In Situ HIGH-RESOLUTION X-RAY TOMOGRAPHY OF FRACTURE MICROMECHANISMS IN ALUMINIUM FOAM

Aluminium foam is an attractive engineering material that offers potential-energy-absorption capacity during deformation, which is useful for efficient crash-energy management. Figure 1 shows the typical cell structure of aluminium foam. The typical cell size is a few mm, which is unusually coarse for practical structural materials, while the cell wall is sometimes less than 50 µm thick. Such a unique combination of "macro" (i.e., coarse cell structure) and "micro" (i.e., membrane) features makes a mechanistic approach difficult. In particular, the thin cell wall amplifies the effects of the internal microstructure due to the small membrane thickness/microstructural dimension ratio. However, despite the fact that cell materials exhibit microstructural features far more inhomogeneous than these of their dense equivalent, quite a few reports are available in the literature, of the qualitative observation of the 2D microstructural features. X-ray tomography has been used at low-resolution levels which are more than one to two orders of magnitude coarser than the microstructures due to the coarse cell structures.

In this study, high-resolution phase contrast imaging technique achieved at SPring-8 is applied. A combination of several state-of-the-art characterization techniques then enables 3D quantitative image analyses of the microstructures together with the interpretation of deformation and fracture behaviors. The application techniques include the liquid metal wetting technique to visualize microstructural features well below the resolution level, local-area tomography by which large specimens can be visualized at high magnification, and a microstructural gauging technique by which 3D local strain is mapped by tracking microstructural features.

Fig. 1. Tomographic image of typical aluminium foam.

Fig. 2. The test rig specially designed for tomographic *in situ* observations in the experimental hutch.

High-resolution X-ray tomography was performed at beamlines **BL20B2** and **BL47XU**. Monochromatic X-ray beams having a photon energy of 20 keV from double-crystal monochromators were used. Cooled 1000×1018-element or 4000×2624-element CCD detectors were positioned 50 mm behind samples, thereby making the imaging systems sensitive to phase modulation. Isotropic voxels with a 0.5 µm edge at maximum were achieved in the reconstructed slices. *In situ* compression tests were performed using the material test rig shown in Fig. 2, which was specially designed for the CT at SPring-8.

Owing to the superlative optical setup, the microstructural features, such as micropores, intermetallic particles and solute atom segregation, could be clearly visualized. Since the images of virtual slices are as distinct and offer similar detail as a high-magnification optical microscope image, 3D quantitative image analysis (such as center of gravity, volume, surface area, etc.) was readily performed using the Marching Cube algorithm. The 3D distribution of micropores within a rendered cell wall is shown in

Fig. 3. A large number of micropores is observed in the volume. A point to note is that the coarse micropores tend to lie on periodic lines, suggesting a characteristic solidification pattern during its production process, probably due to the lack of sufficient nuclei for solidification. A characteristic crystallographic structure was also revealed by the liquid metal wetting technique, indicating that single-crystal membranes of a few hundred micrometers in width are patched up two-dimensionally to form each cell wall.

Sequential observations of static deformation behaviors have revealed the contribution of each microstructural feature to the overall fracture. Centroid locations for each micropore were tracked as a function of applied strain in the sequential tomographic scans, thereby allowing us to estimate the local strain distribution in the cell materials, as shown in Fig. 4. As such, high-density mapping with micrometer-level resolution has been realized by the procedure as was previously demonstrated by the present authors [1,2]. Locally inhomogeneous strain distribution was found, due particularly to the existence of underlying coarse micropores, which can be readily observed in the rendered 3D images.

In summary, it has been clarified that the microstructures are highly inhomogeneous in the aluminium foam compared to solid materials. Some of the microstructural features are unlikely to have any influence on fracture, while some of them provide premature fracture initiation sites. The results clearly provide a microstructural design concept to enhance the energy absorption capacity.

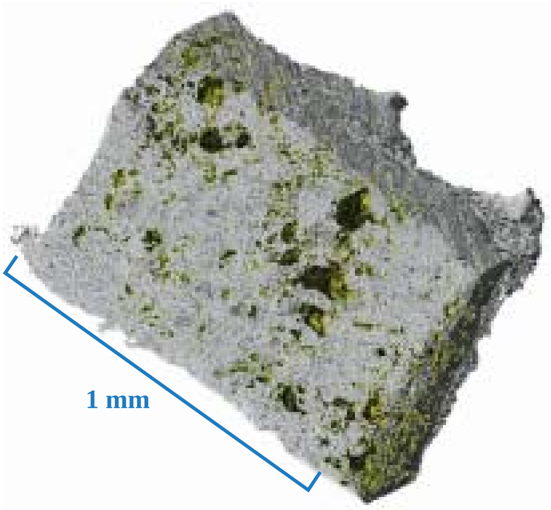

Fig. 3. A 3D rendered perspective view, representing micropore distribution superposed on the surface contour of a cell wall. Aligned coarse micropores indicate the solidification pattern of the cell wall.

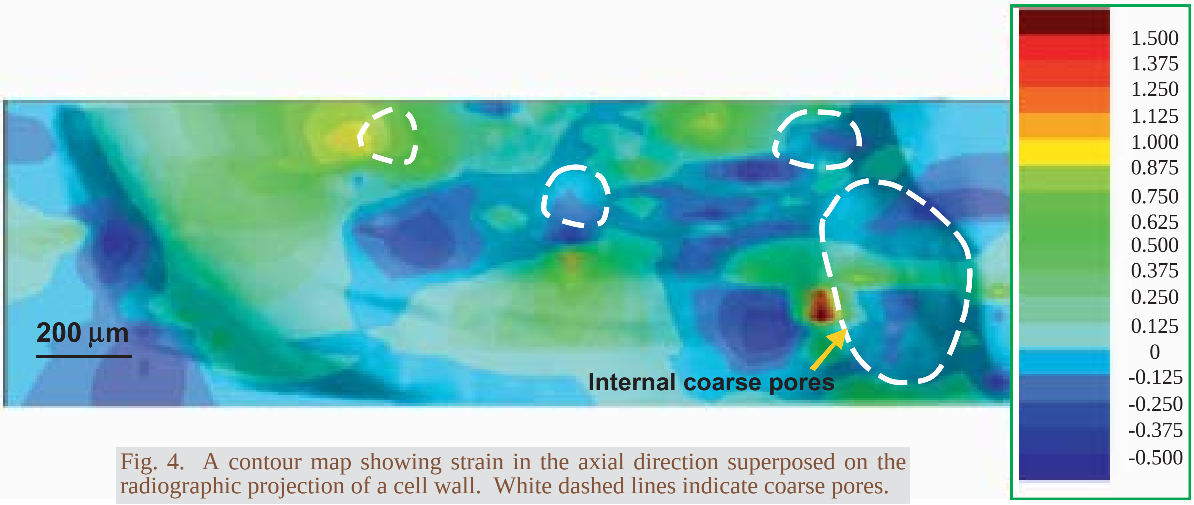

Fig. 4. A contour map showing strain in the axial direction superposed on the radiographic projection of a cell wall. White dashed lines indicate coarse pores.

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