doi:10.1017/S1431927616001379
Microsc. Microanal. 22 (Suppl 3), 2016

Applying Pattern Recognition to the Analysis of X-ray Computed Tomography Data of Polymer Foams

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X-ray computed tomography (CT) of materials provides large, three dimensional (3D) image data sets (i.e., tomograms), resolving both surface and subsurface features. Tomograms of open-cell polymer foams typically reveal a two-phase material consisting of the supporting polymer ligament material and the void structure (Fig. 1, left). Segmenting the tomograms for the void structure, rather than the polymer ligaments, allows for measuring the void structures in 3D (Fig. 1, right). The equivalent diameter of a void, which is the measure of the void diameter assuming the void is a perfect sphere, is a common singular metric used to describe and differentiate polymer foams. However, for stochastic and irregular void structures, this singular metric can be insufficient when comparing two or more polymer foam samples (Fig. 2). Therefore, multiple 3D void descriptors are typically required, though more than three measurements can lead to difficulty in interpretation. Thus, a statistically-based pattern recognition technique, Principal Components Analysis (PCA), has been implemented to aid in the interpretation of multivariate tomogram data sets of polymer foam systems. PCA transforms N-dimensional data into a reduced number of dimensions which capture most of the data's variance and is commonly used for pattern recognition in experimental sciences, thus enabling easy visualization of sample groupings based on several descriptors.

For this preliminary, proof-of-concept study, tomograms of 30 polymer foam samples were acquired using a lab-based Xradia MicroXCT X-ray microscope. The purpose of this study was to use the foams' 3D morphology for classification based on their location within a larger part and their use history. Three samples each were punched from five separate locations of two separate larger parts (one larger part has been used for its intended purpose; the second larger part has been unused in storage), comprising the 30 samples. Samples taken from Locations A, B, C, and D were deemed as equivalent to one another, whereas samples taken from the fifth location, Location E, were deemed as inequivalent to Locations A-D. Using Avizo Fire, a 3D image processing software program, 11 separate 3D void shape descriptors were calculated for each sample. The corresponding means and standard deviations of these 3D void shape descriptors (resulting in a 30 x 22 matrix) were used as inputs into PCA, which then reduced the number of variables from 22 to 2 (Fig. 3). These two new variables together represent over 75% of the variance in the 22 initial 3D void shape descriptors. As can be seen in Figure 3, results are promising in that the PCA model adequately differentiates the polymer foam samples based on sample location, part origination, and part use.

A similar analysis has been conducted on 2 different open-cell silicone foam systems using 4D X-ray CT data (the 4th dimension being time) of the foams undergoing dynamic compression acquired at Argonne National Laboratory's Advanced Photon Source. Results (not shown) from the PCA of these 4D tomogram data sets show that stress-strain states for both foams can be differentiated based solely on these 3D void shape descriptors. PCA also reveals which 3D void shape descriptors dominate each stress-strain state.

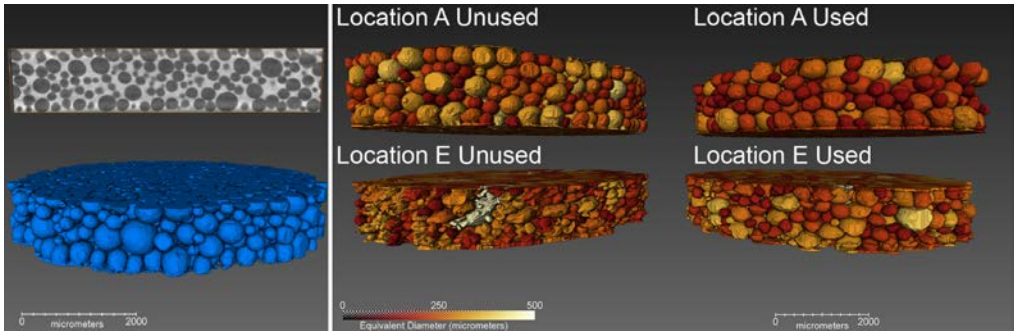

Figure 1. Left: A reconstructed XZ slice, acquired using X-ray computed tomography, of a polymer foam showing ligaments (top) and a volume rendering in of the polymer foam void structure (bottom). Right: Tomographic volume renderings of the void structure of four polymer foam samples, taken from Locations A and E. Samples were taken from both an unused and used part. Voids are colored by equivalent diameter. A significant difference in void morphology is observed between samples taken from Location A and Location E.

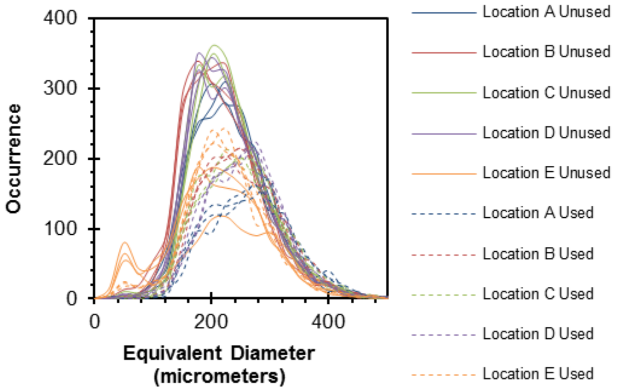

Figure 2. Histograms of the void equivalent diameters of 30 polymer foam samples, which highlights the difficulty in grouping these samples using a singular void metric.

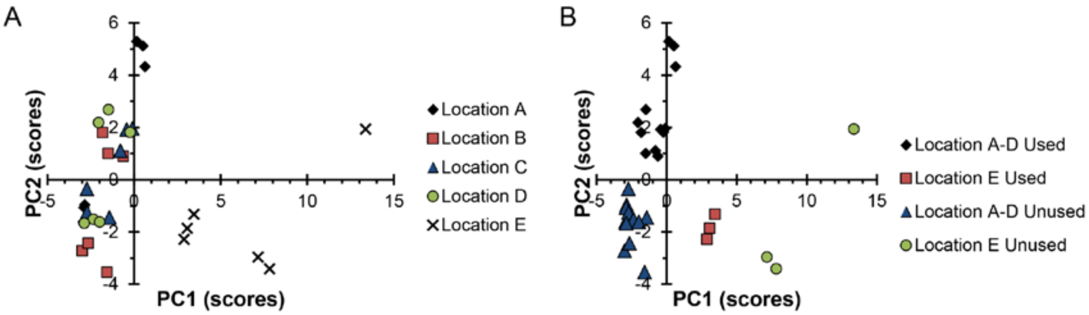

Figure 3. Scores plots of Principal Component 1 vs. Principal Component 2. A: Samples from Locations A, B, C, and D (black diamonds, red squares, blue triangles and green circles, respectively) group well with one another, whereas samples from Location E (black crosses) are loosely grouped separately, indicating large differences in void morphology. B: Data are colored by their history (Locations A-D Used, black diamonds; Location E Used, red squares; Locations A-D Unused, blue triangles; Location E Unused, green circles).