TOPOLOGY/GEOMETRY EVOLUTION OF CLOSED-CELL ALUMINIUM FOAM DURING IMPACT

M. A. Kader[*1,2], P.J Hazell[2], J. P. Escobedo[2], M. Knackstedt[1], M. Saadatfar†[1]

[1]Department of Applied Mathematics, Australian National University, Australia
[2]University of New South Wales, Canberra, Australia

Keywords: X-ray tomography, Metal foam, Impact behaviour, FE simulation

Summary: The deformation propagation and the formation of collapse bands are investigated in a closed cell aluminium foam system by means of lab-based experiment, x-ray micro-tomography and the finite element modelling. We report mechanisms leading to the plastic strain localisation. We find that the local magnitude of the plastic strains inside the collapse bands are high compared to the applied bulk strain. The regions with large pores predominantly undergo collapse and subsequently, the structural heterogeneity slightly reduces. Additionally, we find that pores become increasingly connected due to the fracturing of cell walls.

1. INTRODUCTION

The applications of closed-cell aluminium foams are increasing day by day. The wide ranges of applications of these materials are the consequences of their outstanding impact energy absorption capacity and light weight. A number of previous experimental works on aluminium foams have been performed to investigate their mechanical response during quasi-static compression. However, foams are principally used to mitigate impact loads [1]. Although the quasi-static compression analyses provide some important information about the deformation behaviour, they do not truly reflect the impact phenomenon. Several research groups [2-4] carried out experimental investigations on low-velocity dynamic collapse behaviour of aluminium foams, and they reported that the pore collapse mechanisms under impact loading significantly affect the mechanical response of foams. However, the observation of post-impacted samples in experimental approaches was not sufficient to understand the collapse mechanisms. Moreover, most previous numerical analyses on drop impact were based on continuum geometry, thus making it impossible to explain the collapse process. There are a few studies in which the X-ray tomography-based geometry has been used. But none of them investigate the structure-property relationship of metal foams during dynamic loading. In the present study, we have investigated the structure-property relationships of such disordered cellular material and analysed the deformation mechanisms in detail with several qualitative and quantitative analyses using XCT based 3D digital images of the foam sample. The deformation mechanisms have been correlated with the mechanical response in order to understand the significance of foam deformation on mechanical performance at the scale of individual cells and above. Moreover, finite element simulations (FE) have been performed to further elucidate volumetric collapse of foam structures subject to a wide range of strain rates. The pore collapse mechanism and the effect of pore distribution on collapse have also been explored.

2. EXPERIMENTAL METHOD

An INSTRON CEAST 9350 instrumented drop tower was used to conduct the low velocity impact experiments for the present research. The drop tower is equipped with a free falling carriage which contains the impactor and a 90kN load cell. The tests were carried out at room temperature, with constant mass of the impactor unit (5.639kg), and with the sample resting on a flat and rigid steel platen inside the test chamber. The platen and impactor interfaces were lubricated to reduce the effect of friction. The experimental sample was imaged via XCT before and after deformation (shown in Fig. 1 (a)) using the micro-CT facility of Australian National University (ANU). A flat panel detector (pixel size 0.14 μm) and micro-focus x-ray source (acceleration voltage 100 kV and current 100 μA) supplied by Hamamatsu (Japan), were used for imaging. The sample was placed on a motor controlled rotating stage and radioscopic projections were taken after each degree of rotation.

*e-mail: MdAbdul.Kader@anu.edu.au
†e-mail: Mohammad.Saadatfar@anu.edu.au

The raw XCT datasets were processed with the Medial Axis and Network Generation (Mango) software tool at ANU to obtain binarized and labelled datasets (Fig. 1(b)). After that we have conducted a number of shape, geometry, topology analyses, which were carried out on the volumetric datasets of binarized and labelled data. Moreover, an X-ray CT based actual foam geometry was developed for FE modelling. Tetrahedral elements were used to mesh the geometry due to the complex geometrical structure. Then, the meshed geometry was converted to ABAQUS-friendly format and imported to ABAQUS/Explicit for the simulations.

3. RESULTS

A reasonably good agreement is found between the experimental results and FE simulation except for minor discrepancy when capturing the initial elastic loading (shown in Fig. 1 (c)). The present FE simulation with XRT-based geometry is able to show the whole volume at any particular instant. It shows that deformation initiates at thin cell-walls and subsequently the load is transmitted to surrounding cell-walls and plateau borders (junctions) where the next weakest region will begin to collapse, and so-forth. That is, the deformation is a continuous process of cell-wall rotation, bending, buckling and tearing. In experimental approach, the geometrical evolution of the examined sample due to impact loading is examined by measuring the changes of pore volumes, length of long axis, elevation angle and azimuth angle of long axis during impact through the loading axis. It is observed that the deformation propagates by forming several narrow collapse bands in which the plastic strain localises, and the local magnitude of the plastic strains inside the collapse bands are extremely high compared to the applied bulk strain. It is also observed that the average elevation angle θ and azimuth angle φ increase with increasing the impact step. The amount of increase is more significant at the lower half of the sample wherein the maximum collapse/deformation was observed. This indicates that the pores rotate or change their shape from spherical to elliptical during impacts.

References

[1] A, Hanssen, L. Olovsson, T. Børvik, M. Langseth. Close-range blast loading of aluminium foam panels: A numerical study, IUTAM Symposium on Mechanical Properties of Cellular Materials. Springer, 169-180, 2009.

[2] M. Altenaiji, Z. W. Guan, W. J. Cantwell, Y. Zhao, G. K. Schleyer. Characterisation of aluminium matrix syntactic foams under drop weight impact. Materials & Design 59, 296-302,2014.

[3] M.A. Islam, A.D. Brown, P.J. Hazell, M.A. Kader, J.P. Escobedo, M. Saadatfar, S. Xu, D. Ruan, M. Turner, Mechanical response and dynamic deformation mechanisms of closed-cell aluminium alloy foams under dynamic loading, International Journal of Impact Engineering 114, 111-122, 2018.

[4] Pinnoji, P.K., Mahajan, P., Bourdet, N., Deck, C., Willinger, R. Impact dynamics of metal foam shells for motorcycle helmets: Experiments & numerical modelling. International Journal of Impact Engineering 37, 274-284, 2010.

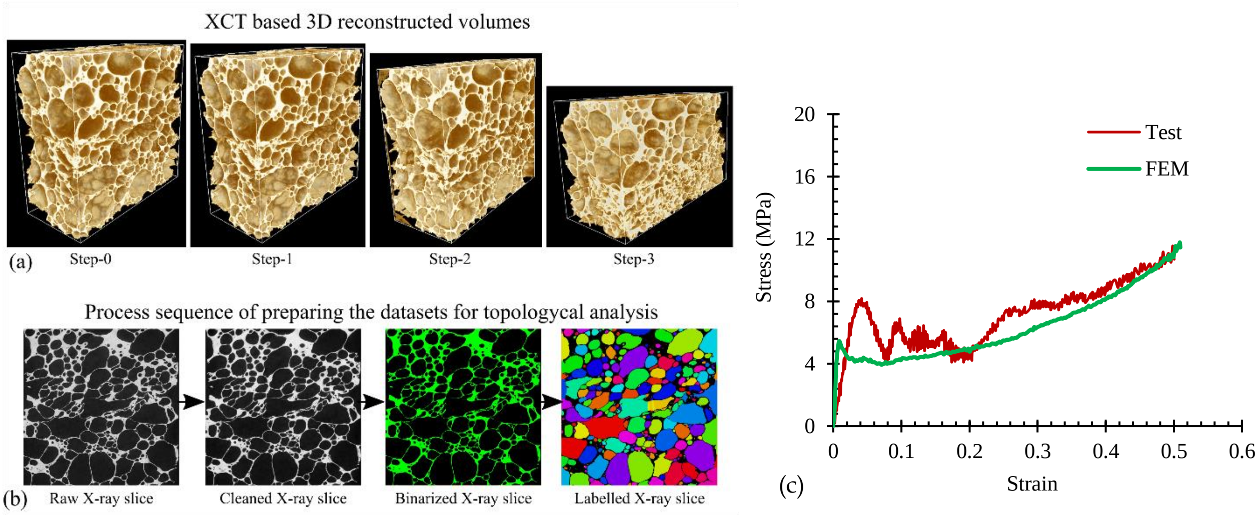

Figure 1: (a) XCT based reconstructed 3D volume at different strains. (b) Flow diagram to show the process sequence of preparing the datasets for quantitative topological analysis (c) Comparison of stress-strain response for FE simulation and experimental result (impact velocity of 2 ms^{-1}).