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Multifunctional Bio-inspired Advanced Materials for Extreme Environments

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Natural systems have developed well-orchestrated strategies to synthesize and construct materials from a limited selection of available starting materials. The resulting structures display multiscale architectures that exhibit properties that are frequently superior to those exhibited by engineering materials[1]. Some comparative analyses of multiscale structures have pinpointed which design principles have arisen convergently. A prime example is the evolution of toughened structures in disparate lineages within plants, invertebrates, and vertebrates. Here, we describe a few of these systems and describe how controlled syntheses and hierarchical assembly using organic scaffolds[2-6] lead to these integrated macroscale and multifunctional structures[7-9]. We describe their function and translation to bio-inspired advanced materials used for extreme engineering applications[10-13].

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4. “Mesocrystalline Ordering and Phase Transformation of Iron Oxide Biominerals in the Ultrahard Teeth of Cryptochiton stelleri,” T. Wang et al., *Small Structures*, (2022) 2100202.
5. “Fibrous Anisotropy and Mineral Gradients within the Radula Stylus of Chiton: Controlled Stiffness and Damage Tolerance in a Flexible Biological Composite”, J.E. Lee et al., *J. Comp. Mater.*, **57** (4) (2022) 565-574.
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8. “The Stomatopod Dactyl Club: A Formidable Damage-Tolerant Biological Hammer”, J. Weaver et al., *Science*, **336** 1275-1280 (2012).
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10. “Bioinspired SiC/Chitosan impact resistant coatings”, T. Hao et al. *Adv. Funct. Mater.*, **35** (2025), 2417291.
11. “Direct ink write printing of chitin-based gel fibers with customizable fibril alignment, porosity, and mechanical properties for biomedical applications”, D. Montroni, et al., *J. Funct. Biomat.*, **13** (2) (2022) 83.
12. “Electrocatalytic N-Doped Graphitic Nanofiber - Metal/Metal Oxide Nanoparticle Composites”, H. Tang et al., *Small*, **14**, 1703459 (2018).
13. “Bio-Inspired Impact Resistant Composites”, L.K. Grunenfelder et al., *Acta Biomat.*, **10**, 3997-4008 (2014).