Steering Fracture in Metamaterials – Synergy of Plasticity and Fracture in Slender Beams

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Abstract

Metamaterials have been of increasing interest in various applications fields, such as absorbing shocks or vibrations, as well as damage prevention. So far, they have been developed with a goal to increase toughness, reduce weight, increase durability of structures, all of them aiming at fracture prevention. While conventional fracture mechanics aims to prevent the initiation and propagation of cracks, a novel approach seeks to utilize the phenomenon of fracture in our favour, by steering fracture through exploiting the geometry of metamaterials. In this work, we aim to gain the opportunity to precisely control and steer the crack propagation route in compression, by taking advantage of controlling the metamaterials design and thus their mesh properties. Starting from a deeper understanding of crack propagation during compression, we investigate the mechanisms that determine the crack path in both brittle and ductile materials. Firstly, we compress beams of different slenderness, cross section shape, and materials, using a system of two displacement-controlled fixed grippers. We analyse with both a high-speed and a regular camera, and we look into the simultaneous effect of buckling and plasticity and its impact on the fracture propagation. For elasto-plastic materials, if the plastic regime is already reached when the fracture starts, the effective cross section area reduces during the crack propagation while the stiffness is considerably reduced, causing an unusual fracture response. By tuning this effect, designing more complex structures and applying our findings on fundamental beams to them, fracture propagation can be used as a design tool, instead of being dreaded and avoided. Our findings highlight the potential of intentionally directing fracture as a design tool, opening up new avenues for the design of safer, more efficient materials in applications where fracture control is critical, such as helmets and battery shells.

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