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Original Research

Electrochemical corrosion behavior of the cobalt modified aluminide coating in 3.5 wt% NaCl solutions[☆]

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ABSTRACT

In this paper, we achieved the Co modified aluminide coating on nickel base superalloys by pack cementation process. The corrosion currents (i_{corr}) of coated and uncoated substrate after 1 h of immersion tested by potentiodynamic polarization in 3.5 wt% NaCl solutions are 9.73b $\times 10^{-7}$ A/cm^2 and 1.31 $\times 10^{-6}$ A/cm^2, respectively. With the immersion time extension, the i_{corr} of the coating decreases and the values of |Z| by EIS increase, indicating that the electrochemical reaction rate of the coating becomes slower. The coating presents good corrosion resistance due to the Al_2O_3 formed on the surface.

1. Introduction

Nickel base superalloys have been widely applied in the aerospace, industrial gas turbine and marine turbine industry, such as turbine blades for hot sections of jet engines, because of their good mechanical strength and creep resistance at high temperatures [1–4]. Moreover, due to the nickel base superalloys used for hot section components suffer expose to a hostile environment, the protective coatings on it have been extensively studied to further improve the high temperature corrosion and oxidation resistance [5–10]. The aluminide diffusion coatings on the nickel base superalloy components are good protections against high-temperature oxidation, depending on the formation of a nickel aluminide (mostly as β-NiAl) layer, which then forms a dense, stable, adherent, continuous and slow growing oxide layer of α-Al_2O_3 on the coating surface [11–13]. Over the past few years, some researchers have found that codeposition of Al/Si or Al/Cr diffusion coatings could be achieved under adequate control of pack compositions and deposition conditions [14–17]. Recently, Qiao etc. have shown that the Co or Co/RE modified aluminide coatings could form the intermetallic β-CoAl phase, which could be beneficial for providing the oxidation and hot corrosion resistance at high temperature ($>$ 1273 K), with a high melting point (1913 K) [18–26].

However, the turbine engine does not work under high temperature continuously. It is even longer to stay at the fields at room temperature than to work in the sky. Although the coating has been studied in high temperature and hot corrosion environments, few reports show corrosion resistance of the coating in marine atmosphere at room temperature. Chen etc. have researched the influence of surface modifications induced by machine hammer peening on pitting corrosion behavior of nickel-base alloy 718 [27]. Electrochemical tests results showed that machine hammer peening had a beneficial influence on the corrosion resistance. Therefore, the electrochemical corrosion behavior of the coating, which is used as the reference for judging the corrosion resistance, should be investigated. In the present work, the cobalt modified aluminide coatings were achieved by pack cementation process. Furthermore, the electrochemical corrosion behavior and corrosion products of the coating in 3.5 wt% NaCl solutions were studied.

2. Experimental

The substrates used in the experiments are commercial alloy DZ125 with the nominal composition of 60.3Ni-10Co-8.9Cr-7W-5.1Al-3.8Ta-2Mo-1.5Hf-1Ti (wt%). The diameter of the rod alloy is 12 mm and the thickness is about 3 mm. The surfaces were ground and polished to a mirror surface. Then the samples were degreased and cleaned by ultrasonic before the pack cementation process.

Powders of Al_2O_3, Co, Al and NH_4Cl with all the average particle sizes less than 100 mesh were mixed. The pack 7.6Al-20Co-4NH_4Cl-68.4Al_2O_3 (wt%) was used for the codeposition of Co and Al. Firstly, the substrates were buried in a cylindrical alumina crucible, which was full of well-mixed powders, with the diameter of 20 mm and the length of 35 mm. The crucible was sealed with an alumina lid and cement. Then, the packs were loaded into batch-type furnace circulated with the shielding gas of Ar. The furnace was raised to 1323 K at a heating rate

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of 5 K/min and sustained for 10 h, and then was cooled down to room temperature naturally. Last, the coated samples prepared by the pack cementation process were cleaned by ultrasonic before the electrochemical experiments.

The phase structure of the coated surface was analyzed by x-ray powder diffraction (XRD, Model D/Max 2500PC Rigaku, Japan) operated at 40 kV and 40 mA with Cu Kα radiation. The scan angle was 10–90° with a scan rate of 6°/min. The surface and cross-section morphologies of this work were studied by scanning electron microscope (SEM, CS3400, CamScan, UK) with energy dispersive spectroscopy (EDS). The thickness of the coating was evaluated from the EDS data by plotting the element concentrations as a function of distance from surface. The element composition of the coating surface was analyzed by x-ray photoelectron spectrometry (XPS, Axis Ultra, Kratos Analytical Ltd., UK). The depth profiles were obtained by Argon ion bombardment with an ion energy of 2 kV over an area of 6 × 6 mm^2. The energy scale of XPS spectra and possible charging effect were corrected using the C 1 s peak of adventitious carbon at a binding energy (EB) of 284.8 eV.

The corrosion behavior of the coatings was determined by potentiodynamic polarization curves and electrochemical impedance spectroscopy (EIS) tests using a classical three electrodes system. The coated or uncoated substrate specimens were used as working electrode. The reference electrode and counter electrode were saturated calomel (SCE) and platinum, respectively. The surface area of the specimens exposed for corrosion study was 1 cm^2. The corrosion electrolyte for the corrosion tests was 3.5 wt% NaCl solutions at room temperature. The EIS measurements were carried out with the signal amplitude of 5 mV (rms–root mean square), and the frequency range was from $10^5 - 10^{-2}$ Hz. The EIS results were simulated using the software “ZsimpWin”.

3. Results and discussion

3.1. Structure and composition

Fig. 1 shows the cross-section morphology and concentration distribution of the coated specimen held at 1323 K for 10 h. It can be seen in Fig. 1a that the coating structure is divided into two layers: an outer layer and a diffusion zone underneath. The existence of the diffusion zone indicates that the formation of the coating is mainly attributed to the outward diffusion of the Ni atoms [13,19,28]. As seen in Fig. 1a, the thicknesses of the outer layer and diffusion zone are approximately 18.4 μm and 14.1 μm respectively. The composition of the outer layer is about 57Ni-29Al-14Co (wt%) by EDS, and the diffusion zone is about 45Ni-14Al-11Co-18W-10Cr-2Mo (wt%) (Fig. 1b) in which the concentrations of Al and W are obviously increased and the Ni is noticeably decreased compared to the composition of the substrate.

The XRD patterns of the coated surface are shown in Fig. 2. It can be observed that the outer layer is composed of $Al_{0.9}Ni_{1.1}$ (JCPDS NO. 22-1185 [29]), in which part of Ni atoms are replaced by Co atoms.

3.2. Potentiodynamic polarization Curves

Fig. 3 shows the potentiodynamic polarization curves of the substrate and coated specimens with different immersion time in 3.5 wt% NaCl solutions. Table 1 summarizes the corrosion potential (E_{corr}) and corrosion current density (i_{corr}) obtained from these polarization curves. It can be seen from Table 1 that the i_{corr} of the coated specimen with 1 h immersion time (9.73×10^{-7} A/cm^2) is less than that of the uncoated substrate (1.31×10^{-6} A/cm^2). With the immersion time extension, the i_{corr} of the coated specimens gradually decreases. It is possible that the corrosion products form between the coating surface and NaCl solution and retard the corrosion reaction. Obviously, the Co modified aluminide coating presents good electrochemical corrosion resistance and could protect the superalloy substrate.

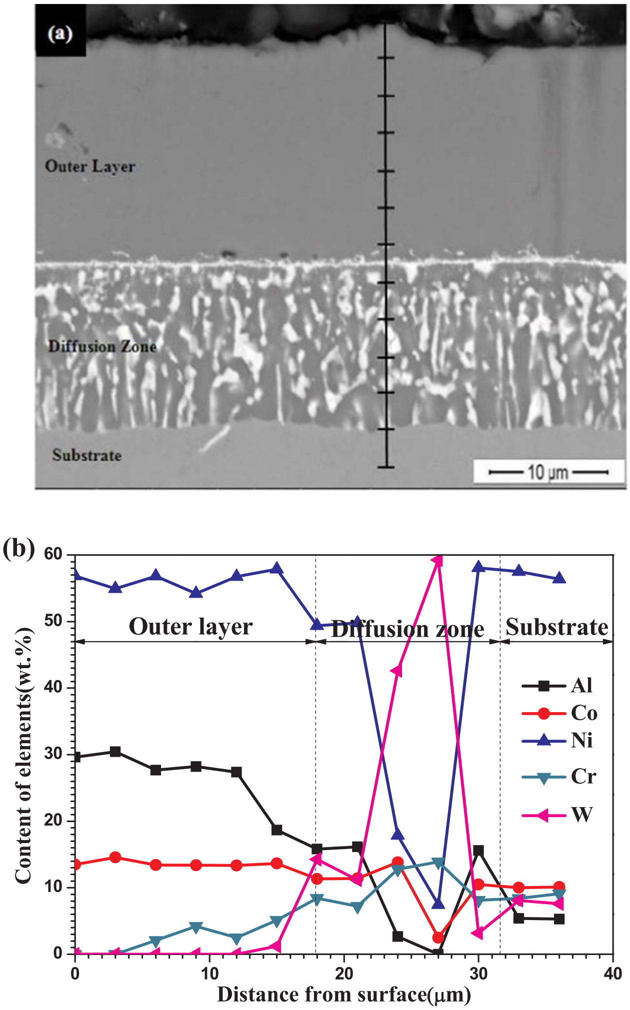

Fig. 1. Cross-section SEM image (a) and major elemental concentration distribution (b) in the coating layers for an as-coated specimen codeposited at 1323 K for 10 h.

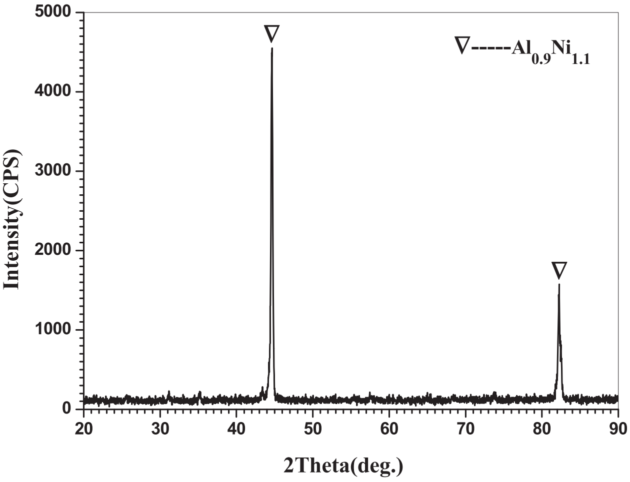

Fig. 2. XRD patterns of the as-prepared coating on DZ125 superalloy.

3.3. Corrosion products

The scanning electron micrographs (SEM) were taken and observed in order to support our conjecture. SEM surface morphologies of the coated specimens after immersing for 24 h, 240 h, and 480 h in 3.5 wt% NaCl solutions are presented in Fig. 4(a-c). It can be seen that the