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Exploiting the Structural Diversity in Nature as a Path Toward Mechanical Enhancement

Taking clues from biological systems, we are interested in understanding the design rules employed by Nature and applying these strategies to the development of mechanically-enhanced and tunable materials.

One area of particular interest is the incorporation of responsive, supramolecular reinforcing elements in polymeric composites with the goal of combining superior mechanical behavior that can be tuned with additional functionality, such as sensing and bioactivity. In one approach, a cholesterol-derived diacetylene low molecular gelator has been designed to self-assemble into one-dimensional fibers within an elastomeric matrix. Highlighted in this design strategy is the ability to induce inherent dispersion via molecular-level control of filler assembly and to manufacture these composites via a facile process. Bio-inspired composites were also derived from hierarchical electrospun nanofiber fillers that exhibited interfacially-controlled, mechanical switchability and tunable transport behavior. These ion- or water-responsive systems have unique applications in therapeutic delivery, chemical/biological protection, and actuation.

Inspired by natural materials, such as spider silk, bone, and collagen, we have also designed a series of polymer-peptide polyurethane/urea to explore the hierarchical arrangement critical to energy absorption and mechanical enhancement. We have addressed design strategies for hierarchical assembly and the influence of the interfacial region on mechanical behavior via the incorporation of ordered regions. Multi-block copolymers, which mimic the microstructure of numerous natural materials, are ideal systems with which to explore ‘soft’ domain ordering via variations in secondary structure of nature’s building blocks – peptides. The sheet-dominant hybrid materials were typically tougher and more elastic due to intermolecular H-bonding facilitating load distribution, while the helical-prevalent systems generally exhibited higher stiffness. It is envisioned that these peptide-polymer platform materials will advance technologies related to biomedical devices and smart coatings/fibers.

Biological systems also illustrate the power of non-covalent interactions to mediate assembly phenomena, responsiveness, and mechanical enhancement. We have developed supramolecular elastomers and interpenetrating network systems that probe the interplay of non-covalent and covalent interactions in structural organization and mechanical response. In this research, concepts of interfacial control of self-assembly, composition, and dynamics as it relates to mechanical behavior are examined. These systems show promise in smart coating applications and for the development of functional polymer blends.