Piezoelectric truss metamaterials: data-driven design and additive manufacturing

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Abstract

Mechanical metamaterials enable a variety of tailored physical characteristics such as negative Poisson's ratio, selective energy dissipation, non-reciprocity, shape morphing, and elastic waveguiding. Incorporating the concept of metamaterials with active materials leads to the development of *smart metamaterials,* which opens the possibility of having unique characteristics in multiphysics-coupled phenomena. Though mechanical metamaterials have been designed to achieve tuneable anisotropy of mechanical response through inverse design, there is an unexplored potential for metamaterial design and fabrication for tailored piezoelectricity. Here, we design novel piezoelectric truss metamaterials using machine learning to efficiently harness the full design space of tuneable electromechanical response. An electromechanically coupled computational framework based on the finite element method and deep learning is developed to surrogate the effective elastic, electrical, and electromechanical response of a unit cell. Based on this computational framework, an inverse model is trained to efficiently and systematically reverse engineer the geometry and topology of the metamaterial unit cell with the tailored, effective piezoelectric response of the metamaterial. We explore auxetic piezoelectricity, uni-directional piezoelectricity, and arbitrary ratios of shear and normal piezoelectric coefficients through the architectures designed with the inverse-design framework. As a proof of concept, lattices with exotic properties are additively manufactured, and their piezoelectric response is characterized.

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