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Biologically inspired and impact-resistant composites

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There is an increasing need for the development of multifunctional lightweight materials with high strength and toughness. Natural systems have evolved efficient strategies, exemplified in the biological tissues of numerous animal and plant species, to synthesize and construct composites from a limited selection of available starting materials that often exhibit exceptional mechanical properties that are similar, and frequently superior to, mechanical properties exhibited by many engineering materials. These biological systems have accomplished this feat by establishing controlled synthesis and hierarchical assembly of nano- to micro-scaled building blocks. This controlled synthesis and assembly require organic that is used to transport mineral precursors to organic scaffolds, which not only precisely guide the formation and phase development of minerals, but also significantly improve the mechanical performance of otherwise brittle materials. However, Nature goes one step further, often producing materials with that display multi-functionality in order to provide organisms with a unique ecological advantage to ensure survival.

In this work, we investigate a few organisms that have taken advantage of hundreds of millions of years of evolutionary changes to derive structures, which are not only strong and tough, but also demonstrate multifunctional features dependent on the underlying organic-inorganic components. We discuss, for example, (i) the hyper-mineralized combative dactyl club of the stomatopods, a group of highly aggressive marine crustaceans, (ii) an elytra from an impact resistant beetle and (iii) an ultrahard and light diffusing shell of a bioluminescent gastropod that uses its thick shell not only for protection but also to ward off predation through illumination. Many of these tissues include both fibrous organic components that improve toughness as well as, in many cases, guide mineral growth. Spider silks are renowned as high-performance materials and compare favorably with the best manmade fibers in strength and toughness. Thus, we also highlight some recent work on spider silks, investigating fundamental ultrastructure-property relationships in thermally annealed silks, which are utilized via bio-inspired designs in mimetic composites.