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Multiscale Optimization using Surrogate Constitutive Models for Programmable Mechanical Metamaterials

A. Leichner[1*], T. Lichti[1], H. Andrä[1], F. Wenz[2], C. Eberl[2], A. Schwarz[3], C. Hübner[3]

[1] Fraunhofer ITWM, Department of Flow and Material Simulation, Kaiserslautern
[2] Fraunhofer IWM, Department of Meso- and Micromechanics, Freiburg
[3] Fraunhofer ICT, Department of Polymer Engineering, Pfinztal

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Programmable metamaterials introduce a new subset of metamaterials offering controllable and variable physical properties. As metamaterials, they are architectured materials, and are specifically tailored for engineering purposes. In particular, one objective would be to replace complex components, which capture environmental stimulus through sensors and actors, with only one material, "programmed" to behave identically.

The synthesis of metamaterials is usually carried out by mostly homogeneous layout of unit cells, the basic elemental structures architectured materials are composed of. They are designed to satisfy certain structural requirements when arranged in a large array and usually exhibit elastic behavior. Programmable metamaterials, however, are constructed by unit cells which show nonlinear deformation in arrays. In addition, their mechanical behavior can be controlled by geometrical design parameters. In contrast to standard metamaterials, the arrays for programmable metamaterial have a heterogeneous layout with locally varying unit cell parameters. The purpose of this is to satisfy custom intentions more effectively than with uniform compositions. To his end, we consider multiscale optimization for the implementation of customized material behavior and propose a computational framework, similar to topology optimization, as solution method.

Besides this multiscale aspect, our work is based on a data approach, allowing a broad range of application: We are able to include freely designed unit cells into our optimization framework, although no constitutive model are available for them. In an offline phase we compute strain-stress responses for all important design and loading cases of unit cells by using numerical homogenization. Due to the design parametrization, collecting all effective properties results in a high dimensional tensor, to which we apply tensor decomposition methods in order to compress the amount of data. A consecutive interpolation yields fast computable surrogate material models for arbitrary unit cells, such that fully resolved geometry models can be avoided in the online optimization.

In this contribution, we present the complete process chain from a parametrized unit cell till the final model of the programmable metamaterial, ready to be manufactured. In the end, we show numerical results with different unit cells and compare them to fully resolved simulations and manufactured samples.

REFERENCES

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