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Homogenization-based Optimization of Lattice structure using Granular Micromechanics Approach

Abstract

With the recent progress in additive manufacturing, lattice structures are being intensively researched for applications such as shock absorption, biomaterial scaffolds, and aerospace structures. They can be considered as structures at the scale of the lattice features, but materials at scales which are orders of magnitude larger. The materials and geometry of lattice structures can be optimized to meet target mechanical properties at the larger scale. In particular, homogenization-based optimization has been extensively studied since it saves computational resources as compared to full-resolution analysis. In this work, we show that the granular micromechanics approach is especially suitable for homogenization-based optimization because of the possibility to obtain closed form relationships between the macro-scale properties and the microstructural features. In particular, for bending- dominated lattices, we have come up with a method to calculate strain concentration tensors based on interpolation between the case of zero-stiffness joints or hinges, and the case of affine strain. In contrast to affine approximation which gives stiffness that differ from the finite element analysis results by an order of magnitude, those from this method closely match the finite element analysis. We show that the method is effective for two-dimensional lattices with slender beam elements, including auxetic lattices. The theoretical framework developed in this work can be extended to three-dimensional lattices as well. Effects of inter-nodal stiffness and orientation distribution of the struts on the macro- scale properties are specifically determined and compared against results from finite element analysis. Finally, the developed approach has been implemented in an optimization scheme to tune the element orientations and stiffnesses for target mechanical properties of the lattice.

References:

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