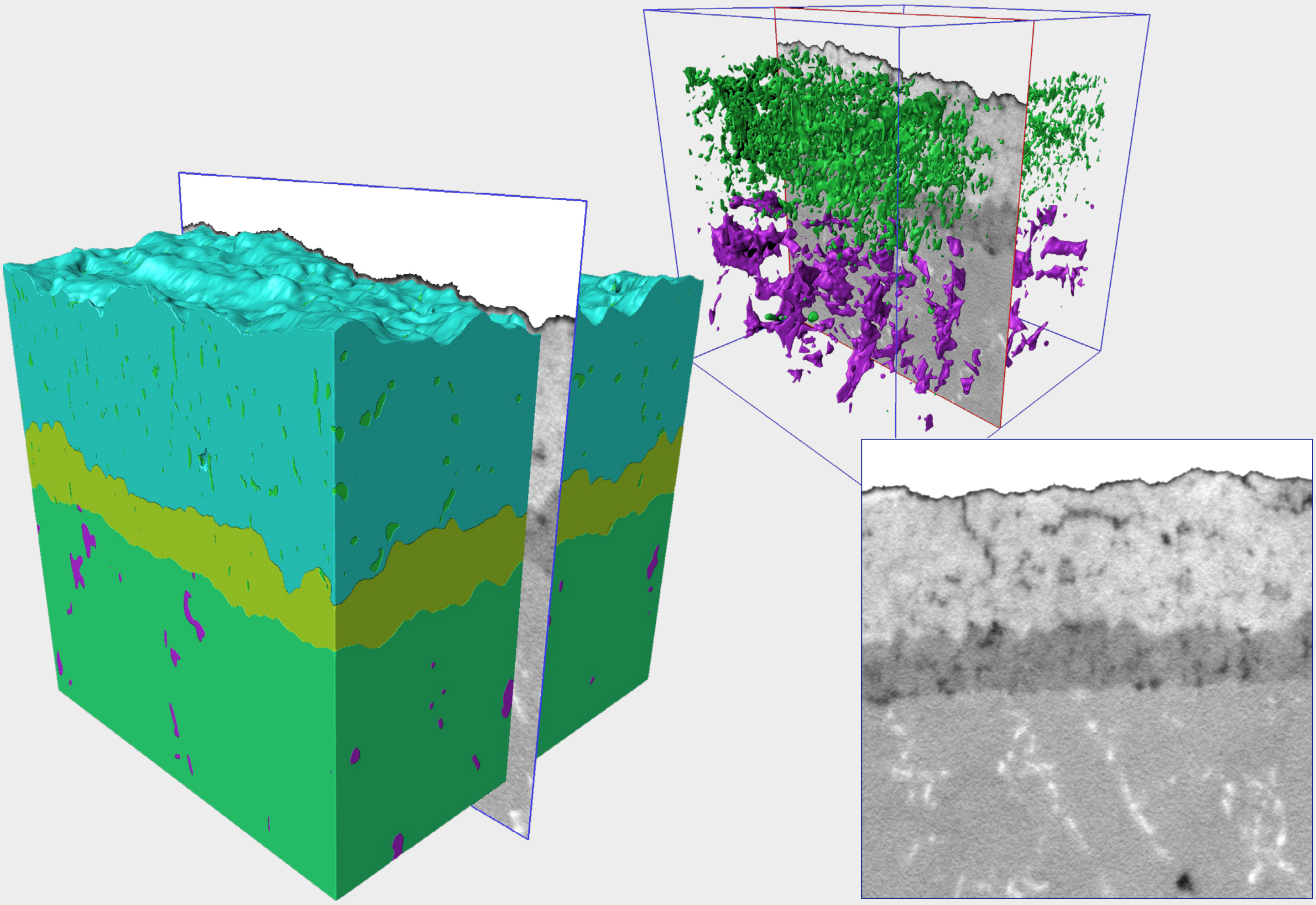

Non-destructive Microstructural Characterization of Thermal Barrier Coating (TBC)

ZEISS X-ray Microscopes

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Thermal barrier coatings (TBC) are advanced material systems commonly used in high-temperature gas turbines, aero-engines, and combustion engines. Due to their low thermal conductivity and high chemical stability, TBCs are commonly applied to metal substrates to serve as a resistant barrier against thermal degradation and oxidation.

Introduction

A typical TBC system consists of three layers of materials: metal substrate, bond coat, and top coat. Bond coat, usually made of aluminum oxide, offers an interfacing layer between metal and top coat. It also serves as a layer resistant to oxidation and hot corrosion. Top coat, typically yttria-stabilized zirconia (YSZ), has very low thermal conductivity for insulation, enabling higher operating temperatures and reducing air-cooling requirements.

TBC properties and insulating performance are largely deter-mined by its microstructures, including pore morphol-ogy, porosity, coating thickness, and microcrack formations. Porosity change in thermal cycles, for example, has significant effect on thermal conductivity, resulting in the variance in strength of top coating. In order to control the micro-structures and coating properties, it is critical to understand the links between microstructures and TBC properties.

Xradia Versa is a lab-based 3D X-ray microscope that offers a novel solution for submicron (500 nm) imaging and three-dimensional characterization of TBC systems. X-ray imaging is non-destructive in nature, and the system's unique architecture enables high resolution imaging of interior structures in relatively large TBC samples.

Benefits of 3D X-ray Microscopy over Traditional Methods of Analysis

Optical microscopy and scanning electron microscopy alone have been prevalent methods for TBC microstructural characterization in the past, but the common disadvantage of these techniques is that they only offer 2D information and destroy the specimen to observe interior structures. The physical cross-sectioning required also can introduce artificial cracks and may cause delamination of the top coat. More recently, 3D optical coherence tomography and thermal tomography techniques have been used to characterize TBC layers. Although non-destructive in nature, they are limited by either low penetration depth (a few hundreds of microns) or poor spatial resolution (a few tens of microns).

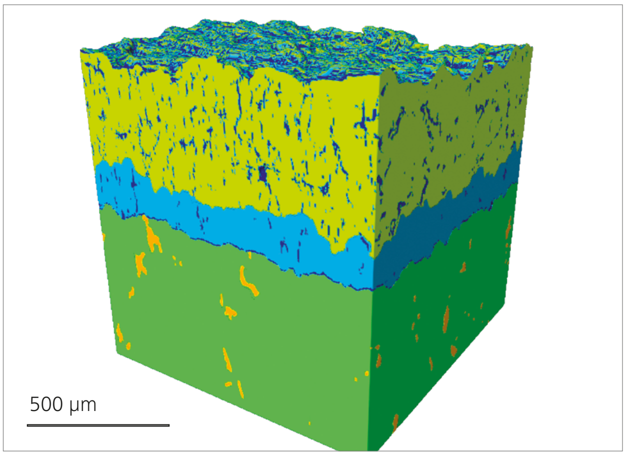


Figure 1 3D surface color-rendered image of a TBC system. Metal substrate (Ni super-alloy) is labeled in green at the bottom; bond coat in light-blue in the middle and top coat in yellow on the top. The blue in the top coat layer represents internal voids or cracks. The orange in Ni super-alloy substrate represents high-Z material segregation.

Methodology and Results

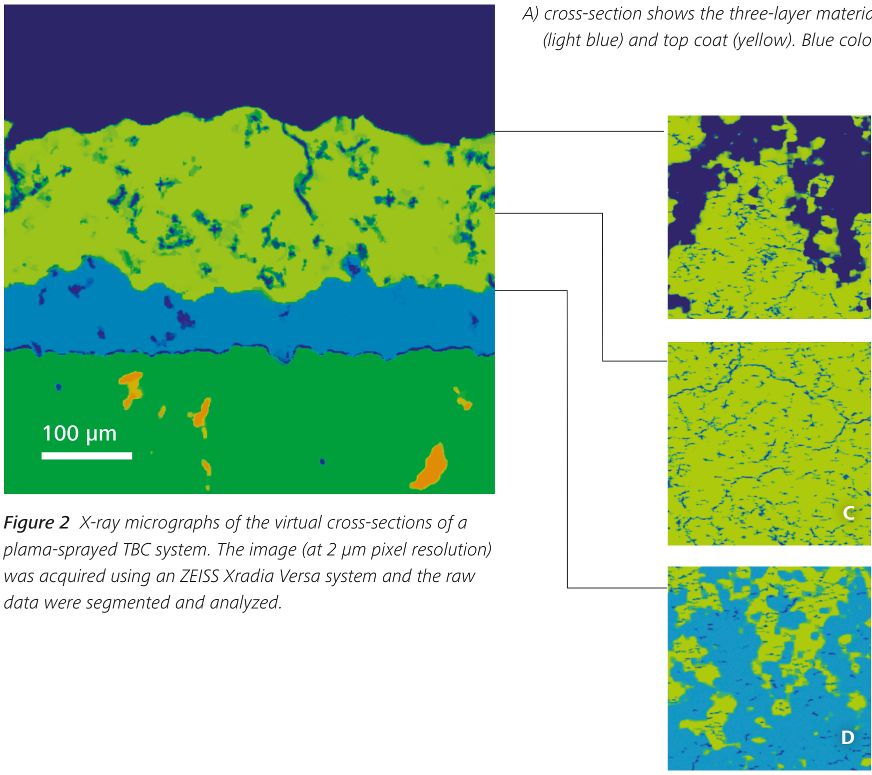
In this example, we present imaging and analysis results of a 1 mm thick thermal-cycled TBC system that was fabricated using a plasma-sprayed coating process (Figure 1). The tomography was acquired using ZEISS Xradia Versa, operating at 150 kV. Segmentation and quantitative analysis were performed using water-shed algorithm and tophat techniques.

We found the Ni super-alloy substrate had 5% high-Z inclusion, originating from material segregation during high-temperature thermal cycles. The porosity of bond coat and top coat is about 1.2% and 7.8%, respectively. Suspected delamination at the interfaces of bond coat and top coat were not found, indicating that the TBC system was still in good condition after thermal cycles. Cracks that were several microns to hundreds of microns long appeared in the layer of top coat (Figure 2c) due to the thermal mismatch of the top coat and bond coat.

The observed micro-cracking is an important failure mode of TBC systems because it potentially results in topcoat delamination. Virtual cross-sections throughout the 3D TBC image also indicated that the three TBC layers interfaced in a more complex geometry than simple sinusoids, which had been the assumption of the researchers when building models.

Conclusion

ZEISS Xradia Versa X-ray microscopes can provide unique value for the 3D characterization and quantitative analysis of TBC systems, which are often difficult to achieve with other traditional microscopic techniques. Due to its non-destructive nature and unique architecture design, ZEISS Xradia Versa is able to acquire high-resolution and artifact-free 3D images of TBC systems from which one can extract volumetric and quantitative information of key features of interest, such as layer interface, pore morphology and volume percentage, voids, and microcracks.



A) cross-section shows the three-layer materials system: Ni super-alloy (green), bond coat (light blue) and top coat (yellow). Blue color represents internal voids or cracks

B) interface of top coat and air (dark blue)

C) a cross-section of the top coat

D) interface of the bond coat and the top coat.

The relative positions of cross-sections (B-D) to (A) are indicated by the markers pointing left.

Figure 2 *X-ray micrographs of the virtual cross-sections of a plama-sprayed TBC system. The image (at 2 µm pixel resolution) was acquired using an ZEISS Xradia Versa system and the raw data were segmented and analyzed.*

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