Design of optimal architectures for ultra-light isotropic microtruss-based metamaterials

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Abstract

Microtruss-based architectured materials offer unique opportunities for tailoring mechanical properties, enabling novel combinations of stiffness, strength, and density. Their exceptional stiffness-to-weight ratios have spurred interest, particularly in transportation applications. However, the inherent anisotropy of most proposed architectures poses challenges in characterizing their fracture behavior on macroscopic scales (1).
In this work, we introduce a novel class of microtruss-based metamaterials designed to exhibit isotropy at small scales. These isotropic architectures were developed using an advanced computational framework, enabling precise structural generation and the creation of digital twins to predict mechanical properties comprehensively (2). The resulting materials demonstrate exceptional stiffness-to-density ratios that approach the theoretical upper limits established by the Hashin–Shtrikman bounds for isotropic porous solids (3).

While these materials exhibit exceptional stiffness, their compressive strength and fracture resistance remain areas of improvement. To address these challenges, we propose two complementary approaches. The first involves a statistical spatial modulation of local microbeam properties-such as diameter, shape, and material composition. This method leverages scale-invariant parameters to preserve overall isotropy while enabling fine-tuning of local autocorrelation properties with minimal control variables. The second approach draws inspiration from nacre, employing a monomaterial composite architecture that combines soft and hard microstructural elements (4). By interleaving these contrasting architectures, we achieve tunable elastic modulus and significantly enhanced fracture resistance. Together, these strategies enable the optimization of mechanical properties for a broader range of applications, balancing stiffness, strength, and toughness as needed.

This talk will present the design methodology, numerical tools, and mechanical performance of these isotropic architectured materials, along with ongoing efforts to enhance their compressive strength. These advances open new avenues for the application of microtruss-based metamaterials in engineering and material science.

References:

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