# HEXRD Measurements of In-plane Residual Stress in Plasma Spray Thermal Barrier Coatings

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## Introduction

The demand to increase gas turbine engine performance in terms of higher thermal efficency and lower emissions has continued to be a driving force in the development of thermal barrier coatings (TBCs), which commonly consist of a MCrAlY oxidation-resistant bond coating and a yttria-stabilized zirconia (YSZ) top coating. Plasma spray is one of the major methods used to deposit TBCs. As a result of the plasma spray deposition process, the coating contains residual stresses. There are two major sources of residual stresses during thermal spraying of a coating [1]. First are quenching stresses that come from the rapid contraction of individual droplets as they cool from the deposition temperature to the temperature of the underlying materials. Second are thermal stresses that contribute to the thermal-expansion mismatch between the coating and the substrate material when the sample or part cools from the deposition temperature to room temperature. The residual stress is a crucial factor that affects TBC durability. In this work, we measure the distribution of these stresses with depth by using high-energy (HE) x-rays, with the ultimate goal being to control their formation and evolution during service.

## Methods and Materials

A CoNiCrAlY bond coat and YSZ top coat were deposited on 25.4 × 50.0 × 2.4-mm Hastelloy® X substrates by air plasma spray. The thickness of the YSZ layer and bond coat layer were 1.2 mm and 0.17 mm, respectively. The specimen was sectioned to a 3-mm width by a precise diamond saw. Figure 1 is a schematic of the transmission geometry used. Samples were investigated at beamline station 11-ID-B at the APS. Slits were used to define a 92.6-keV beam having a size of dY = 0.03 mm by dX = 0.1 mm. The depth profile of the residual stress across the TBC was measured by translating the sample along Y with respect to the fixed beam, at a step size of 0.05 mm. X-ray diffraction data were collected at each position by using a 2-D Mar345 detector.

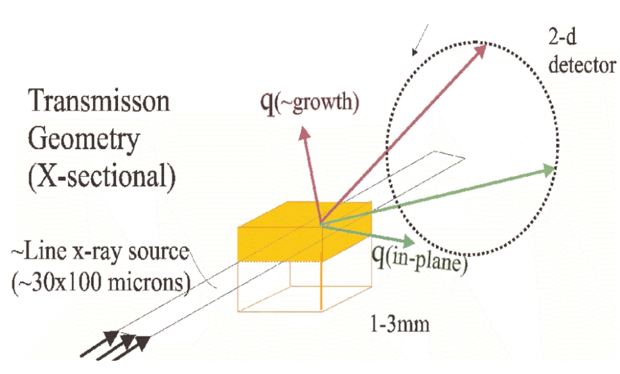


*FIG. 1. Schematic of transmission geometry employed.*

## Results

Figure 2 shows the x-ray transmission across the specimen. It shows that the bond coating had higher x-ray transmission than did the YSZ ceramic coating. The results were used to identify the interface and top surface of the coating.

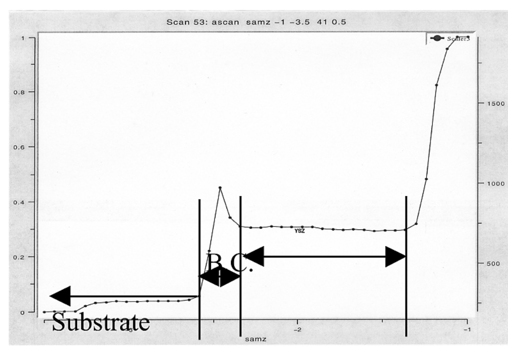


*FIG. 2. X-ray transmission across the specimen.*

Figure 3 shows a typical 2-D x-ray diffraction (XRD) pattern taken from TBC. A cake of –5° to +5° along the x-axis was selected to measure in-plane residual stress, which was the direction of primary interest. The selected data were transferred to a plot of x-ray intensity versus d-spacing (Fig. 4).

The major diffraction peaks were identified as tetragonal YSZ. The YSZ(220) diffraction peak was selected to calculate the in-plane lattice strain in the TBC. These strains were converted to stresses by using an elastic modulus of E = 36 GPa and Poisson ratio of 0.11. Figure 5 shows the resulting depth profile of the in-plane residual stress in the TBC.

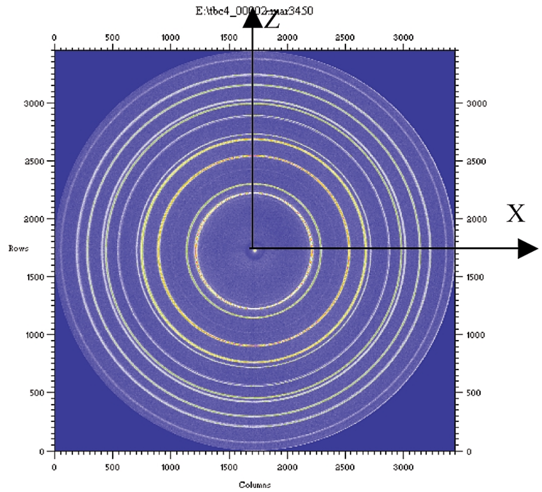


*FIG. 3. A typical 2-D XRD pattern of YSZ TBC.*

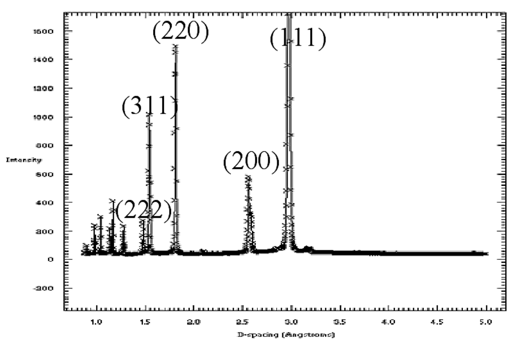


*FIG. 4. A plot of d-space versus x-ray intensity around the x-axis from Fig. 3.*

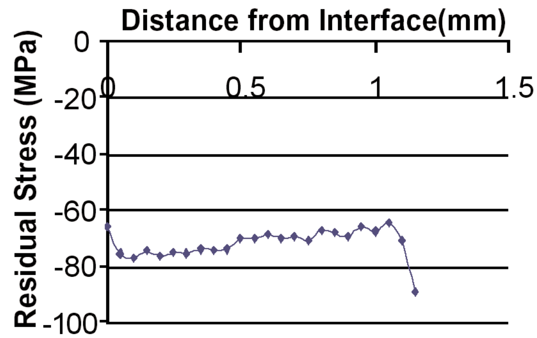


*FIG. 5. Depth dependence of the residual stress in the YSZ top coat.*

## Discussion

Using HEXRD and transmission geometry to measure residual stress as a function of depth in TBCs has been shown to be feasible. The results indicate that there was an in-plane compressive stress in the TBC. The residual stress varies only slightly across the top coat's thickness, except at the interface of the TBC and bond coat and near the top surface.

We attribute the compressive nature of the residual stresses to the sample cooling from the spray temperature due to the thermal-expansion mismatch between the substrate and coating. The formation of any quench stresses, which are predicted to be tensile in TBC as a result of the shrinkage of hot ceramic drops on the colder substrate [2], might be released by microcracking of TBC.

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## References

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