Available online at www.sciencedirect.com
ScienceDirect
Surface & Coatings Technology 201 (2007) 4653–4658
www.elsevier.com/locate/surfcoat

Thermal cyclic behavior of air plasma sprayed thermal barrier coatings sprayed on stainless steel substrates

A. Nusair Khan [a,*], J. Lu [b]

[a] Metallurgy Division, GPO Box No. 502, Rawalpinidi, Pakistan
[b] LASMIS, BP 2060, 12 Rue de Marie Curie, Université de Technologie de Troyes, 10000 Troyes, France

Received 27 May 2006; accepted in revised form 2 October 2006
Available online 28 November 2006

Abstract

Thermal barrier coatings (TBCs) were deposited by an Air Plasma Spraying (APS) technique. The coating comprised of 93 wt.% ZrO_2 and 7 wt.% Y_2O_3 (YSZ); CoNiCrAlY bond coat; and AISI 316L stainless steels substrate. Thermal cyclic lives of the TBC were determined as a function of bond coat surface roughness, thickness of the coating and the final deposition temperature. Two types of thermal shock tests were performed over the specimens, firstly holding of specimens at 1020 °C for 5 min and then water quenching. The other test consisted of holding of specimens at the same temperature for 4 min and then forced air quenching. In both of the cases the samples were directly pushed into the furnace at 1020 °C. It was observed that the final deposition temperature has great impact over the thermal shock life. The results were more prominent in forced air quenching tests, where the lives of the TBCs were observed more than 500 cycles (at 10% spalling). It was noticed that with increase of TBC's thickness the thermal shock life of the specimens significantly decreased. Further, the bond coat surface roughness varied by employing intermediate grit blasting just after the bond coat spray. It was observed that with decrease in bond coat roughness, the thermal shock life decreased slightly. The results are discussed in terms of residual stresses, determined by hole drill method.

Keywords: Air Plasma Spraying; Thermal barrier coatings; Thermal shock test; Residual stresses

1. Introduction

Thermal barrier coatings (TBCs) can be considered as a three layer material system, consisting of (1) a substrate, (2) an oxidation-resistant metallic bond coat, usually MCrAlY or a platinum aluminide coating, and (3) the ceramic top coating, usually 6 to 8 wt.% yttria-stabilized zirconia deposited either by plasma spray or electron beam physical vapor deposition process. The zirconia topcoat has excellent thermal shock resistance, low thermal conductivity and relatively high coefficient of thermal expansion (CTE) [1]. The MCrAlY bond coats provide a rough surface for mechanical bonding of the ceramic top coat, protect the underlying alloy substrate against the high temperature oxidation corrosion, and reduce the CTE mismatch between the substrate and ceramic top coat materials [2].

Thermal barrier coatings, however, have a tendency to spall, or debond, under cyclic high temperature conditions. It is believed that spallation of the ceramic component in TBC's is a result of the stresses generated in service [3]. The performance of TBC's is also affected by thermal expansion mismatch between the ceramic and the metal, thermal stresses generated by the temperature gradients in the TBC, ceramic sintering, phase transformation, corrosive and erosive attack, and the residual stresses arising from the deposition process.

Thermal barrier coatings offer the potential of increasing turbine operating temperature up to 150 °C, which permits a reduction in the mass of cooling air required while maintaining the turbine operating temperature giving improved specific fuel consumption [4,5]. Increasing the thickness of the coating can increase the temperature resistance property. However, the thickness of the coating is limited by mechanical and thermal stresses and the thermal cyclic life of the coating. Moreover, increased resistance of plasma sprayed coatings to cyclic thermal exposure can be achieved by increasing the strain

* Corresponding author.
E-mail address: nusairy@yahoo.com (A.N. Khan).

0257-8972/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.surfcoat.2006.10.022

tolerance of the ceramic and by controlling harmful residual stresses. These residual stresses can be controlled by the substrate roughness [6], and final deposition temperature.

Residual stresses, originate from the large temperature differences, and are divided into two main groups: quenching and thermal stresses [7]. Quenching stresses develop while the semi-molten particles strike to the relative colder substrate surface where the temperature drops drastically. Consequently, these semi-molten particles try to contract over the underlying metal, where the substrate restricts them as a result tensile stresses develops within the coating material. The thermal stresses generate while the whole system, i.e. deposit and substrate cool down to room temperature. A thermal mismatch stress develops due to the difference in thermal expansions of each material. Since these stresses are associated with temperature differences thus by controlling the temperature history one can control the residual stresses. The deposition temperature can be controlled by varying the substrate to torch distance, gas cooling during spraying, and pre-heat treatment of the substrates. In our study we controlled the residual stress profile by changing the torch distance vs substrate.

In this paper we will study the effects of bond coat surface roughness, coating thickness effects and the final deposition temperature over the thermal cyclic life of TBC.

2. Experimental

2.1. Materials

The thermal barrier coatings, composed of a bond coat and a top coating, were air plasma sprayed onto a stainless steel AISI 316L samples. The powder used for the bond coating was CoNiCrAlY (AMDRY® 995(4)), had spherical free flowing gas atomized powder with grain size, 20±10 μm. The top coating material (NORTON HW 1193) was consisted of spherical particles with grain size 25±15 μm, and the powder was porous in nature with chemical composition $93ZrO_2$–$7Y_2O_3$, wt.%.

2.2. Deposition process

Circular substrates with a diameter of 25 mm and a thickness of 10 mm were grit blasted on the flat surface to be coated. Just after the grit blasting the samples were subjected to Air Plasma Spraying. Fig. 1 shows the schematic view of the experimental arrangement. A DC, PT-2000 Plasma Tenhnik AG Switzerland, gun was utilized for the deposition of both the bond and top coating. The plasma gun moved up and down in the vertical direction, in each passage depositing a thin layer of molten material on the rotating substrates. The bond coating was sprayed to a total thickness of 45±10 μm whereas 300 to 500 μm thick top coatings were produced by the same technique.

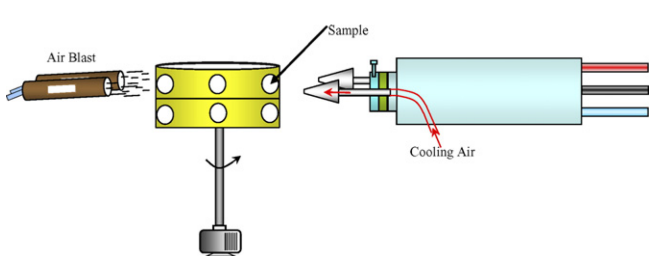

Fig. 1. Schematic view of the experimental arrangement.

During the spraying of both bond and top coatings the substrate temperature was controlled by air jets. Pressurized air jets were blown from two directions, one directed parallel to the plasma torch, and the other behind the rotating fixture of substrates. The spraying distance between the torch and the substrates was 125 mm. The temperature measurements were made by an optical pyrometer, fixed close to the rotating assembly of the samples.

2.3. Thermal shock test

Two different types of thermal shock tests were performed. In both cases the samples were heated in the muffle furnace. When the temperature of the furnace reached up to 1020 °C, the samples were pushed into the furnace. In water quenching thermal shock tests, the samples were held about 300 s into the furnace and then directly quenched into the water. The temperature of the water throughout the cycling was between 20 and 35 °C. whereas, in compressed air quenching test the samples were held about 240 s into the furnace at 1020 °C and then quenched by compressed air. The cooling time for air quenching was about 90 s. After 90 s, the samples were on room temperature. More than 50% of the spalled region of the surface of the top coating was adopted as criteria for the failure of the coating in both water and air quenched samples. At least three samples were tested for each condition. This type of thermal shock testing was also performed by other investigators [8–11].

2.4. Residual stress and Roughness measurements

The residual stresses were measured by hole drill method. In this method a blind hole is brought step by step into the surface of the component. The residual stresses are relieved by material removal (blind hole), deform the surface around the hole and are measured as relaxed strains at the surface by means of strain gauges. Together with calibration curves, Young's Modulus and Poisson's ratio the measured relaxed strains at the surface are transformed into true strains at the bottom of the drilled hole. Out of the strains at the bottom, plane stresses are incrementally determined by Hook's law [12]. The Young's Modulus and Poisson's ratio were taken from the published literature i.e. 30 GPa and 0.2 respectively [13]. The roughness was measured by Taylor Hobson roughness meter. For this purpose Ra values were considered.

3. Results and discussion

The observations and possible discussion during the water and forced air quenching for different parameter are presented below.