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Using X-ray Tomography and DVC to Study Damage Evolution in Syntactic Foam

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Abstract

The specific syntactic foam of interest in this work is Sylgard® 184, impregnated with hollow A16 Glass Microballoons (GMBs) that have high elastic stiffness and large energy absorption. While it is known that the fracture and collapse of GMBs lead to the large energy absorption of Sylgard, the initiation and evolution of GMB damage are not well understood. In this work, we developed the in-situ X-ray Computed Tomography (XCT) mechanical testing method that coupled the in-situ mechanical loading with the XCT imaging to study the damage mechanism of GMBs inside the Sylgard as the material was subject to mechanical loading. High resolution (1.5 µm per voxel) XCT imaging was performed at different loading levels to visualize the GMB collapse during the compression of Sylgard. Feret shape of GMBs were calculated from these high resolution XCT images to determine whether the GMBs were intact or fractured, as well as the relationship between the size distribution of GMBs and their Feret shapes. Low-resolution (10 µm per voxel) XCT scans were also performed at each loading level and digital volume correlation (DVC) was applied to these low-resolution images to calculate the local deformation of Sylgard specimen. The hollow GMBs that were randomly distributed throughout the foam matrix provided sufficient image contrast and were suitable as the speckle patterns for DVC to measure the deformation even after a substantial portion of GMB had collapsed. Via these in-situ XCT experiments, we not only understood the failure mechanism of GMBs, but also achieved a quantitative measurement of local deformation of the Sylgard specimen. These experimental results and large XCT data analysis provided analysts with first-hand information for better model development and damage assessment and prediction.

Keywords: **Syntactic foam, Glass Microballoons (GMB), x-ray tomography, Digital volume correlation (DVC)**

1. Sample Preparation

The material of particular interest in this work is Sylgard® 184, impregnated with a high volume fraction of A16 glass microballoons (GMBs). Sylgard GMB specimens were prepared by mixing two-part Sylgard 184 silicone elastomer (Dow Corning) with A16 glass microballoons (3M) and curing agent. The mixture was then injected into a cylindrical syringe and cured at room temperature with an accelerator. After curing, the syringe mold was carefully cut open and the specimen was removed from the mold. The cylinder specimen has diameter of 4.8mm. It was then carefully sliced into shorter cylinders of 7 mm height.

2. In-situ XCT experiment

The compressive behavior of the cylinder specimens was first characterized using Instron machine to provide reference for the in-situ x-ray tomography experiment. Fig 1 shows a representative stress versus strain curve for the compression of the Sylgard specimen. There is a large hysteresis where the onset and evolution of GMB collapse occurs. This has motivated us to conduct the in-situ xct experiment that can visualize the GMB microstructure and damage behavior, as well as to collect data from large enough volume to capture the macroscopic deformation related to the GMB collapse. Therefore, the current in-situ xct experiment performed scans at two spatial resolutions: high spatial resolution (1.5 µm/voxel) scan and low spatial resolution scan at (10 µm/voxel) at the original undeformed state and each incremental loading step of 7% up to 49% of global compression. Fig 2 shows the representative low and high resolution xct slices at selected states at original, 28% and 49% of compression.

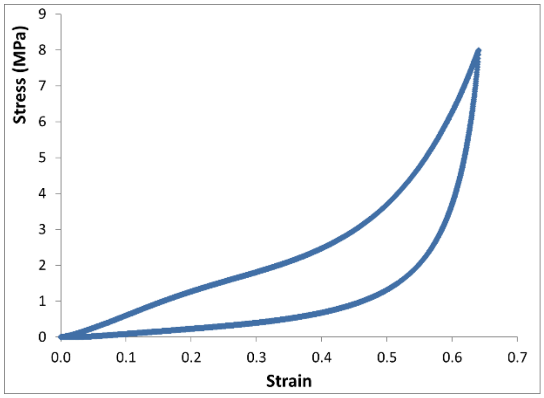
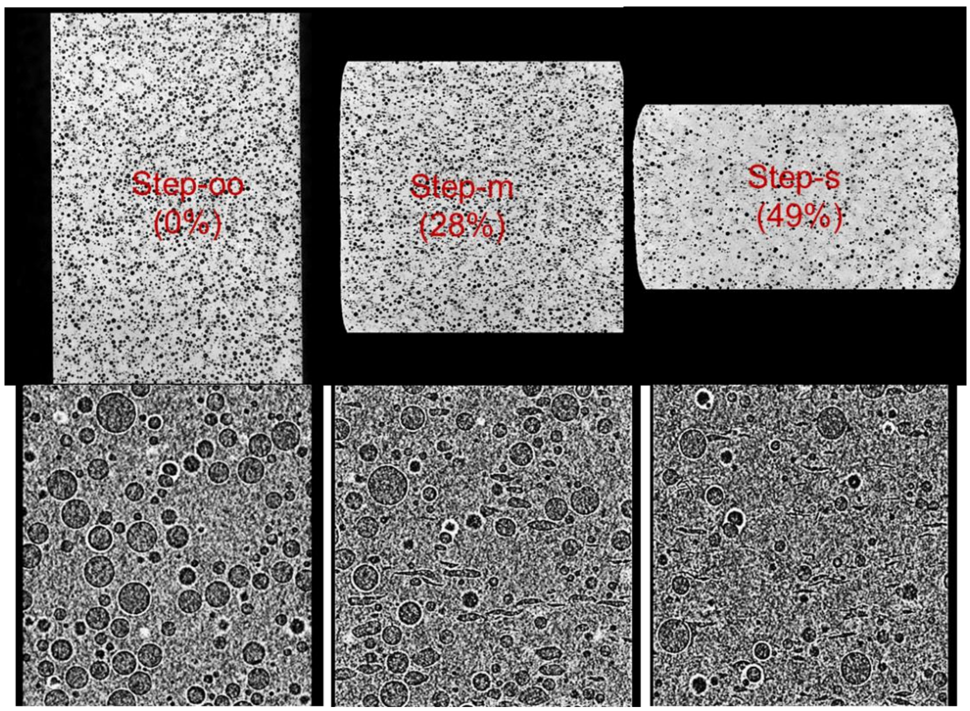


Fig 1. A typical engineering stress~strain curve for current Sylgard specimen at quasi-static compressive loading



(a) (b) (c)

Fig 2. Selected low and high resolution xct slices at (a) original state, (b) 28% and (c) 49% of compression

3. Data analysis

The high resolution xct image set was rendered using Avizo to visualize and demonstrate the GMB evolution during the loading. The parameter Feret shape number was introduced to quantify the individual GMB shape evolution. The GMB size distribution was measured for each loading step. It was found out that the GMB damage and failure evolution does not have size preference.

Digital volume correlation (DVC), a three-dimensional extension of the widely-used digital image correlation (DIC) technique, was applied to the image sets with low spatial resolution to extract the displacement and strain information between the current deformed and the original undeformed states. The localization of compressive axial ε_{zz} obtained from DVC indicated the damage propagation of GMBs.

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