Alloy Life Improvement

Research Team
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Introduction

The heat-treating industry is in need of heat-treatment furnace materials and fixtures that have a long service life and reduced heat capacity. Many of the fixtures are consumed within 1 year of exposure in high temperature carburization atmospheres. Most of these fixtures are manufactured using heat resistant alloys. Iron-nickel based and iron-nickel-chromium based alloys are experiencing a variety of degradation mechanisms. Based on microstructural analysis of components that were used until failure in carburization furnace application, it was found that the primary reason for failure was the excessive carburization that leads to "metal dusting" and subsequent cracking. Aluminizing is widely used to increase the high temperature oxidation and carburization resistance of nickel-based alloys.

In this project, RA330, RA602CA, 304L/316L, Inconel 625 alloys were selected to study their performance in an industrial carburization furnace for times up to two years. These alloys were exposed in both the as-fabricated and aluminized condition. The test samples were exposed to Cp=0.7-1.3 carburizing atmosphere at approximately 900℃ for 3 months, 6months, 12months, 18 months and 24months. The oxidation properties and oxide stability at high temperatures will be presented. In addition, the analysis of microstructural development during long term exposure experiments in an industrial carburizing furnace will be presented. These samples were characterized using optical and scanning electron microscope, EBSD, and x-ray diffraction. It was found that the aluminized alloys exhibited lower weight gain and carbon uptakes.

Methodology

Extension of the service life for high temperature structural alloys is the goal for this project. In this research, failure modes of alloys in gas and vacuum carburization furnace were investigated. Aluminizing and pre-oxidation treatment were also studied in this project. Aluminizing is a coating that widely used in aerospace industry, especially in turbine blade applications. It is also known that carbon has very low solubility in alumina. In that case, aluminizing could be a good method for protecting high temperature structural alloys. Therefore, microstructural development during the carburizing process will be presented. And the degradation of chromium oxide as well as alumina oxides will be identified. The weight gain of each alloy was measured for various exposure times, aluminizing coating, and surface treatments (Dip aluminum, pre-oxidization).

Salient results

RA330 is a widely used alloy in carburizing furnaces. RA330 test samples were aluminized to form an alumina-rich coating at the surface. After exposure in the furnace for 3, 6, 12, 18 and 24 months, both as fabricated and aluminized RA330 samples were removed. The SEM micrographs after 3 months service in the carburizing furnace is seen in Figure 1. Samples were electrolytic etched with 10% oxalic acid at 10V for 30 seconds.

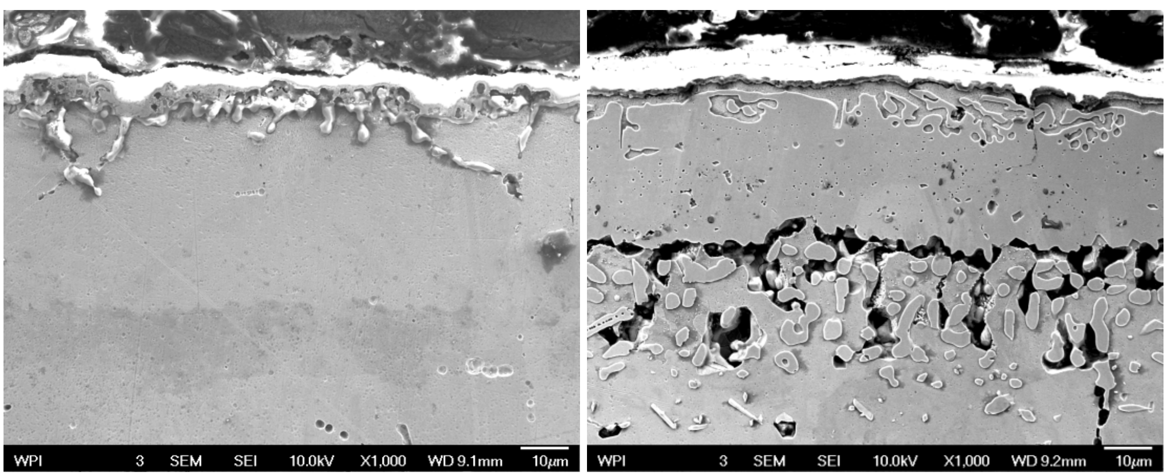

Figure 1： SEM micrographs of as fabricated RA330 (left) and Aluminized RA330 (right) exposed for 3 months

Right picture of Figure 1 shows the aluminized coating at the surface of RA330, which is composed of two layers. The XRD pattern revealed that the outer layer is mainly nickel aluminides (β-NiAl) with some aluminum oxides (Corundum: α-Al_2O_3). And the EDS analysis presents that the inner layer is discontinuous nickel aluminide (β-NiAl) in the austenite (FeNi) matrix. It can be seen that the aluminized RA330 had better carburization resistance than the as fabricated RA330.

RA602CA is an oxidation resistant high strength nickel based heat resistant alloy. High chromium, aluminum, and an yttrium addition permit it to develop a compact chromium oxide scale with an alumina subscale. Chromium carbides precipitate at the grain boundaries due to 0.2% carbon content. [1]

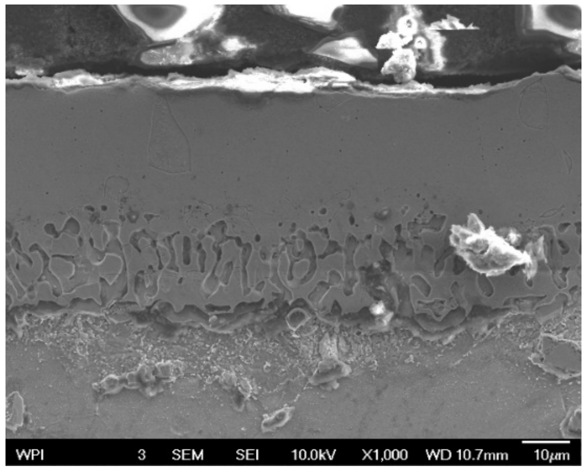

Figure 2: SEM micrograph of Aluminized RA602CA exposed for 3 months

Figure 2 shows corundum Al_2O_3 phases at surface of aluminized RA602CA and the thickness of alumina was about $2\mu m$. The premier phase $\beta - NiAl$ near the surface shown in Figure 2 which act as the pool of aluminum content for Al_2O_3 layer on the surface.

Failure analysis indicated that the failure of fixtures in gas carburization furnace is due to the excessive carburization that leads to formation of $M_{23}C_6$ and M_7C_3 carbides in the grain boundaries, and subsequent cracking because of embrittlement of carbides [2]. High temperature carburization and oxidation are two main causes of corrosion for the alloys used in gas carburizing furnaces. High temperature corrosion resistance is provided by the presence of stable, fine, dense and adhering protective oxides. In this case, the key to suppressing metal dusting is to stop the dissociation of the carbon source or subsequent carbon diffusion into the susceptible materials [3].

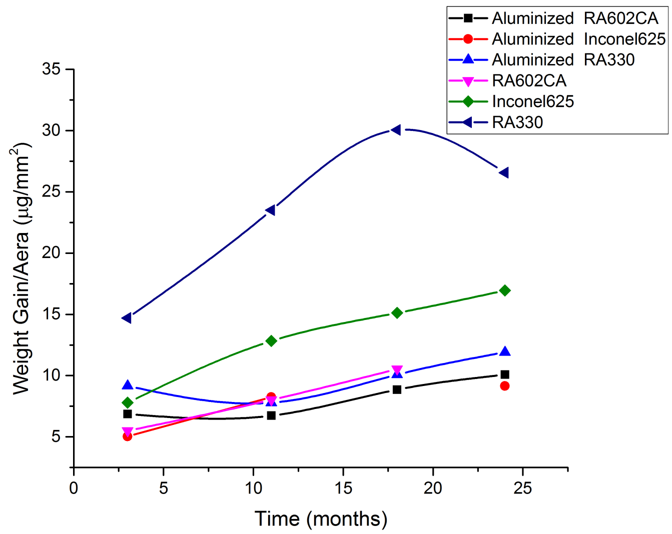

Figure 3: The weight gain per area of exposed alloys

Weight gain of test samples exposed to carburizing atmosphere were measured. It was found that the weight gain for the aluminized alloys was uniformly less than the as-fabricated alloys (Figure 3). Continuous $\alpha - Al_2O_3$ layer on the surface of aluminized alloys was maintained after 24 months exposure in gas carburization furnace. This alumina resulted in a reduced oxidation rate and decreased carbon absorption. $\beta - NiAl$ layer is important for maintaining effective protection for aluminized alloys or alloys that contain high aluminum content. After aluminizing process, the anti-corrosion properties of alloys increased significantly.

Aluminizing coating extended the life of alloys in gas carburizing atmosphere. The service lifetime of alloys in furnace and fixtures increased by at least two year because $\beta - NiAl$ kept providing Al_2O_3 on the alloy surface, which decreased the inward diffusion of carbon.

References

[1] Marc Glasser, "RA602CA: *An Alloy for the Highest Temperature Processes",* 28th ASM Heat Treating Society Conference, 2015

[2] H. J. Grabke, "Metal dusting," Materials and Corrosion, Vol. 54, No. 10, (2003) pp. 736-746

[3] A. Wang, R.D. Sisson, Jr. *"Microstructure and Failure Analysis of Austenitic Fe-Ni alloys and Ni-Cr-Fe alloys for Furnace Alloys and Fixtures",* ASM International - 28th Heat Treating Society Conference, HEAT TREATING 2015