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Multiscale Structural Design and Fracture Control of High-Performance Biomimetic Materials

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ABSTRACT

Bioinspired architectural design for composites with much higher impact-resistance and fracture-resistance than that of individual constituent remains a major challenge for engineers and scientists. Inspired by the survival war between the mantis shrimps and abalones, we develop multiscale mechanical methods to design structures and control fractures in high-performance biomimetic materials. The first point is the optimization design of impact-resistant nacre-like materials [1-4]. By a combination of simulation, additive manufacturing, and drop tower testing we revealed that, at a critical interfacial strength or a critical prestress, the competition between intralayer cracks and interlayer delamination, or the synergistic effect between the prestress-enhanced tablets sliding and prestress-weakened structural integrality, result in optimized impact resistance of nacre-like structures. Furthermore, the interfacial strength design and the prestressing strategy were easily implemented to a designed nacre-inspired separator to enhance the impact resistance of lithium batteries. Later, we designed a discontinuous fibrous Bouligand (DFB) architecture [5], whose fracture-energy dissipations are insensitive to initial crack-orientations and show optimized values at critical pitch angles. Fracture mechanics analyses demonstrate that the hybrid toughening mechanisms of crack twisting and crack bridging mode arising from DFB architecture enable excellent fracture-resistance with crack-orientation insensitivity. The compromise in competition of energy dissipations between crack twisting and crack bridging is identified as the origin of maximum fracture energy at a critical pitch angle. We further illustrate that the optimized fracture energy can be achieved by tuning fracture energy of crack bridging, pitch angles, fiber lengths and twist angles distribution in DFB composites. Our findings shed light on how nature have evolved materials to exceptional impact resistance and fracture toughness, and provide the generic design strategies for bioinspired formidable impact-resistant and fracture-resistant materials.

KEYWORDS

Biomimetic design; impact resistance; fracture resistance; energy-dissipation mechanism; optimization strategies

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