Three-dimensional X-ray Microtomography and Virtual Reconstruction of a Solid Foam

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Introduction

Solid foams are used for a variety of industrial applications, including filtration, shock absorption, and lightweight building material. Despite this fact, few studies investigate in detail the relationship between foam microstructure and elasticity in three dimensions [1]. We report here on 3-D imaging of mass density distribution in an open-cell polyurethane foam by using synchrotron x-ray microtomography (XMT) and on the virtual reconstruction (VR) of the foam by using medial axis software. Simple knowledge of the spatial distribution of mass in a sample, as provided by XMT, allows many important structural parameters to be calculated. However, the VR of a material opens a far wider range of possible investigations, through system-specific high-order correlations and data-initiated simulations [2, 3].

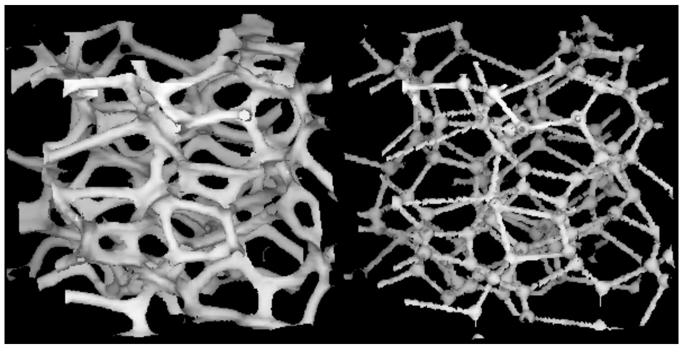

FIG. 1. Left: A 3-D surface rendering of a tomogram subsection, 1.33 mm on a side. Right: A virtual reconstruction of the same subsection.

Methods and Materials

This experiment was performed at the Pacific Northwest Consortium Collaborative Access Team (PNC-CAT) bending magnet beamline (sector 20-BM) at the APS. This beamline is optimized for x-ray absorption spectroscopies with a double Si <111> monochromator with an energy bandwidth of less than 2 eV for the photon energies used here. The narrow bandwidth of this monochromator is not necessary for tomography, but we have found that the incident flux is still sufficient for rapid XMT of many samples. The monochromator is detuned ~20% to effectively eliminate the contribution to the flux from Bragg harmonics. All data were collected during top-off mode operation of the synchrotron.

The area detector of our tomography apparatus follows the general considerations of Koch et al. [4] and uses a 12-bit thermoelectrically cooled charge-coupled device (CCD) camera (Roper Scientific). The scintillator is a 0.5-mm-thick YAG:Ce plate, and a Nikkor 24-mm (1:2.8) camera lens was used to focus the radiogram onto the CCD so that the effective pixel spacing is approximately 16.7 μm.

The tomography sample stage consists of two small linear translators for centering, mounted on an air-bearing rotation stage (Precision Instruments) and actuated by a stepper-motor-driven worm gear. The motorized rotary stage is itself mounted on a tilt stage with a tilt axis approximately parallel to the x-ray beam detection. A second tilt axis in the horizontal plane but normal to the beam is provided by the independent vertical adjustment of the legs of the experiment table in 20-BM-B. These two tilts are adjusted to ensure that the rotation axis is simultaneously perpendicular to the beam direction and to the effective CCD line scan direction with a precision of 0.5 mrad. The GRIDREC fast Fourier tranform (FFT)-based algorithm is used to reconstruct the tomograms from the rotational sequence of radiograms.

The sample studied was an open-cell polyurethane foam with approximately 60 pores per inch. Polyurethane foams like this one are frequently used for shock absorption and as a lightweight packing material. The sample was manually cut into an $8 \times 8 \times 20$-mm shape. A rotation sequence of approximately 1600 radiograms was obtained at a photon energy of 7 keV. Each radiogram was white-field and dark-field corrected and exposed for 2.5 s, for a total experimental time of 90 min.

A virtual reconstruction of the sample was performed by using the 3DMA software developed by Lindquist [5], which extracts the medial axis skeleton. This reduces the sample to a collection of idealized structural units; for an open-cell foam, these units correspond to edges and vertices.

Results

The left side of Fig. 1 shows a 3-D surface rendering of a region of the tomogram of the polyurethane foam, 1.33 μm on a side. This represents approximately 0.5% of the total volume imaged. On the right is the virtual reconstruction of the same region of the sample, with the location of each vertex in the foam identified. Visual inspection shows that the virtual reconstruction corresponds very well to the structure of the original data; this is corroborated by statistical measures discussed elsewhere [6].

Discussion

The high quality and rapid acquisition time of foam tomograms achieved by using synchrotron XMT makes this a useful tool for imaging microstructures. By considering a virtual reconstruction of the sample, microstructural properties such as edge length, vertex angle, cell size distribution, and cell genus can be obtained. Further analysis and characterization of the microstructure of this foam will be described elsewhere [6]. Additionally, the virtual reconstruction can be used as input for future data-initiated simulations of cell compression under stress, leading to a better understanding of how foam microstructure is related to elastic properties.

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