Quantitative Density Analysis of Ultra-Low Density Polymer Foams Using Various X-ray Imaging Techniques

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Laboratory-based nano-scale X-ray computed tomography is a valuable tool for the visualization and quantification of microstructures within various materials. With approximately 150 nm 2D resolution, internal structures of a system can be probed non-destructively, which is not available with other imaging systems. Of significant interest is the microstructure of high internal phase emulsion (HIPE) chlorinated polystyrene foams for use in inertial confinement fusion targets.[1,2] In addition to local microstructure, another important property of polystyrene foams is the density of the foam; this property is traditionally measured using gravimetric methods. However, this is a bulk method which can be plagued with large uncertainties if the sample is of ultra-low density. Furthermore, this method yields no information of larger scale density gradients within the foam. A solution to this analytical problem is monochromatic X-ray radiographic imaging.[3] With this characterization technique, a quantitative density measurement is possible based on the X-ray transmission of the sample. In addition, density gradients within the polystyrene foams can be observed. Herein, we report the microstructural characterization of a series of HIPE polystyrene foams using laboratory-based nano-scale X-ray computed tomography. As can be seen in the nano-scale CT reconstructed slice, presented in Figure 1, these low-density foams contain an internal void microstructure. The densities of these foams were also measured from radiographs (Fig. 2) obtained non-destructively using a monochromatic X-ray imaging system utilizing a chromium source operating at 5.4 keV. The densities of these foams range from ~70 to 160 mg cm⁻³, as determined by X-ray imaging. The majority of the X-ray based density measurements agree well with measured gravimetric densities; however, a subset of the polystyrene foams exhibit relatively large diameters (~400 μm), resulting in low X-ray transmission (~0.9%) and large relative percent differences between the image-based measurements and gravimetric measurements (Fig. 3). This result highlights the need for a monochromatic X-ray imaging system which operates at higher energy which would allow for a relatively larger transmission through thick foam samples.

References
Figure 1. A reconstructed slice of polystyrene foam imaged using nano-CT in phase contrast mode. Bright areas correspond to foam ligaments, dark areas correspond to voids within the foam structure. Isotropic voxel size is 65 nm.

Figure 2. Radiographs of three polystyrene foams imaged using the monochromatic X-ray imaging system.

Figure 3. The relative percent density difference of the gravimetric density and the density determined from X-ray imaging as a function of percent X-ray transmission, highlighting the need for higher energy X-ray source to adequately determine the density of thick polystyrene foams.