
Aperiodic lattice metamaterials with improved resilience to impact

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Abstract

Protective structures are designed to shield and safeguard vital assets must absorb and dissipate the energy imparted by an impact without losing structural integrity. The absorbed energy is dissipated due to the formation of local structural damage. Theoretically, the material could absorb the energy until it melts, but structures fail long before that due to stress concentration, an inherent feature of unstructured solid materials. The impact causes localized stress to increase, exacerbating the damage and promoting crack formation. Once a crack propagates, the structure fails, but the pieces of a failed structure can absorb additional energy if appropriately integrated into a resilient design. The design of resilient metamaterials aims to counteract the natural tendency of stress concentration and subsequent crack propagation. These metamaterials are designed to allow the initiation and sequential arrest of faults in different places without compromising the overall structural integrity, which enables the structure to absorb more energy without catastrophic failure. This paper explores the failure mechanisms of lattice structures and the designs that enhance the resilience of them. We perform numerical experiments on the dynamic of lattices with breakable links and study various structural means that increase resilience. Namely, we find that resilience increases due to the following means:

- (a) Adding additional "sacrificial" links to the structure that absorb energy but prevent the damage of the essential structural links.
 - (b) Use an aperiodic structure to eliminate the directions of easy damage propagation. A study of Penrose's aperiodic lattice reveals that the damage is scattered away, forming a damaged spot rather than cracks.
 - (c) Random perturbation of lattice node positions and the use of sacrificial links break the symmetry and induce delocalization: more links that are not fully destroyed but only partially damaged.
 - (d) Random perturbation of link strength also reduced the crack growth.
- We measure the quality of equally impacted structures by comparing the dissipated energy (number of broken links) and radii of significantly and lightly damaged zones. Our findings suggest that using asymmetric geometry and sacrificial links in protective lattice structures significantly improves structural integrity.

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