Impact of structural disorder on the micromechanical behavior of shell-based micro-architected metamaterials

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Abstract

Architected (meta)materials allow unique structure-mechanical properties that surpass classical engineering materials. Such metamaterials encompass a myriad of material classes and properties that can be tailored to dedicated engineering applications yielding new opportunities in various technological fields. With the aim to create bio-inspired metamaterials, recent efforts target to harness characteristic features omnipresent in nature: heterogeneity, randomness and disorder. Objectives include stress de-localization, defect insensitivity and increased ductility. Advances in additive manufacturing now enable us to synthesize micro-architectures with nanoscale features necessary to replicate the internal structural complexity in such bio-inspired architected materials. In this study, we outline how we can control the degree of disorder in micro-architected metamaterials ranging from periodic to random topologies with the aim to tailor their microscale elasto-plastic behavior. We use shell-based topologies due to their superiority regarding energy absorption, strength and stiffness at a low weight. Arrays of polymeric micro-architectures featuring 11 different degrees of randomness were 3D-printed using two-photon lithography (Photonic Professional GT2, Nanoscribe, Germany). For a selection of these architectures, we also varied the relative density. *Pre-* and *post*-test imaging was done with a high-resolution SEM (Tescan, CZ) and the effect of disorder on the micromechanical behavior quantified by *in situ* experiments using a portable nano-indenter (FemtoTools, CH) integrated into an SEM. Uniaxial micro-compression tests were performed displacement-controlled and at a quasi-static strain rate (10-3 s-1) up to an engineering strain of 50%. Mechanical properties such as Young's modulus, yield strength and energy absorption were extracted using a custom-written Python code. Results show that transitioning from periodic to random architectures leads to a reduced yield strength but a highly homogeneous deformation, characterized by a lack of softening, a prolonged plastic plateau and stress-delocalization. For the micromechanical behavior and all mechanical properties, including energy absorption, we observe two clusters of data with distinct differences. Our data also suggest that the effect of disorder is disguised at higher relative densities. Using nanoscale resolution 3D printing while controlling the degree of disorder of micro-architectures creates new opportunities for highly multifunctional (meta-)materials.

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