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Scope and Future of Architectured Metamaterials in Aerospace Engineering

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Abstract

Lattice metamaterials are a class of artificially engineered materials that possess customized multifunctional properties, catering to specific applications across various length scales. These materials' effective properties depend on the geometric arrangement of constituent unit cells, in addition to their intrinsic material properties. As a result, macroscale material properties can be tailored for specific applications, enabling the creation of advanced materials with novel functionalities. Recent advancements in additive manufacturing and material fabrication have significantly contributed to the growing interest in application-specific metamaterials, as they allow the fabrication of complex structures that were previously unattainable. This article aims to enhance the effective mechanical properties of bending-dominated lattice metamaterials. Over the past decade, research in artificially engineered lattice metamaterials has intensified due to the escalating demand for tailored materials to fulfill specific applications, which cannot be achieved with naturally occurring materials. Among various cell geometries of lattice metamaterials, honeycomb lattice metamaterials have drawn significant attention due to their higher strength-to-weight ratio and exceptional modulation capability of multiple mechanical properties. Consequently, numerous studies have been conducted to determine the effective material properties of honeycomb lattice metamaterials. These studies often consider a single unit cell to analyze the effective material properties of the periodic microstructures. Conventional bending-dominated lattices exhibit less specific stiffness compared to stretching-dominated lattices while showing high specific energy absorption capacity. This article aims to improve the specific stiffness of bending-dominated lattices by introducing elementary-level programmed curvature through a multi-level hierarchical framework. The influence of curvature in the elementary beams is investigated here on the effective in-plane and out-of-plane elastic properties of lattice materials. The beam-like cell walls with out-of-plane curvature are modeled based on 3D degenerated shell finite elements. The numerical results reveal that the effective in-plane elastic moduli of lattices with curved isotropic cell walls can be significantly improved without altering the lattice-level relative density, while the effective out-of-plane elastic properties reduce due to the introduction of curvature. To address this issue, we further propose laminated composite cell walls with out-of-plane curvature based on the 3D degenerated shell elements, which can lead to holistic improvements in the in-plane and out-of-plane effective elastic properties. The proposed curved composite lattice materials would enhance the specific stiffness of bending-dominated lattices to a significant extent, while maintaining their conventional multi-functional advantages

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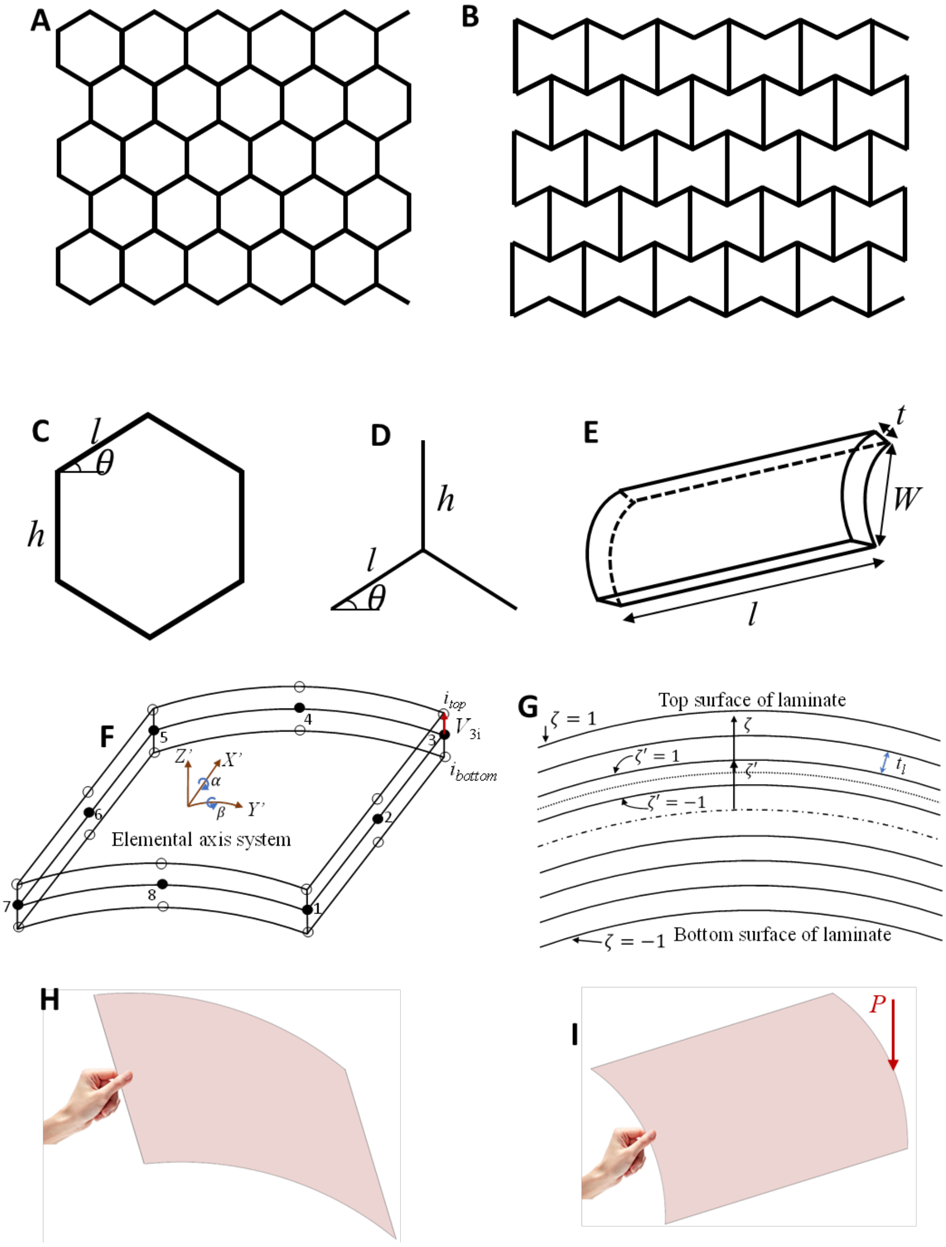

Fig. 1 Introduction of programmed curvature in lattice metamaterials. (A - B) Typical representation of non-auxetic and auxetic lattice metamaterials. (C) Honeycomb unit cell of lattice metamaterials. Note that a general hexagonal unit cell can be readily converted to rhombic and rectangular unit cell by considering special cases with h = 0 and θ = 0, respectively. A negative value of θ leads to auxetic configurations. (D) Inverted Y shaped unit cell of lattice metamaterials. (E) Curved geometry of lattice cell walls. The entire lattice can be conceived as a periodic network of such cell walls. (F) 8-noded degenerated shell element. (G) Cross-section of composite laminates along with the numerical integration scheme. (H - I) Demonstration of the stiffening effect in a thin paper through the introduction of curvature