



Preheating treatment of thermal barrier coatings by supersonic plasma jet



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ABSTRACT

The low thermal cycling life is a big concern for plasma sprayed thermal barrier coatings (TBCs). This paper presents a novel and effective preheating treatment conducted by one supersonic plasma jet, which has been proven to significantly improve the anti-oxidation and thermal shock resistance of TBCs. After preheating treatment, the surface roughness (Ra) of metallic bond coat decreased by nearly 30%, while one dense oxide layer appeared on its surface. This oxide layer effectively suppressed the growth of thermally grown oxides (TGOs), resulted in the improvement of anti-oxidation of TBCs. The results of water-quenching test from 1100 °C into room temperature showed that the thermal cycling life of preheated TBCs reached 846 cycles, approximately 126 cycles higher than their counterparts without preheating.

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1. Introduction

The MCrAlY (M=Ni, Co or both) bond coat plays an important role in the thermal barrier coatings (TBCs) systems, since it enhances the adhesion of the ceramic thermal barrier layer and also provides oxidation and corrosion protection to the substrate metal [1]. During high-temperature oxidation, a thermally grown oxides (TGOs) layer is formed between the metallic bond coat and the ceramic top coat.

Previous results showed that the initial dense oxide scale (mainly refer to Al_2O_3) that formed on the surface of bond coat could effectively inhibit the growth of TGOs during service of TBCs [2]. For this reason, the TBCs were usually pretreated in a vacuum or low-pressure oxygen environment to form a dense oxide scale. However, the size of workpiece is restricted by the chamber volume. Additionally, the high-cost greatly limit the wide application of vacuum pretreatment. Therefore, one more effective pretreatment method with a lower cost is needed to be explored.

The high-efficiency supersonic atmospheric plasma spraying (SAPS) is gaining increasing attention due to its high energy density and high-velocity plasma jet, which is caused by the structural design of spray gun with a Laval nozzle [3]. This supersonic plasma jet is expected to remove the unmelted particles on the surface of bond coat and reduce its surface roughness with a lower cost. In the meantime, one dense oxide scale is assumed to

form on the surface of bond coat. However, the related research is not reported. Hence, in the present work, the supersonic plasma jet is introduced to preheat the bond coat in order to improve the anti-oxidation and thermal shock resistance of TBCs.

2. Experimental

The sizes of substrate (GH4169) for isothermal oxidation and thermal cycling test were $3 \times 15 \times 35 \text{ mm}^3$ and $\Phi 18 \text{ mm} \times 10 \text{ mm}$, respectively. The commercial Co-32Ni-21Cr-8Al-0.43Y (AMDRY 995 M) powder was used for spraying the bond coat. One spray dried and sintered 8 wt% yttria partially stabilized zirconia (YSZ) powder with particle size of 10–45 μm was used to spray the top coat. The top coat (approximately 200 μm) and bond coat (approximately 80 μm) were both deposited by SAPS. Before spraying the top coat, the bond coat was preheated by the spray gun (supersonic plasma jet) for 50 times with an 800 mm/s moving speed. The spray parameters are listed in Table 1.

All the surfaces of isothermal oxidation specimens were covered by the coating. During isothermal oxidation test, specimens were placed in alumina crucibles, and oxidized at 1100 °C and then cooled in air to room temperature at regular intervals for mass measurements (accuracy was 0.1 mg). In thermal cycling test, specimens were pushed into muffle furnace (1100 °C) for 5 min, and then directly quenched into water (20–30 °C). About 10% of the spalled region of the surface of the top coating (quantitatively calculated by Image-Pro Plus software) was adopted as criteria for

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Table 1
Parameters for plasma spraying and preheating.

Parameters	Spraying the bond coat	Spraying the top coat	Preheating the bond coat
Primary gas Ar (slpm)	95	70	70
Second gas H ₂ (slpm)	9.6	22	22
Voltage U (V)	137	140	140
Current I (A)	400	497	497
Powder feed rate (g/min)	35	–	–
Spray distance (mm)	110	–	90
Thickness of coat (μm)	80	200	–

the failure of the coating.

The specimens were observed by scanning electron microscopy (SEM, JSM-7000F, Japan). The surface roughness (R_a) was measured by a Color 3D Laser Scanning Microscope (VK 9510, KEYENCE, Japan). The stress distribution along the bond coat/top coat interface was simulated by finite element code ANSYS (ANSYS Inc., Canonsburgh, PA, USA).

3. Results and discussion

Fig. 1 shows the surface and cross-sectional morphology of as-sprayed coatings with or without preheating. It was clear from Fig. 1a and d that the coating surface was remelted after preheating and the number of unmelted particles was reduced. The surface roughness (R_a) of preheated coating was $20.8 \pm 0.6 \mu\text{m}$, which was lower than $28.7 \pm 1.6 \mu\text{m}$ of the un-preheated coating (decreased by 28%). A detailed view (Fig. 1b and e) indicated that only few island-like particles were scatteredly distributed on the surface of un-preheated coating. However, the island-like particles were connected to each other and formed a dense oxide scale on the surface of preheated coating. Additionally, as seen from Fig. 1c and f, a thin oxide layer appeared at the bond coat/top coat interface of preheated coating. During the preheating process, the

weakly bonded unmelted particles on the bond coat surface were cleared out by the impact of supersonic plasma jet. Meanwhile, the outer surface of bond coat was remelted due to the high temperature of plasma jet. Moreover, some air was entrained into the plasma jet and reacted with the melted alloy, leading to the formation of oxide scale (mainly Al_2O_3).

Fig. 2 depicts the results of isothermal oxidation and thermal cycling of preheated or un-preheated coatings at 1100°C . The oxidation kinetics curves of both coatings exhibited the same growth trend. However, the weight gain rate of preheated coating was significantly lower than that of un-preheated coating. The parabolic rate constant k_p was calculated from the steady-state portions of the weight gain curves [4]:

$$\Delta W = (k_p \cdot t)^{1/2} + C_0 \quad (1)$$

where ΔW is the oxidation weight gain per unit surface area at any time t (s), k_p is the parabolic rate constant, and C_0 is a constant. The values of k_p for the preheated and un-preheated coatings are $4.92 \times 10^{-5} \text{mg}^2 \text{cm}^{-4} \text{s}^{-1}$ and $6.14 \times 10^{-5} \text{mg}^2 \text{cm}^{-4} \text{s}^{-1}$, respectively. The results indicated that the initial dense Al_2O_3 scale that formed during preheating process effectively decreased the oxidation rate of TBCs. As seen from the surface morphology after thermal cycling failure (Fig. 2b), many fine net cracks formed in both coatings. For the un-preheated coating, the obvious spallation was found at the central area of sample (the black area) after 620 cycles. When the thermal cycling reached 720 cycles, the spalled surface area reached 9.8%. However, for the preheated coating, the evident spallation appeared after 738 cycles, and sustained up to 846 cycles, about 9.3% of surface area spalled. Furthermore, the thermal cycling life of preheated coating was approximately 120% higher than the highest experimental value in the previous work where the same test method was used [5].

Fig. 3 shows the cross-sectional morphology of coatings after thermal cycles and the ANSYS simulation result on the stress distribution along the bond coat/top coat interface for different TGOs thicknesses. Cross-sectional microstructural analysis (Fig. 3a) revealed that many chromia, spinel and nickel oxides (CSN) [2] clusters formed on the convex portion of bond coat surface in the un-preheated coating, leading to the nucleation and propagation of cracks along the bond coat/top coat interface. Additionally, the

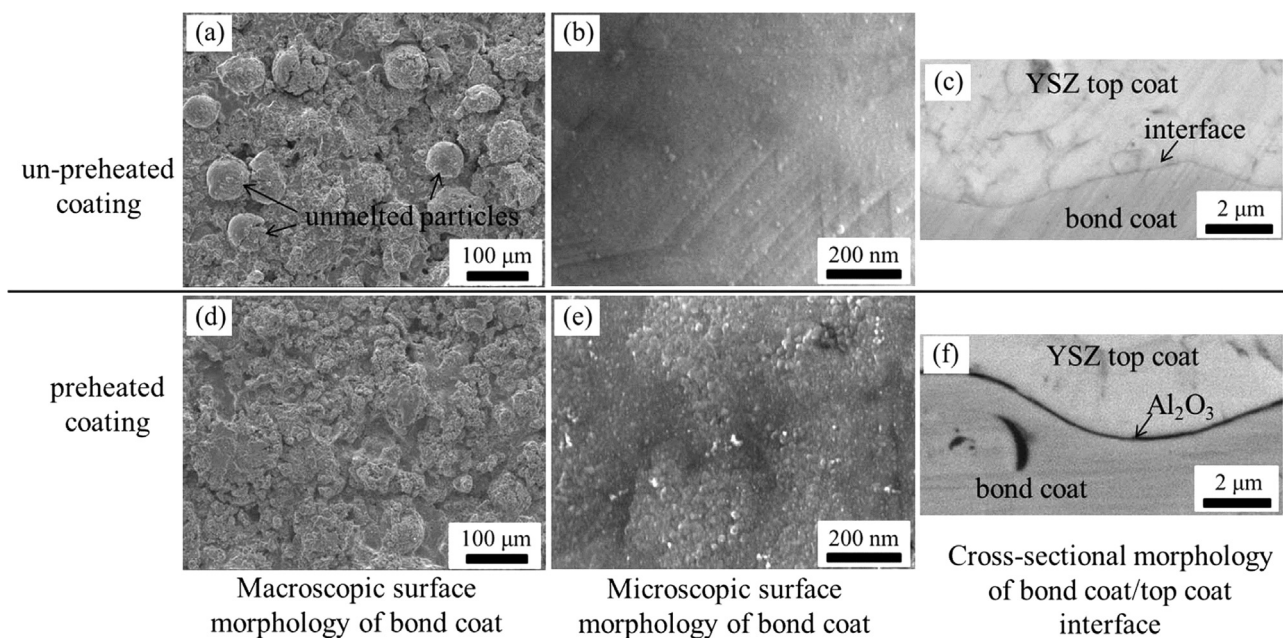


Fig. 1. Surface and cross-sectional morphology of as-sprayed coatings.

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