Abstract

This thesis explores the intersection of bioinspired design and architected materials to develop novel materials with superior functionalities. Architected materials are known for their exceptional mechanical properties that traditional materials cannot match, for instance, the ability to achieve high strengths at low densities. On the other hand, biological materials, shaped by the forces of evolution, exhibit remarkable multifunctional capabilities owing to their material, structural and multiscale hierarchical features. This work attempts to bridge these fields by gleaning design principles from nature to create advanced architected materials across polymeric and metallic platforms.

Curved shells inspired by the ridged carinae of the mantis shrimp telson are shown, through finite element simulations and patented experiment test setups, to exhibit strong snap-through instabilities, reversible bistability, and large hysteresis loops. Introducing these ridges decouples stiffness from peak moment and increases energy dissipation by nearly at least six orders of magnitude relative to smooth shells while remaining within manufacturable design spaces. A data-driven inverse-design framework that couples supervised learning with genetic optimization demonstrates that ridge patterns can be chosen to independently tune stiffness, peak load, and dissipation, establishing a scalable route for programming instabilities in thin-shell systems.

Shape-memory behavior is pursued through geometry and composite interactions instead of intrinsic phase-change materials. Micromechanical modeling of avian feather shafts shows that hydration-induced softening of the amorphous keratin matrix, rather than swelling, is the dominant driver of recovery, enabling stiff β-keratin fibers to release stored elastic energy and restore shape. These principles are abstracted into phase-transforming cellular materials coupled with elastic springs, which, under thermal softening, exhibit 100% shape recovery, tunable deadweight lifting capacity, and antagonistic two-way actuation. Macro-scale 3D-printed prototypes validate the simulations while discussions are provided regarding the challenges and remedies of manufacturing these systems at the micro- and nano- scales.

Metallic implementations use laser powder bed–fused microlattices made from an oxide-dispersion-strengthened nickel alloy to probe how topology governs deformation, grain reorientation, and defect sensitivity. Discussions are provided on the strong influence of as-fabricated defects relative to ideal CAD geometries. Architecture-dependent behavior is observed across straight-bar, elongated honeycomb, and BCC lattices, and hybrid stacking sequences that combine stretching- and bending-dominated layers show that strength–ductility trade-offs can be tuned through layer ordering and interfacial connectivity by using architected bonding elements.

Complementary studies on the feeding apparatus of chitons reveal how magnetite–chitin material gradients steer cracks to promote self-sharpening and avoid catastrophic failure, while stylus heterogeneity and interface design create a spring–bar-like linkage that transmits force, enhances maneuverability, and localizes damage in a sacrificial zone. A CT-to-CAD workflow and dimensionless design space are established to enable future radula-scale optimization. Finally, additional case studies on mosquito antennae, diabolical ironclad beetles, and sea urchin stereom show how nature uses resonant architectures, evaporative cooling, and Voronoi-like porous regularity to achieve selective acoustic sensing, passive thermoregulation, and distributed damage tolerance, respectively. Together, these studies show that carefully abstracted biological principles can be systematically re-engineered into architected material systems that couple mechanical robustness with adaptive functionality.