

# Oxidation characteristics of a platinized MCrAlY bond coat for TBC systems during cyclic oxidation at 1000 °C

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## Abstract

The scale growth mechanisms of a platinized NiCoCrAlY bond coat (BC) beneath a ceramic thermal barrier coating (TBC) were studied during cyclic oxidation in air at 1000 °C. The thermally grown oxide scales (TGO) after exposure times ranging from 100 to 9100 h were characterized by scanning electron microscopy and laser fluorescence spectroscopy. The TGO appeared to consist of alumina and no oxides of the other elements present in the NiCoCrAlY coating were detected. Up to exposure times of 1000 h substantial amounts of metastable alumina were found in the outer part of the TGO. This is probably the reason for the formation of a porous, mixed alumina/zirconia layer at the TBC/TGO interface. This layer was prone to micro-crack formation, which did, however, not result in macroscopic TBC failure. The latter occurred after crack formation at the TGO-BC interface.

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## 1. Introduction

In aero and stationary gas turbines, the life time of blades and vanes can substantially be increased by the use of ceramic thermal barrier coatings (TBCs). Commonly, the TBC consists of yttria stabilized zirconia ( $ZrO_2-8\%Y_2O_3$ ) and is applied by air plasma spraying (APS) or electron beam assisted physical vapour deposition (EB-PVD) [1,2]. Before applying the ceramic TBC, the base material is commonly coated with an alumina forming bond coat (BC). Depending on the actual application, the BC can for example be of the type NiAl, (Ni,Pt)Al [3–7] or MCrAlY [8–10].

Although the exact parameters governing TBC life during high-temperature service are still subject of debate, it is generally accepted that the growth rate, morphology, microstructure and adherence of the aluminium-based

thermally grown oxide scale (TGO) which forms on the BC surface during high-temperature service is of crucial importance for the eventual occurrence of TBC failure [11–14]. If an MCrAlY bond coat is being used, the TGO frequently exhibits an inhomogeneous morphology and/or composition, especially in the early stages of oxidation [15]. This is caused by the multiphase character of the MCrAlY coating, which commonly consists of  $\gamma$ -Ni and  $\beta$ -NiAl; depending on composition and temperature, further phases, such as  $\gamma$ -Ni<sub>3</sub>Al,  $\alpha$ -Cr, Ni-Y and/or  $\sigma$ -CoCr may be present [16]. Upon first exposure at a high temperature, i.e., during heat treatment, coating manufacturing and/or actual service, every individual phase prevailing in the coating will tend to form a different type of oxide, e.g.,  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>,  $\theta/\gamma$ -Al<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, NiO, (Ni,Co)(Cr,Al)<sub>3</sub>O<sub>4</sub> etc. [15]. The transition of this heterogeneous scale into a stable  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>-based layer can lead to stress initiation and/or result in formation of cracks which may be starting points for failures during high-temperature service and especially thermal cycling. This problem can be overcome by applying a Pt-rich layer on the MCrAlY-BC prior to applying the ceramic TBC [17].

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In the present paper, the oxidation properties of a Pt-covered NiCoCrAlY bond coat beneath an EB-PVD TBC during thermal cycling at 1000 °C will be presented. Main emphasis will be put on the time dependence of the TGO composition and morphology as well as on the crack formation and growth within and in the vicinity of the TGO.

## 2. Experimental

Cylindrical specimens of a single crystalline Ni-base alloy of 10 mm in diameter and 30 mm in length, with rounded edges, were used as substrates. A commercial BC of the NiCoCrAlY type of approximately 200  $\mu\text{m}$  in thickness was applied to the cylindrical specimens by conventional vacuum plasma spraying. The surface of the MCrAlY coating on the coupon was modified in such a way that the surface zone was Pt-enriched. For this purpose, a 8- $\mu\text{m}$ -thick layer of Pt was applied, and subsequently, the specimens were heat treated in vacuum for 2 h at 1080 °C. Subsequently, the coupons were coated with a 200- $\mu\text{m}$ -thick YSZ-TBC, using a conventional EB-PVD process [1,2].

The coated specimens were subjected to cyclic oxidation testing at 1000 °C in air, each cycle consisting of 120 min at temperature and 15-min cooling under flowing air. The specimens were visually examined every 24 h for cracking or spalling of the TBC. The oxidized specimens were characterized in metallographic cross-sections by scanning and transmission electron microscopy (SEM and TEM) with energy dispersive X-ray analysis (EDX). Additional identification of the TGO phases was accomplished by laser-induced fluorescence optical spectroscopy (LIFOS).

## 3. Results

Fig. 1 shows that in the as-received condition the outer part of the bond coat contains, as expected, Pt-rich phases. The chemical compositions of the different

Table 1

Chemical composition in atomic percent of the different phases in the outer part of the BC in the as-received condition (numbers 1–4 relate to Fig. 1)

Nr.	Ni	Cr	Co	Al	Pt	Phase
1	22.9	26.1	34.4	7.8	–	$\gamma$ -Ni
2	25.9	7.6	12.5	31.3	22.6	$\beta$ -(Ni,Pt)Al
3	24.4	25.8	35.7	7.4	6.6	$\gamma$ -Ni(Pt)
4	32.6	8.1	16.0	29.3	13.9	$\beta$ -(Ni,Pt)Al

phases are given in Table 1. In the as-received state, the BC is already covered by an oxide layer of approximately 3  $\mu\text{m}$  in thickness. It originates from the high-temperature treatment prior to and during the EB-PVD process.

Unlike conventional MCrAlY bond coats, which tend to form a TGO consisting of various oxides during the early stages of oxidation [10,17], the platinized MCrAlY bond coat is covered by a single-phase alumina scale. The TGO consists of two sub-layers which possess different morphologies: an inner dense part and an outer micro-porous part. The latter shows a needle-like structure and, based on TEM studies, consists of a mixture of  $\text{Al}_2\text{O}_3$  and YSZ (Fig. 2). LIFOS revealed the TGO to consist of  $\alpha$ - and  $\theta$ - $\text{Al}_2\text{O}_3$  whereby the latter phase is mainly present in the outer part of the scale (Fig. 2).

After 100 h of cyclic exposure (i.e., 100-h total heating time at 1000 °C, this including 50 thermal cycles), the TGO has thickened and substantial porosity is found in the outer part of the scale (Fig. 3a). Also, a minor number of micro-cracks is present in this part of the TGO. The micro-porosity possibly originates from the (partial) transformation of the initially formed  $\theta$ -alumina into the  $\alpha$ -form, although LIFOS revealed that the transformation has not yet been completed after the 100-h exposure. The metastable  $\theta$ -alumina phase could even be found after cyclic exposure times of 1000 h (Fig. 3b). After 3100 h indications for presence of  $\theta$ -alumina were no longer detected.

After all exposure times crack formation was observed in the outer part of the TGO (see, e.g., Fig. 4). In some areas of the specimen, crack propagation occurred from within the TGO into the TBC (Fig. 4). However, these

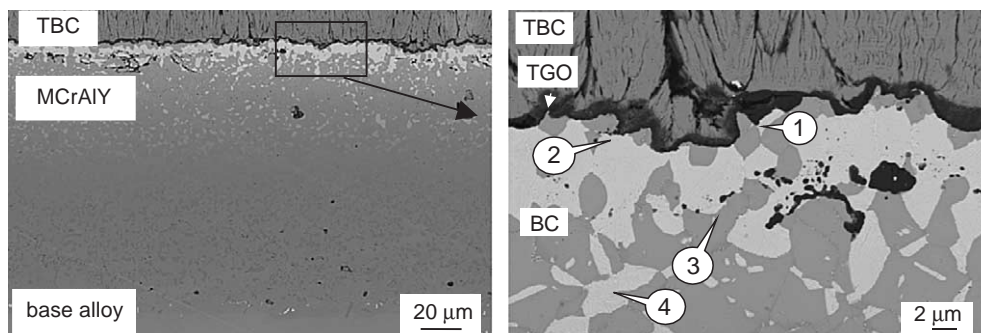


Fig. 1. SEM cross-sections of the platinized MCrAlY bond coat in the as-received condition. Numbers refer to analysis points given in Table 1.

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