STRAIN MEASUREMENTS IN POROUS MATERIAL UNDER COMPRESSIVE LOADS USING DIGITAL VOLUME CORRELATION AND MICRO FINITE ELEMENT MODELING

Sriram K (2015AMZ8220)

Abstract

Micro-CT is a non-destructive technique to quantify the morphology of cellular structures. An in-situ testing device and micro-CT enable a qualitative understanding of the microstructural changes due to loading conditions. The quantitative understanding of displacements and strains is obtained by the image-based FE analysis (Micro-FE) of cellular structures. However, the validation of such models is critical due to many influencing parameters.

Digital Volume Correlations (DVC)is an image-based technique to quantify the internal displacements and strains of cellular structures. The technique is also used as a validation tool for micro-FE displacements and strains. Nevertheless, most of these validation has only been performed within the 6-7% strain range. A good comparison between DVC and micro-FE results was obtained when DVC interpolated boundary conditions were implemented. However, the applicability of DVC interpolated boundary conditions in large deformations cases is not studied in detail.

The present study uses DVC and micro-FE techniques to evaluate the internal displacements and strains in closed (CCF) and open (OCF) cell foams under compressive loading conditions. A multi-step compression procedure achieves large deformations (up to 20%) in foams. A local DVC algorithm is implemented to quantify the deformations in the foams. The micro-FE analysis of both foams is performed with DVC interpolated boundary conditions (IPBC) and experiment-based boundary conditions (ExBC). A detailed comparison of the predicted and measured displacements and strains is performed at macroscopic and microscopic levels. An image-based anisotropy evaluation of foams and the changes in the anisotropy of foams are determined up to 20% strain.

Within the elastic regime, IPBC predicted displacement components showed a good match to the DVC measurements. While ExBC showed a good agreement for transverse displacements only. The statistical analysis of displacement components supported the above mentioned trends in sectional and volume level comparisons. Even though the displacements matched well, the normal strain components were not predicted well.

For large deformation analysis of CCF samples, at volume level comparison, the axial displacement contour was better predicted by ExBC and IPBC, where the correlation values are R2 >0.70. Even though the ExBC predicted transverse displacement contours differed from DVC, a reasonably well statistical correlation was identified (R2 >0.70). However, the individual sectional comparison showed a lower correlation (R2 <0.60), especially for axial displacements predicted by both IPBC and ExBC. For OCF samples, significant differences in the displacement contours predicted by IPBC and ExBC were observed. The statistical comparison showed a variation in the correlation value between 0.04<R2 <0.67 for transverse displacements, while the axial displacement has a better correlation value range (0.65<R2 <0.87). The displacement components failed to correlate well at the sectional level. Even though the measured and predicted strain ranges were similar for both foams, the local strain values differed significantly.All micro-FE results were obtained using the full integration scheme because at large deformations, reduced integration produced a higher artificial energy level (5%>). The deformations of up to 20% strain in both OCF and CCF samples could not significantly alter the anisotropy of the foams. The deformation mechanism predicted by micro-FE using IPBC and ExBC for open and closed-cell foam was similar to that captured by micro-CT in large deformation cases.

A CT scan based transversely isotropic inhomogeneous Finite Element model of the femur was developed. The failure probability of the femur bone was determined at the critical yield location, and the sensitivity analysis of the femur identified Young’s modulus, shear strength, and the joint contact forces as critical parameters that affect the failure probability of the femur.

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