Tension-compression elastic asymmetry in application to lattice-structured metamaterials

Aleksandr Morozov[1], Sergei Khakalo[2]

[1] Technical University of Berlin, Germany. morozov@tu-berlin.de
[2] Aalto University, Finland. sergei.khakalo@aalto.fi

Paper ID: 298
Symposium S4: Mechanics of architected materials: Experiments and modelling

Abstract

Recent advances in additive manufacturing have made the mass production of functional materials with substructures, so-called metamaterials, economically feasible. As a result, predicting the effective mechanical behavior of micro-architected structural elements has become a key challenge in engineering science. Many materials commonly used in stereolithography (e.g., epoxy resins and nylons [1]) and laser powder bed fusion (e.g., some metallic alloys [2]) exhibit different elastic responses in tension and compression. At the microscale, this asymmetry can be explained by presence of microcracks or micro voids, inhomogeneous microstructures, and residual stresses induced by nonuniform solidification. These effects can significantly influence the effective mechanical properties of manufactured metamaterials [3]. In this work, we propose a constitutive material model that captures tension-compression asymmetry within a strain-driven framework, whereby the elastic response depends on the sign of a specific combination of principal strains. We solve one-dimensional strain- and stress-controlled benchmark problems analytically to establish the relationship between effective tensile and compressive moduli and compare these relations with commonly used, e.g., [4-6]. We also discuss the decomposition of elastic strain energy and the eigendirections of the stress and strain tensors for bi-modulus materials. Finally, we numerically analyze the impact of tension–compression asymmetry on the bending stiffness of triangular lattice-structured beams.

Keywords:

Tension-compression asymmetry Bi-modulus materials Metamaterials Triangular lattice structure

References:

[1] H. Fallahi, F. Taheri-Behrooz, and A. Asadi "NonlinearMechanical Response of Polymer Matrix Composites: AReview", Polymer Reviews 60.1 (2020), 42-85

[2] N. Pai, I. Samajdar, and A. Patra. "Microstructural andmechanistic insights into the Tension-Compression asymmetryof rapidly solidified Fe-Cr alloys: A phase field andstrain gradient plasticity study". J. Mech. Phys. Solids189 (2024), 105695

[3] H. Hatami-Marbini, and M. Rohanifar. "Stiffness ofbi-modulus hexagonal and diamond honeycombs". J. Mech. Sci.Technol. 33.4 (2019), 1703-1709

[4] S.A. Ambartsumyan. "Elasticity theory of differentmoduli" (RF Wu, YZ Zhang, Trans.). Beijing: China RailwayPublishing House, 1986.

[5] M. Latorre and F. J. Montáns. "Bi-modulus materialsconsistent with a stored energy function: Theory andnumerical implementation". Comput. Struct. 229 (2020),106176

[6] A. Misra, L. Placidi. "Emergence of bimodulus(tension-compression asymmetric) behavior modeled ingranular micromechanics framework". Math. Mech. Solids.30(8) (2025), 1711-1726