009-ENGR

A generalized algorithm for the topological design of multistable tensegrity structures

Tensegrity structures attain their form and structural integrity through discontinuous compression members enclosed in a continuous network of pre-tension. The disjointed compression or "floating struts" in class 1 tensegrities and relative compliance of tension members endows them with high impact resilience, active multi-modal mobility control, and energy efficiency. The effective mechanical properties of mechanical metamaterials formed using tessellating tensegrity unit cells can be tuned using not only their microstructural geometry, but also their level of prestress. Null self-stress tensegrity-like metamaterials with unit cells architecturally identical to tensegrity structures show promising effective mechanical properties including order of magnitude improvements in strength and toughness driven by delocalized deformation. Tensegrity-like metamaterials of unit cells with bistable tensegrity architectures further demonstrate tunable reversible nonlinearity. Class 1 tensegrity metamaterials with non-zero self-stress formed by tessellating multi-stable tensegrity unit cells (MSTUC) are expected to open new and unexpected paradigms of mechanical behavior which could be exploited to produce exotic materials for e.g. shape configurable adaptive smart materials, damage free reversible shock-absorbers, and energy trappers. However, the investigation of such metamaterials is still in its infancy owing to significant challenges including: (a) generalized topology design methods for tessellating MSTUC in three dimensions in the space of class 1 tensegrities, (b) efficient algorithms which can construct and explore the potential energy space for a MSTUC and its supercell, and determine the load-deformation paths between the energy extrema, (c) discrete-continuum multi-scale formulation which can capture the high geometric non-linearity and instabilities in a MSTUC and its supercell, and (d) 3d printing strategies for additive manufacturing of tensegrity metamaterials achieving pre-stress without post-printing assembly. An interdisciplinary team of researchers are addressing these challenges using a novel algorithm that combines topology design with identification of local maxima in the potential energy landscape. The force deformation path between multiple stable states is computed using gradients within the explored regions of the potential energy landscape. The algorithms are verified and validated using structural phase transition experiments on physical models of class 1 tensegrities constructed using wood struts for compression members and rubber bands for tension members.