

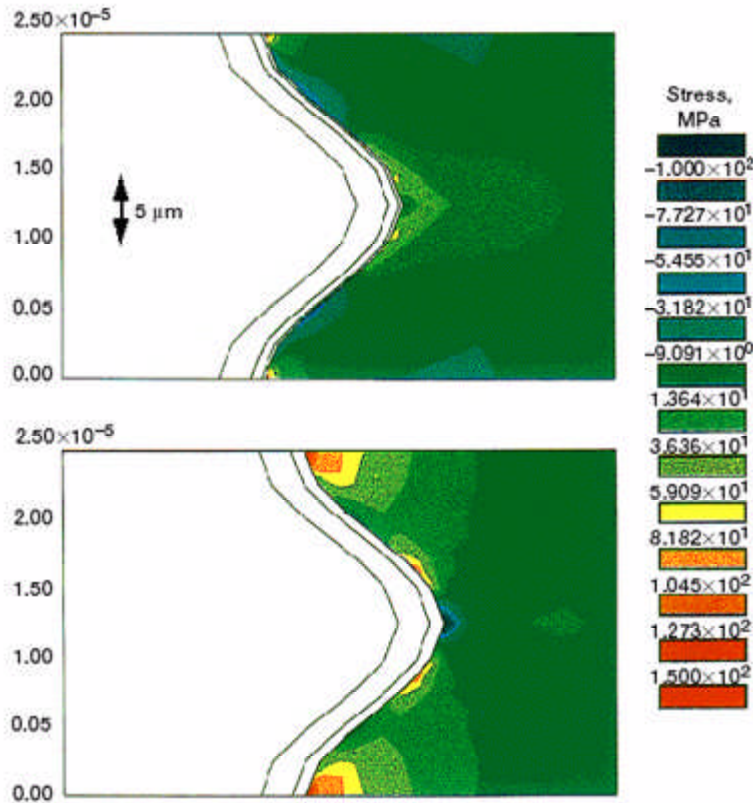
Residual Stresses Modeled in Thermal Barrier Coatings

Thermal barrier coating (TBC) applications continue to increase as the need for greater engine efficiency in aircraft and land-based gas turbines increases. However, durability and reliability issues limit the benefits that can be derived from TBC's. A thorough understanding of the mechanisms that cause TBC failure is a key to increasing, as well as predicting, TBC durability.

Oxidation of the bond coat has been repeatedly identified as one of the major factors affecting the durability of the ceramic top coat during service. However, the mechanisms by which oxidation facilitates TBC failure are poorly understood and require further characterization. In addition, researchers have suspected that other bond coat and top coat factors might influence TBC thermal fatigue life, both separately and through interactions with the mechanism of oxidation. These other factors include the bond coat coefficient of thermal expansion, the bond coat roughness, and the creep behavior of both the ceramic and bond coat layers.

Although it is difficult to design an experiment to examine these factors unambiguously, it is possible to design a computer modeling "experiment" to examine the action and interaction of these factors, as well as to determine failure drivers for TBC's. Previous computer models have examined some of these factors separately to determine their effect on coating residual stresses, but none have examined all the factors concurrently. The purpose of this research, which was performed at DCT, Inc., in contract with the NASA Lewis Research Center, was to develop an inclusive finite element model to characterize the effects of oxidation on the residual stresses within the TBC system during thermal cycling as well as to examine the interaction of oxidation with the other factors affecting TBC life.

The plasma sprayed, two-layer thermal barrier coating that was modeled incorporated a superalloy substrate, a NiCrAlY bond coat, and a $ZrO_2-8 \text{ wt } \% Y_2O_3$ ceramic top coat. We examined the effect on stress during burner rig thermal cycling of the following independent variables: creep in the bond coat and top coat, oxidation, bond coat coefficient of thermal expansion, number of thermal cycles, and interfacial roughness. All these factors were suspected of influencing TBC failure.



Contour plots showing the change in stress distribution with increasing oxide thickness at increased numbers of cycles. Top: the bond coat peak region is primarily tensile at 4 cycles, while the tensile region in the valley is quite small and adjacent to a compressive region. Bottom: At 51 cycles, the tensile region over the valley has grown substantially, while the peak region has become compressive.

The model showed that all the material properties studied had a significant effect on the coating's residual stresses if the interface of the bond coat was rough. Bond coat expansion, bond coat oxidation, and bond coat creep had the highest effect on coating stresses, and these were highly interactive. The model also showed that the mechanism of stress generation during thermal cycling changed with the number of thermal cycles. Bond coat and top coat creep dominated stress generation during early thermal cycles, greatly increasing delamination stresses at the peaks of the bond coat. Therefore, creep is the prime driver for delamination cracking early in life, but cracking is limited to the bond coat peak region. Oxidation of the bond coat, on the other hand, tended to dominate stress generation during later cycles by greatly increasing delamination stresses over bond coat valleys. These results indicate that oxidation is the driver for the continued cracking necessary to cause ceramic layer spallation.

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