Combined Diffraction and Tomography Analyzing Controlled Residual Stress in Solid Freeform Fabrication

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Introduction

With their high modulus, hardness, and chemical stability, ceramic materials are ideal for applications under significant compressive stress and wear. However machining of ceramics is difficult—limiting many applications requiring complex geometries. A new rapid prototyping method, robocasting, enables direct fabrication of complex ceramic parts.[1, 2] Beyond control over complex external form of parts, its precise geometric control over constituent phases and mixing allow interface construction including graded interfaces. With this precise control over the geometry and phase, ceramics with similar sintering temperatures but different coefficients of thermal expansion, may be robocast with a compressive residual stress at an interface or surface to inhibit crack initiation and improve damage tolerance.

Using 2-BM of the Advanced Photon Source, the residual stress at an interface of a robocast ceramic-layered composite was determined. The combined use of imaging and diffraction allowed precise positioning of the micro-beam and geometry relevant measurement of residual strains.

Methods and Materials

A cylindrical test specimen using layers of alumina and zirconia inks was chosen for application to combined X-ray micro-tomography and X-ray micro-diffraction (as in [3]). At 17.9 keV a Be parabolic refractive X-ray lens [4] facilitated fast switching between the large parallel imaging beam and the micro-diffraction beam (Fig. 1). The imaging detector allowed for exact positioning of the beam spot at interesting regions of the sample geometry determined by tomography and radiography. Accurate alignment is necessary for registration of the strains to locations in the images.

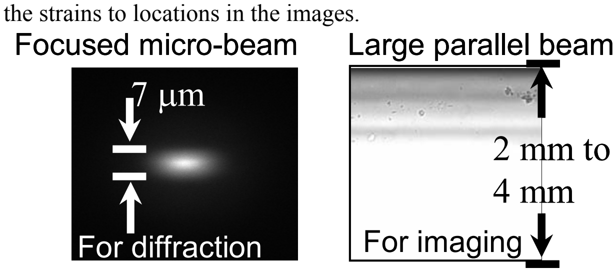

Fig. 1 Two transmission CCD images. Left: Diffraction beam spot (Be lens in). Right: The direct beam (Be lens out).

Results

Referenced to a monolithic sample, the composite showed compressive residual strain near the interface (stress direction: σ, Fig. 2). The strains relaxed approaching a stress-induced crack in the alumina phase (Fig. 2). Fit errors for the strains are marked with error bars. Tomography provided the geometry of the crack with phase contrast enhancing crack detection. X-ray transmission provides a component of the stress tensor integrated through the sample as opposed to other methods that observe only surface strains.

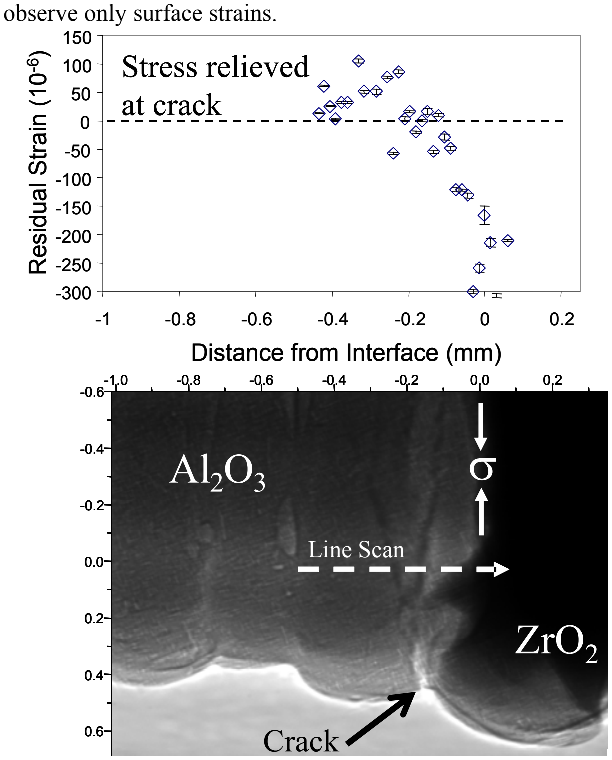

Fig. 2 Top: Residual strain, along σ, in the alumina phase at steps following the dashed line in the radiograph. Bottom: Radiograph showing a crack and the interface.

Discussion

Tomography provides density and a detailed 3-D digitized surface. The measured residual strain provides critical information on the mechanical state of the interface. Both data aid understanding and modeling the mechanical performance of ceramic composites. Stress relaxation at the crack and during cooling help explain the magnitude of stresses observed.

Acknowledgments

Use of the Advanced Photon Source was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-Eng-38.

References

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