Researchers unravel secrets of mussels' clinginess

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A mussel collected in Boston Harbor clings to a clay slab, attached by an array of thin filaments called byssus threads. New MIT research has revealed the secret of the resilience of these threads. Credit: Markus Buehler and Zhao Qin

Unlike barnacles, which cement themselves tightly to the surfaces of rocks, piers or ships, the clamlike bivalves called mussels dangle more loosely from these surfaces, attached by a collection of fine filaments known as byssus threads. This approach lets the creatures drift further out into the water, where they can absorb nutrients—although in the process, it exposes them to the risk of being torn away by the force of crashing waves.

But that almost never happens.

Despite the outwardly thin and fragile appearance of these threads, it turns out that in the dynamic, sloshing environment of waves and currents they can withstand impact forces that are nine times greater than the forces exerted by stretching in only one direction.

The secret to these tiny natural bungee cords has now been unraveled by MIT research scientist Zhao Qin and professor of civil and environmental engineering Markus Buehler. Their findings appear this week in the journal *Nature Communications*.

Byssus threads, they found, are composed of a well-designed combination of soft, stretchy material on one end and much stiffer material on the other. Both materials, despite their different mechanical properties, are made of a protein closely related to collagen, a main constituent of skin, bone, cartilage and tendons.

The team combined computer modeling and laboratory tests on the threads. To carry out their experiments, they placed an underwater cage in Boston Harbor for three weeks, during which time mussels attached themselves to the surfaces of glass, ceramics, wood and clay in the cage. Back in the lab, the mussels, threads and substrates were mounted in a tensile machine designed to test their strength by pulling on them with controlled deformation and recording the applied force during deformation.

"Many researchers have studied mussel glue before," Qin says, referring to the sticky substance that anchors byssus threads to a surface. But the static strength of the glue, and of the thread itself, "is not sufficient to withstand the impact by waves," he says. It's only by measuring the system's performance in simulated wave conditions that he and Buehler could determine how it accomplishes its amazing tenacity.

"We figured there must be something else going on," says Buehler, who heads MIT's Department of Civil and Environmental Engineering. "The adhesive is strong, but it's not sufficient."

The distribution of stiffness along the threads is key, Qin and Buehler found, suggesting that the distribution of intrinsic material properties and the overall architecture of the mussel attachment are important.

The distribution of stiffness in the mussels' threads enables them to be subjected to very large impact forces from waves. About 80 percent of the length of the byssus threads is made of stiff material, while 20 percent is softer and stretchier. This precise ratio may be critical, the researchers found: The soft and stretchy portions of the threads attach to the mussel itself, while the stiffer portion attaches to the rock. "It turns out that the … 20 percent of softer, more extensible material is critical for mussel adhesion," Qin says.

In their simulations, Qin and Buehler systematically tested other ratios of the material composition and found that the 80-20 ratio of stiff to soft leads to the smallest reaction force. Having more of the softer material increases the reaction force because the material cannot effectively slow down deformation. Moreover, having more stiff material in byssus threads has other advantages, as it prevents the mussels from being pulled too far out by waves, which "would make it easier to hit other objects" and be damaged, Qin says.

These findings, Qin and Buehler say, could help in the design of synthetic materials that share some of these properties. For example, surgical sutures used in blood vessels or intestines are subjected to pulsating or irregular flows of liquid; the use of materials that combine stiffness and stretchiness, as byssus threads do, might provide advantages. The researchers say there may also be applications for materials to attach instruments to buildings, or sensors to underwater vehicles or sensing equipment in extreme conditions.

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