
3D straw-based metamaterials: modeling, experimental characterization, and tunable mechanical properties

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Abstract

Straw-based truss metamaterials are composed of multistable, straw-like elements interconnected by rigid links, creating highly reconfigurable structures with multiple stable states. Their mechanical properties, such as Poisson's ratio, Young's modulus, and shear modulus, are adaptable based on their configuration, making them promising for applications in energy absorption, deployable structures, and soft robotics. To leverage these characteristics for engineering applications, we present a quasi-static computational framework in 3D space to model those metamaterials. Starting with a single straw element, we introduce nodal and internal degrees of freedom (DOFs) alongside holonomic constraints. The straw element exhibits infinite anti-symmetrical stable states in 3D without theoretical energy barriers, yet experiments reveal a damping force during transitions. We characterize this force and amend the model with an artificial friction term. Subsequently, the model is extended to represent complex 3D structures with multiple unit cells and rigid links. After characterizing the model coefficients, experiments are carried out for model validation with the help of force sensors and computer vision techniques. Finally, we demonstrate the model's configuration-dependent properties, including tunable Poisson's ratio, energy absorption, and adjustable stiffness, highlighting its potential for a wide range of engineering applications.

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