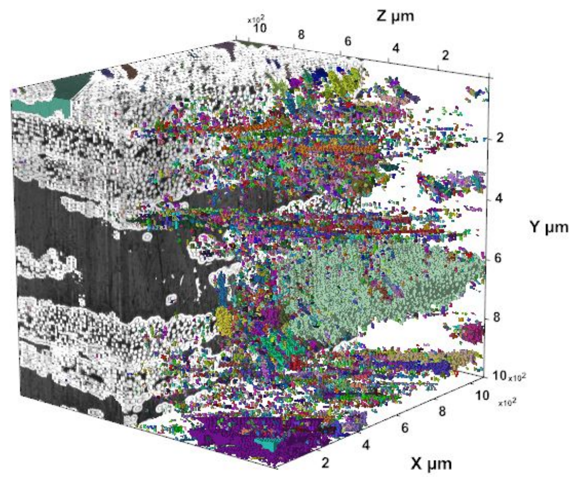
3D INSIGHTS



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3D Characterization of Porosity and Fiber Orientation in a Ceramic Matrix Composite Preform

We analyzed the porosity, volume percentage of fibers or matrix phases, and fiber orientation of a ceramic matrix preform using Robo-Met.3D®. The Robo-Met.3D system revealed the desired features in the CMC. Post processing segmentation was used to reveal the pore and fiber distribution separately, with their volume percentages.

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MATERIAL BACKGROUND

Accurate characterization of fiber and pore micro-structures plays a central role for material scientists to analyze physical properties of continuous fiber reinforced composite materials[i.] Ceramic matrix composites (CMCs) have the potential to enable the next generation of high speed hypersonic vehicles and/or significant improvements in gas turbine engine performance[ii.] Developing a more thorough understanding of open and closed pores and fiber orientation in CMC preforms is a vital aspect of generating an accurate predictive model for the processing response of CMCs. In this application note we describe the serial sectioning analysis of a CMC preform.

AUTOMATED SERIAL SECTIONING ANALYSIS USING ROBO-MET.3D®

RoboMet.3D is a fully automated serial sectioning system that generates two-dimensional optical microstructural data for three dimensional reconstructions. Common applications of Robo-Met.3D include studying additively manufactured components[iii], analysis of welds and thermal barrier coatings[iv], and fiber orientation effects in ceramic matrix composites[v]. A Hi-Nicalon-S partially densified preform, with a BN fiber coating and a SiC overcoat was provided UES, for analysis of open vs closed porosity. Optical images were automatically acquired with the microscope built into the Robo-Met.3D system, at a magnification of 100x. The resultant spatial resolution was 1.08 microns along X and Y axes. Over a millimeter of z-dimension was analyzed (1056.5 microns) in 124 slices at an average slice thickness of 8.5 microns. Each slice contained a montage, for an image size of 1000 microns along x and y axes each.

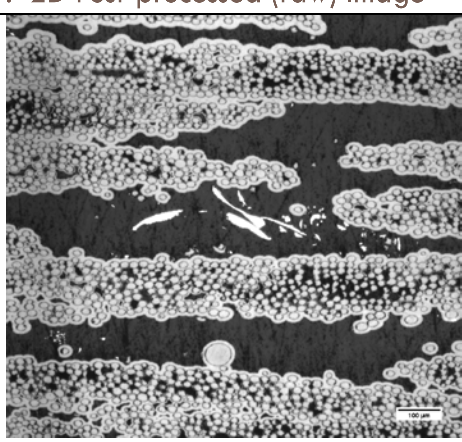
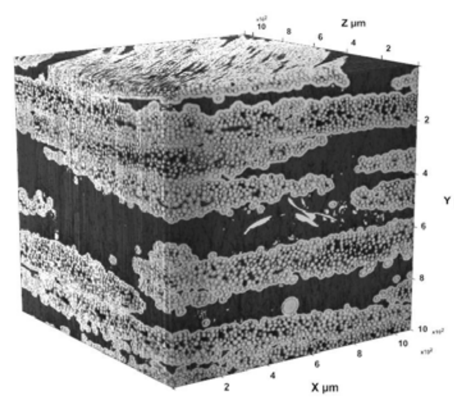
Fig. 1: 2D Post-processed (raw) Image	Fig. 3: 3D Image (stack of 124 slices)
	

IMAGE PROCESSING

The 2D image tiles from each layer were stitched into montages (or mosaics) and then registered with the images from the next layer using Fiji and Image J software. 3D analysis was performed using Image-Pro Premier 3D v.9.2.2 (Media Cybernetics, Inc., Washington, USA). For 3D analysis, the loaded z-stack of 124 slices was processed with full resolution along X, Y and Z directions. A 3D isosurface was created without any filtering to extract the volume distribution of the fiber and pore phases, and infiltrated mount compound in the preform (Figs. 4, 5). An image histogram was used to threshold the porosity and fiber phases. Based on intensity values and the intensity, the range for porosity is set to 0-119 (including mount compound), and fiber phase to 120-255. For quantification, size threshold feature was set to 5 microns along width, height, and depth; and volume parameters were extracted. The segmented images were analyzed using routines built into Image-Pro, to analyze the percentage of pores and fibers. The volumetric conclusions (with ~ 1% error) are presented in the table below.

Fig. 4: Segmented Fiber Phases

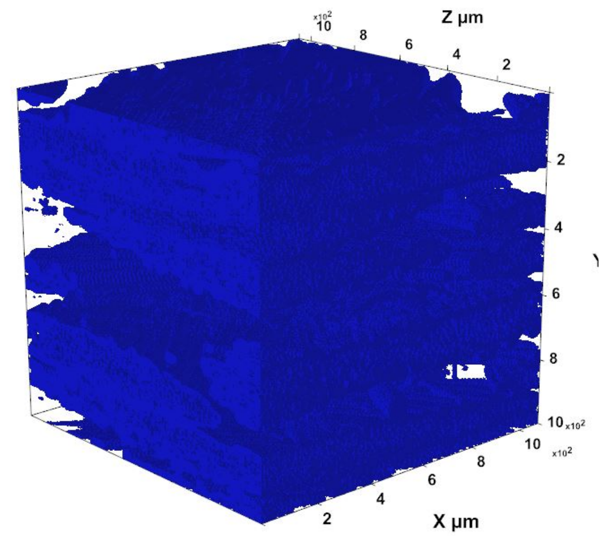
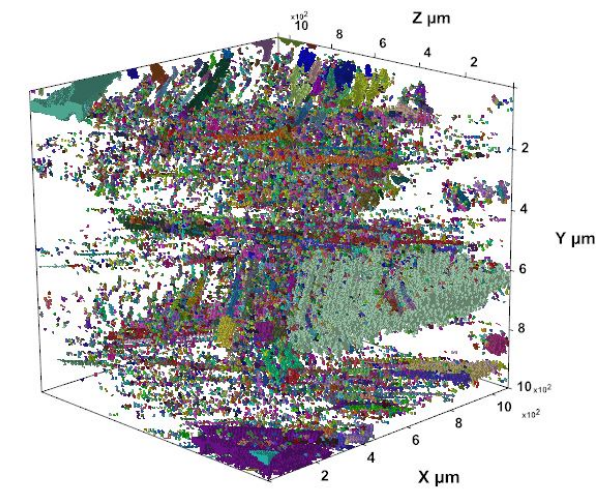


Fig. 5: Segmented Pore Phases



Each pore was identified with specific index value based on size. The porosity of the CMC is calculated by the volume of pores divided by the total volume of the sample. Closed porosity was approximately 2.68 vol %. A majority of the pores were sized between 5-100 microns (Feret diameters). Average values of Feret maximum and minimum diameters obtained were 21.9 and 7.3 microns.

Table 1: Volumetric Analysis of the Regions

Color Label	Feature	Volume Percentage
Blue	Fiber	60.9%
Others	Closed Porosity	2.7%

Orientation and wave of the fiber are clearly visible in the 3D analyses. In reviewing the images, it is possible to observe the evolution of potential inclusions, as well as an anomalously large fiber transitioning through the volume. The segmented fiber phase, shown in greater magnification in Fig. 6, illustrates the detail to which fiber orientation can be captured. Recent advances in applying serial sectioning for metallic textiles[vi], analyzing the bonding efficiency and weave geometry to inform the weave processing as well as incorporate these parameters in the development of material models for more accurate performance prediction, may be the next evolution of CMC serial sectioning analysis as well.

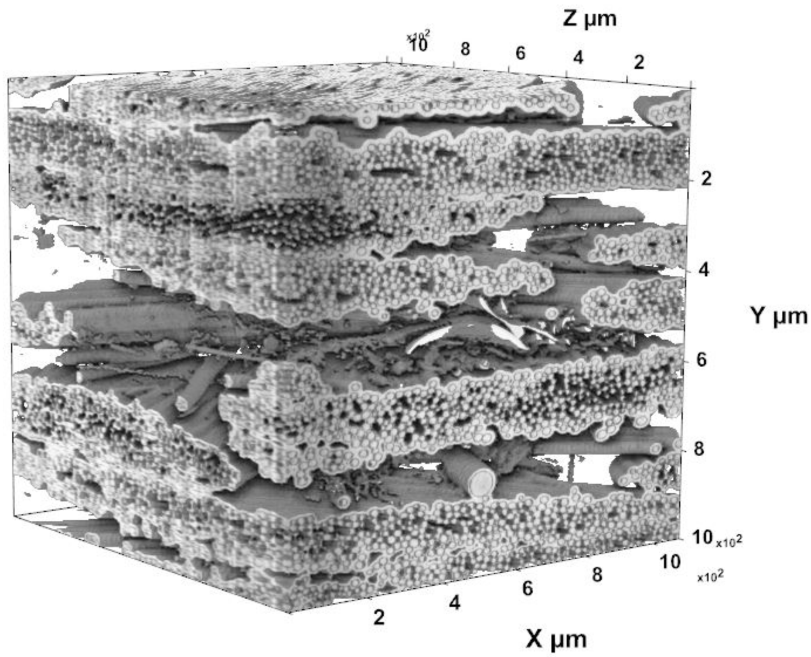


Fig. 6: Fiber Phase of CMC Preform

CONCLUSIONS

From this analysis, we were able to conclude that identification, segmentation and quantification of the defect such as porosity, fiber content and orientation was possible using Robo-Met.3D aiding in structural analysis of the CMC.

CONTRIBUTORS

We are grateful to Michael Cinibulk of the US AFRL/RXCC for CMC sample. Bryan Turner (UES), and Satya Ganti (UES) performed the image collection and post-processing, and Kristin Keller contributed to the analysis. Animated views of the data are available at http://www.ues.com/forums/forum/applications/.

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