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Effect of shot peening on the oxidation behavior of thermal barrier coatings

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ABSTRACT

A conventional thermal barrier coating (TBC) system is made up of a multilayered coating system that comprises a metallic bond coat including oxidation-resistant MCrAlY and a thermally insulating ceramic top coat including yttria stabilized zirconia (YSZ). In this study, in order to improve the oxidation behavior in conventionally produced TBC systems, shot peening process is applied for modification of surface layer structure of atmospheric plasma spray (APS) bond coats. The oxidation behavior of TBCs, produced by the APS process and subjected to shot peening, was investigated. Oxidation tests were performed under isothermal conditions at 1000 °C for different time periods. The coatings produced by the APS process include high porosity and oxide content due to atmospheric production conditions as well as exposure to very high temperature. In this study, the coatings, produced by the APS process, subsequently subjected to shot-peening, were compared with the ones which were not shot peened. Following the application of the shot peening process, a dense structure is obtained due to the plastic deformation effect in the metallic bond coating structure at a certain distance from the surface. To this end, the effects of the shot-peening on the high temperature oxidation behavior of the coatings are investigated and evaluated.

1. Introduction

The production of thermal barrier coatings (TBCs), applied to improve the efficiency of hot section components like turbine blades, vanes and combustor parts in gas turbine engines, has been among the most attractive subjects in the field of high temperature applications in recent years [1–4]. Typically, a TBC system consists of bond coat (MCrAlY) and top coat (YSZ) above a super alloy substrate. MCrAlY (M = Ni and/or Co) is widely used to provide a good thermal expansion match between the top coat and substrate [5,6]. Bond coat does not only provide better adhesion and bonding to top coat and substrate but also provides protection against oxidation and hot corrosion while top coat provides good thermal insulating [7].

The TBCs, exposed to high temperature during service conditions, exhibit a thermally grown oxide (TGO) layer between bond and top coat due to oxidation. The TGO-related volume expansion results in compressive residual stress at the TBC interface [8]. During the cooling period the thermal energy mismatch led to formation of stress energy, subsequently causing the formation of spalling as a TGO layer failure. In order to improve and prolong the life-time of TBC, formation of TGO should be minimized using different production methods and applications [9].

Recently, Vacuum Plasma Spray (VPS), High Velocity Oxygen Fuel (HVOF) and Cold Gas Dynamic Spray (CGDS) have been the preferred methods to obtain a bond coat content with high density and low porosity and to get a better resistance against oxidation and corrosion for TBC [10]. Although these are considered to be better alternatives for APS coatings, APS method is still a simpler method with a higher cost-efficiency. In this process, coating microstructure exhibits high porosity levels and includes oxidized particles due to high operating temperature [11].

Shot-peening is preferred for machine components such as gears, shafts or springs to increase fatigue life through formation of compressive residual stress, obtain a denser surface and remove the pores [12]. Additionally, the shot-peening process protects the material against penetration of undesirable gasses and liquids through removal of porosities [12,13]. In this process, machine

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component surfaces are bombarded with spherical balls in the form of metal, ceramic or glass bead with high velocity. During this bombardment, the balls colliding to the surface, generate pits, bumps, hence a plastic deformed region [14]. As a result of this process, compressive residual stresses, occurring on the surface, prolong fatigue life of materials due to the increased hardness value, varying surface roughness and removal of porosities [15–18]. The purpose of this study is to produce a dense interface using shot peening, obtain a better resistance against high temperature oxidation and decrease TGO formation through decreased surface roughness.

In this study, prior to the production of ceramic top coat, shot-peening process is applied on the bond coat surface with different intensities, in an attempt modify the bond coat and gain a denser surface similar to the ones obtained with VPS, HVOF and CGDS methods. Thus, improvement of microstructural properties of APS bond coats through shot peening for obtaining a more economic and durable TBC structure is aimed. The effect of shot peening on the TBC structure produced was observed following the exposure to high temperature oxidation service conditions. According to the results, TBCs modified through shot peening process yielded more uniform TGO structures with a lower thickness.

2. Experimental procedure

2.1. Material

Inconel 718 nickel-based superalloy disk-shaped samples with a diameter of 25.4 mm and thicknesses of 5 mm were used as substrate material. Chemical composition of commercial Inconel 718 Ni-based superalloy (wt.%) is given in Table 1.

2.2. Spraying processes

CoNiCrAlY (Sulzer-Metco USA, Amdry 9951, 5–37 μm) and $ZrO_2 + Y_2O_3$ (GTV Germany, −45 + 20 μm) powders were used as the feedstocks for the deposition of the bond and top coats. Spray gun and deposited powder properties with coating thicknesses are shown in Table 2. Firstly, prior to the deposition of substrate material, undesirable residues like lubricant, impurities or inclusions were removed from the surface through grit blasting, also a predefined surface roughness was obtained on the surface to gain a good adherence to surface and an increased splice strength. Grit blasting with 2.5 bar and angle of 75° was applied at a distance of 10 cm from the surface using Al_2O_3 grits (60 mesh) and then the samples were cleaned by ethanol in ultrasonic bath.

Secondly, substrate materials were coated with CoNiCrAlY using a GTV F6 APS system. CoNiCrAlY bond coat parameters are shown in Table 3. The thickness of the bond coats were measured as 100 μm. Similarly, top coat of TBC was produced using ZrO_2–%8 Y_2O_3 powder as-sprayed coating. The thickness of the ceramic top coat was measured as 300 μm. YSZ top coat parameters are shown in Table 3.

2.3. Shot peening processes

After coating deposition, bond coat samples were exposed to shot peening process with different Almen intensities (6–8 A) and (8–10 A) using Micropeen-Peenmatic 2000S shot peening tool. Process parameters of shot peening are shown in Table 4. After the shot peening process, surface roughness values of coatings were measured using the surface roughness tester (SJ-310, Mitutoyo, USA) according to DIN EN ISO 3274. Surface roughness values of coatings are shown in Table 5. Afterwards, shot peened coatings were coated with YSZ using APS method. All coated samples were subjected to metallographic process for characterization and evaluation.

2.4. Porosity and hardness measurements

Porosity contents of bond and top coats were observed and calculated using the "Clemex Vision Lite" software program. Porosity measurements of bond and top coats of TBCs were performed on 10 images taken for each coating layer, on which the microstructure of matrix and porosity structures were defined using an image analysis program.

Porosity measurements were carried out through acquisition of 10 microstructure images from each coating layer and definition of matrix and porosity structures using an image analysis software. During the assessment of porosity by use of software, it is essential to have a thorough knowledge of coating and microstructure properties. It is also essential to ensure that the images are analyzed

Table 1
Chemical composition of commercial Inconel 718 Ni-based (wt.%) superalloy.

Elements, % chemical composition (wt.%)							
Ni	Cr	Nb	Mo	Ti	Al	Co	Si
53.55	18.0	5.31	3.03	0.96	0.56	0.27	0.09
Cu	Mn	C	Ta	P	B	S	Fe
0.06	0.06	0.03	0.01	0.007	0.004	0.001	Balance

Table 2
Properties of spray gun and deposited powder for each coating type.

Coating type (thickness)	Spray gun		Powder material properties	
	Method	Firm	Powder firm	Nominal particle size
Bond Coat (100 μm)	APS	F6-GTV, Germany	CoNiCrAlY, Amdry 9951 (Sulzer Metco)	5–37 μm
Top Coat (300 μm)	APS	F6-GTV, Germany	ZrO_2/Y_2O_3, 92/8 (GTV)	−45 + 20 μm

Table 3
Plasma spray parameters for bond and top coat deposition.

APS CoNiCrAlY bond coatings		
Arc current	Electrical power	Argon flow rate
600 A	40 kW	65 slpm
Hydrogen flow rate	Powder feed rate	Stand-off distance
14 slpm	30 g/min	140 mm
APS YSZ top coatings		
Arc current	Electrical power	Argon flow rate
630 A	40 kW	44 slpm
Hydrogen flow rate	Powder feed rate	Stand-off distance
13 slpm	25 g/min	90 mm

Table 4
Shot peened CoNiCrAlY bond coats.

Almen intensity	Shot peening intensity
1. Almen intensity	6–8 A
2. Almen intensity	8–10 A
Ball type	S180
Saturation rate	%100
Air pressure kPa (psi)	520 (75)

Table 5
Bond coat and shot peened bond coat surface roughness values.

Coating system	Surface roughness (Ra-μm)
As-sprayed APS bond coat	7.34
APS bond coat + shot peened (6–8 A)	3.21
APS bond coat + shot peened (8–10 A)	2.92

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