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DETERMINATION OF FOUR CHARACTERISTIC REGIONS IN THE STRESS–STRAIN RESPONSE OF APM FOAM UNDER COMPRESSION USING DVC

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1. Introduction

The Advanced Pore Morphology (APM) foam element is a recently developed cellular material composed of spherical metallic elements with favourable mechanical properties. Owing to their ability to sustain large deformations under compression, APM foams are used as energy-absorbing structures, stiffening and damping elements, core layers, and fillers in composite materials. A major advantage lies in their straightforward application as fillers in hollow components, such as automotive parts, where they markedly enhance energy absorption with only a minimal weight penalty.

Although several studies have investigated APM foams [1, 2], their mechanical characterization remains limited. Hence, this investigation aims to determine the compressive behaviour of individual APM foam element under quasi-static loading through 3D strain measurement from an *in-situ* XCT compression test. Bulk kinematics were quantified using global Digital Volume Correlation (DVC) with finite element discretization [3], while global material behaviour was derived from mean nodal DVC strain levels obtained via the virtual gauge [4].

2. Experimental procedure

The investigated specimen was a spherical APM foam element with a diameter of 10 mm, characterized by an extremely high pore count of approximately 10^4 pores smaller than 0.1 mm. The pore radii span a wide range, from as small as 5 µm up to 2.1 mm. Although micropores dominate in number, the pore count decreases significantly with increasing pore size, reflecting the foaming process. The pores are not uniformly distributed, with a considerably greater number concentrated near the outer surface, while the highest average pore radius is shifted towards the periphery rather than the center. This distribution enables the formation of several large pores around the edges instead of a single central pore, a feature that may provide structural advantages and positively influence the mechanical performance of APM elements (Fig. 1).

An in-situ monotonic compression test was performed on a single APM foam element under displacement control at a prescribed stroke rate of 10 µm/s, with the loading sequence incorporating 20 programmed interruptions (see Fig. 2). After each interruption the maximum displacement was increased in increments of 250 µm, up to a total prescribed displacement of 5000 µm (Fig. 1). During each plateau the stroke was kept constant while the specimen was rotated through 360°, enabling volumetric imaging at defined load levels.

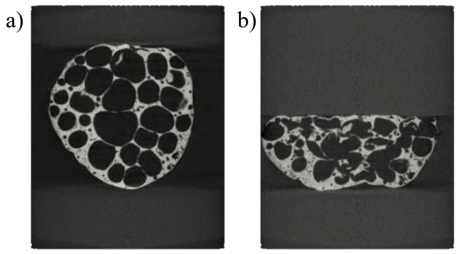

Fig. 1. Mid slices of the APM element in the a) reference configuration and at b) 50% deformation.

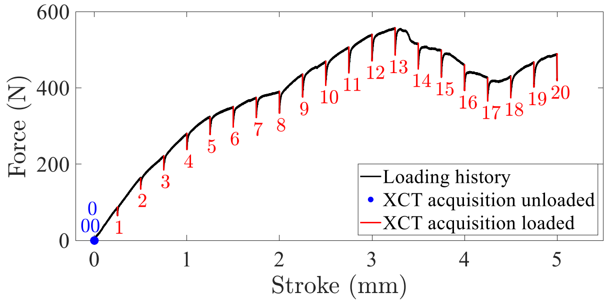

Fig. 2. Loading and acquisition history of the *in-situ* compression test.

CT scans were acquired using 1434 projections with an exposure time of 200 ms per projection. Data acquisition was performed with binning 2, a 2 mm aluminium filter, and a frame rate of 5 fps, resulting in a total duration of approximately 11 minutes per scan. The images were recorded at 8-bit gray-level depth. After cropping the extracted volumes of 665 × 751 × 601 voxels were defined with a spatial resolution of 17.92 µm/voxel. The maximum registered force during compression reached 560 N. The APM foam element exhibited a characteristic multi-stage compressive stress–strain response, and pronounced force relaxation was observed during the scanning process (Fig. 2).

3. Results and Conclusion

The DVC analysis was performed between the undeformed volume (scan 0) and 20 deformed volumes. From the measured displacement fields, principal strains were computed. The maximum principal strain field (ε_1), shown in Fig. 3, presents the strain distribution for the final scan. The resulting map reveals highly strained regions corresponding to macro cracks formed under compressive loading.

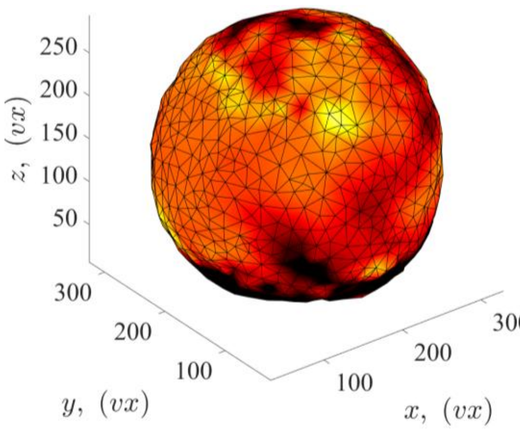

Fig. 3. An isometric view of the major eigen strain field calculated at the final loading step (*i.e.*, scan 20).

Using the virtual gauge, mean nodal strain levels were obtained (see Fig. 4). The results show that DVC-based measurements effectively capture the compressive response of APM foam (see Fig. 4) and clearly distinguish four characteristic regions of the stress–strain curve (i.e., elastic regime, pore collapse, localized deformation with shear band formation, and densification) which are less evident in the conventional stress–strain curve derived from machine loading data (Fig. 2). The formation of strained shear bands marks the onset of structural instability and progressive damage. Overall, the study highlights the advantages of volumetric 3D measurements for simultaneously characterizing global deformation behaviour and localized damage mechanisms in porous materials such as APM foam.

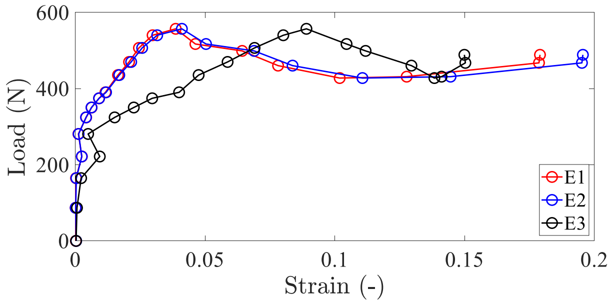

Fig. 4. Load-mean strain history over the *in-situ* compression test.

Acknowledgments

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