Modeling and Simulation of Superelastic Lattice Structures

Tim Munhowen

Institute of Lightweight Design and Structural Biomechanics, TU Wien

Context

This thesis was created in the context of an EU-funded research project with the aim of advancing sustainability in aviation by developing a morphing wing structure that is partly manufactured out of 3D printed lattice structures of superelastic material. To facilitate the development and manufacturing of the morphing wing, a research group at TU Wien was tasked with developing an effective way of simulating additively manufactured superelastic lattice structures.

Summary

Superelasticity is a prominent effect in shape memory alloys that enables the recovery of large amounts of strain. The superelastic effect is initially induced by mechanical loads and is a direct result of solid-solid diffusionless phase transformations between the austenite and martensite phase.

To predict the influence of superelastic parent material in lattice structures with the aid of the Finite Element method, reliable constitutive material models are required. In the paper authored by Schasching et al. [1] a hypoelastic material model for beam elements which aims to predict the superelastic material response of additively manufactured lattices is proposed, and a corresponding verification of said material model is provided. The aim of this thesis is the extension of that verification by utilizing the Finite Element method and applying the material model on lattices with more complex unit cell designs.

The verification process is based on comparisons with a well-established material model integrated in the commercial software package *Abaqus*. According to a proposed framework, numerical simulations are conducted via the Finite Element method on continuum and beam models of three different unit cell designs, shown in Figure 1. Those unit cell designs are each variations of an initial cross-shaped geometry, and differ from each other both in complexity and in unique features. Here, a distinct modeling strategy is applied to the beam models, to properly represent the aforementioned features.

The load cases applied to them are the load case of uniaxial tension and pure shear. To calculate the stress-strain response of the lattice material, two approximations

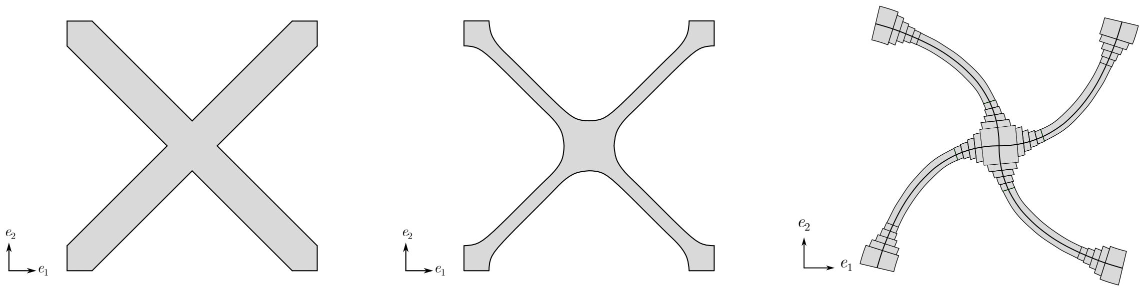

Figure 1: The three different unit cells investigated in this thesis

are made. First, a homogenization method in the form of the periodic microfield approach is applied. Second, to evaluate the homogenized stress-strain response of the lattice structure, a method based on linear homogenizations is utilized. Thus, depending on the load case and the symmetry of the investigated unit cell, periodicity or symmetry boundary conditions are applied. The adoption of these simplifications means that the computationial effort decreases significantly as now the behavior of an infinite lattice structure can be determined by performing the simulation of only a single unit cell.

In this thesis, a total of seven comparisons (or verification steps) are conducted with the aim of reaching a proper verification of the material model through logical connections among them. For each verification step, first the stress-strain relation is plotted and discussed and then the transformation zone is evaluated by focusing on two distinct transformation strain states: (1) the state of first full local phase transformation and (2) the state at which the maximum load is applied. For both transformation strain states, the contour plots are displayed making a proper identification and discussion of the emergence of the transformation zone and its further development possible. In one specific case, due to the combination of the geometry and the applied load case, instabilities are encountered in the form of buckling, which are circumvented by introducing a slight perturbation. This imperfection is analyzed by first conducting a buckling analysis followed by a sensitivity analysis.

The results of the numerical simulations show that the investigated uniaxial hypoelastic material model is well suited for the analysis of lattice structures made of superelastic material. The material model provides a straightforward calibration with a direct link to the experimental data. It is therefore an effective solution for research fields such as additive manufacturing of lattice structures in which frequent shifts of material properties need to be handled when different processing parameters are investigated.

Bibliography

[1] M. M. Schasching, O. Červinek, D. Koutný, H. E. Pettermann, and M. Todt, "A uniaxial hysteretic superelastic constitutive model applied to additive manufactured lattices," *PAMM*, vol. 25, 2025.