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Isothermal oxidation and hot corrosion behaviors of diffusion aluminide coatings deposited by chemical vapor deposition

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A B S T R A C T

Aluminization has been employed on superalloys to form dense and adhesive alumina surface layers to prolong their service life at high temperature. A chemical vapor deposited aluminizing process had been employed to deposit nickel aluminide coatings on the nickel-based single-crystal superalloys. The kinetics behavior, phase evaluation, microstructure and chemical composition of the aluminide coatings after oxidation and hot corrosion tests were studied in detail. After isothermal oxidation test, a dense and protective α-Al_2O_3 surface layer is formed on the aluminized superalloy and phase transformation reactions occur in the aluminide layer and interdiffusion zone. The inward diffusion of Al element toward the substrate and formation of micro-pores in the interdiffusion zone are probably the main degradation modes of the aluminide coating. Corrosive medium including of mixed of aviation fuels and artificial seawater has not serious deterioration of aluminide coating after hot corrosion at 1123 K, although large of micro-pores and few of microcracks are observed within the aluminide layer, and the typical morphology of the aluminide layer becomes corse and disorder to a certain extent.

1. Introduction

Nickel-base superalloys have been widely used in established military and commercial gas turbine engines for combustion cans, blades and other high temperature structural components due to their good combination of high temperature strength and excellent oxidation resistance for long-term exposure. In gas turbine applications, the components are subject to repeated oxidation and hot corrosion cycles, which occur during cruise and marine environment. The property of superalloys under oxidation and corrosion environments is an important issue. In addition, the operation temperature of modern gas turbine engines is getting higher to improve engine efficiency and performance [1–4]. For superalloys used at high temperature, it is a common practice to coat a high aluminum-containing layer onto the surface by pack cementation aluminizing [5], slurry [6] and chemical vapor deposition (CVD) [7] processes. After exposure to an appropriate temperature, a dense and adhesive Al_2O_3 layer will be formed on the surface of aluminide coatings, which is protective against high temperature oxidation and hot corrosion attack [1,8,9].

Up to now, large of blades and vanes are coated with diffusion aluminide coatings by chemical vapor deposition [2]. As reported by previous paper [10] that diffusion aluminide coatings could serve as bond coats for thermal barrier coatings. In this study, a chemical vapor deposited aluminizing process has been employed to deposit nickel aluminide coatings on the nickel-based single-crystal superalloys. Isothermal oxidation and hot corrosion tests at 1323 K and 1173 K have been conducted to evaluate the performances of diffusion aluminide coatings, respectively. The phase evoluation, microstructure, kinetics behavior and chemical composition of the aluminide coatings after oxidation and hot corrosion have also been investigated to determine the possible degradation behaviors of the diffusion aluminide coatings.

2. Experimental

2.1. Preparation of diffusion aluminide coatings

The substrates (15 mm × 10 mm × 1.5 mm) were ground before the diffusion aluminide coatings of NiAl were deposited by CVD reactor. In the CVD aluminization method, $AlCl_x$ ($x = 1$–3) precursor vapors reacted with Ni from the Ni-based superalloy to form β-NiAl in the presence of H_2, at temperatures of about 1273–1373 K. The gas flow of HCl used for formation of precursor vapors was in the range of 1–3 L/min. The vertical hot-wall reactor was used in this study. The gas pipe lines were wrapped with heating tapes from the vaporizer to the reactor, and then the temperature was controlled to ~673 K, which was slightly above the

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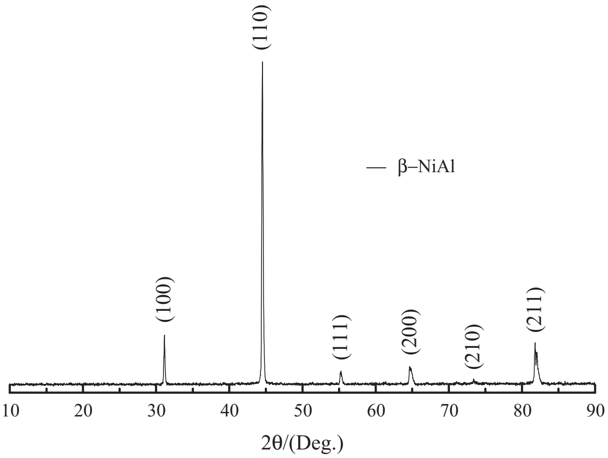

Fig. 1. XRD pattern of the as-posited NiAl coating.

sublimation temperature of $AlCl_x$ and further prevented its condensation in the gas lines. Since an excess of $AlCl_x$ was used to ensure the uniformity of the NiAl coating, a water-cooled chamber was simultaneously used to collect unreacted $AlCl_x$ waste before it entered into a liquid-ring vacuum pump. The rector chamber pressure was monitored to be about $0.5–4 \times 10^4$ Pa during the deposition of NiAl coatings.

2.2. Isothermal oxidation and hot corrosion tests

The isothermal oxidation of aluminide coatings was carried out at 1323 K in a furnace with airflow. Before the oxidation experiment, the specimen crucibles were heated at 1373 K until a constant weight was obtained. After the oxidation for a certain time, the oxidized specimens were removed from the furnace and air-cooled to room temperature. The specimens were then balanced with an automatic electronic balance (BS110S, 0.1 mg), and the weight change as a function of time was recorded.

Table 1
Elemental contents of Areas a and b in Fig. 2 (wt.%).

Elements	Al	Cr	Co	Ni
Area a	23.56	6.39	7.97	62.08
Area b	24.07	6.41	8.80	60.72

The solution including of mixed of aviation fuels and artificial seawater was used as corrosive medium during hot corrosion at 1173 K in a gas-fired furnace. The composition of artificial seawater was including of NaCl, $MgCl_2$, KCl and $CaCl_2$ with concentration (g/L) ratio of 27:12.8:1:1, respectively. After the hot corrosion for 25 h, 50 h, 75 h and 100 h at a fixed time, the tested coating samples were then removed from the furnace and air-cooled to room temperature. Similarly, the samples were also balanced with an automatic electronic balance, and the weight change as a function of time was recorded.

2.3. Characterizations

After preparing of the coating samples, the surface of the aluminide coatings was characterized using the scanning electron microscope (SEM, FEI-Quanta 600). The coating samples were embedded in a transparent cold-setting epoxy and then sectioned, ground and polished with diamond pastes down to 1 μm. SEM equipped with EDS (Oxford INCAx-sight 6427) was applied for the microstructure and composition evaluation. X-ray diffraction (XRD, Bruker D8 Advance) with Cu Kα radiation at a scan rate of 4 min^{-1} was employed to analyze the phase structural evolution of the coatings after isothermal oxidation and hot corrosion. Coatings without polishing were used directly for XRD measurement.

3. Results and discussion

3.1. Surface topologies of the as-deposited aluminide coatings

The crystal structure of NiAl coating is determined to be single phase β-NiAl by XRD (Fig. 1), with higher intensity peaks at the

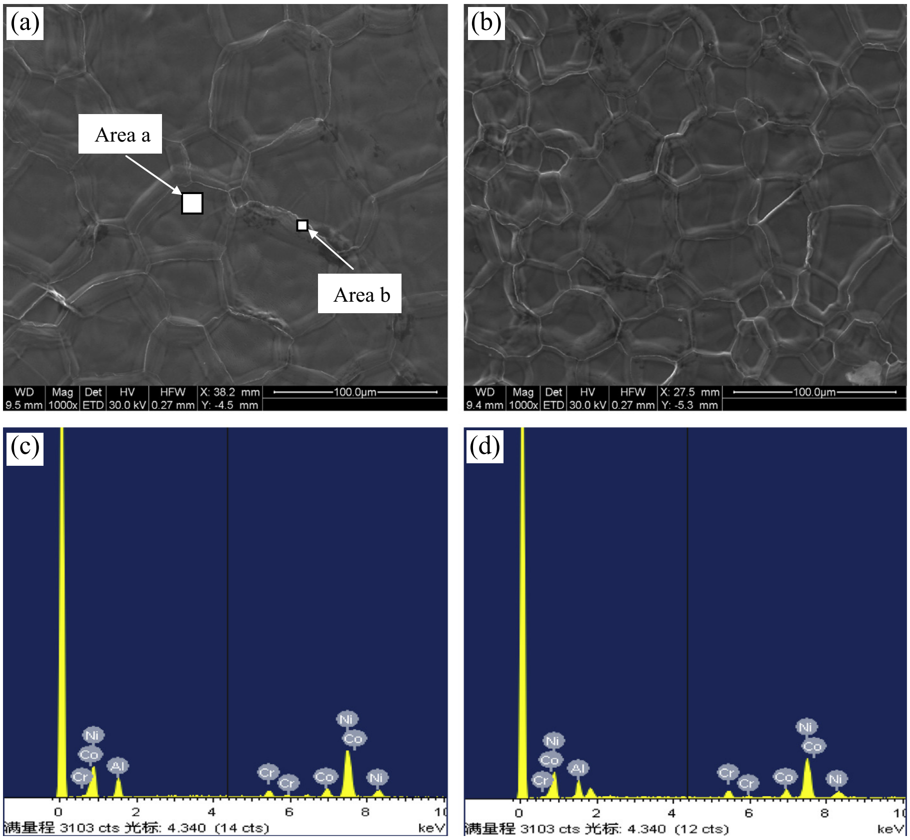

Fig. 2. SEM images of surface morphologies of (a and b) as-deposited NiAl coatings. (c) and (d) are the corresponding EDS spectra of Areas a and b in (a), respectively.