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Incremental auxetic response of composite lattices under isotropic prestress

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Abstract

This work studies the constitutive response of two- and three-dimensional lattice materials subject to isotropic prestress, with focus of the elastic stiffness moduli that can be directly measured through experimental tests. The unit cell of the examined lattices is formed by an arbitrary number of junctions attached to a junction. Analytic formulae for the elastic stiffness coefficients of stretching-dominated lattices are provided. In addition, numerical results for the incremental elastic moduli of composite lattices equipped with hard and soft rods are presented. The given results highlight that isotropically pre-tensioned lattices may exhibit marked variations of the elastic stiffness moduli in the prestressed state, over the values competing to the stress-free con guration. This study also discloses that prestressed lattices may feature incremental auxetic response, when composite architectures suitably combining hard and soft materials are employed for their fabrication.

Keywords: lattice materials, stretching-dominated response, prestress, elastic moduli, auxetic response

1. Introduction

Recent research in the area of lattice mechanics has revealed that suitably designed, micro- and nano-lattice materials are able to achieve extreme properties over more than several orders of magnitude in density, being able to ll holes in the current material property charts, through an optimal control of material and space [1]-[19]. Stretching-dominated lattices can achieve extremely high stiffness-to-density ratios [6]-[19], while bending-dominated lattices generally exhibit more compliant but more recoverable response under large strains [3, 4, 15]. Hierarchical architectures and structures equipped with hollow tubes have been employed to combine high strength and high recoverability [6, 7, 14, 17, 18], since standard stretching-dominated lattice materials are typically affected by failure under buckling, which may reduce strength and cyclability of the material [7, 13, 14]. Increasing attention are also receiving the so-called isogrid and anisogrid lightweight structures [20]-[23]. A special class of lattice materials with extremal response is that of *auxetic lattices*, which are endowed with peculiar microstructures (e.g., honeycomb architectures with re-entrant corners) that allow the material to exhibit strains of equal signs both in the direction of the applied load, and in the transverse direction (i.e., negative Poisson s ratios) [24]. It has been show that auxetic structures are well suited for the manufacturing of impact- and vibration-resistant materials, in biomedical applications, and for the fabrication of innovative bre-reinforced composites, just to mention few relevant examples [25]-[28].

The effects of initial stresses on the incremental constitutive response of elastic solids have been longly investigated in the literature (refer, e.g., to [29]-[36] and references therein). Initial stresses may refer to the state of stress of a body that has undergone a previous story of nite elastic deformations (*prestressed body*), and/or to self-equilibrated (or *residual*) stresses arising in a body in absence of external loads, due to manufacturing processes, growth processes, hygrothermal effects, etc. [35]. Such stresses are diffusely present in biological structures, like arteries and soft tissues [34], and their action may signi cantly affect the constitutive response and the propagation of mechanical waves in elastic materials [35, 36]. The effects of geometric stiffness terms due to large displacements and initial stresses in tensegrity structures and other prestressed lattices are diffusely analyzed in [37–39] and references therein. The relevant role played by such effects on the incremental response of prestressed lattices structures is nowadays well

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