

## PARTITION OF UNITY BASED COHESIVE CRACK MODELING IN A PHASE-CHANGING MEDIUM

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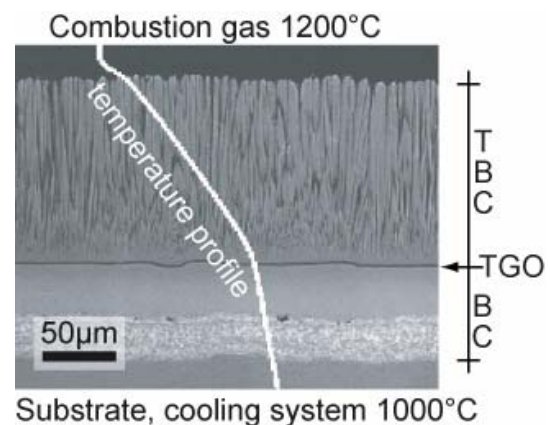
### ABSTRACT

Thermal barrier coating (TBC) systems are applied for the protection of high pressure turbine blades of aircraft jet engines. They increase the thermodynamical efficiency of the engine by allowing for higher service temperatures and they improve the chemical durability of the coated Ni-based single-crystal superalloy.

To excel in both tasks, TBC systems are designed of three different components, see Figure 1. The bond coat (BC) adheres the TBC system to the substrate. Furthermore, it functions as an aluminum reservoir for the perpetual formation of the thermally grown oxide layer (TGO). This relatively thin layer warrants the oxidation protection function since it is almost impermeable to gas diffusion. Due to its low heat conductivity, the top coating, or TBC layer, gives rise to a substantial temperature difference between the combustion gas and the substrate.

TBC systems ultimately fail when parts of the TBC layer spall off after coalescence of microcracks in the vicinity of the TGO layer. Many mechanisms have been identified to trigger this process [1], most of which are driven by the strain energy induced in the system by the large variations of temperature in combination with mismatching coefficients of thermal expansion. The presented thermo-mechanical formulation includes specific bulk constitutive models for the TBC components, among which an elasto-plastic BC model and a transversely isotropic elastic model for the TBC layer.

Special attention is dedicated to the modeling of nucleation, propagation and coalescence of discrete cohesive cracks in a mesh-independent fashion [2,3]. The developed cohesive crack model proves to be numerically stable within the framework of an implicit solution procedure. This has been achieved through several adaptations of the more-conventional way of cohesive zone modeling. When a sample point in the



*Figure 1: Micrograph section of a TBC system showing the layered composition and the temperature profile.*

bulk material reaches the fracture strength, a cohesive zone is inserted. Here, the applied cohesive law is initially rigid (i.e. the initial elastic stiffness is infinite) and is derived from an initially compliant formulation. This is done by adding an initial crack opening to the true crack opening when evaluating the initially compliant cohesive law. The initial crack opening is locally determined at the moment of crack nucleation such that the initial cohesive traction matches the stress state of the uncracked material [4,5].

The time- and temperature dependent growth of the TGO layer is modeled as a phase transformation from a BC material to a TGO material, which is driven by the local oxygen concentration. The simulation of the thermo-mechanical problem is preceded in every time step by the solution of a diffusion problem that results in an updated field of volume fractions of TGO material. The thermo-mechanical material properties at the interface between the TBC and BC explicitly depend on this volume fraction through a phase transformation model, with the BC and TGO materials as the parent and product phases, respectively. Furthermore, the crack model—designed to locally warrant continuity of the tractions at the moment of crack nucleation—had to be generalized to account for this phase transformation. This is done by making the initial crack opening a function of the TGO volume fraction.

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