Mechanical Engineering Doctoral Defense

Field Driven Design of Graded Cellular Structures

School for Engineering of Matter, Transport and Energy

Mandar Shinde

Advisor: Dhruv Bhate

Abstract

The design of energy absorbing structures is driven by application specific requirements like the amount of energy to be absorbed, maximum transmitted stress that is permissible, stroke length, and available enclosing space. Cellular structures like foams are commonly leveraged in nature for energy absorption and have also found use in engineering applications. With the possibility of manufacturing complex cellular shapes using additive manufacturing technologies, there is an opportunity to explore new topologies that improve energy absorption performance. This thesis aims to systematically understand the relationships between four key elements: (i) unit cell topology, (ii) material composition, (iii) relative density, and (iv) fields; and energy absorption behavior, and then leverage this understanding to develop, implement and validate a methodology to design the ideal cellular structure energy absorber. After a review of the literature in the domain of additively manufactured cellular materials for energy absorption, results from quasi-static compression of six cellular structures (hexagonal honeycomb, auxetic and Voronoi lattice, and diamond, Gyroid, and Schwarz-P) manufactured out of AlSi10Mg and Nylon-12. These cellular structures were compared to each other in the context of four design-relevant metrics to understand the influence of cell design on the deformation and failure behavior. Three new and revised metrics for energy absorption were proposed to enable more meaningful comparisons and subsequent design selection. Triply Periodic Minimal Surface (TPMS) structures were found to have the most promising overall performance and formed the basis for the numerical investigation of the effect of fields on the energy absorption performance of TPMS structures. A continuum shell-based methodology was developed to analyze the large deformation behavior of field-driven variable thickness TPMS structures and validated against experimental data. A range of analytical and stochastic fields were then evaluated that modified the TPMS structure, some of which were found to be effective in enhancing energy absorption behavior in the structures while retaining the same relative density. Combining findings from studies on the role of cell geometry, composition, relative density and fields, this thesis concludes with the development of a design framework that can enable the formulation of cellular material energy absorbers with idealized behavior.

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