HIGHLY STRETCHABLE AND TOUGH PANTOGRAPH-INSPIRED LATTICE METAMATERIALS

Lattice metamaterials which can magnify the elastic limit and fracture strain of their constituent parent materials are highly sought after in applications including wearable electronics and batteries, impact absorbents, switchable acoustic modulators, soft robotics, rehabilitation devices, tissue scaffolds, and drug delivery vehicles. Current strategies for increasing stretchability include kirigami and origami-based, serpentine, bi-layer, as well as pantographic designs. The former three of these designs rely on out-of-plane buckling, while the latter two exploit torsional compliance between component layers. Here we present multi-layer pantograph-inspired lattice structures modeled on hexagonal and diamond templates since they are tessellating mechanisms for ideal hinges. Proof-of-concept samples were additively manufactured using stereolithography from commercially available acrylate-based resins. Axial and flexural stiffnesses of the struts were made large enough that lattice deformation was predominantly accommodated in the cylindrical connectors by torsion at small deformations, and flexure-shear-torsion at large deformations. Experimental observations at the scale of individual elements were obtained using digital image correlation and effective elasticity tensors under plane stress were assembled. A discrete-to-continuum bridging was developed by homogenizing the lattice structures to effective continua using the granular micromechanics framework within linear elasticity. In the discrete description, the joints between the struts were visualized as grains interacting with their nearest neighbors, with the elastic interaction energy being a function of the Euclidean distance between two grain pairs and the relative rotation between nearest neighbor inter-layer struts. The discrete-continuum kinematic relationships were developed as an interpolation between perfectly hinged cases and rigid joint cases. The experimental results show reasonable agreement with the granular micromechanics model for cases where the flexure-shear deformation of the cylindrical connectors is negligible. For slender connectors with significant flexure-shear deformation, the agreement was poor, and the effective values of intergranular stiffnesses are currently being re-examined to include the effects of flexure-shear deformation. In agreement with geometric compatibility analysis, the diamond lattice shows better strength retention under increasing stretchability as compared to the hexagonal lattice.

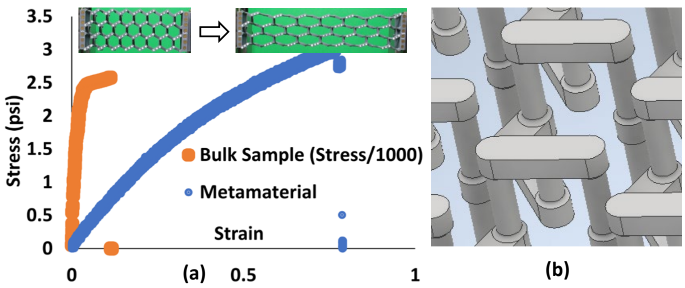

Figure 1(a) Stress-strain curve of bulk material vs metamaterial (b) zoomed view of lattice structure.

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