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The isothermal and cyclic oxidation behaviour of two Co modified aluminide coatings at high temperature

Q.X. Fan [a], X. Peng [b], H.J. Yu [a], S.M. Jiang [a], J. Gong [a], C. Sun [a,*]

[a] State Key Laboratory of Corrosion and Protection, Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, PR China
[b] College of Materials and Metallurgy, Northeastern University, Shenyang 110006, PR China

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ABSTRACT

The isothermal and cyclic oxidation behaviour of two Co modified aluminide coatings together with the simple aluminide coating were performed at 1000 °C and 1100 °C. All the three coatings show a much lower oxidation rate compared with the bare alloy. Results also indicate the addition of Co to the aluminide coating decreases the oxidation resistance slightly. It can be ascribed to that Co is easier to be oxidized than Ni at high temperature, and the Cr(W) rich phases which could act as a diffusion barrier are less in the coating with higher Co content.

1. Introduction

As the operating temperatures of large turbine engines have been increasing to improve efficiency, it becomes necessary to use high temperature protective coatings on all the high-pressure turbines [1]. The protective coatings used on hot section components typically can be divided into four types: (i) simple aluminide coating, (ii) modified aluminide coating, (iii) MCrAlY overlay coating, and (iv) thermal barrier coating [2,3]. In spite of the presence and development of overlay coatings, aluminide diffusion coatings are still used widely and have been applied to more than 80% of the first-stage-blade airfoils [4], for their low cost, easy processing and good oxidation resistance. Simple aluminide coating is mainly composed of intermetallic compound β-NiAl, which has a high melting temperature, low density, excellent oxidation resistance and thermal conductivity [5–7]. At elevated operating temperature, the high content of Al in the aluminide coating guarantees the exclusive oxidation of Al to form a dense and continuous protective scale in the initial stage, which could block the inward diffusion of oxygen and hence substantially reduce the oxidation rate of the substrate [8]. However, the simple NiAl phase is susceptible to brittle cracking and possesses inferior thermal fatigue resistance as well as corrosion resistance [9,10], thus some beneficial elements like Cr, Pt, Si and reactive elements are applied into the NiAl coatings or alloys to ameliorate their properties [4,11–16].

Some researchers have revealed that the addition of Co could promote the formation of alumina scale in the Ni_3Al alloy at high temperature [17], and it is beneficial to decrease the internal oxidation of Al in the β-NiAl alloy [18]. Ni_3Al and NiAl are the primary phases in the aluminide coating, inferring that the addition of Co could improve the oxidation resistance of the aluminide coating. Besides, adding bits of Co into the nickel superalloy has been reported to enhance the creep resistance and increase the stress rupture life [19], which means Co applied to aluminide coating on nickel superalloy might be helpful to increase the mechanical property of both the coating and substrate. To find out the influence of Co on the high temperature oxidation of the simple NiAl coating, two Co modified aluminide coatings with different Co contents are prepared by a combined method of pack cementation and chemical vapour deposition. The formation mechanism and type-I hot corrosion test of the coatings have been studied in our previous paper [20]. In this paper, we focus on the high temperature oxidation behaviour of the two Co modified aluminide coatings in comparison with the simple aluminide coating. In addition, the degradation process of the coatings at elevated temperature will be discussed in detail as well.

2. Experimental

A nickel based alloy (nominal composition: 10.48 wt.% Co, 15.28 wt.% Cr, 5.13 wt.% W, 3.10 wt.% Al, 4.40 wt.% Ti, 2.08 wt.% Mo, 0.19 wt.% Nb, 0.31 wt.% Hf, 0.08 wt.% B, balanced Ni) was used as the substrate. Specimens with dimensions of $15 \times 10 \times 2\ mm^3$

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* Corresponding author. Tel.: +86 24 83978081; fax: +86 24 83978232.
E-mail address: csun@imr.ac.cn (C. Sun).

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were ground down to 800 # SiC paper, followed by ultrasonically cleaning within acetone, ethanol and deionized water successively. The coating 1 and coating 2 were Co modified aluminide coatings prepared by a two-step process, firstly depositing Co by pack cementation and then aluminizing by chemical vapour deposition. For the coating 1 and coating 2, Co was deposited at 1000 °C and 850 °C for 6 h separately prior to aluminization which was conducted at 1000 °C for 5 h. The coating 3 was simple aluminide coating prepared under the same aluminization condition as that of the coating 1 and coating 2. The details about the Co deposition and aluminization process have been reported elsewhere [20].

Isothermal oxidation tests of the three coatings were conducted in static air at 1000 °C for 500 h and 1100 °C for 200 h respectively. Specimens placed in crucibles were taken out of furnace and cooled down to room temperature at intervals for mass measurement. The mass gains of the specimens together with crucibles were measured to count in the mass of the spalled oxide. The cyclic oxidation tests were performed at 1000 °C for 200 cycles and 1100 °C for 100 cycles separately. Each cycle consisted of heating and holding the samples at the high temperature for 50 min, and then cooling down to room temperature for 10 min. In this case, only the mass of the oxidized specimens was recorded, without the mass of the spalled oxide counted. The sensitivity of the electronic balance was 10^{-5} g. For each test, three parallel samples were adopted to obtain the average value of the mass change.

A D/MAX-RA X-ray diffractometer (XRD) was used for the major phase identification. Microstructure and elemental compositions of oxidation products were characterized by a JSM-6301F scanning electronic microscope (SEM) equipped with an energy disperse spectroscope (EDS). A SHIMADZU EPMA-1610 electron probe microanalysis (EPMA) was also used for elemental distribution mapping of the coatings after oxidation. Ni–P electroless plating was introduced to protect the oxidation scale from being destroyed during the cross-sectional sample preparation process. The electroless plating bath consists of 20 g/L nickel sulphate, 10 g/L sodium citrate, 30 g/L ammonium chloride and 30 g/L sodium hypophosphite.

3. Results

3.1. The microstructure of the coatings before oxidation

Fig. 1 shows the cross-sectional images of the coatings 1, coating 2 and coating 3 before oxidation. All the three coatings possess a two-layered structure. The outer layer is made of single β-(Ni,Co)Al phase (abbreviated as β in the following paragraph), and the inner layer is the inter diffusion zone composed mainly of Cr(W) rich phases. The dotted grey phase dispersed between the outer layer and inter diffusion zone in the coating 1 and coating 2 is mainly TiN formed during the preparing process. The diffraction peaks of TiN are detected by XRD, which has been shown in our previous paper [20]. The average elemental compositions of the outer layer and inter diffusion zone in each coating are shown in Table 1. Because of the different treatment process before aluminization, the Co and Cr contents in the three coatings decrease successively from the coating 1 to the coating 3, while the Al and Ni contents follow a contrary law.

3.2. Isothermal oxidation

3.2.1. Oxidation kinetic curves

The mass gains of the bare alloy, coating 1, coating 2 and coating 3 after isothermal oxidation at 1000 °C and 1100 °C are presented in Fig. 2. According to Fig. 2(a), the bare alloy has the largest mass gain, and remains a rapid oxidation rate throughout the whole 1000 °C oxidation test. The parabolic rate constant (Kp) of the bare alloy is about $2.171 \times 10^{-10}\ g^2\ cm^{-4}\ s^{-1}$ which is much larger than that of the three coatings shown in Fig. 2(b). The coatings go through a rapid increase of mass gain in the initial 40 h, and then transit to a steady stage keeping a small weight gain

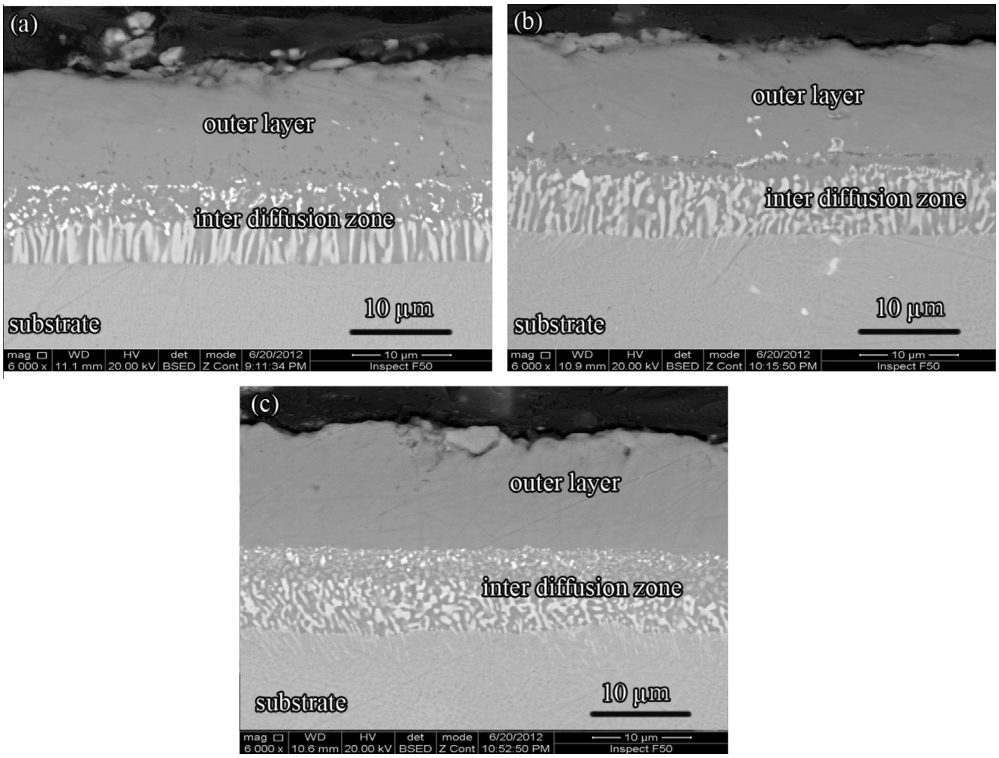

Fig. 1. The cross-sectional images of the coating 1 (a), coating 2 (b) and coating 3 (c).