



# Improved hot corrosion resistance of Y–Ce–Co-modified aluminide coating on nickel base superalloys by pack cementation process



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## ABSTRACT

Y–Ce–Co-modified aluminide coating on nickel base superalloys was prepared by pack cementation method. The microstructure and hot corrosion behavior of the coating were investigated. The results indicate that Y–Ce–Co-modified aluminide coating has a mass gain of only 0.32 mg/cm<sup>2</sup> after hot corrosion at 1173 K for 100 h. The coating exhibits superior hot corrosion resistance to the Y–Co-modified and Co-modified aluminide coatings. The improved hot corrosion resistance of the Y–Ce–Co-modified aluminide coating is mainly attributed to the synergistic effect of Y and Ce.

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## 1. Introduction

As the structural basis of modern turbine blades of jet engines, nickel base superalloys have been applied extensively in aerospace, gas-turbine industry and marine turbine industry owing to their excellent mechanical strength and creep resistance at high temperatures [1]. Nevertheless, when engines operate in locations where salts can be ingested, i.e., coastal areas and regions with high levels of airborne pollutants, salts deposit on the surface of gas-turbine hardware leading to severe hot corrosion of the materials [2]. The aluminide diffusion coatings are generally deposited on the surface of the superalloys to separate the nickel base superalloys from salt deposits by forming Al<sub>2</sub>O<sub>3</sub> scales as a protective barrier [3–5]. However, with the increasing thrust-weight ratio of engines, conventional aluminide coatings can hardly meet the demanding of service conditions. In general, the potential application of the simple aluminide coatings is limited by two main shortcomings, poor adhesion and hot corrosion resistance in high temperature [6].

To overcome the hindrance, Si, Co, Cr were added to aluminide coatings to improve the type II hot corrosion performance and Pt, Hf were added to aluminide coatings to improve oxidation resistance [7–13]. Task et al. [14] discovered that Co, and Cr addition could increase the hot corrosion resistance of β-NiAl alloys by accelerating the formation of a thermally grown Al<sub>2</sub>O<sub>3</sub> scale and healing this scale in the event of damage. Moreover, according to the reactive element effect (REE), adding few reactive elements

can improve the adhesion and promote the formation of protective oxide scale simultaneously such as Y, Ce, La, and Dy or their oxides [15–18]. Seybolt [19] found that CeO<sub>2</sub> and La<sub>2</sub>O<sub>3</sub> additions could reduce the extent of hot corrosion attack by getting the sulfur to form oxysulfides of the form M<sub>2</sub>O<sub>2</sub>S. The researches by Zhou et al. [20] showed that Y addition in the Co-modified aluminide coatings on nickel base superalloys could accelerate the diffusion of Co and thus increase the hot corrosion resistance of the coatings. Furthermore, Wang et al. [21] demonstrated that the corrosion performance of the laser clad nickel-base self-fluxing alloy coatings could be improved obviously by the addition of CeO<sub>2</sub>, because the addition of Ce could lead to a finer microstructure and less inclusions in the coatings.

Despite these exciting performance, the benefit of a single RE addition on hot corrosion resistance of Si-, Pt-, Co-, Cr-, Hf-modified aluminide coatings is still limited. The RE elements have low solid solubility in NiAl and high oxygen affinity which can cause serious internal oxidation [22]. In recent years, co-doping of two beneficial elements has been put forward to overcome the above problem. According to the research by Lan et al. [23], the Pt–Dy co-doping on (Co, Ni)-based alloy could reduce oxidation rate effectively. In addition, Guo et al. [24] discovered that the Si/Cr co-doped NiAlDy alloys exhibited better hot corrosion resistance, as compared to the NiAlDy or the Cr-doped NiAlDy alloys. However, the co-doping effect of two REs on the hot corrosion behavior of Co-modified aluminide coating is not yet explored.

In the current study, Y–Ce–Co-modified aluminide coating on nickel base superalloys was prepared by pack cementation process. The microstructure, composition and hot corrosion resistance of Y–Ce–Co-modified aluminide coating were evaluated. The

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mechanism of the Y and Ce effect on the hot corrosion resistance of the coating was discussed.

## 2. Experimental

### 2.1. Coating process

The nickel base superalloy DZ125 (Beijing Institute of Aeronautical Materials, China) with a composition of 63.5Ni–6.2Co–8.9Cr–7.0W–6.1Al–3.8Ta–2.0Mo–1.5Hf–1.0Ti (wt.%) was used as the substrate in this study. The alloy rod was sliced into buttons in the dimensions of  $\varnothing 14$  mm  $\times$  3 mm by wire-electrode cutting. The buttons surface and side were completely rubbed with emery papers of 800-grade and were degreased in a solution of acetone ultrasonically.

Commercial pure powders of Co, Al,  $\text{Al}_2\text{O}_3$ ,  $\text{NH}_4\text{Cl}$ ,  $\text{NH}_4\text{I}$ ,  $\text{Y}_2\text{O}_3$  and  $\text{CeO}_2$  ( $\geq 99.8\%$  grade, Beijing Chemical Works, China) with average particle sizes of all less than 100 mesh were used as the basic powders of pack mixture for the pack cementation process. The halide salts  $\text{NH}_4\text{Cl}$  and  $\text{NH}_4\text{I}$  were used as activator which would react with the depositing elements to form a series of halide vapors during pack cementation process. Based on the results of thermochemical analysis in Ref. [25],  $\text{NH}_4\text{I} + \text{NH}_4\text{Cl}$  proved to be a more favorable activator for codepositing Co–Al–Y compared to  $\text{NH}_4\text{I}$  or  $\text{NH}_4\text{Cl}$ . The pack activated by  $\text{NH}_4\text{Cl}$  could not generate adequately high vapor pressures of Co-chlorides, which are necessary to induce simultaneous deposition of Co in presence of Al and Y. Therefore, in order to achieve codeposition of Co, Al, Y and Ce, the  $\text{NH}_4\text{Cl}$  and  $\text{NH}_4\text{I}$  are used as activator in this paper. The pack powders were weighed proportionally in accordance with the composition listed in Table 1. The substrates were buried in the well-mixed pack powders in a cylindrical alumina retort ( $\varnothing 20$  mm  $\times$  35 mm). Subsequently, the retort was heated to 1323 K at a rate of 5 K  $\text{min}^{-1}$  and was held at this temperature for 10 h. After that, the power supply was cut off and the retort together with specimens cooled down to room temperature naturally while keeping the argon gas flowing.

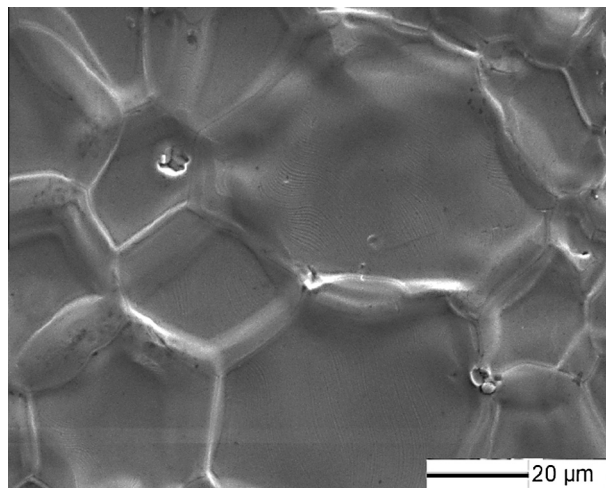
### 2.2. Hot corrosion tests

The hot corrosion test was carried out in an open-ended tube furnace for 100 h at atmospheric pressure with a temperature of 1173 K. The saturated salt solution with a mixture of 25 wt.% NaCl + 75 wt.%  $\text{Na}_2\text{SO}_4$  served as the corrosion medium in this study. The specimen was firstly preheated at about 373 K on a hot plate. Then the saturated salt solution was sprayed on the surface of the specimen evenly by sprayer. The water in solution would soon evaporate at 373 K and then salts deposited on the surface of the specimen. The specimen was weighed before and after salting to assure a salt supply of 3  $\text{mg}/\text{cm}^2$  on the surface. The alumina crucible was used as the specimen container which required to be heated at 1173 K in advance for a stable weight. The specimen was placed in a square alumina crucible individually and then be positioned in the tube furnace. The specimen was taken out after 1, 3, 5, 10, 15, 20, 40, 60, 80, and 100 h, and weighed together with the alumina crucible. The mass gains of the specimen were measured by an electronic balance (Model BS 224S Sartorius, Germany) with an accuracy of 0.1 mg.

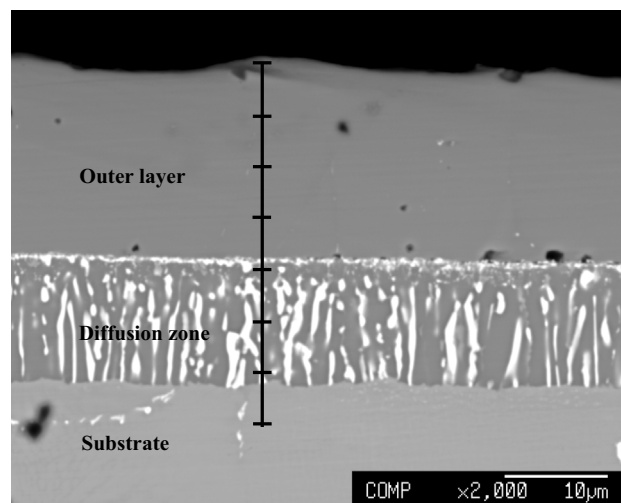
**Table 1**

Composition of Co–Al–Y–Ce compound pack mixtures.

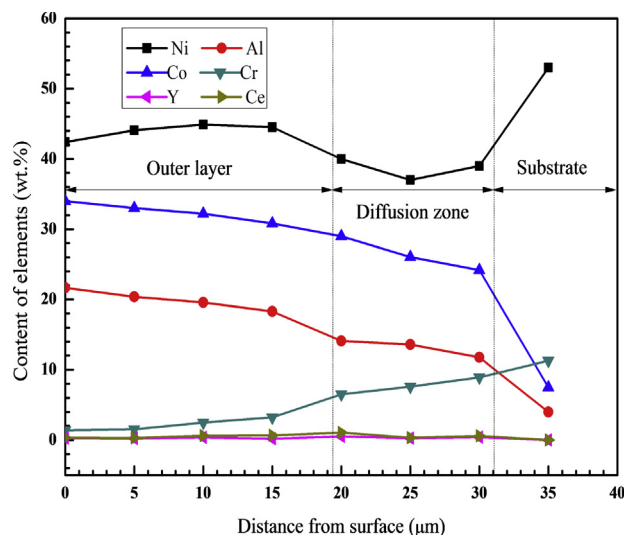
Pack	Co	Al	$\text{Y}_2\text{O}_3$	$\text{CeO}_2$	$\text{NH}_4\text{Cl}$	$\text{NH}_4\text{I}$	$\text{Al}_2\text{O}_3$
Mass fraction of composition/%	20	7.6	1.5	1.5	4	4	61.4



**Fig. 1.** Surface morphology of the Co–Al–Y–Ce coating codeposited on DZ125 superalloy at 1323 K for 10 h.



(a) Cross-sectional SEM image



(b) Major elemental concentration

**Fig. 2.** Cross-sectional SEM image (a) and major elemental concentration profile (b) of the Co–Al–Y–Ce coated specimen held at 1323 K for 10 h.

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