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Life time dependency on the pre-coating treatment of a thermal barrier coating under thermal cycling

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Abstract

A thermal barrier coating system consisting of the single crystalline Ni-based superalloy CMSX 4, a Pt aluminide bond coat and an EB-PVD processed ceramic top coat was thermally cycled in order to study the influence of three different treatments prior the deposition of the ceramic top coat. Besides the standard treatment, one type of treatment was annealing in vacuum, while the other was annealing in an O containing ArH atmosphere; in both cases for 4 h at 1080 °C.

Compared to the standard treatment, annealing in vacuum almost doubled and annealing in ArH atmosphere almost tripled the cyclic life time of the ceramic coating. The improvement was related to the creation of a defined alumina scale before and during TBC deposition.

Keywords: Thermal barrier coating; Bond coat; Cyclic life; Thermal fatigue; CMSX-4; Platinum–aluminide

1. Introduction

Thermal barrier coatings (TBCs) on advanced turbine blades considerably increase the engine efficiency and blade performance. State-of-the-art TBC systems consist of a metallic bond coat and a ceramic top coat of partially yttria stabilized zirconia, deposited by electron beam physical vapor deposition (EB-PVD) or plasma spraying. The EB-PVD process provides a columnar microstructure of the ceramic coating exhibiting superior strain and thermal shock tolerance. Metallic bond coats commonly used are Pt modified aluminides and *M*CrAlYs (*M*=Ni and/or Co).

The thermally grown oxide (TGO), which develops at the interface between TBC and bond coat at high temperatures, plays an important role for TBCs performance; failure in EB-PVD TBCs is almost always initiated at or near the TGO, mostly along the TGO/bond coat interface. Some investigations have already shown the high sensitivity and decisive role of the interplay between the constituents of a TBC system consisting of substrate, bond coat, TGO, and ceramic top coat [1]. To give an example, a dramatic decrease of TBC life time until spallation is reported on NiCoCrAlY bond coats as soon as conventionally cast polycrystalline substrate material is exchanged for single crystalline alloys [1,2]. To extend the life of TBCs, optimized TGO formation is a proper and non-costly way. It aims to optimal adhesion of the ceramic top coat on a slow growing TGO; commonly α-alumina is considered to be the optimum. It has been shown for MCrAlY [3,4] as well as for Pt modified aluminide [5,6] bond coats, that formation of a stable TGO prior to TBC deposition offers a valuable way to increase life time. Moreover, a stable oxide present prior to pre-heating and deposition steps in the EB-PVD equipment enhances robustness of the whole manufacturing route [5] since it can tolerate production inherent changes in the processing parameters much better than in the case when TGO formation relies on e.g. exact preheating conditions.

The aim of this study is to investigate the effect of the pretreatments of Pt aluminide bond coats prior to the ceramic topcoat

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Table 1
Composition (derived by EDX) in [at.%] of the indicated phases for the CMSX-4 substrate and for the bond coat, the latter after different thermal histories

Pre-heat treatment		Sample number	Phases	Al	Cr	Co	Ni	Mo	Ta	W	Re	Pt	Ti
None	CMSX-4	N0	γ/γ'	5	6	9	59	1	6	9	4		1
None	Bond coat, as-received	N0	β near surface	56	1	4	35					4	
			$PtAl_2$ near surface	58	9		13					19	1
			Precipitate near surface	52	5	2	22			8		11	
			β near substrate	34	5	7	49		1	1			3
			Precipitate near substrate	8	25	15	22	2	12	10	5	0	1
None	Bond coat, after TF	N2	β near surface	32	5	7	52		1			2	1
			γ' near surface	16	2	9	63		5	1		1	2
			Precipitate near surface	11	16	14	32	2	3	14	8	1	
ArH	Bond coat	A0	β near surface	50	2	5	39					4	
			$PtAl_2$ near surface	53	8	2	20					17	
ArH	Bond coat after TBC deposition	A1	β near surface	52	1	5	38		1			4	
			$PtAl_2$ near surface	56	9		11		5	1		23	2
			β near substrate	36	5	8	50	1					
			Precipitate near substrate	4	28	16	18		6	19	9		
ArH	Bond coat after TF	A3	β near surface	32	5	7	52		1			2	1
			γ' near surface	17	3	9	62		5	1		1	2
			Precipitate near surface	1	22	17	20	3	3	21	13		
			β near substrate	31	5	7	53		1			2	1
			γ' near substrate	17	3	9	63		5	1		1	1
			Precipitate near substrate	1	22	18	18	3	4	21	13		
Vacuum	Bond coat	V0	β near surface	51	1	5	37					6	
			$PtAl_2$ near surface	56	8		13					23	
Vacuum	Bond coat after TF	V2	β near surface	33	5	7	52		1			2	
			γ'	Not analysed									
			Precipitate near surface	9	18	14	28	2	3	16	9	1	

deposition on cyclic life. Special attention was paid to the formation of the oxide scale before TBC deposition during annealing in vacuum or in an O containing ArH atmosphere.

2. Experimental approach

2.1. Specimens

The substrate is CMSX-4, a second-generation single-crystal Ni-based alloy with the typical cubical γ/γ' structure. The concentration of the main elements of CMSX-4 is given in Table 1. The specimens were cylindrical rods, with a length of 65 mm and a diameter of 6 mm within the coated area.

Table 2
Summary of pre-coating treatments and cyclic life time of individual samples

Sample number	Thermal pre-treatment	TBC applied	TF cycle number
N0	None	No	–
N1	None	Yes	–
N2	None	Yes	582
N3	None	Yes	393
V0	Vacuum	No	–
V1	Vacuum	Yes	–
V2	Vacuum	Yes	980
V3	Vacuum	Yes	393
V4	Vacuum	Yes	1299
A0	ArH	No	–
A1	ArH	Yes	–
A2	ArH	Yes	1467
A3	ArH	Yes	1482
A4	ArH	Yes	1214

The commercially available Pt modified diffusion aluminide bond coat was prepared by electroplating platinum and subsequently diffusing aluminium into the substrate by high activity chemical vapour deposition. Preceding the bond coat deposition the substrates have been cleaned by grit blasting.

An yttria stabilized zirconia top coat as TBC was added by EB-PVD at the German Aerospace Centre, using standard deposition conditions at ~1000 °C substrate temperature and with a controlled, permanent amount of oxygen bled in the deposition chamber [7], leading to the typical columnar structure.

Some of the bond coated specimens were lightly grit blasted with alumina grit and than subjected to an annealing at 1080 °C

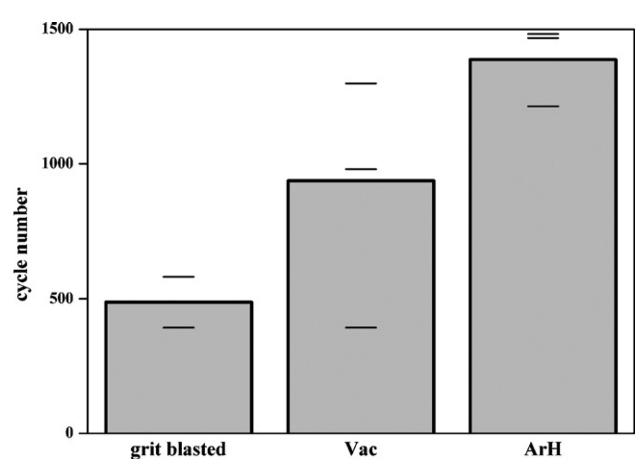

Fig. 1. Life time of the TBC in dependence on the different pre-treatment (bars: average, lines: actual cycle number for the different specimens).