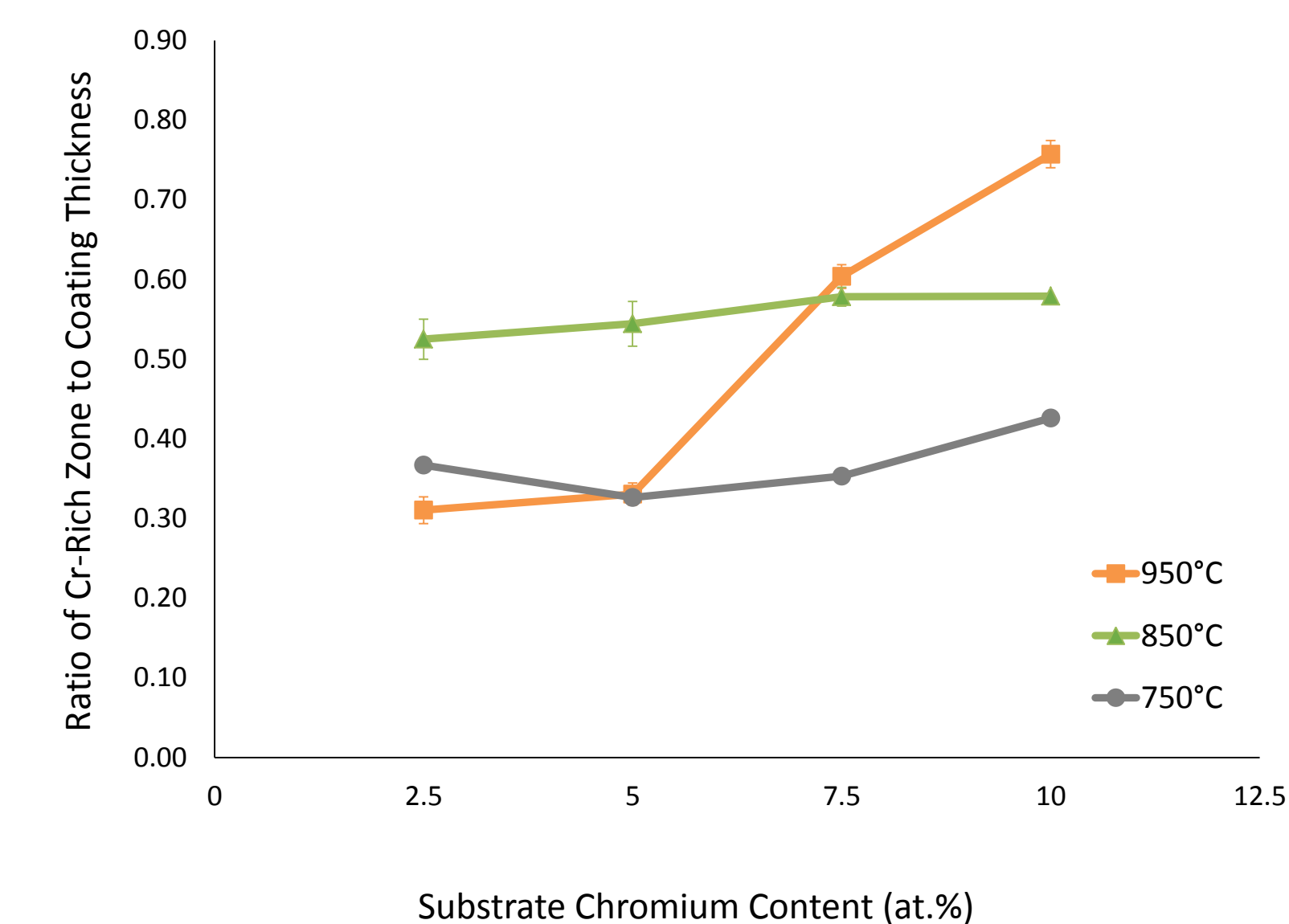


Figure 4: Thickness of the chromium-rich zone of aluminized nickel-chromium specimens.

5. Conclusion

Ni-Cr alloys were coated with aluminides in order to increase the corrosion resistance of the substrate. The aluminized alloys were characterized using SEM coupled with EDS. It was found that the higher the chromium content in the substrate, the thicker the chromium-rich zones. This reservoir of chromium may allow for better formation of the protective chromium-oxide layer when exposed to corrosive, higher-temperature environments.

6. Future Work

The concentration profiles produced through experimental means will be compared to a ternary diffusional model of aluminide coatings on nickel-chromium.

7. References

1. V.A. Ravi. Pack Cementation Coatings, *Corrosion: Fundamentals, Testing, and Protection*, ASM Handbook, Vol 13A, ASM International (2003): p 763-771.
2. M. Aliofhazraei & M.C. Galtz. *Coatings for Superalloys*, InTech (2015): p 277-298.
3. D.C. Tu & L.L. Siegle. *Kinetics of Formation and Microstructure of Aluminide Coatings on Ni-Cr Alloys*, Thin Solid Films, Vol 95 (1982): p 47-56.

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