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Mechanisms governing the thermal shock and tensile fracture of PS-PVD 7YSZ TBC

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ABSTRACT

Thermal barrier coating (TBC) system including NiCoCrAlYTa metallic bond coating and 7YSZ (7 wt%Y_2O_3-ZrO_2) ceramic top coating was deposited on nickel-based superalloy by plasma spray-physical vapor deposition (PS-PVD). Thermal shock property of 7YSZ TBC was characterized by water-quenching test at 1100 °C and its failure behaviors were investigated in detail. Besides, tensile test was performed for TBC sample and its cross-sectional fracture microstructure was studied as well. The results showed that after water-quenching test lots of pitting spallation took place in TBC surface, but no obvious microcracks were observed. Additionally, the tensile test indicated that fracture occurred in 7YSZ coating near the interface of ceramic-bond coating. After conduction of water-quenching and tensile testing, a lot of spherical particles and nano-sized agglomerated clusters were observed in the quasi-columnar structured 7YSZ coating. These lead to the formation of weak inter-column bonding and the failure of PS-PVD 7YSZ TBC. Moreover, in order to better understand the failure process, a deposition mechanism of coating was proposed.

1. Introduction

The use of thermal barrier coating (TBC), generally consisting of a ZrO_2-7 to 8 wt% Y_2O_3 (7-8YSZ) ceramic coating, a metallic bond coating and a superalloy substrate, has provided significant improvements in durability and efficiency of gas turbine engines [1,2]. Typically TBC was made by atmospheric plasma spraying (APS) and electron beam-physical vapor deposition (EB-PVD) [3,4]. But recently, a novel technology plasma spray-physical vapor deposition (PS-PVD) was proposed, named for vapor phase deposition through using plasma spray [5–7]. When the working pressure of PS-PVD is controlled at 50–200 Pa, the plasma jet is less cooled and decelerated, which results in a plasma jet more than 2000 mm in length and a diameter ranging from 200 mm to 400 mm [8]. Thus, PS-PVD has been developed for deposition of thin and uniform functional coatings. With electric input power improved up to 180 kW, the feedstock material can be evaporated so that coating deposition mainly comes from vapor phase [9,10]. The high velocity vapor phase of feedstock provides opportunities for non-line-of-sight deposition, featured with high quality feather-like columnar structured coating not only on the front side of substrate but also on the shadowed parts for substrates, which makes it a very good method to prepare TBC of multi-blades in turbine engine.

Conventional APS and EB-PVD TBC, YSZ ceramic coating fails by the spallation of the YSZ coating at or near the interface of ceramic-bond coating during thermal cycling or tensile test, which means that the interface of ceramic-bond coating has weak combination in the TBC system [11–13]. In thermal shock like water-quenching test, TGO (thermal grown oxide) formation of metallic bond coating and CTE (coefficient of thermal expansion) mismatch between ceramic and bond coating are the mainly two factors resulting in spallation failure [14,15].

Regarding to the deposition mechanism of coating, PS-PVD differs from APS and EB-PVD. The APS TBC has a typical laminar structure based on molten, semi-molten and un-melted particles deposition [16]. The EB-PVD TBC has a columnar structure deposited by vapor particles [17]. However, in the PS-PVD, through adjustable parameters, the injected powders can be melted or evaporated forming variable coating structures including dense lamellae, hybrid structure as well as quasi-columnar coating, where the quasi-columnar coating has similar property to the EB-PVD TBC [18,19]. It is noteworthy that in the quasi-columnar coating of PS-PVD mainly depending on vapor phase deposition, lots of spherical particles and clusters can be observed [19], leading to the failure mechanism (such as thermal cycling and tensile test) of PS-PVD TBC that has its particularity in thermal shock and

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Table 1
Parameters of NiCoCrAlYTa and 7YSZ coating prepared by PS-PVD.

Net power (kW)	Current (A)	Ar (slpm)	N_2 (slpm)	H_2 (slpm)	Feed rate (g/min)	Stand-off distance (mm)	Chamber pressure (mbar)
46	1650	110	0	6	20	350	40
57	2600	35	60	0	18	900	1.5

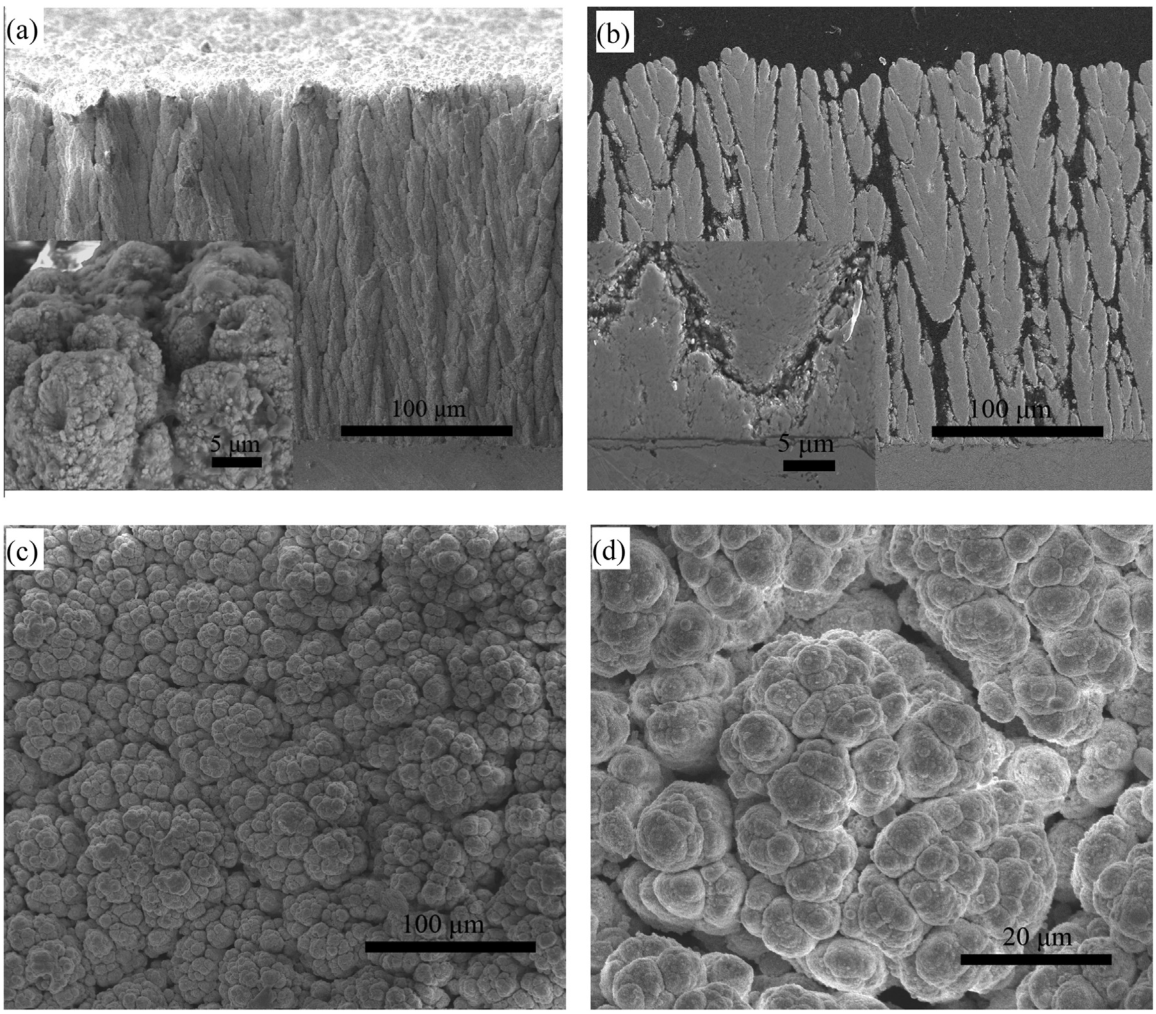

Fig. 1. Cross-section and surface morphologies of 7YSZ coating, (a) as-sprayed cross-section, (b) polished cross-section, (c) low magnified surface, (d) high magnified surface.

tensile fracture compared with EB-PVD. Therefore, in order to better understand the failure mechanism, the deposition mechanism of 7YSZ coating needs to be further investigated.

2. Experimental procedures

2.1. TBC preparation

The facility used in the experimental is PS-PVD Multicoat system (Oerlikon Metco) was obtained by the reconstruction of a conventional LPPS system. By the addition of a large vacuum blower, the pumping capacity at the PS-PVD working pressures of 50–200 Pa was enhanced, and the electrical input power was up to 180 kW. For PS-PVD operation a modified single cathode O3CP gun was used.

The feedstock material was agglomerated 7YSZ designated as M6700 (Oerlikon Metco). Disks made of superalloy K417, with a diameter of 25.4 mm, were used as substrates and the topside edge of the specimens was rounded. Before the application of TBC, the substrates were coated with a 150 µm thick NiCoCrAlYTa bond coating (Amdry 386, Oerlikon Metco) by using the PS-PVD. The detailed spray parameters are shown in Table 1. With the aim to improve the durability of PS-PVD TBC, the specimens coated with polished bond coating were heated up in the vacuum chamber by the plasma jet to generate α-Al_2O_3 layer on the bond coating. In the pre-heating process, a oxygen flow of 4 slpm was led into the chamber and the specimens surface temperature was controlled around ~1100 °C. During the 7YSZ coating process, an additional oxygen flow of 2 slpm was used to prevent the loss of oxygen in the 7YSZ coating resulted from the reducing condition in the low pressure plasma plume.

2.2. TBC characterization

The microstructure of PS-PVD 7YSZ TBC was characterized by Field Emission-Scanning Electron Microscope (FE-SEM, Nova-Nono430, FEI) and Transmission Electron Microscopy (TEM, Titan Themis 200, FEI) assisted with Focused Ion Beam (FIB, 450S, FEI) milling. Moreover, micrographics of TBC (sample size: 2 × 2 × 2 mm) were observed by 3D X-ray CT (computed tomography, Xradia 510 Versa, ZEISS), where