Large deformation response of 3D printed soft lattice structures using micromechanical finite element analysis

M. Jamshidian[†]*, N. Boddeti[†], D. W. Rosen[†], O. Weeger[††]

[†] Singapore University of Technology and Design, Digital Manufacturing and Design Centre,
8 Somapah Road, Singapore 487372, Singapore
Email : mostafa_jamshidian@sutd.edu.sg
Email : gowri_boddeti@sutd.edu.sg
Email : david_rosen@sutd.edu.sg

[††] TU Darmstadt, Department of Mechanical Engineering, Dolivostraße 15, 64293 Darmstadt, Germany
Email: weeger@cps.tu-darmstadt.de

ABSTRACT

Soft lattice structures made of hyperelastic rubbery materials via 3D printing can undergo large elastic deformations of 100% strain and more. Using additive manufacturing processes, soft lattice structures can be designed and fabricated for a wide range of applications such as energy dissipation and storage, thermal conductivity, self-assembly and other types of functionalized behaviour. However, engineering scale applications of soft lattice structures demand for macroscale continuum models that enable efficient, stable, robust and accurate computer simulations. Such phenomenological constitutive models are commonly fed and calibrated by experimental test results. These standard tests may include uniaxial, biaxial and planar tension and compression, simple shear and volumetric compression. However, all these tests may not be feasible for the delicate and porous soft lattice structures. To circumvent this hinderance, alternative simulation experiments based on a micromechanical model of a lattice structure can be employed to evaluate the large deformation response of lattice structures under various loading cases. To do so, a representative unit cell of the lattice structure under periodic boundary conditions is modelled by beam elements. Proper periodic boundary conditions corresponding to each of the standard tests are applied to the unit cell. As the highly nonlinear large deformation response of soft lattices involves the microbuckling of struts in both tensile and compressive tests, postbuckling analysis is used in the microscale simulations. Such analysis is performed by incorporating geometrical imperfections derived from a preliminary eigenvalue buckling analysis. Particularly, a primitive eigenvalue buckling analysis is employed to determine the critical buckling loads and buckling mode shapes. These mode shapes with appropriate scale factors are utilized as the initial geometrical imperfections in the postbuckling analysis. The imperfection scale factors are chosen to be in the order of the resolution of the 3D printing process. Considering the critical buckling loads, postbuckling and imperfection sensitivity analysis is performed to improve the robustness and reproducibility of the simulated results. The computational model is validated against the uniaxial tensile and compressive experiments of a 3D printed sample lattice structure. Finally, the proposed modelling strategy is used to extract and analyse the large deformation response of various unit cells under standard tests. The outcome provides a basis for the development and calibration of the macroscale continuum constitutive theories applicable to the large deformation modelling of soft lattice structures.