How to build a "bridge"?
Nature's strategy for connecting hard and soft materials

Benny Bar-On

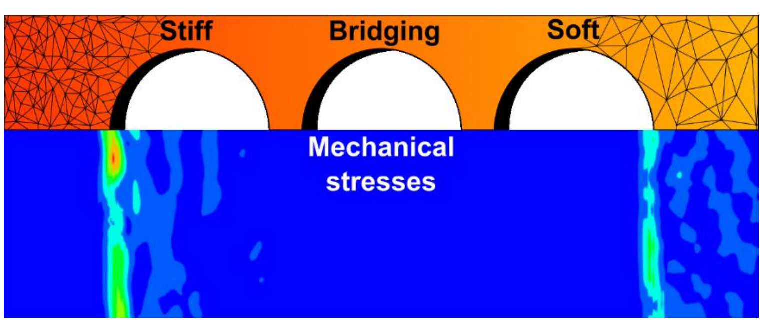
Department of Mechanical Engineering, Ben-Gurion University of the Negev, Israel.

Abstract

Load-bearing biological materials employ specialized bridging regions to connect material parts with substantially different mechanical properties (hard vs. soft). While such bridging regions have been extensively observed in diverse biomaterial systems that evolved through distinctive evolutionary paths—including arthropod parts, dental tissues, and marine threads—their mechanical origins and functional roles remain vague.

In my talk, I introduce a hypothesis that these bridging regions have primarily formed to minimize the near-interface stress effects between the connected material parts preventing their splitting failure, and obtain a simple theoretical law for the optimal mechanical properties of such bridging regions. I demonstrate this principle through Finite-Element simulations and physical experiments on a model synthetic-material system and verify its predictability for different biomaterial systems (spider fangs, squid beaks, and byssus threads). Then, I extend the theoretical concept into mechanically graded bridging regions and obtain an exponential function that corresponds well to experimental profiles of a broad range of biomaterial systems (sponge spicules, human dentin, prawn incisor, and beetle seta). The theoretical-experimental compatibility for biomaterials across different phyla, including materials made of various building blocks (biopolymers, biominerals, and their bio-composite combinations), suggests that the bridging regions of load-bearing biological materials are indeed functionally adapted to minimize the near-interface stress effects—granting them high resilience to interfacial splitting failures.

Practically, the bridging principles of biological materials can be implemented into advanced material designs and realized by various engineering platforms, e.g., polymer synthesis, nanocomposite assemblies, and 3D printings, —paving the way to new forms of architected materials and composite structures with extreme load-bearing capabilities.



Reference: Uzan, A. Y., Milo, O., Politi, Y., & Bar-On, B. (2022). Principles of elastic bridging in biological materials. Acta Biomaterialia, 153, 320-330.