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Full Length Article

Hot corrosion behavior of YSZ, $Gd_2Zr_2O_7$ and YSZ/$Gd_2Zr_2O_7$ thermal barrier coatings exposed to molten sulfate and vanadate salt

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ABSTRACT

Thermal barrier coatings (TBCs) are mostly used in critical components of aircraft gas turbine engines. Hot corrosion is among the main deteriorating factors in TBCs which results from the effect of molten salt on the coating–gas interface. This type of corrosion is observed as a result of contamination accumulated during combustion processes. Fuels used in aviation industry generally contain impurities such as vanadium oxide (V_2O_5) and sodium sulfate (Na_2SO_4). These impurities damage turbines' inlet at elevated temperatures because of chemical reaction. Yttria stabilized zirconia (YSZ) is a conventional top coating material for TBCs while $Gd_2Zr_2O_7$ is a new promising top coating material for TBCs. In this study, CoNiCrAlY metallic bond coat was deposited on Inconel 718 nickel based superalloy substrate material with a thickness about 100 μm using cold gas dynamic spray (CGDS) method. Production of TBCs were done with deposition of YSZ, $Gd_2Zr_2O_7$, YSZ/$Gd_2Zr_2O_7$ ceramic top coating materials using EB-PVD method, having a total thickness of 300 μm. Hot corrosion behavior of YSZ, $Gd_2Zr_2O_7$, YSZ/$Gd_2Zr_2O_7$ TBC systems were exposed to 45 wt.% Na_2SO_4 and 55 wt.% V_2O_5 molten salt mixtures at 1000 °C temperature. TBC samples were investigated and compared using scanning electron microscope (SEM), energy dispersive spectroscopy (EDS) analysis and X-ray diffractometer (XRD). The hot corrosion failure mechanisms of YSZ, $Gd_2Zr_2O_7$ and YSZ/$Gd_2Zr_2O_7$ TBCs in the molten salts were evaluated.

1. Introduction

Thermal barrier coatings (TBCs) are widely used in components that are exposed to high temperatures in gas turbines of engines operating at very high temperatures [1–3]. The main purpose of a TBC system is to provide thermal insulation of gas turbine engine parts and to protect these components from harmful effects of oxidation, hot corrosion, wear and fly ash [4,5]. In general, a typical TBC system consists of a ceramic top coat stabilized with rare earth elements in order to provide thermal insulation, a metallic bond coat used to minimize the thermal expansion mismatch and to increase the adhesion of the ceramic top coat, and a high temperature resistant nickel based superalloy substrate material [6,7]. The most common use of nickel-based alloys is the Inconel 718 superalloy substrate material, which has good resistance to oxidation and corrosion [8–10].

MCrAlY-type coatings as metallic bond coating materials is used to protect superalloy base materials in the hot parts of land and aviation gas turbines from oxidation and hot corrosion.The element, also referred to as "M" in the coating is generally nickel or cobalt [11–13]. Chromium and Aluminum are added to the coating content to increase resistance against oxidation and hot corrosion. The Yttrium (Y) element added in low amounts is also added to increase adhesion strength to the substrate surface of the oxide layer in the coating [1–4,14–16]. MCrAlY-type coatings are generally produced using thermal spray coating methods such as Atmospheric Plasma Spray (APS), Super Sonic Atmospheric Plasma Spray, Detonation gun (D-gun), High Velocity Oxy Fuel (HVOF) and Cold Gas Dynamic Spray (CGDS). Among these thermal spray methods used, CGDS method is called as cold spray method because it is performed at lower temperatures than other methods In this method, the coating is carried out by deposition of coating material onto the substrate surface at high speeds [14,17]. The main principle of the system is to ensure that material to be coated with severe plastic deformation adheres onto the substrate surface. The low temperature during the coating process ensures that the oxide and porosity ratio is minimized in the microstructure of the resulting coating [14,17–19]. Porosity measurements of the CGDS coating vary between 1 and 1.5%. Atmospheric plasma spraying (APS) and electron beam vapor deposition (EB-PVD) methods are used for the production of ceramic top coating materials [1,17,19]. The APS method is a cheap and conventional method. APS method is widely

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Table 1
Deposition parameters for metallic bond and ceramic top coats.

Bond coat	Spray pressure (bar)	Gas temperature (°C)	Working gas (slpm)	Spray distance (mm)	Gun speed (mm/s)
CoNiCrAlY	30	600	Helium(1000)	15	20
Top coat	Voltage (kV)	Temperature (°C)	Vacuum (Torr)	Rotation speed (rpm)	Condensation ratio (μm/min)
YSZ	20 kV	$800 \pm 20\,°C$	$5 \times 10^{-5} - 1 \times 10^{-4}$	25	4,5
$Gd_2Zr_2O_7$	20 kV	$800 \pm 20\,°C$	$5 \times 10^{-5} - 1 \times 10^{-4}$	25	3,7
YSZ/$Gd_2Zr_2O_7$	20 kV	$800 \pm 20\,°C$	$5 \times 10^{-5} - 1 \times 10^{-4}$	25	3,5/4,1

used because it is economically preferred in TBCs production. Since the coating process in APS method was carried out at high temperature in open atmosphere, a highly porous coating microstructure with low density was obtained [2,14]. In addition, the material to be coated in this method is deposited on the surface in a laminar form. In EB-PVD method, which has been widely preferred as a novel method for deposition of TBCs, the substrate material is produced in ingot form and the coating process is applied via physical vapor deposition under vacuum conditions, thus resulting in a less porous coating microstructure with higher density [6,17]. Moreover, in this method the coating process is deposited as a columnar and frequent coating structure as opposed to the laminar structure of the APS method.

The low porosity between the columns allows providing a more durable coating against failure mechanisms caused by molten salts such as hot corrosion and CMAS effect in the TBC system [6,8,20,21]. As the most important failure mechanism, hot corrosion occurs as a result of reaction of air and fuel impurities such as Na_2SO_4 and V_2O_5 with the top coating layer at high temperatures resulting in failures in the coating structure [21–23]. As a means to minimize the effects of hot corrosion, alternative TBC production methods have been applied in addition to the use of rare earth elements as top coating materials. The most commonly used ceramic coating material against this damage mechanism is Zr_2O (YSZ) stabilized with Yttria due to its low thermal conductivity and good phase stability [4,5,7,22]. In recent years, zirconates stabilized with rare earths as top coating materials in TBC systems have begun to be preferred due to the phase transformation temperatures, higher melting points and lower thermal conductivity than YSZ. The general formula for rare earth zirconates is $A_2B_2O_7$. These zirconates which are A plus 3 charged cation, B plus 4 charged cations are described [4,7,24]. The thermal correlation will decrease due to the fact that partial or complete replacement of the anions in the ionic crystal by other elements will increase the phonon distribution [1,25]. Therefore, rare earth zirconate ceramics having a pyrochlore structure or fluorite type structure such as $La_2Zr_2O_7$,

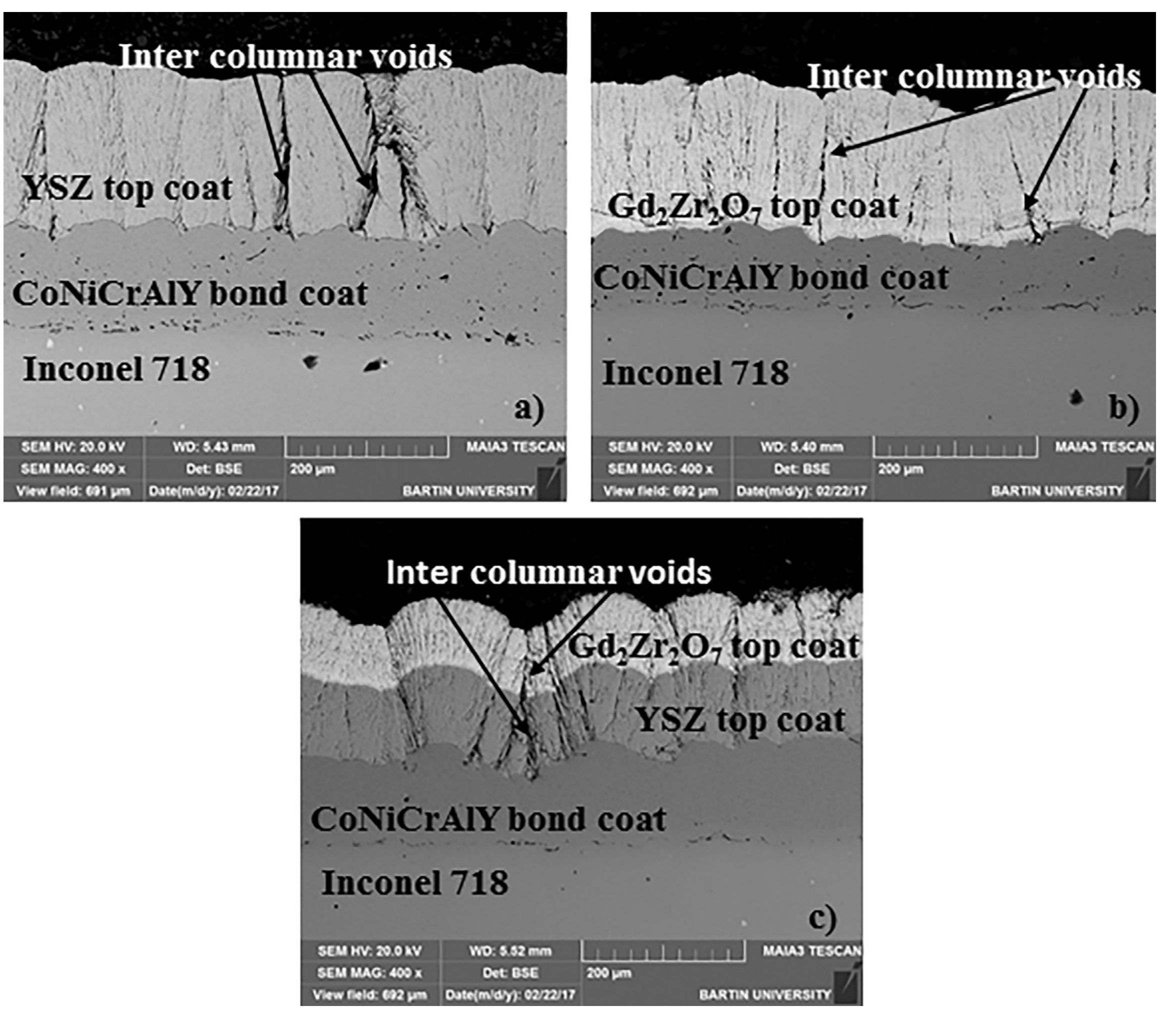

Fig. 1. As-sprayed cross-sectional micrograph of YSZ, $Gd_2Zr_2O_7$ and YSZ/$Gd_2Zr_2O_7$ TBCs produced by EB-PVD method with CGDS CoNiCrAlY bond coat.