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SYNCHROTRON MICRO-TOMOGRAPHY WITH IN-SITU ENVIRONMENTS AT THE ADVANCED LIGHT SOURCE

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Summary: Synchrotron sources provide high flux X-ray beams enabling time-resolved microscale tomography. Beamline 8.3.2 at the Advanced Light Source performs these analyses at high temperatures, pressures, with mechanical loading, and other realistic conditions using environmental test cells to observe dynamic microstructural phenomena. We present recent instrumentation developments aimed at improving temporal resolution and enabling the next generation of sophisticated in-situ experiments.

1. INTRODUCTION

The Advanced Light Source (ALS) is a third-generation synchrotron X-ray source that operates as a user facility with more than 40 beamlines hosting thousands of users every year. The ALS provides high quality X-ray beams, with flux that is several orders of magnitude higher than lab-based sources. High flux beams enable time-resolved microscale imaging and computed tomography (μCT). Beamline 8.3.2 at the ALS performs these analyses using environmental test cells to provide high temperatures, pressures, mechanical loading, and other realistic test conditions to study a variety of materials and applications.

With the 4.3 T superconducting bend magnet source at 8.3.2, μCT scan times of 10s-100s of seconds are readily achieved, enabling in-situ studies that capture the microstructural evolution of materials on relatively short timescales. This is done primarily with quasi-static experiments, whereby specimens can be exposed to incremental mechanical or thermal loading with scans between each step to observe changes of the materials structure as conditions are applied.

Improving the tomography scan rate to $\sim$1 scan/sec is advantageous for experiments that evolve on fast timescales or experiments that cannot be performed quasi-statically. Fast tomography requires optimization the X-ray imaging system, data acquisition, and data processing to maximize image quality, all currently being explored at 8.3.2. In addition a new tomography stage is currently in development and under construction to accommodate larger environmental chambers and taller samples to enable the next generation of increasingly sophisticated in-situ μCT experiments.

2. IN-SITU ENVIRONMENTAL CELL DEVELOPMENT

Numerous in-situ environmental cells have been developed at 8.3.2 for analysis of materials with mechanical and thermal loads. Uni-axial loading at high temperature ($> 1000°$C) has been performed extensively for aerospace materials in addition more recent developments in in-situ 3-point and 4-point bending tests [1]. For certain advanced materials such as spacecraft heat-shields, the material evolution must be studied continuously over well specified temperature, pressure, reactive atmospheric trajectories. An exciting example of development in this area is a new tomography cell that generates these time varying conditions in-situ to simulate spacecraft atmospheric entry. Preliminary experiments have demonstrated fast μCT, capturing the material's evolution in multiple 3 second scans (figure 1a). Upcoming experiments will combine the capabilities of this in-situ cell with the new tomography stage at 8.3.2 to perform continuous real-time μCT analysis of heat-shield materials.

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3. TOMOGRAPHY STAGE DEVELOPMENT

As more complex experiments are designed and in-situ sample environments become more sophisticated, it is imperative to relieve geometric constraints that limit sample chamber size, while also providing simplified access to fluid, gas, and electrical connections. At 8.3.2, a new tomography stage (figure 1b) was developed and will be installed and in operation by early 2017. This stage features 90 cm of vertical travel and a 15 cm diameter air-bearing rotation stage with clearance for up to 35 cm diameter chambers. In addition, an upper and lower slip-ring assembly that tracks the rotation stage and provides fluid, gas, and electrical connections from above and below enables continuous tomography of complex in-situ cells. Clearance around the stage opens up possibilities for new applications such as biaxial loading in chambers with multiple actuators. Long vertical travel will also benefit studies that require tall specimens, such as agricultural sciences and plant biology where scanning ∼1 m tall live plants is highly desirable.

4. HIGH SPEED TOMOGRAPHY

To increase the rate at which data can be collected, high speed tomography is often performed with shorter exposure times and fewer projections than would give optimal image quality for a static tomography experiment. In many cases, high speed tomography is also performed using sample environments which restrict certain views or in other ways introduce artifacts into the images. Because of these issues, it is critical to take advantage of advanced algorithms that yield maximum quality reconstructions despite the limitations and artifacts present in the raw data. One approach uses machine learning to improve reconstruction quality by learning object-specific and experiment-specific information from data acquired with a static sample [2]. A different approach is to use an acquisition method optimized for time-resolved tomography, and compute reconstructions using an advanced iterative algorithm specifically designed for such data [3]. These topics are being actively explored and will contribute to the quality and speed of our μCT measurements.

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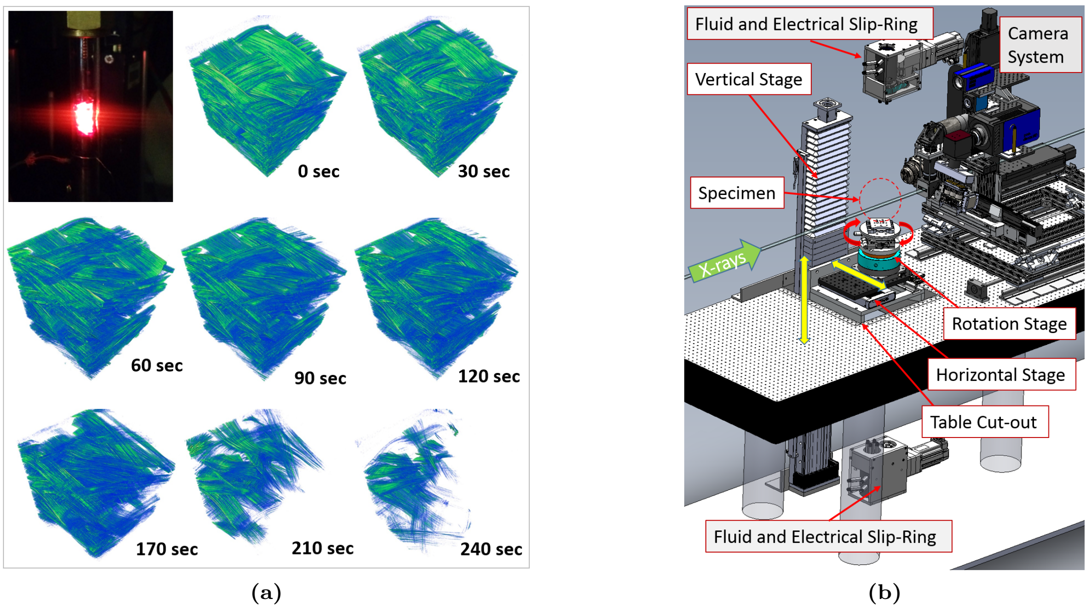

Figure 1: (a) Time resolved atmospheric decomposition of woven carbon fiber heat-shield material observed with μCT. (b) New μCT stage developed at beamline 8.3.2 that can accommodate chambers or specimens up to 1 m tall and 35 cm diameter with rotating electrical and fluid connections from above and below.