MULTISCALE MODELING OF LATTICE STRUCTURES UNDER LARGE DEFORMATIONS

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The rapid advancement of additive manufacturing (AM) enables the fabrication of strong, lightweight structures with a topology that is unreachable using conventional manufacturing processes, such as complex lattice structures. Among these lattice structures, soft lattice structures can undergo large elastic deformations, absorb energy and dampen vibrations in a reversible manner, exploit mechanical instabilities and buckling, exhibit auxetic behaviour, possess negative thermal expansion, and have shape-memory and shape-morphing capabilities. These unique characteristics of soft lattices open up new pathways to a wide range of multifunctional applications, including soft robotics, biomedical devices, energy harvesting, and storage. Hence, the modelling of soft lattice structures has become very important thing.

This research study introduces a computational modelling framework for characterising the effective nonlinear micromechanical behaviour of soft lattice structures under uniaxial loading conditions with large deformations. It also explores the impact and necessity of joint stiffening in modelling soft lattices. Furthermore, it investigates the effects of parameter variations on the overall micromechanical behaviour of unit cells.

Under uniaxial loading, certain soft lattice structures present buckling-dominated behaviour, while others present bending-dominated characteristics. In developing and validating the computational modelling framework, Body Centred Cubic (BCC) structures were used to represent buckling behaviour, and Body Centred (BC) structures were used to represent bending behaviour. Numerical simulations were performed using Abaqus FEA software. For micromechanical analysis, Periodic boundary conditions were applied to simulate unit cell behaviour, facilitating the extraction of effective homogenised responses.

To achieve the required joint stiffness in soft lattices, it is necessary to increase the joint thickness by 100% of the strut diameter for a length equal to the diameter. During uniaxial testing, lattice structures dominated by bending and stretching can be modelled using the ABAQUS/Standard Static General solver, avoiding the introduction of buckling mode shapes. Conversely, lattice structures exhibiting buckling behaviour can be modelled employing the ABAQUS/Standard Dynamic Implicit solver, incorporating proper scaling factors to simulate buckling mode shapes within ideal lattice structures.

The developed effective stress-strain responses of unit cells under uniaxial loading can be used to develop a material model for soft lattice structures. Curve fitting techniques and artificial neural networks are recommended methods for material model development in further studies.

Keywords: Multiscale modelling, Soft Lattice structures, Nonlinear buckling analysis, Computational framework

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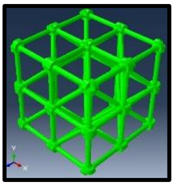
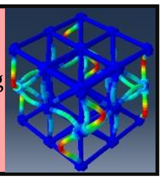
Soft Lattice Structures

Buckling Dominated



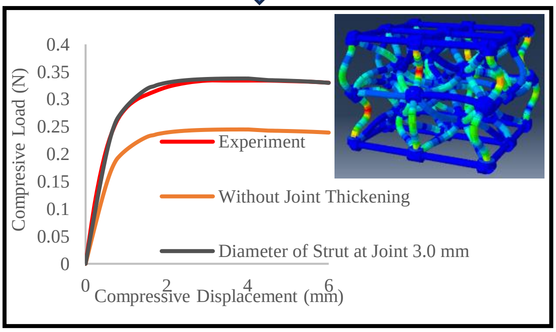
BCC RVE model

Step – 1: Linear buckling analysis

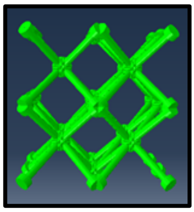


Step – 2: Nonlinear buckling analysis

- Introducing buckling modes $\Delta x_i = \sum_{i=1}^{k} w_i \varphi_i$
- Abaqus/Standard Dynamic Implicit analysis

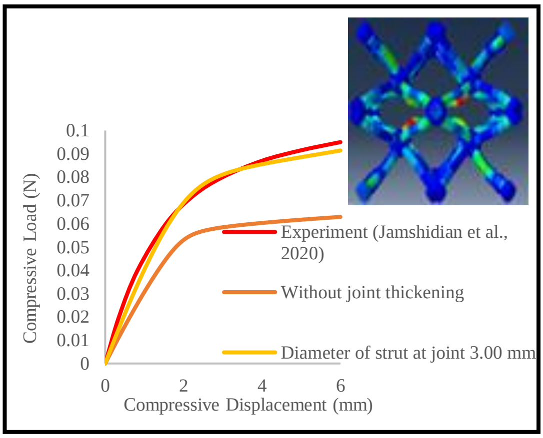


Bending Dominated

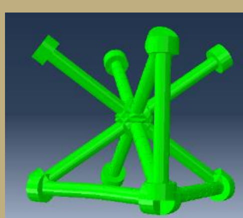


BC RVE model

Geometric nonlinearity
+
Abaqus/Standard Static General analysis



Micromechanical Modelling



BCC unit cell

Periodic Boundary Conditions