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Original research

Microstructural evolution and growth kinetics of thermally grown oxides in plasma sprayed thermal barrier coatings

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Abstract

The formation of thermally grown oxide (TGO) during high temperature is a key factor to the degradation of thermal barrier coatings (TBCs) applied on hot section components. In the present study both the CoNiCrAlY bond coat and ZrO_2-8 wt.% Y_2O_3 (8YSZ) ceramic coat of TBCs were prepared by air plasma spraying (APS). The composition and microstructure of TGO in TBCs were investigated using scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) analysis. The growth rate of TGO for TBC and pure BC were gained after isothermal oxidation at 1100 °C for various times. The results showed that as-sprayed bond coat consisted of β and γ/γ′phases, β phase reducesd as the oxidation time increased. The TGO comprised α-Al_2O_3 formed in the first 2 h. CoO, NiO, Cr_2O_3 and spinel oxides appeared after 20 h of oxidation. Contents of CoO and NiO reduced while that of Cr_2O_3 and spinel oxides increased in the later oxidation stage. The TGO eventually consisted of a sub-Al_2O_3 layer with columnar microstructure and the upper porous CS clusters. The TGO growth kinetics for two kinds of samples followed parabolic laws, with oxidation rate constant of 0.344 μm/h$^{0.5}$ for TBCs and 0.354 μm/h$^{0.5}$ for pure BCs.

Keywords: Thermal barrier coatings (TBCs); Air plasma spraying (APS); CoNiCrAlY; YSZ ceramic coat; Isothermal oxidation; Oxidation rate

1. Introduction

Thermal barrier coatings (TBCs) comprising at least a metallic bond coat (BC) and a ceramic top coat (TC) are widely used in aeroengines for propulsion and power generation to protect the metallic components from the aggressive environment at elevated temperatures. The bond coat (75–150 μm in thickness) typically made of MCrAlY (M is Ni or/and Co) alloy is deposited onto Ni-based alloy followed by ceramic coat (100–500 μm in thickness), which not only improves the compatibility of ceramic coat and superalloy substrates but provides oxidation resistance of the metal substrate [1–3]. A thermally grown oxide (TGO), predominantly alumina, will inevitably form between TC and BC under high temperature condition [2,4]. As a reaction product, TGO can protect the substrate from further oxidation to some extent, while the excessive growth of TGO during thermal exposure is detrimental for TBCs' lifetime [5,6]. Thus, the TGO formation and subsequent thickening, as the crucial factors controlling TBCs' durability [2,3,7], are of significant importance in the TBCs.

Chemical composition and growth process of TGO are crucial factors for the failure of TBCs. α-Al_2O_3, usually with columnar morphology in nature [8], is the preferred oxide developed at the BC/TC interface due to its chemical stability, better adherence to bond coat and lower standard free energies of formation than others [6]. For a MCrAlY-type bond coat, the primary resource of Al to form Al_2O_3 is from the β-CoAl (NiAl) phase within the bond coat, related details about this can be found elsewhere [1,7,9–11]. As the concentration of aluminum decreases, other oxides including NiO, Cr_2O_3 or spinel-type oxides will form in the TGO, the growth of these detrimental oxides can result in the uniformity of the TGO layer as a whole [12,13]. Nath et al. [14] deposited NiCrAlY bond coat and 8YSZ top coat by APS process, the results of isothermal oxidization at 900 °C and 1000 °C show that the

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formation of oxide scales composed of Al_2O_3, CoO, Cr_2O_3 and spinel oxides, without the existence of NiO at the whole stage.

The TGO growth kinetics, can be equally complex, usually have been quantified by measuring the specific change of sample weight or TGO thickness during thermal exposure at elevated temperatures [10,14–18]. Jackson et al. [16] used EB-PVD process to deposit NiCoCrAlY bond coat and YSZ top coat, the results of TGO growth kinetics after oxidation at 950 °C, 1050 °C and 1100 °C follow a general expression of subparabolic equation, the result is also available in other literatures [19–21], Poza et al. [18] deposited NiCoCrAlY bond coat and YSZ top coat by APS process, suggesting that TGO growth follows a power law in the samples treated at 950 °C but two different power laws fit the TGO growth for different stages of oxidation at 1050 °C.

Thus, even though considerable works have been devoted to understanding the oxidation behavior of MCrAlY bond coat, only a few literatures concern the detailed phase composition and microstructural investigations of TGO in APS TBCs systematically after isothermal oxidation. Furthermore, the previous results of TGO growth kinetics are various. For this reason, the aim of this paper is to deeply evaluate microstructural evolution of TGO and the oxidation kinetics of an air plasma sprayed 8YSZ/CoNiCrAlY TBC developed on Inconel 718 substrate after isothermal oxidation, using a combination of optical microscope (OM), X-ray diffraction (XRD) and scanning electron microscopy (SEM) equiped with energy dispersive spectroscopy (EDS). The microstructural evolution of APS TBC will explain the nature of the observed oxidation kinetics.

2. Experimental

2.1. Materials

Co32Ni21Cr8A0.5Y (wt.%) (Amdry 995C, Sulzer Metco Inc., US) and 8 wt.% yttria stabilized zirconia (8YSZ) (Metco 204B-NS, Sulzer Metco Inc., US) powders were used to deposit the bond coat and the top coat, respectively. Fig. 1 shows the surface morphologies of CoNiCrAlY (Fig. 1a) and 8YSZ powders (Fig. 1b). The particle size distribution for CoNiCrAlY powders was 45–90 µm, and that of 8YSZ powders was 45–75 µm. The composition of 8YSZ powders and CoNiCrAlY powders are shown in Tables 1 and 2, respectively. Nickel-based superalloy, Inconel 718, was used as substrate (S).

2.2. Sample preparation

Air plasma spraying device (APS-2000, Beijing Aeronautical Manufacturing Technology Research Institute, China) was applied to deposit bond coat followed by ceramic coat onto the sand blasted substrate with the size of 110 × 11 × 4 mm^3. The plasma gun moved in a “rastered” mode across the stationary substrates, in each passage depositing a thin layer of molten material (about 15 µm). The specific deposition parameters are presented in Table 3. The substrate temperature was cooled down by air jets during the spraying process.

2.3. Oxidation experiments

Isothermal oxidation was performed in static air in a box-type resistance furnace (KSL-1700X-S) which has a maximum operating temperature of 1700 °C. Some of TBC and pure BC samples were oxidized at 1100 °C for 2 h, 5 h, 10 h, 20 h, 50 h, 100 h, 200 h and 350 h, respectively, then the samples were removed from the furnace after the furnace cools to ambient temperature. Both heating and cooling rate were set at 8 °C/min during the isothermal oxidation test. Samples with the size of 11 × 11 × 4 mm^3 were cut from the oxidized and as-sprayed samples with a metallographic cutting wheel. Ceramic sides of two samples were glued together to ensure a flat surface, cross-sectional samples were then grinded with SiC abrasive paper and mechanically finished with abrasive diamond sand up to 0.5 µm. Care was taken to employ applicable polishing times and pressures to minimize the excessive removal of any weakly bonded regions of the

Table 1
Composition of 8 wt.% yttria stabilized zirconia powders.

Composition	ZrO_2	Y_2O_3	HfO_2	T.A.O	TiO_2	MgO	Moisture
Content (wt%)	Balance	7.46	1.64	0.11	0.10	0.02	0.04

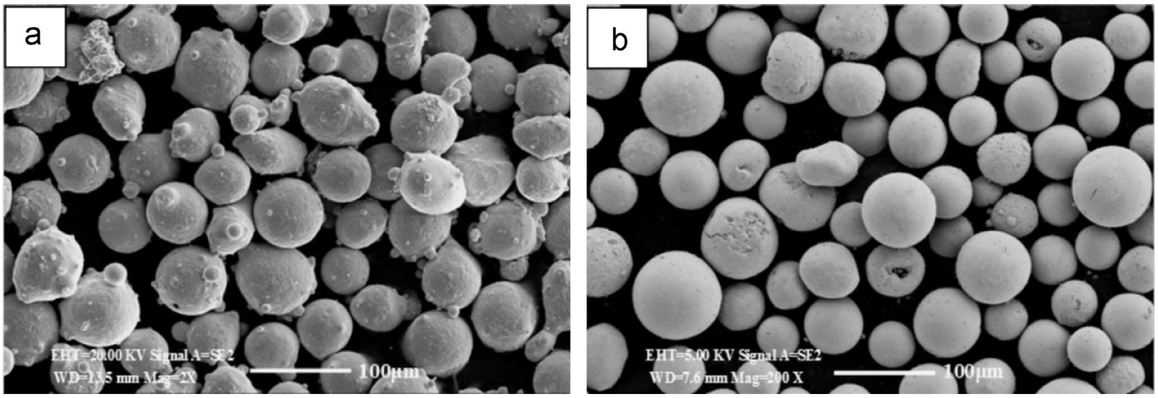

Fig. 1. Surface morphology of the CoNiCrAlY powders (a) and 8YSZ powders (b).