Ph.D. Thesis Defense

by

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“Topics in Stress-Induced Instabilities and Phase Transitions in Lattice-Based Solids”

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Summary:
Mechanical response of a lattice-based solid, where the entire system is built up by a repetitive translation of a unit cell along its principal axes, manifests itself in changes either in the macro or the microstructure of the system. Depending on the loading configuration, drastic and remarkable changes may occur in the mechanical behavior of the entire lattice, often triggered by a macro or micro instability. The outcome of these instabilities varies significantly across different systems and scales, and is often reflected in phenomena such as, but not limited to, defect nucleation, shear bands, phase transitions and pattern formations. The subject of this thesis is to study stress-induced instabilities in certain groups of lattice-based solids, as well as their manifestations on mechanical properties of the whole lattice. Although we choose certain families of materials and metamaterials in our study, the approaches that we employ could be utilized to investigate instabilities of any system with translational symmetry.

We investigate stress-induced instabilities in single crystal metals. We study the onset of symmetry breaking in four distinct metals of both FCC and BCC structure. We subject them to a combined shear and dilation, and examine the Schmid assumption, whereby we identify the onset of plasticity with the onset of instability. We perform both phonon and elastic stability analysis. We study the nature of the instability and show for the first time, to the best of our knowledge, that the short wavelength instabilities are abundant. Our results illustrate the potential pitfalls of relying on the widely used elastic stability analysis and disqualify it as the method of choice.

We also investigate stress-induced material symmetry phase transitions in tensegrity-based metamaterials. We study material symmetries of tensegrity lattice by examining the eigenspaces of the effective elasticity tensor, obtained through a homogenization scheme. We demonstrate symmetry breaking and phase transitions, occurring solely due to pre-stressing the members of the lattice. We observe several phase transitions including cubic to tetragonal and tetragonal to orthotropic and vice-versa. We also demonstrate existence of a discrepancy between the material symmetries of a finite and infinite lattice, and show that imposing periodic boundary conditions can lead to physically incorrect results. Our results suggest new research paths for designing tensegrity-based metamaterials and tuning their properties through adjusting the pre-stretches in the cables.
Finally, we study the mechanical response of homogenous two dimensional tensegrity lattices. We aim to investigate the effect of lattice connectivity on the localization. We propose new designs of two dimensional lattices with very similar geometry, which only differ in the connectivity of compression members. We verify the stability of the proposed lattice, and then compare the mechanical response of two lattices, subjected to uniaxial compression, with connected and isolated compression members. We demonstrate that while local instabilities lead to global instability in the former case, the latter case remains globally stable for a vast regime of deformations. We believe our results create new avenues for investigating the complex problem of emergence of localized deformations.

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