Kinetics of the Evolution of Physical Defects in the TGO and its Vicinity for Life Time Prediction of TBC Systems

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Introduction

Bond coat oxidation is believed to be one of the major degradation mechanism with respect to the life time of thermal barrier coating systems of aero engines and especially of land based gas turbines. For more than a decade the influence of the oxidation behaviour for the life time of TBCs was described by simply the TGO thickness [1,2] but recently it has clearly been shown that the adherence of the bond coat / TGO / topcoat interfaces is the most important parameter for the durability of the system [3]. From a fracture mechanics point of view this adherence of the interfaces is strongly affected by the physical defects like pores, interacting pores and (micro-) cracks which develop in the TGO and its vicinity [4].

Experimental

Isothermal long term oxidation tests were conducted at 950°C, 1000°C, 1050°C and 1100°C up to at least 5000h in a chamber furnace for both APS-top coats and PVD-topcoats. The bond coat was a type of NiCoCrAlY with 12wt-% Al.

After the exposure tests the specimens were transversally and sometimes longitudinally cut and metallographically prepared for microstructural investigations. Then the time and temperature dependent evolution of the physical defects in the TGO and its vicinity were measured on the respective metallographic cross sections by SEM and with the help of an interactive image analysis system. For the case of (micro-) cracks not only the maximum crack lengths were determined but also the location of these cracks has been classified with respect to the local orientation of the interfaces (Fig.1). Details of the procedure are described in [5]

Results

Fig.2 shows examplarily the evolution of cracks in APS systems with time and/or temperature. For short exposure times these microcracks seem to start in the TGO at bondcoat hills and with increasing exposure times these microcracks propagate. All cracks are oriented parallel to the macroscopic BC/TGO/TBC interfaces and in the case of APS systems the longest cracks were either located within the TGO (Mode B) or start in the TGO and penetrate the ceramic topcoat (Mode E). For PVD systems the cracks were mainly of Mode B and Mode C (Fig.3) where the latter means that these cracks are located at the BC/TGO interface and may cut inward growing oxide intrusions. The kinetics of the maximum size of physical defects and of the cracks for a PVD system are given in Fig.4. Pores and composite defects do not play a major role in comparison to the maximum crack lengths (left side) but it has to be considered that they can serve as starting points for cracks. From the right hand side of the picture it can be seen that up to 1000h all different modes of the cracks are in the same order of magnitude, but later on only the Mode B crack propagates significantly.
Tab.1 shows the test matrix of the investigated specimens with respect to macroscopic failure caused by delamination. For 950°C and 1000°C no delamination was observed up to the maximum exposure duration of 5000h. At higher temperatures the ceramic topcoat spalled during cooling. The postexperimental metallographic investigations show two totally different microstructures of the TGO and its vicinity as well as totally different failure crack paths (Fig.5). On the left hand side the sample failed due to the formation of chromia or even Ni(Co,Cr)-spinels within the TGO. Therefore the failure crack path also lies within the TGO (Mode B) and black failure was observed.

On the right side a mixture of black and white mode failure has to be considered and the failure crack path cuts the TGO on the bondcoat hills and the TBC in the bondcoat valleys. Here the sample seems to have failed due to the loss of the adhesion properties of the different interfaces. A second major difference is the thickness of the TGO which is significantly lower in comparison to the left hand sample. These pictures clearly proof that the TGO thickness alone is not suitable for the description of the oxidation behaviour of TBC systems with respect to life time prediction.

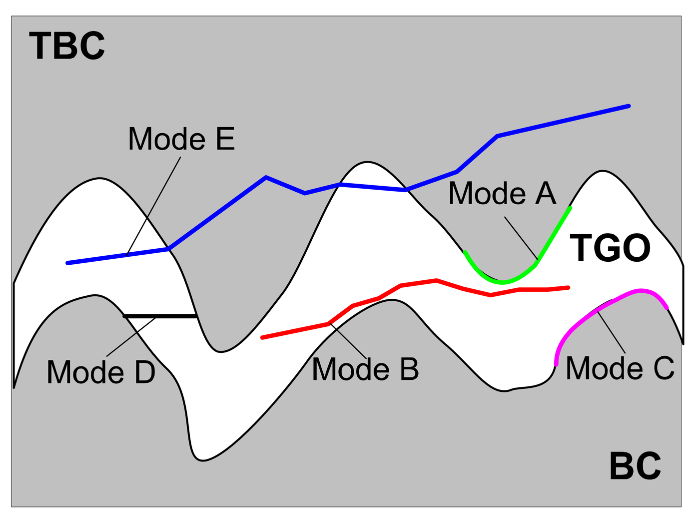

Fig. 1: Schematic of the location of cracks in the TGO and its vicinity

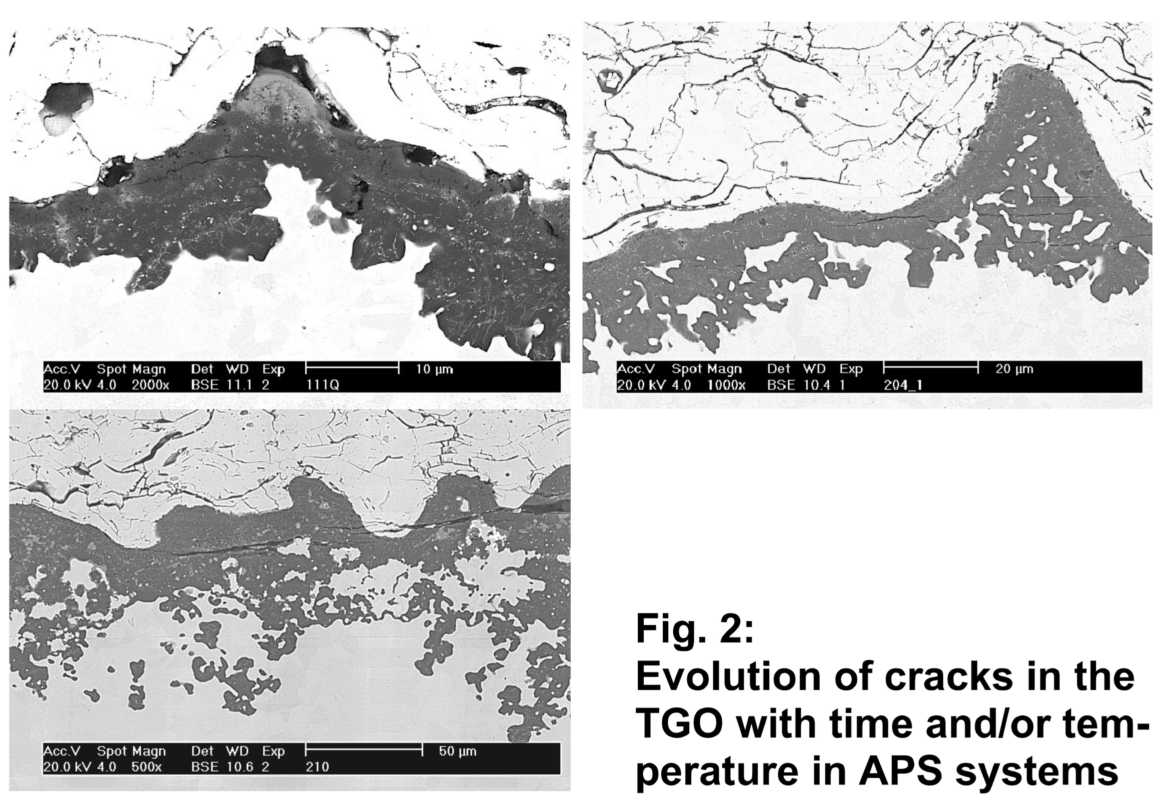

Fig. 2: Evolution of cracks in the TGO with time and/or temperature in APS systems

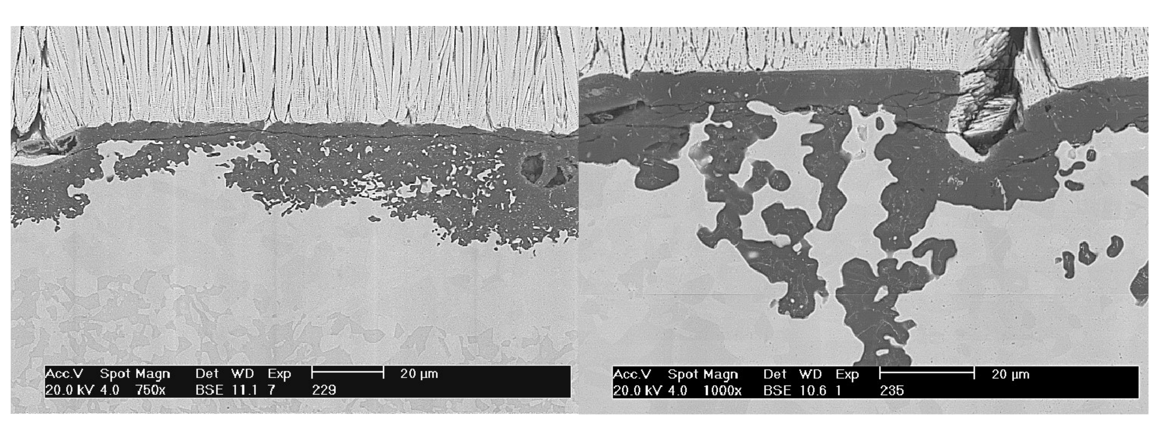

Fig. 3: Example of typical Mode B (left) and Mode C (right) cracks in PVD systems

Test Matrix of the Oxidation Specimens						
		100h	300h	1000h	3000h	5000h
950°C	APS-300		x	x	x	x
	PVD-150		x	x		x
1000°C	APS-300	x	x	x	x	x
	PVD-150	x	x	x	x	x
	PVD-300	x	x	x	x	x
1050°C	APS-300	x	x	x	x	Delamination
	PVD-150	x	Delamination	Delamination	Delamination	
	PVD-300	x	x	x	x	
1100°C	APS-150	x	x	Delamination		
	APS-300			Delamination		

Tab. 1: Test matrix of the oxidation specimens
x = without macroscopic failure
empty = not investigated

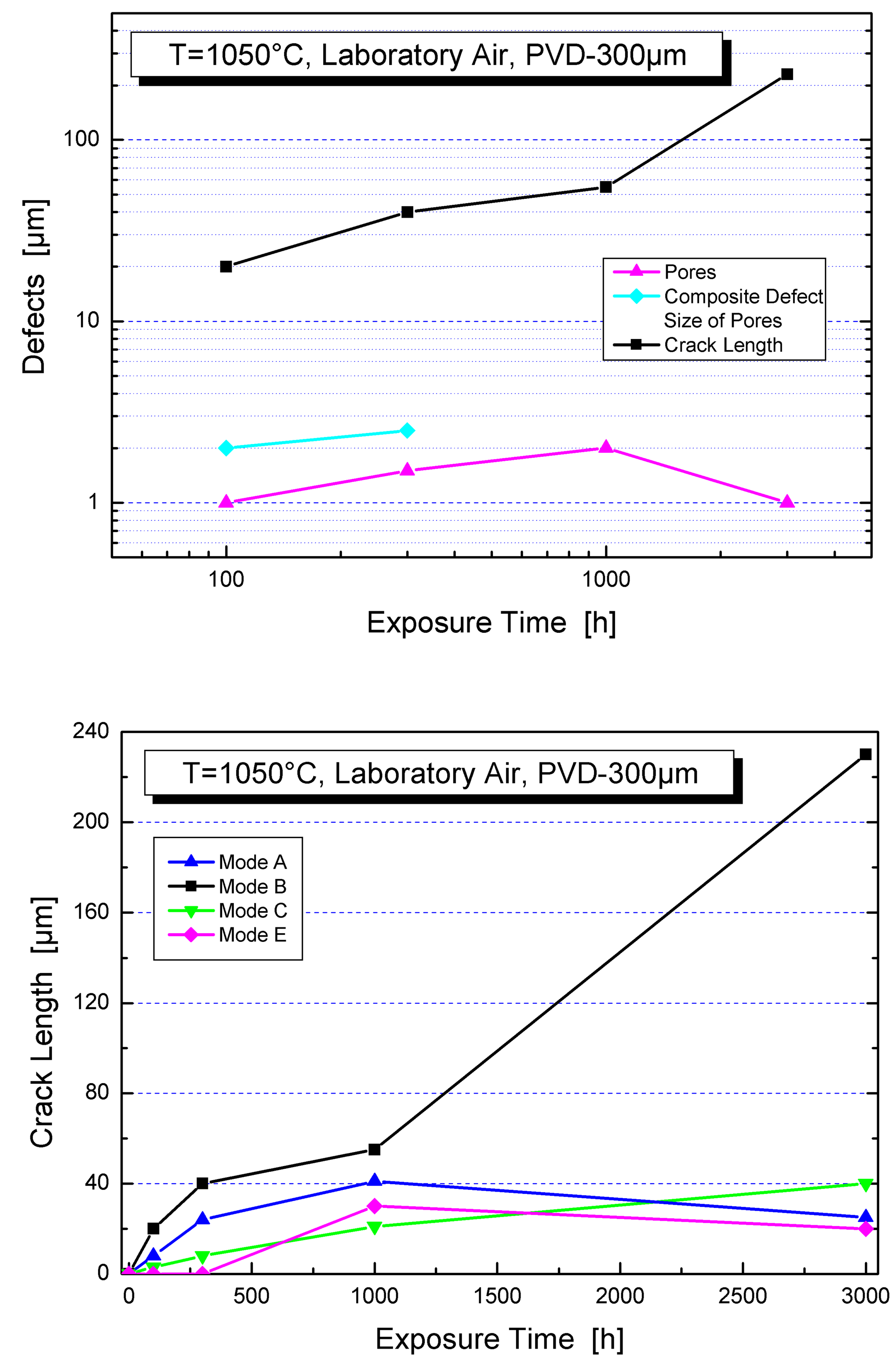

Fig. 4: Example of the kinetics of the maximum size of physical defects and of the different crack lengths

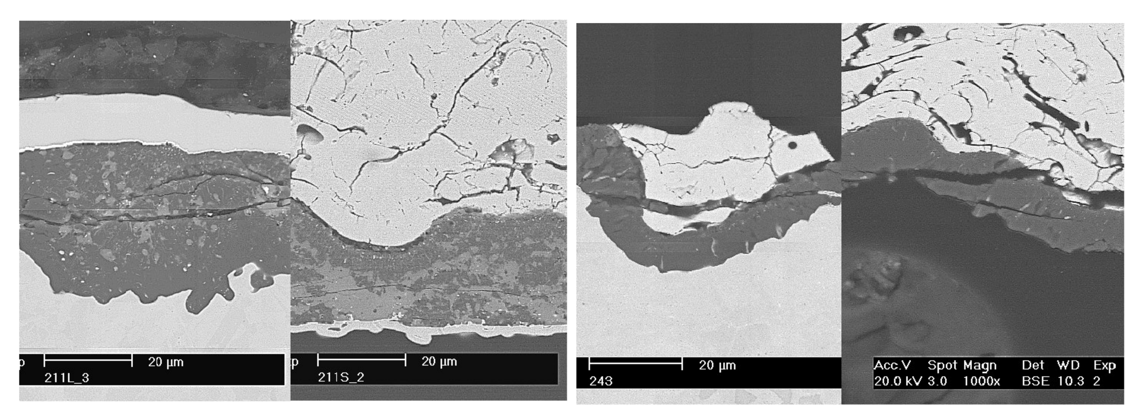

Fig. 5: Failure caused by chromia formation within the TGO, crack path within the TGO (left) and failure caused by the decrease of the adhesion properties of the interfaces, crack path through the TGO and the TBC (right)

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