Stress Measurements in Thermally Cycled Thermal Barrier Coatings

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Thermal barrier coatings are widely used in power generation and transportation engine applications to achieve higher engine efficiency by operating at elevated temperatures. Coating spallation, leaving the bare metal substrate exposed to high temperature, is a major concern. Spallation has been associated with stresses generated in an oxide layer formed during exposure of the coated components to elevated temperature, but the stress evolution and failure mechanisms are not understood. We are measuring these stresses and relating them to microstructure evolution in the oxide layer as a function of thermal exposure.

We are measuring stress evolution in the thermally grown oxide (TGO) that forms in thermal barrier coating (TBC) systems at elevated temperature. The TGO forms between the TBC and the metallic bond coat and forms an oxidation barrier that protects the metallic substrate from chemical attack. Stresses form in the TGO as it grows, and the eventual spallation of the coatings has been attributed to these stresses. However, the evolution of stress with time and the dependence of the stress on microstructural changes that lead to spallation is not understood.

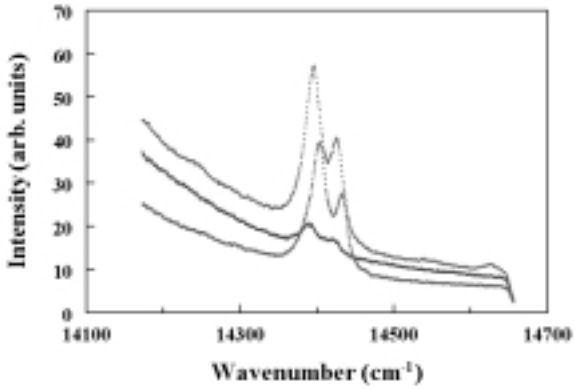

Figure 1: Photoluminescence spectra of the alumina TGO in a plasma sprayed TBC. Differences in peak positions of the three curves reflect different stress states of the TGO.

We are using photoluminescence (PL) of the alumina TGO to monitor the value of the stress tensor as a function of thermal cycles (Figure 1). Our PL data indicate that, after one thermal cycle to 1150 °C, there was a wide range of compressive stress in the alumina (Figure 2). As the number of cycles increased, the range of stress values narrowed substantially. We were surprised to see that the median stress value remained nearly constant during this thermal treatment. After 350 thermal cycles, the coatings completely spalled from the substrates at room temperature, accounting for the stress relief seen in Figure 2.

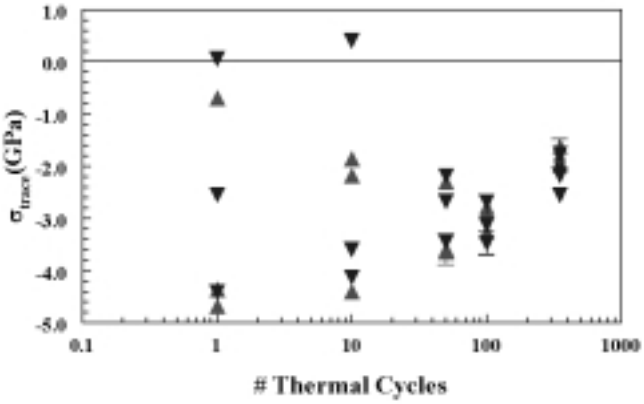

Figure 2: Trace of the stress tensor in the TGO as a function of numbers of thermal cycles. Two specimens were measured after each period of thermal cycles. The wide range of data reflects widely varying stress values from point to point.

Measurements made on the same specimens several weeks after thermal treatment indicate that substantial stress relaxation had occurred (i.e., stress values were still compressive, but were nearer to zero). Micrographs of the TGO show extensive microcracking had occurred. The microcracking was particularly severe for the specimens that had undergone 100 thermal cycles, and the cracks extended into the adjacent TBC.

In contrast, measurements made at room temperature as a function of time after 100 h exposure to 1150 °C but without cycling did not exhibit this stress relaxation. The TBC specimens used in this latter set of experiments were obtained from a different source, although the composition was very similar to the first set of specimens. We are in the process of comparing the microstructure of both sets of specimens to try to understand this difference in behavior.

Contributors and Collaborators

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DoE and NASA were sources of specimens