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The oxidation performance of plasma-sprayed NiAl bond coat: Effect of Hf addition in bond coat and substrate

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ABSTRACT

NiAl bond coats with and without Hf addition (0.1 at.%) were deposited on two types of superalloy substrates (i.e., DZ125L, no Hf, and DZ125, 0.51 at.% Hf) using plasma spraying technique, and isothermally oxidized at 1150 °C. It demonstrates that Hf addition in the bond coat is more effective than in the superalloy substrate for improving the bond coat oxidation resistance. In addition, though the substrate chemistry could affect the bond coat oxidation performance, this effect was very sensitive to the chemistry of the bond coat - obvious for the RE (reactive element)-free NiAl bond coat, but less obvious for the RE-containing bond coats (NiAlHf and NiCoCrAlY). Moreover, compared with the NiCoCrAlY bond coat, the NiAlHf bond coat showed significantly improved oxidation resistance, regardless of the substrate chemistry, suggesting that NiAlHf bond coat prepared by plasma spraying is a promising candidate for the thermal barrier coating application.

1. Introduction

β-NiAl is considered as one of the most promising materials to replace conventional MCrAlY (M = Ni, Co or both) for high temperature protection of superalloys and bond coats in thermal barrier coating (TBC) systems because of its high strength, high melting point, low density, good isothermal oxidation resistance and low cost [1,2]. In view of this, NiAl coatings fabricated by various methods, such as electron beam physical vapor deposition (EB-PVD) [3,4], pack cementation [5–7] and chemical vapor deposition (CVD) [8,9], have been developed and investigated. In general, these coatings possess good oxidation performance while still encounter some problems. For example, the EB-PVD process is high cost and hard to control the composition, and the other methods will usually incorporate a certain amount of elements from superalloy substrate during fabrication (typically at > 1100 °C), which not only deteriorate the chemical stability, but also strongly influence the oxidation performance of these coatings.

As NiAl is a very stable compound, thermal spraying methods are also considered for its deposition. To avoid excessive oxidation of NiAl powder particles during spraying, low temperature spraying methods like high velocity oxygen fuel (HVOF) and even cold spraying are being employed. For example, Hearley et al. [10] investigated the spraying parameters of HVOF on the quality (e.g., oxygen content, porosity) of NiAl coatings. Zhang et al. [11] used cold spraying followed by an annealing process to fabricate NiAl coating. As a versatile and economic method, air plasma spraying (APS) has been widely applied to deposit bond coats (e.g., MCrAlY) in the hot sections of industrial gas turbines [12–14]. However, compared with MCrAlY, deposition of NiAl by APS is more challenging and used less often [15–17]. Firstly, the high content of oxide inclusions formed during high temperature spraying deteriorates the oxidation performance of NiAl. Secondly, the brittleness of NiAl at ambient temperature may affect the adherence with superalloy substrate. Therefore, thermally sprayed NiAl is typically 95/5 or 90/10 wt% composition alloys. However, as will be shown in this work, with optimized processes and parameters, the APS NiAl bond coats reveal good oxidation performance during high temperature exposure.

Previous research shows that though NiAl possesses good isothermal oxidation resistance, the thermally grown oxide (TGO) formed on it spalls readily during thermal cycling due to poor adherence, which hinders its application. To improve the TGO adherence, a third additional element is essential, particularly reactive elements (REs), such as Hf, Zr, Y, which have been reported extensively [18–20]. To take full advantage of the beneficial effect, RE is usually directly added to alloys

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Table 1
Chemical compositions of the bond coats and superalloy substrates (at.%).

Material	Cr	Co	W	Mo	Al	Ti	Ta	Hf	Y	Ni
NiAl	/	/	/	/	50	/	/	/	/	50
NiAlHf	/	/	/	/	49.9	/	/	0.1	/	50
NiCoCrAlY	16.5	22.4	/	/	19.7	/	/	/	0.3	Bal.
DZ125L	10.2	9.96	2.24	1.22	10.9	4.29	1.30	/	/	Bal.
DZ125	9.9	9.89	2.29	1.31	11.6	1.17	1.21	0.51	/	Bal.

Table 2
Air plasma spray parameters for the bond coat deposition.

Spray parameters	Bond coat
Spray distance (mm)	100
Arc current (A)	400
Voltage (V)	148
Ar flow rate (SLPM)	91.5
H_2 flow rate (SLPM)	15.9
Carrier gas flow rate (SLPM)	5
Gun speed (mm/s)	800

SLPM = standard litres per minute.

or bond coats in forms of alloying element or oxide dispersion. In this case, RE is prone to be incorporated to growing the TGO once oxidation occurs, which not only modifies the microstructure and morphology of the TGO, but also influences its growth rate and adherence. Previous reports also showed that the oxidation performance of coatings is strongly dependent on the chemical composition of the superalloy substrate, especially when containing REs, such as Hf, Zr, Ti [5,21,22]. It is suggested that though various substrate elements diffuse into coatings and influence its oxidation performance, the most significant effect should be ascribed to REs. However, comparisons of the effect of RE addition in the bond coat and the superalloy are rarely reported because investigations published so far have tended to consider just a single bond coat or substrate composition. Moreover, it is difficult to isolate the effect of REs from other alloying elements both in the bond coat and superalloy. Therefore, characterization of the effect of RE both in the bond coat and the superalloy substrate on the bond coat oxidation performance is very meaningful.

This work attempts to develop an economic and high oxidation performance bond coat applied in the industrial gas turbines, together with characterization of RE effect both in the bond coat and superalloy substrate. In this work, Hf is chosen as the model element, which is the most widely used additive element both in superalloy and bond coat [5,18,23]. Four bond coat systems were used: undoped NiAl and Hf-doped NiAl bond coats both deposited on one Hf-free superalloy (DZ125L) and one Hf-containing superalloy (DZ125), respectively. DZ125L alloy is a directionally solidified nickel-based superalloy, and its improved version DZ125, is widely used for gas turbines and boilers due to its good thermo-mechanical properties [24,25]. In addition, a conventional NiCoCrAlY bond coat was also deposited on these two superalloys for comparison. The oxidation behavior of the bond coats, including the oxidation rate, TGO microstructure and phases, TGO spallation were examined, and the influencing factors were also analyzed and discussed.

2. Experiment

2.1. Materials and sample preparation

The nominal compositions of the bond coats and the superalloy substrates are given in Table 1. The composition of NiAl is stoichiometric (50:50 in atomic ratio), and the NiAlHf is Ni-49.9Al-0.1Hf (in at.%). Both materials were obtained by arc-melting, and then annealed at 1200 °C for 100 h in argon flow to homogenize the composition. The feedstock powders for APS were obtained by crushing and milling the bulk obtained from arc-melting in a planetary ball mill, and then sieved to the range of 40–110 μm. The NiCoCrAlY powder is commercial (Amdry 365-2, Sulzer Metco).

The superalloy substrates ($60 \times 40 \times 4\,mm^3$) were grit blasted

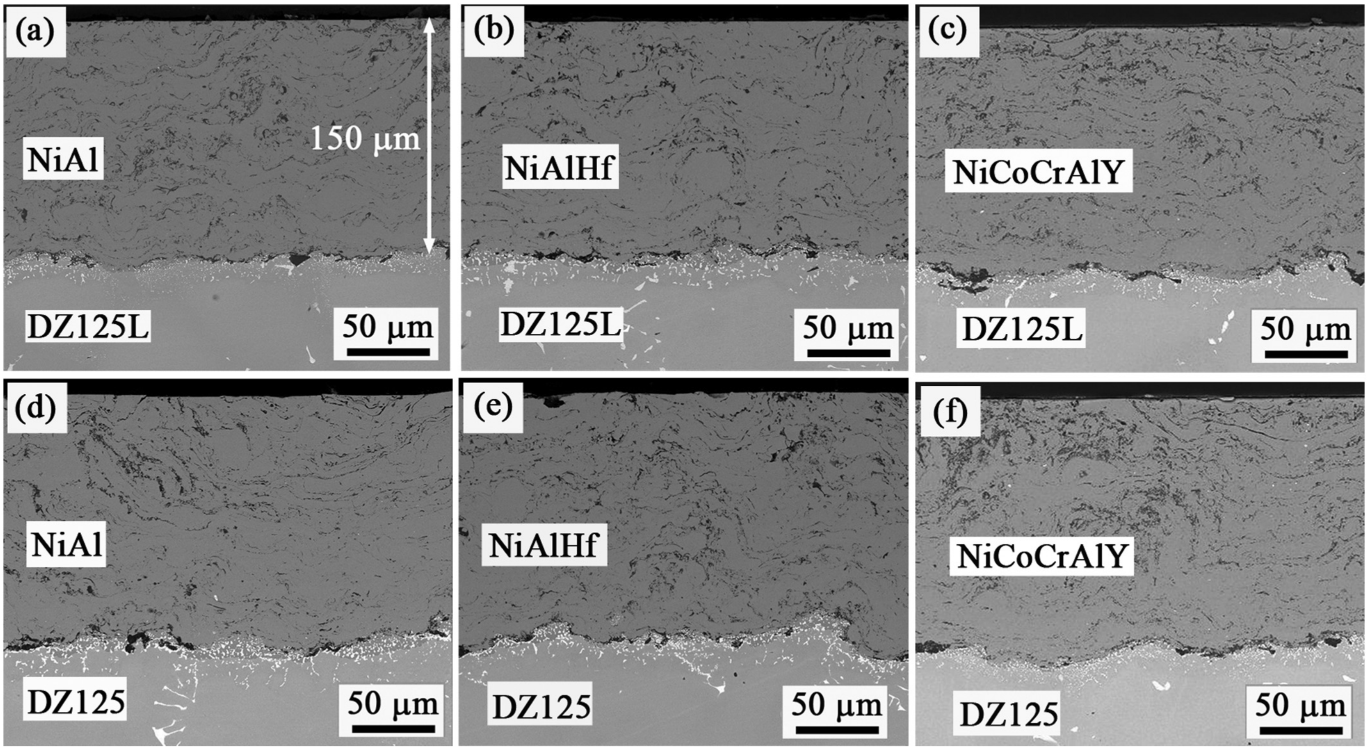

Fig. 1. The microstructures of the as-received samples after vacuum annealing: (a–c) NiAl, NiAlHf and NiCoCrAlY bond coats deposited on DZ125L, respectively; (d–f) NiAl, NiAlHf and NiCoCrAlY bond coats deposited on DZ125, respectively.

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