Nonlinear metamaterials with engineered heterogeneities

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Abstract

Nonlinear metamaterials with engineered mesoscale architectures consisting of different constituents with contrasting mechanical properties are expected to offer superior combinations of strength and toughness. Such structures are found in nature as well; whereas biological materials rely on a limited choice of organic and mineralized constituents, modern additive manufacturing methods offer a wider palette of materials and material combinations including metals, ceramics and polymers to design multi-material architectures that can display superior performance under a wide range of loading conditions. Here, an investigation of the fracture behavior of a "lamellar" meso-scale architecture is presented as a model system, which is made up of alternating layers of two steels with contrasting strength and ductility. The lamella widths are varied between 0.3 and 10 mm, which represents the "meso-scale" for this material combination. The load-deflection response of the lamellar specimens comprises of alternating segments of plateau and sharp load drops. For certain lamella length scales, the peak load and the energy dissipation are seen to be higher than those of even the base materials, demonstrating that meso-scale architecting is an effective materials design strategy to enhance effective strength and toughness simultaneously. An investigation of the underlying mechanisms reveals that the enhancement of effective properties is due to a combination of crack tip shielding and unstable crack propagation; analysis also suggests an optimal length scale, which is seen in the experiments as well. Although this investigation discusses a lamellar architecture, the question of optimal topology remains open. Further, a combined experimental and computational investigation of dynamic shear localization of heterogeneous architectures is also presented. It reveals the potential for designing materials with superior performance for impact loading conditions. Challenges and opportunities in developing new experimental diagnostic techniques and theoretical analyses in characterizing and predicting the response of heterogeneous materials are also discussed.

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