



# Thermal barrier coating adherence to Hf-modified B2 NiAl bond coatings

R.W. Jackson<sup>a,\*</sup>, D.M. Lipkin<sup>b</sup>, T.M. Pollock<sup>a</sup>

<sup>a</sup> Materials Department, University of California, Santa Barbara, CA 93106, USA

<sup>b</sup> GE Global Research, Niskayuna, NY 12309, USA

Received 14 May 2014; received in revised form 11 July 2014; accepted 13 July 2014

## Abstract

The durability of thermal barrier coatings (TBCs) deposited on Hf-modified B2 NiAl bond coatings has been investigated under thermal cycling conditions. The rate of bond coat oxidation and rumpling during thermal cycling was characterized and the cycles to failure measured. The location of cycling-induced cracks in the TBC multilayer was influenced by the bond coat composition but variation in TBC lifetime was small, despite the different failure modes. Analysis of the cycle-dependent degradation phenomena demonstrate a trade-off between rumpling resistance and interfacial toughness as a function of bond coat composition.

© 2014 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

**Keywords:** Thermal barrier coating; Delamination; Rumpling; Bond coat; Hafnium

## 1. Introduction

Material systems used in the hottest sections of gas turbines are layered composites with four primary constituents [1–4]. The main structural element is an internally cooled nickel-based superalloy that is designed to have high creep strength. The superalloy is typically coated with an aluminum-containing intermetallic, known as the bond coat (BC), which provides environmental protection by forming a slowly growing oxide scale, the thermally grown oxide (TGO), which is ideally  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. On top of the bond coat, a thermally insulating, porous ceramic layer, the thermal barrier coating (TBC), most commonly yttria-stabilized zirconia, is deposited to decrease the temperature of the metallic components.

Resulting from differences in the coefficient of thermal expansion (CTE) of the constituents, stresses develop during thermal cycling, and these stresses can degrade the

physical integrity of the system through a myriad of mechanisms [5]. The thermal stresses greatest in magnitude are generated in the TGO and are augmented by oxide growth stresses [6,7], and as a result the predominant failure modes are associated with the stored elastic strain energy in the TGO [1,8–10]. When the interfaces between the layered constituents remain planar, failure is most commonly observed at the BC/TGO interface [11–13]. As the thickness of the TGO increases with time at temperature, the stored elastic strain energy increases, eventually exceeding the toughness of the interface. Delamination can proceed either via the propagation of an edge crack [14] or through buckling of the TGO/TBC bilayer [11,14,15]. Both failure modes require initiation sites. For edge cracking this can be manifested through the presence of a free surface, such as the edge of a coupon specimen or a planar vertical crack through the TBC. In order for the coating to buckle, a large interfacial flaw must develop [14], which is believed to generate through the coalescence of small flaws along the interface via thermal fatigue mechanisms [16]. Time to failure is primarily governed by the growth rate of the

\* Corresponding author. Fax: +1 (805) 893 8486.

E-mail address: [rwesleyjackson@engineering.ucsb.edu](mailto:rwesleyjackson@engineering.ucsb.edu) (R.W. Jackson).

TGO and the bond coat/TGO interfacial toughness, which may evolve during cycling.

Most combinations of materials in the multilayered TBC system do not maintain planar interfaces when thermally cycled to temperatures greater than 1100 °C [17–20]. The large compressive stresses in the TGO can be relaxed through elongation, and during thermal cycling to very high temperatures this energy minimization occurs through out-of-plane displacements, resulting in an undulating “rumpled” structure. These displacements are mediated through plasticity in the bond coat, and the rate of displacement is a function of a number of factors, with the temperature-dependent creep rate of the bond coat being of central importance. Analytical and numerical models have been developed by Hutchinson and co-workers to describe this phenomenon [21–24].

As rumpling proceeds, cracks form at the TGO/TBC interface and within the TBC near the interface. Upon further cycling, these cracks grow parallel to the TBC surface and coalesce, creating a separation large enough for the TBC to buckle [9,25]. For a given TGO growth rate and interfacial toughness, the lifetime of a system maintaining a planar interface will typically exceed that of a rumpled system by a factor of 2, depending on the rumpling rate and frequency of thermal cycling [9,26].

The present investigation is part of a broader effort to examine the role of composition on the lifetimes of B2 bond coats under thermal cycling conditions [27–31]. In a previous investigation [29], four Hf-modified B2 bond coats (Table 1) were thermally cycled to a maximum temperature of 1150 °C and the oxidation and rumpling behavior of the coatings were characterized. Large differences in the cyclic oxidation behavior were observed between the alloys, with a Pt-containing alloy exhibiting a lifetime twice as long as alloys without Pt. Additionally, all of the bond coats rumpled at a similar rate for the first 200 cycles, with only the Pt-containing alloy continuing to increase in roughness beyond 1000 cycles. In the present investigation, a YSZ TBC was deposited on the aforementioned Hf-modified coatings as well as a state-of-the-art platinum aluminide bond coat and these samples were subjected to thermal cycling. The oxidation rate, morphological evolution and eventual TBC failure mode were characterized. Significant differences in coating life with and without the presence of a TBC were observed and analyzed in detail.

## 2. Experimental procedure

The samples investigated consisted of René N5 superalloy substrates, 24.5 mm in diameter and 2 mm in thickness, with bond coats applied by ion plasma deposition (IPD) [32]. The nominal as-deposited compositions of the IPD bond coats are listed in Table 1. The coatings had an average thickness of approximately 40 μm. Following deposition, the coatings were heat-treated for 10 h at 1079 °C under vacuum, then lightly grit blasted with 67 μm alumina media using a pressure of 0.21 MPa.

Thermal barrier coatings were deposited on each bond coat composition by electron-beam physical vapor deposition (EB-PVD) at Praxair Surface Technologies (Indianapolis, IN). The coatings were approximately 130 μm thick and composed of 7 wt.% *t'* yttria-stabilized zirconia (7YSZ). Five samples of each composition were cycled to a maximum temperature of 1163 °C. Three of these coatings were cycled to failure, denoted as the spallation of 20% of the TBC; the other samples were removed after 10 and 100 cycles, respectively (though 5Pd underwent 180 instead of 100 thermal cycles).

Additionally, four platinum aluminide coatings were deposited on René N5 substrates (25.4 mm diameter, 2 mm thickness) by the Howmet Corporation (Whitehall, MI) using a high-temperature, low-activity coating process described in Ref. [33]. Three samples were cycled to failure and the fourth was removed after 100 cycles.

The 1 h thermal cycle consisted of a 45 min dwell period at 1163 °C, with heating and cooling rates of approximately 200 °C min<sup>-1</sup>. The TGO thickness was calculated by taking 30 measurements of scanning electron microscopy (SEM) cross-sections. The surface evolution was quantified by measuring the length of the interface from the SEM measurements.

## 3. Bond coat oxidation

Cross-sectional SEM micrographs of the four IPD bond coats following 10 furnace cycles are presented in Fig. 1. The scales formed on the IPD coatings were primarily Al<sub>2</sub>O<sub>3</sub>, with HfO<sub>2</sub> particles (bright phases) present within the scale and as protrusions extending into the alloy. Additionally, an Al<sub>2</sub>O<sub>3</sub>-ZrO<sub>2</sub> intermixed zone [34] formed adjacent to the TBC. The intermixed zone develops when outward-growing transient aluminas form during TBC

Table 1  
Nominal bond coat composition.

	Ni (at.%)	Al (at.%)	Cr (at.%)	Hf (at.%)	Pd (at.%)	Pt (at.%)
+5Ni	60	34	6	0.3	0	0
5Pd	56	33	6	0.3	5	0
5Pt	55	34	6	0.3	0	5
5Pd–12Cr–23Al	60	23	12	0.3	5	0
PtAl	50	38	5	0	0	7

Download English Version:

<https://daneshyari.com/en/article/7880971>

Download Persian Version:

<https://daneshyari.com/article/7880971>

[Daneshyari.com](https://daneshyari.com)