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Ceramics International 41 (2015) 9972–9979

CERAMICS INTERNATIONAL

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Thermal shock resistance of thermal barrier coatings for nickel-based superalloy by supersonic plasma spraying

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Received 27 February 2015; received in revised form 13 April 2015; accepted 15 April 2015
Available online 23 April 2015

Abstract

Double-layer thermal barrier coatings (TBCs), including a top ZrO_2 layer and an inner CoNiCrAlY layer, were deposited on nickel-based superalloy using supersonic atmospheric plasma spraying (SAPS). Thermal shock resistance of the TBCs between 1200 °C and room temperature was investigated. After thermal shock test, the adhesive strength of the coatings was evaluated through scratch test. The SAPS–TBCs present good thermal shock resistance, exhibiting only 0.26% mass gain up to 150-time thermal cycling. Before thermal cyclic treatment, SAPS–TBCs exhibited a strong adhesion with the absence of the thermally grown oxide (TGO) between out and inner layer. With the increasing of thermal cycles, the TGO layer was formed and its thickness firstly increased and then dropped down. The critical load fell down by about 32% for topcoat–bondcoat adhesion (up to 50 cycles) and 35% or so for TBCs–substrate adhesion (up to 150 cycles) compared to the counterpart of as-sprayed specimens. The strain introduced by the existence of TGO and mixed oxides resulted in a varied adhesion for TBCs on nickel-based alloy during thermal cycling.

Keywords: C. Thermal shock resistance; Thermal barrier coatings; Supersonic atmospheric plasma spray; Adhesion; Thermally grown oxide

1. Introduction

Nickel-based superalloy has been widely used in aviation and navigation field [1–3], and some applications require it to survive in a thermal cyclic environment. For example, the gas turbine often operates from the static environment of nearly room temperature to the working condition above 1000 °C [1]. Some hot-section devices even need to work in a cyclic combustion gas and wind tunnel environment [4,5]. At high temperature, the poor oxidation resistance and relatively short thermal cycling life of nickel-based superalloy limit its further application. Employing thermal barrier coatings (TBCs), by plasma spraying or vapor deposition, is a reliable approach to protect nickel-based superalloy against corrosion and oxidation [1,6].

Owing to high temperature of plasma flame, high efficiency of energy consumption and high impact velocity of in-flight particles [7], supersonic atmospheric plasma spraying (SAPS) exhibits obvious superiority for obtaining coatings with high-quality structure (such as ultrafine columnar crystal grain, compact splat layer, little fraction of pore [8,9]) and preferential performance (including good oxidation resistance and long thermal cycling life) on carbon substrate [10] and metal matrix materials [11] as compared with air plasma spraying(APS) [8]. As for nickel-based superalloy substrate, the TBCs fabricated by SAPS (SAPS–TBCs) exhibit outstanding oxidation resistance against 1100 °C for 1000 h with only 6.8 mg/cm^2 weight gain, about 43% lower than APS TBCs [12]. Up to now, there are few literatures about SAPS–TBCs on nickel-based superalloy. The previous work about TBCs by SAPS concentrated mainly on their oxidation behavior in static air.

As we known, coating performance closely depends on its adhesion to substrate. Therefore, the evolution of the coating adhesion during thermal cycling has a direct relation on its service life. It is reported that TBCs, fabricated by APS [13] and high velocity air–fuel spray (HVAF) [14], shown a

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http://dx.doi.org/10.1016/j.ceramint.2015.04.077
0272-8842/

reducing tendency of bond strength during oxidation duration or thermal cyclic treatment. Unfortunately, previous reports only revealed a qualitative conclusion that the coating spallation could be attributed to a weak adhesion. Little work was focused on the adhesion evolution about SAPS–TBCs during thermal cycling.

Table 1
Composition for nickel-based superalloy substrate.

Elements	Cr	Co	C	Ti	Mo	Al	Ni
wt%	18.67	13.18	4.69	3.10	1.79	1.75	56.82

Table 2
Parameters of the spraying process.

Parameters	Coating	
	CoNiCrAlY	ZrO_2
Spraying power, kW	40–50	50–60
Primary gas Ar, L/min	80	74
Carrier gas Ar, L/min	10	10
Second gas H_2, L/min	2.5	5
Powder feed rate, g/min	10	20
Spraying distance, mm	100	100
Nozzle diameter, mm	6	6

In the present work, a double-layer TBC was prepared on nickel-based superalloy by SAPS. The top layer was comprised of partially stabilized ZrO_2 and the inner coating (or bond coating) consisted of CoNiCrAlY. The inner coating can relieve the mismatch of different coefficient of thermal expend (CTE) between the top coating and substrate as well as play a significant role for improving the coating adhesive strength. The thermal shock resistance of SAPS–TBCs at 1200 °C was tested and the corresponding adhesive strength was investigated through micro-scratch test. The microstructural characterization was carried out by scanning electron microscopy (SEM) whereas the phase analysis was carried out by X-ray diffraction (XRD). The adhesion evolution after different thermal cycles was discussed.

2. Experimental

2.1. Substrate materials

The specimens with the size of $10 \times 10 \times 1$ mm^3 were wire-electrode cut from bulk nickel-based superalloy. The

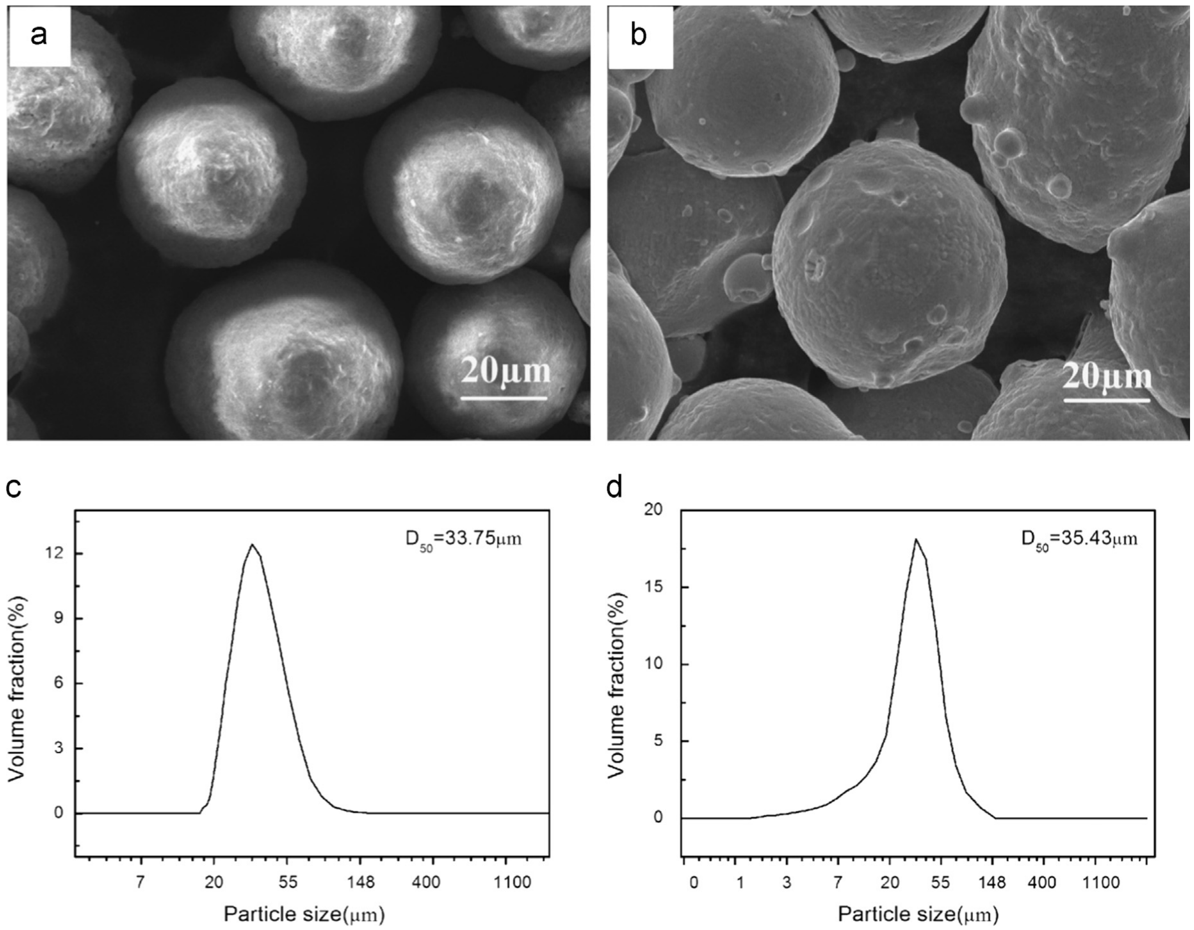

Fig. 1. SEM images and particle size distribution of the original sprayed powders. (a) 8% Y_2O_3–ZrO_2; (b) CoNiCrAlY; (c) particle size distribution of 8% Y_2O_3–ZrO_2; (d) particle size distribution of CoNiCrAlY.