Computational Modeling of Metamaterials for Impact Protection

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Introduction

Mechanical metamaterials are man-made materials which derive their unusual properties from the geometry of their microstructure rather than their constituents/composition. Auxetic metamaterials (so-called negative Poisson's ratio materials) have been demonstrated to exhibit a number of mechanical properties in the (quasi) static regime that are potentially very promising for impact protection, given these properties are preserved in the highly dynamic regime. In this regime it is an open question to which extent the mechanical properties are retained and can possibly be compensated for by adjustments in the microstructure, since the highly dynamic impact regime is typically accompanied by large plastic deformations, geometrical and material nonlinearities, as well as rate and inertia effects. Examples of this behaviour in the static case are given in Fig. 1.

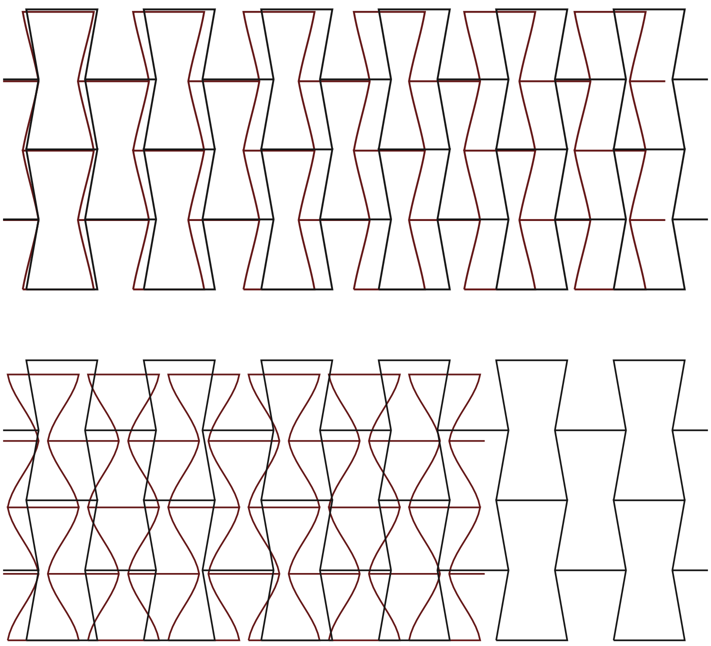

Figure 1: compression of re-entrant honeycombs
(upper: horizontal / lower: vertical)

Project

This projects aims to develop adequate computational models to guide the design of impact resistant metamaterials in the dynamic regime.

The research is subdivided into the following steps:

- Modeling of the material on the microscale including nonlinearities
- Surrogate modeling and macroscale simulation including nonlinearities
- Inclusion of design parameters into the surrogate model & optimization based on parametric surrogate models

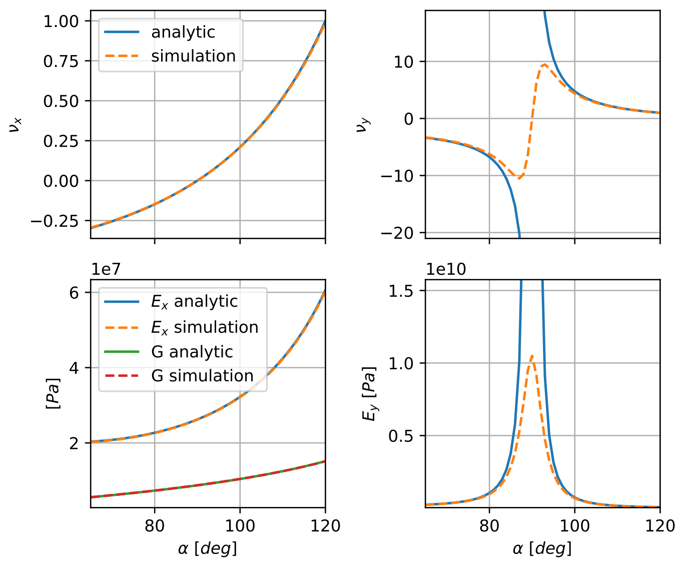

Figure 2: Comparison of model with (linear) analytic results

Initial Results and Outlook

In a first step, a Finite Element model using special Cosserat rods was implemented. It's results – in the linear regime – are well in accordance with analytic results from literature [1] (see Fig. 2). Besides 2D-structures, also 3D-structures are to be investigated. Here especially lattices, that offer different symmetries, and the effect of those symmetries onto the homogenization are of interest. E.g. nearly transversely isotropic lattices - with a hexagonal or triangular unit cell in-plane - could offer further benefits. One possible design is depicted in Fig. 3.

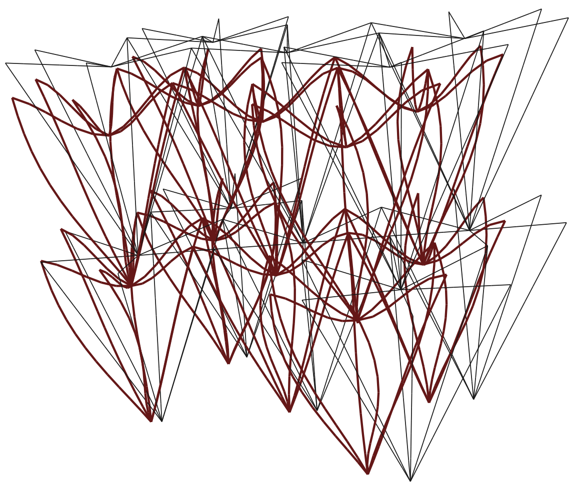

Figure 3: Envisioned transversely isotropic 3D-lattice

References

[1] Gibson L. J. et al., The mechanics of two-dimensional cellular materials. Proc. R. Soc. Lond. A 1982, 382(1782): 25–42.