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SiC fiber and yttria-stabilized zirconia composite thick thermal barrier coatings fabricated by plasma spray

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ABSTRACT

Approximately 4 mm-thick SiC fiber/yttria-stabilized zirconia (YSZ) composite thermal barrier coatings (TBCs) were prepared by atmospheric plasma spray (APS). The composite coatings have a 'reinforced concrete frame structure', which can protect the coating from failure caused by increasing thickness of coating. The SiC fiber plays an important role in reducing the residual stress level of the composite coatings. The thermal conductivity (TC) value of the composite coatings is 0.632 W/m K, which is about 50% reduction compared to that of typical APS YSZ TBCs. And the composite coatings have higher fracture toughness and better thermal shock resistance than the YSZ TBCs.

1. Introduction

TBCs have been widely used for turbine and aerial craft to protect components from high temperature environment [1–3]. At present, most of the commercial TBCs are made of YSZ because of its relatively high expansion coefficient and fracture toughness [4–8]. To enhance the energy efficiency of the systems, the operating temperature is increased to above current system limit temperature, which requires a decrease of TC and an increase of TBCs' thickness.

Reduced TC can increase component durability and thermodynamic efficiency. Some researches have shown that rare earth elements and YSZ composite TBCs have lower TC. But the composite coatings are more expensive, and its fracture toughness was always low. As a result, only one of the composite coatings is in commercial use [5,6].

The research shows that the cooling effectiveness could be improved by the use of thicker TBCs. The increase of coating thickness reduces the surface temperature of the cooled components in gas turbine engines at the rate of 4–9 K per 25.4 μm [7]. When the thickness of TBCs is 1.5 mm, compared with a 0.25–0.35 mm thick TBCs, it can reduce the amount of cooling air required by hot components to 60%. That means achieving 0.5% more engine efficiency [8,9]. However, when the thickness of TBCs is increased above 1.5 mm, the TBCs spontaneously fail during preparation or in service [9]. The increased thickness of coating will increase the elastic strain energy and hence the crack of coatings will increase for energy release [8–11], and further caused the spalling failure of the TBCs.

The objective of the present study is to explore the use of the APS for manufacturing multilayer SiC fiber/YSZ composite thick TBCs in a tube component. Premixed perlite and YSZ composite powders (P7216) are used as the transition layer to improve the wettability between SiC fiber and YSZ. The microstructure and residual stress of the composite TBCs, particularly transition layer of SiC fiber/YSZ and top-coating, are examined. And the performance comparison between SiC fiber/YSZ TBCs and YSZ TBCs were studied.

2. Experimental procedure

2.1. Powders preparation

In the process of P7216 suspension preparation, 8 mol% sub-micron YSZ (average particle size of ~200 nm) and perlite powders were dispersed in an aqueous solution, its solids content is about 50%. The resulted suspension was stirred for at least 2 h to uniformly disperse the perlite and YSZ. The suspension was then milled using a high shear mode on a colloid mill. The pump speed was fixed at 2900 rpm. The milling processing continued for 2–3 h until particles in the desired size range (diameter of less than 0.5 μm).

Spray drying granulation of the suspension was performed by using a high-speed centrifugal spray drier. Granulation was carried out using the following process parameters in the top spray mode: Inlet stream temperature of 473 K, outlet stream temperature of

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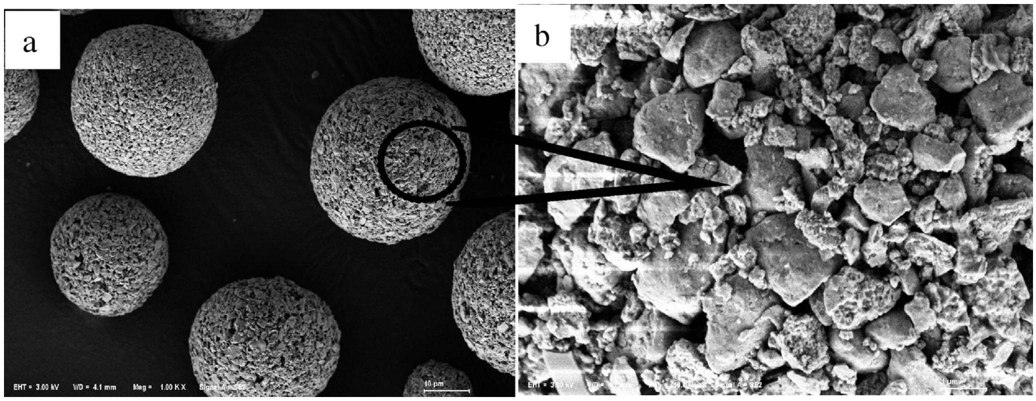

Fig. 1. SEM micrographs of the P7216 powders with different magnification factor. (a) 1k and (b) 10k.

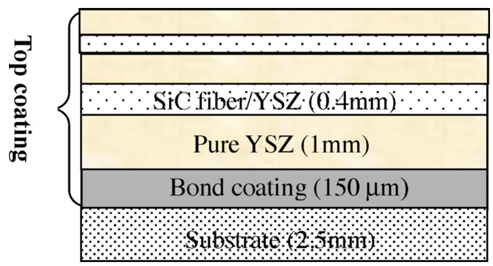

Fig. 2. Schematic illustration of SiC fiber/YSZ composite TBCs (approximate value).

343 K and the feed pump rate of 300 rpm. The P7216 powders between 45 and 63 μm was collected as the thermal sprayed feedstock, and the feedstock was dried in an oven at 393 K for 2 h. The P7216 with a chemical composition of 10perlite-90YSZ (in wt.%) were used to deposit the SiC fiber/YSZ layer. The scanning electron microscope (SEM) observation of the P7216 is shown in Fig. 1. The powders used have an almost spherical shape with agglomerates structure. An 8 mol% YSZ agglomerated powders were prepared using the same process.

2.2. Preparation of coatings

All coatings were prepared by plasma spray (APS-3000, China National Aviation Corp, CHINA). Before spraying, the stainless tube (Ø 60 mm × 2.5 mm) substrates were immersed in the ethanol for ultrasonic cleaning with the dwell time 15 min. After taking out the substrates, the substrates were then degreased and grit blasted with brown corundum in order to increase the bonding strength. Then the 8 mol% YSZ agglomerated powder, NiCoCrAlY, the P7216 powders were deposited onto the substrates in turn and the SiC fiber/YSZ composite TBCs can be fabricated. The thermal spray parameters are shown in Table 1.

The as-deposited approximately 4 mm-thick SiC fiber/YSZ composite TBCs system was cut into adequate size, then the specimen were polished and dipped into 50 wt.% ferric chloride to etch substrate. The schematic of composite coatings were illustrated in Fig. 2, the top coating is multilayer structure, which is composed of darker SiC fiber/YSZ layer and pure YSZ layer. Fig. 3(a) shows the composite coatings macro sectional view of axial direction along the cylinder. The darker SiC fiber/YSZ composite layer has obvious black breakpoint fiber cross-section. Fig. 3(b) shows the morphology for the coatings sectional view of axial direction along the cylinder. Raman peak shift measurement and X-ray diffraction (XRD) strain measurement were used to measure residual stress of TBCs. The TC and morphology of TBCs were detected by laser flash thermal analyzer and SEM, respectively.

Approximately 1.5 mm-thick pure YSZ TBCs were fabricated by the same process. Then the coating specimen was used to compare the fracture toughness and the thermal shock of the SiC fiber/YSZ composite coatings.

Table 1
The product conditions of plasma spraying.

Spraying condition	YSZ	P7216	NiCoCrAlY
Working current, A	500	450	400
Ar gas flow rate, L/min	0.55	0.5	0.5
N_2 gas flow rate, L/min	0.3	0.3	0.3
Powder feed rate, g/min	15	20	10
Spray distance, mm	80	85	120
H_2 gas flow rate, L/min	0.15	0.075	0

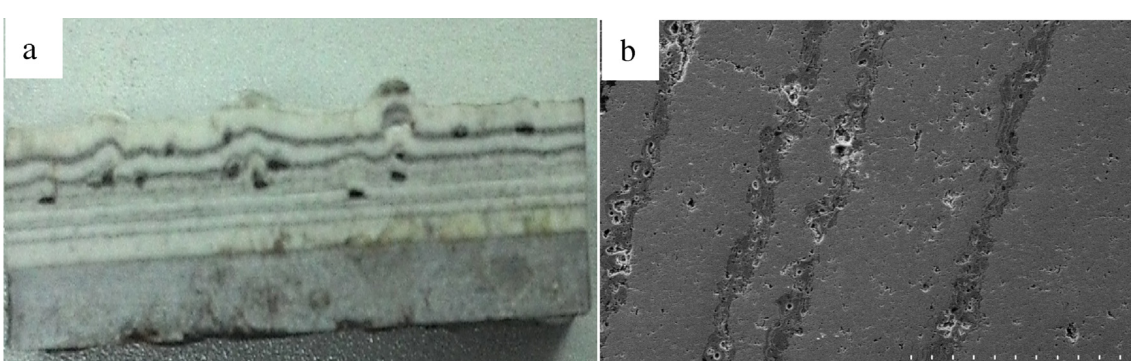

Fig. 3. The cross-section of composite TBCs systems: (a) digital camera and (b) SEM.