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Buckling-Induced Fracture Regimes in Slender Beams Under Compression

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Abstract

Slender structures are ubiquitous, from tall columns in buildings to the intricate patterns inside advanced engineered designs. Their fracture behaviour has long posed challenges, noted by Feynman in his observation of how dry pasta shatters into multiple fragments upon bending. Whereas bending refers to the deformation of a structure under transverse loading, buckling arises as an instability under compressive axial loads, leading to sudden lateral deflection. However, the way the fracture path propagates in slender buckling beams under compression remains largely unexamined. In this study, we investigate the interplay between two mechanical instabilities, buckling and fracture, and how their interaction governs failure mechanisms and crack-propagation paths. Fracture path is tracked in molded polymer-based beams, using high-speed cameras while the stress response is monitored, during compression. We identify distinct fracture regimes governed by beam slenderness, which are common across different material systems, indicating a dominant role of geometry-mediated stress redistribution rather than intrinsic material properties alone and we discuss the physical mechanism that triggers fracture in regards to the stress distribution at the onset of fracture. These findings advance the fundamental understanding of fracture path evolution under compressive loading, paving the way for the design of materials with programmable failure modes

—from high-performance protective systems, such as helmets, to architected food structures with optimized sensory responses.

Keywords:

fracture slender beams crack path crack propagation slenderness elastic instability buckling compressive failure