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Deposition and properties of a multilayered thermal barrier coating

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ABSTRACT

The widely used air plasma sprayed thermal barrier coatings (TBCs) in industrial gas turbine engines are limited by its durability. The failure of plasma sprayed TBCs in thermal cycling is usually induced by the spallation of ceramic coating within the ceramic coating near the top coat/bond coat interface. In this research, a multilayered ceramic coating architecture is introduced comprised of the layers of segmentation cracks, porous and dense. The segmented yttria stabilized zirconia (YSZ) layer was deposited at the substrate temperature of 750 °C without any artificial cooling, which resulted in the formation of YSZ layer with obvious columnar crystal structure and segmentation cracks. And a dense top YSZ layer was also included on the top to restrain the penetration of oxygen and the molten calcium–magnesium–alumina-silicate (CMAS) glass deposits. Additionally, the conventional porous YSZ coating was preserved in order to get the low thermal conductivity. The thermal cycling tests show that the lifetime of the multilayered TBCs increases by a factor of 2 compared with that of the conventional one, which could attribute to the high strain tolerance and fracture toughness of the segmented and columnar microstructure. Oxidation resistance and CMAS corrosion resistance are also better for the multilayered TBCs compared with that of the conventional one, due to the suppression function of dense top YSZ layer. It is potential to obtain the high performance TBCs by adjusting plasma spraying.

1. Introduction

In order to get high thrust-weight ratio and combustion efficiency, the working temperature of gas turbine has been increased constantly. With the application of thermal barrier coatings, the superalloy can be used close to its melting point [1]. The typical thermal barrier coating system includes a superalloy substrate, a metallic bond coat and brittle ceramic top coating. However, under the high temperature working condition, the metallic bond coat is easy to be oxidized, forming the thermal grown oxide (TGO) around the interface between the bond coat (BC) and the top coat (TC). There are several methods to deposit thermal barrier coatings, such as air plasma spraying (APS) and electrical beam-physical vapor deposition (EB-PVD), etc. APS process seems to be more attractive commercially for its low production cost and versatility [1–4]. Previous works mentioned that the finally failure position of APS TBCs is around the TC/TGO/BC interfaces driven by the out-of-plane stresses [1,5–7]. Additionally, some researchers also observed that before the spalling around the TC/BC interface, the cracking failure in ceramic coating has already occurred [8–10]. Therefore, in order to increase the service life of TBC, the top ceramic coatings should be paid more attention.

It has been reported that APS ceramic coating is generally of a lamellar structure, with a large amount of non-bonded lamellar interfaces exist between the lamella. And the influences of non-bonded interfaces on the properties of TBCs, such as the mechanical properties, electric properties and thermal stability have been studied, which shows the controlling role of bonding ratio of coatings [11–13]. It is pointed out that the lamellar structured plasma-sprayed ceramic coating has low compliance between the ceramic coating and substrate compared with the columnar crystal EB-PVD TBCs [14]. However, the distributing direction of non-bonded interface in APS TBCs is different from those in EB-PVD TBCs. A previous work has reported that segmented ceramic coating in APS TBCs leads to an improved in-plane tensile strength during the thermal cycles, due to the opening of vertical cracks to compensate the mismatch between different material systems [15,16]. Specifically, these segmentation cracks will open under tension and close up under compression, which is the key to preserve the integrity of TBC system [17]. While the dense microstructure in the segmented TBCs will increase its thermal conductivity, it is undesirable for the thermal insulation function [18,19].

The inward diffusion of oxygen through the porous ceramic coating towards the bond coat is the important oxidation mechanisms for APS TBCs. Many investigators reported that the formation of the brittle and damaging oxides will accelerate the cracking behavior of ceramic coating and lead to premature failure, with volumetric expansion and

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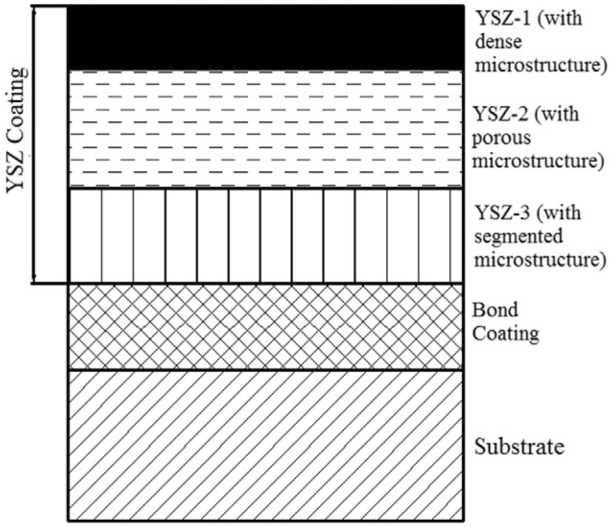

Fig. 1. A schematic diagram of the structure of the proposed multilayered TBCs.

Table 2
Original compositions of CMAS.

Composition	SiO_2	$CaCO_3$	MgO	Al_2O_3	Na_2CO_3	K_2CO_3	Fe_2O_3
wt.%	42.4	44.7	2.4	4.8	1.2	1.7	2.8

worsen mismatch by TGO growth [20–21]. The dense layer can prevent the penetration of oxygen in terms of physics. At the meantime, with working temperature increasing, the calcium–magnesium–alumina-silicate (CMAS) problem can't be neglected. Evans et al. [22] mentioned that the degradation mechanism of CMAS is its penetration into the TBC, changing the mechanical properties and chemical stability of YSZ coatings. The dense layer designed in the present multilayered TBCs is also expected to play a role in restraining CMAS erosion.

In order to obtain good performance under these serious working conditions, some multilayered TBC architectures have been tried in the previous researches [14,23]. They tried to increase the thermal cycling life of TBCs by changing the porosity of the double-layered top-coat. It is pointed out that the dense vertically cracked coatings show high toughness and high thermal cycles compared with those dense coating without segmentation cracks [23]. Therefore, in this study a multilayered TBC architecture (shown in Fig. 1) is provided, including the dense layer and segmented layer. Considering the thermal insulting function, the porous layer is settled between the two layers to guarantee the low thermal conductivity of TBCs. Thermal cycling test, oxidation experiment and CMAS test were employed to compare the corresponding properties of multilayer TBCs with the conventional TBCs.

2. Experimental procedure

2.1. Design of the spraying parameters for multilayered TBCs

YSZ coatings were applied on grit blasted IN738 substrates in a disk shape with the dimensions of Ø 25.4 μm × 3 μm. The spray powder for all the bond coats is NiCrAlY (−74–+44 μm, Sunspraying Inc., Beijing, China). Both the ceramic coating and bond coat were sprayed using a commercially APS system (APS-2000, Beijing Aeronautical Manufacturing Technology Research Institute). In this spraying system, argon is used as the primary plasma operating gas and hydrogen is selected as an auxiliary gas. During all the spraying procedure, the pressure of argon and hydrogen is fixed at 0.4 MPa and 0.25 MPa, respectively.

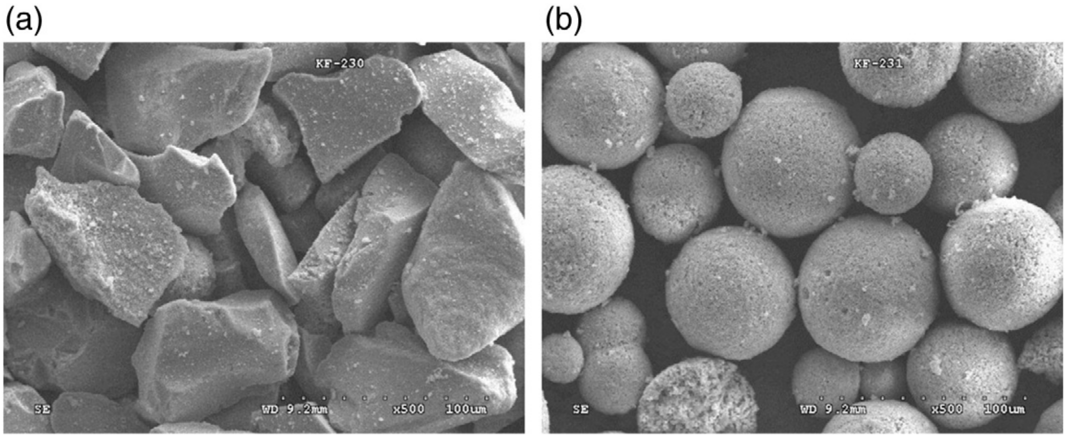

Fig. 2. Morphologies of 8YSZ powders employed for the deposition of YSZ coatings. (a) fuse-crushed 8YSZ with an irregular morphology; (b) 8YSZ with a spherical morphology.

Table 1
Plasma spray parameters for three YSZ layers in multilayer TBCs.

Spraying parameters	YSZ-3	YSZ-2	YSZ-1
Current/A	600	600	600
Voltage/V	65	60	65
Pressure of primary gas/MPa	0.25	0.25	0.25
Pressure of secondary gas/MPa	0.4	0.4	0.4
Spraying distance/mm	80	85	80
Powder feeding rate/g/min	~15	~10	~12
Preheating temperature/°C	750	200–300	750
Cooling condition	No extra cooling	Compressed air	Compressed air
Thickness/μm	~100	~120	~50