Towards Proactive Design of Fracture Resistance in Mechanical Metamaterials

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Abstract

Fracture is a classical topic in solid mechanics, while mechanical metamaterials represent an emerging field enabling innovative applications. The intersection of these areas presents both significant challenges and unique opportunities. In this study, we demonstrate that the fracture toughness of lattice metamaterials is profoundly influenced by their topology, with shell-based lattice metamaterials exhibiting superior fracture resistance compared to their truss-based counterparts. We reveal a topology-induced intrinsic toughening mechanism in shell-based lattices and identify a distinct fracture dissipation mechanism, termed structural plasticity. Additionally, we show that fracture behaviors in mechanical metamaterials can be proactively controlled. By harnessing elastic instability, we regulate the plastic zone size in pseudoplastic metamaterials, thereby amplifying structural plasticity. Through a combination of experimental and computational approaches, we realize distinct fracture behaviors, including the intrinsic-to-extrinsic transition in fracture toughness. This work demonstrates a framework for transitioning from passive understanding to proactive control of fracture behavior through mechanical metamaterials, deepening the understanding of the interplay between fracture and mechanical metamaterials and opening avenues for advanced material design.