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4D Characterization of Deformation Processes in Aluminum Foams: New Dimensions in Materials Engineering

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Recent activity in metallographic research has lead to several interesting developments. Metals are ubiquitous as structural reinforcements, but have found applications in high-temperature environments as well as many commercial products, such as automobiles.

Metal foams, in particular, have been the subject of substantial industrial interest, due to their light weights, high thermal conductivities, low densities with high ductility, and low costs, as well as their abilities to absorb large amounts of energy. Aluminium foams are recyclable and environmentally non-polluting, are fire-resistant, and have high stiffness-to-weight ratios for a variety of applications. In the aerospace and automotive industrials, aluminium foams are used as sandwich panels and in crash boxes, while in other commercial sectors these foams have been used as acoustic dampeners and heat exchangers.

While the fabrication methods for aluminium foams are well established, characterizing the deformation of the porous structures is traditionally challenging. Mechanical tests, such as compression and flexural testing, are historically employed, but these tests only offer a strength measurement, saying little about the reasons for the results. Due to the high degree of heterogeneity of the foams, mechanical testing can often produce confusing results (if, for example, the fabrication method was met with imperfections), and proper characterization relies on high sampling statistics - that is, many samples must be tested and the confusing results tossed away as outliers. This leads to a very time-consuming characterization routine, which can produce results that do not properly reflect the relationship of structure to performance.

Here, the technique of X-ray microscopy (XRM) is employed featuring a compression cell that allows for in-situ mechanical testing and microstructure observation, producing a 4D dataset that relates 3D microstructure to mechanical behavior. The data analysis technique of digital volume correlation (DVC) is subsequently employed, which reveals the 3D strain and 3D shear tensors responsible, at the microstructural level, for the deformation observed, spanning up to several hundred newtons of compression (data analysis is performed for the uncompressed to 200N compression state, but high compression levels will be visualized up to 400N). These 4D observations reveal the nucleation sites for the deformation process within a primarily elastic regime, showing the compression effects occurring in the microstructure, as they relate to macro-scale phenomena. Further applications of the 3D X-ray microscopy technique for metals characterization will additionally be discussed, as well as future directions for grain orientation measurements, pointing to future capabilities for non-destructively relating 3D grain orientation to mechanical properties and deformation processes.

References:
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[4] The authors gratefully acknowledge the support of Sowbaranigha. C. J., Steven Flores, and Jeffrey Kmiec at San Jose State University for their assistance in the experiments and for many fruitful discussions.

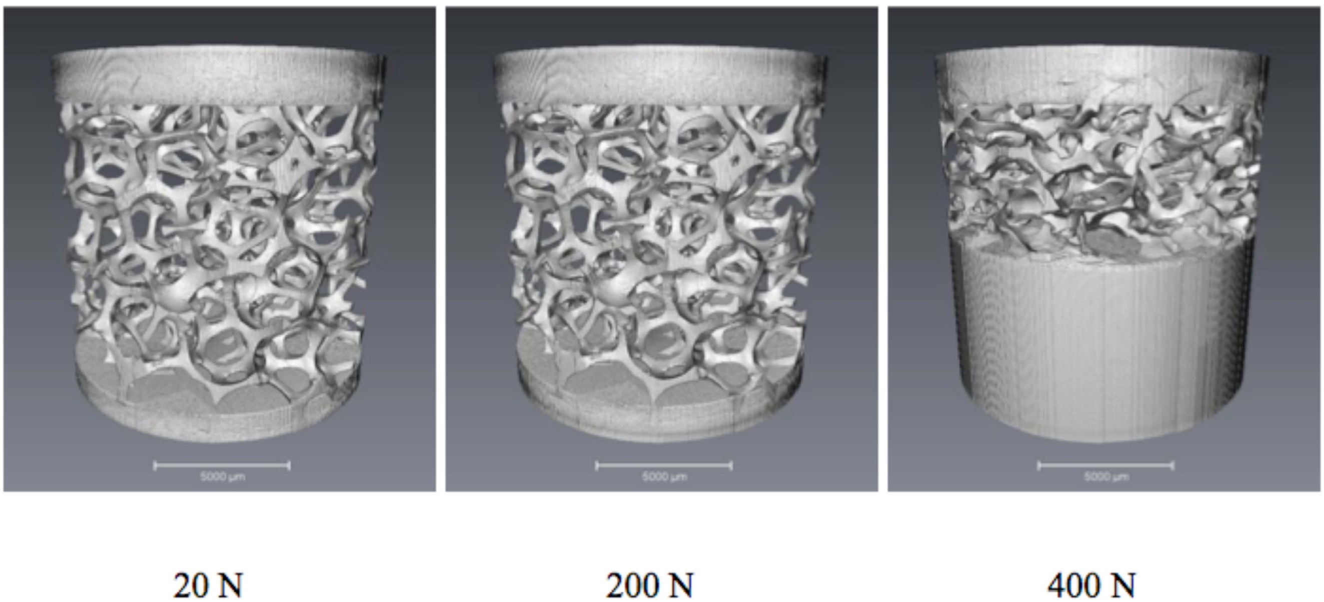

Figure 1. Aluminum foam sample showed under sequential compressive loads, as revealed by the X-ray microscopy technique. The solid, shaded areas at the top and bottom of each image are the jaws of the in-situ load cell as the pore space deforms.

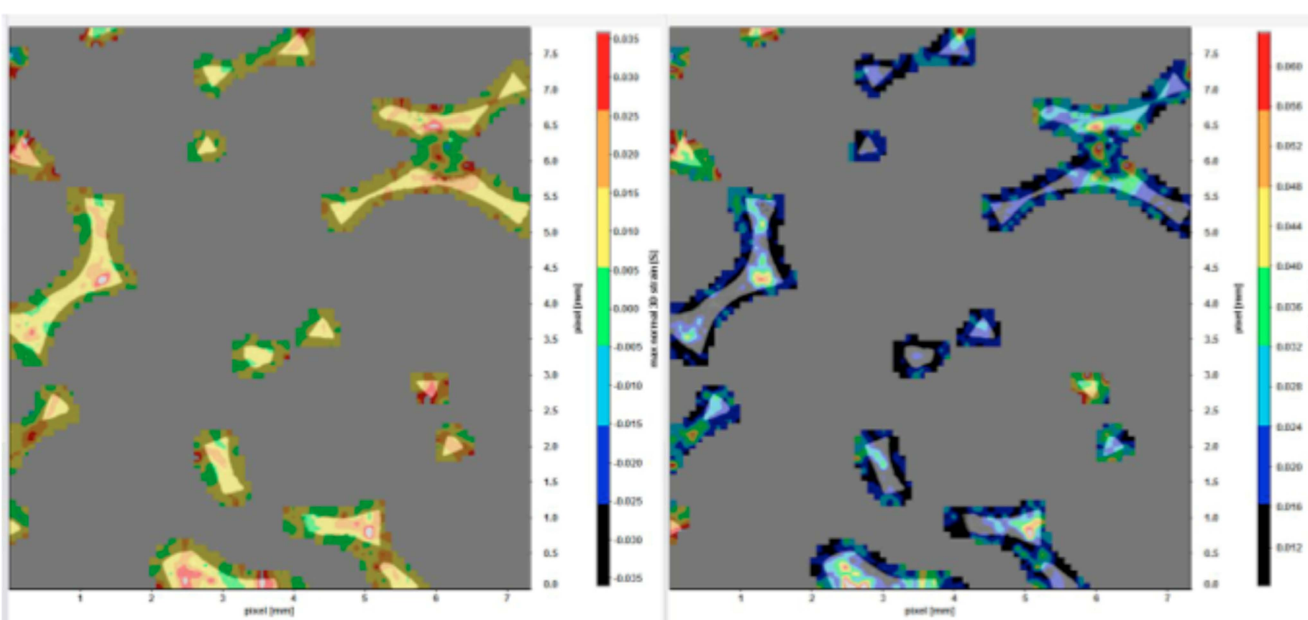

Figure 2. 3D strain (left) and 3D shear (right) for one virtual slice of the Al foam sample after 200N applied load, obtained from digital volume correlation analysis. The orange and red show the highest magnitudes of 3D strain, while the blue and black show the highest magnitudes of 3D shear.

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