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Featured Letter

Gradient $La_2Ce_2O_7$/YSZ thermal barrier coatings tailored by synchronous dual powder feeding system

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ABSTRACT

Progress in the design and fabrication of thermal barrier coating (TBC) is strongly dependent on the application of new materials and deposition methods. In this work, one novel and efficient plasma spraying method was employed to deposit a $La_2Ce_2O_7$ (LC)/YSZ gradient TBC using a synchronous dual powder feeding system, in which the melting state and feeding rate of LC or YSZ feedstock powder can be precisely controlled. The experimental and simulation results suggested that the as-sprayed LC/YSZ TBC presented an obvious gradient change along the coating thickness direction. The heat insulation temperature and thermal cycling property of gradient TBC were greatly improved compared to its double-layer-structured counterpart due to the increased interfaces and deflection of fatigue cracks resulted from the gradient structure.

1. Introduction

High-performance thermal barrier coating (TBC) system is required for the long life and high efficiency of next-generation aero engines. Functionally graded TBC, which produces a more gradual transition in properties along the coating thickness direction, can effectively avoid the sudden change of properties in the traditional monolithic ceramic TBC system and thereby significantly enhance its resistance to the spallation failure [1,2].

Progress in the design and preparation of TBC is based upon the application of new materials and deposition techniques. As one of promising TBC candidates, $La_2Ce_2O_7$ (LC) has attracted increasing attention because of its low thermal conductivity and potential capability to be operated above 1200 °C [3]. Additionally, compared to the standard TBC material yttria-stabilized zirconia (YSZ), LC has a higher corrosion resistance to the molten CaO-MgO-Al_2O_3-SiO_2 (CMAS) [4]. However, the thermal cycling incapability of LC as a single layer has restricted its application as a sole TBC material, the bi-layered or functionally graded LC/YSZ coating shows not only much longer than that of the single layer LC coating, but also longer than that of the single layer YSZ coating.

Up to now, most of functionally graded TBC systems are obtained by pre-mixed the composite powders [1,5,6]. However, it is not easy to control the spray parameters to form a uniform coating layers as the two types of starting powders usually have different densities, sizes, morphologies, melting points and flowability. In this work, the gradient LC/YSZ TBC was deposited by a new supersonic atmospheric plasma spray (SAPS) method with a synchronous dual powder feeding system, in which the high melting point material (YSZ) and the relatively low melting point material (LC) were injected to the different regions of plasma jet in order to obtain the best melting state respectively and avoid the overmelting of LC and semi-melting of YSZ.

2. Material and methods

An agglomerated $La_2Ce_2O_7$ (LC) powder (Fig. 1a) and a commercial 8 wt% YSZ (Sang Yao Technical Co., Ltd., China) powder (Fig. 1b) are employed as ceramic top coat materials. Bond coat material is CoNiCrAlY (4454, Sulzer Metco Inc., USA). Nickel-based superalloy Inconel738 with 30 mm in diameter and 6 mm in thickness is utilized as substrate material. A high efficiency supersonic atmospheric plasma spraying (SAPS) technique equipped with a synchronous dual powder feeding system is used to deposit the gradient LC/YSZ coating. Two independently controlled powder feeders are utilized to spray the gradient coating by adjusting the feeding rate of YSZ and LC in a proper ratio (listed in Table 1), respectively. As seen from Fig. 1c, two powders with different melting points can be simultaneously injected into the plasma jet

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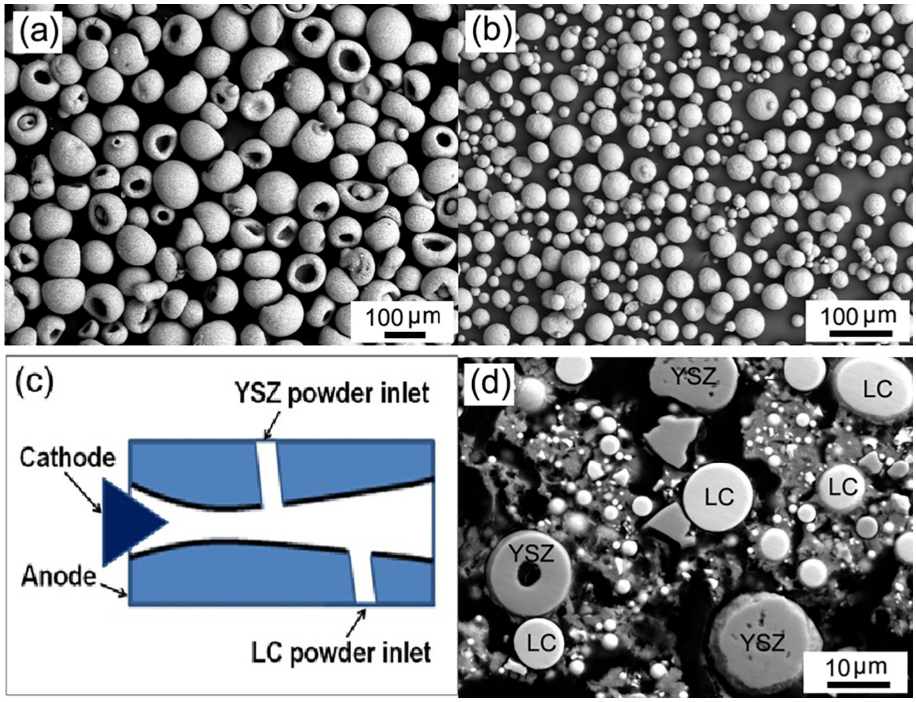

Fig. 1. Original (a) LC and (b) YSZ feedstock powder, (c) synchronous dual powder inlets and (d) collected LC or YSZ particles in distilled water.

Table 1
Spray parameters of gradient LC/YSZ coating.

Layer	Primary gas Ar (slpm)	Secondary gas H_2 (slpm)	Current (A)	Voltage (V)	Stand-off distance (mm)	YSZ feed rate (g min^{-1})	LC feed rate (g min^{-1})	Thickness (μm)
Layer a	90	20	400	120	90	41	0	70
Layer b						30	14	70
Layer c						24	22	70
Layer d						19	29	70
Layer e						0	36	50

through two types of inlets that arranged in different axial positions of the Laval nozzle. This technique is obviously better than the current other deposition methods, where the gradient coatings are fabricated by mixing the powders directly before deposition or by injecting them into two inlets at the same axial position of the nozzle [6,7].Therefore, the melting state or feed rate of the powders cannot be well controlled in these methods due to their different melting points.

The surface temperature of in-flight particles obtained by Spray Watch 2i (Osier, Finland) in YSZ inlet or LC inlet is 3150 ± 4 °C or 2910 ± 3 °C, respectively. Fig. 1d shows the cross-sectional morphologies of LC and YSZ particles collected in a container filled with distilled water through this novel system, both of them exhibit a good melting state.

The microstructures of samples are observed by scanning electron microscope (SEM, TESCAN-VEGAII XUM) equipped with an energy-dispersive X-ray spectroscopy (EDX). Vickers microhardness of the coating is tested by a micro-hardness tester (MICROMETS104, Buehler, USA) with a load of 2.94 N and a holding time of 10 s. Fracture toughness (K_{IC}) of the gradient coating is calculated by the following equation [8]:

$$K_{IC} = 2 \times 0.0319 \frac{P}{a\sqrt{L}} \tag{1}$$

where P is the indentation load, a is the half of the average length of two indents diagonal and L is the total radial and edge crack length.

Thermal cycling property test of TBCs is conducted by a burner rig apparatus with propane-oxygen as the combustion gases. The surface of the sample is heated to 1225 ± 25 °C in 50 s and more detailed information about the thermal cycling test can be found in our previous work [9].

3. Results and discussion

Fig. 2 shows the cross-sectional morphologies and EDX results of the gradient LC/YSZ coating deposited by the synchronous dual powder feeding system. The YSZ and LC phase are apparently distinguished by dark and light color, respectively. EDX line scan analysis (see Fig. 2) from the top to the bottom exhibits a gradient increase of Zr content and a gradual decline of La or Ce content, suggesting a gradient change along the coating thickness direction uniformly.

Fig. 3a and b show the cross-sectional morphologies of double-layer-structured LC/YSZ coating after 693 thermal cycles and gradient one after 896 cycles, respectively. The vertical crack initiates at the top surface of LC layer, and then propagates along the thickness direction in the double-layer-structured coating (see Fig. 3a). In the gradient coating, a large interfacial strain field forms between LC and YSZ phase due to the interface mismatch and their different mechanical performance. When crack tip reaches the strain field, the stress concentration elevates further in the interface, and crack propagates along the weak grain boundaries, resulting in crack deflection (see Fig. 3c) [10]. The occurrence of crack deflection dissipates energy at crack tip and diminishes the driving force for further propagation of crack , thus improving the fracture toughness