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Intermittent Interfaces: Bioinspired Strategies Towards Material Resilience

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Intermittent interfaces: Bioinspired strategies towards material resilience

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In man-made composites, appropriate chemical treatments lead to stronger interface adhesion between the fibers and the matrix, which ensures stress transfer to the fibers and generally leads to higher strength; weaker interfaces, on the other hand, enable inelastic deformations leading to improved toughness. The situation is different in biological composites. For these, various mechanisms such as mineral or organic bridges, tablets interlocks, topological anchors/obstacles, and more [1-3], lead to simultaneous interfacial strengthening and toughening. The aragonite tablets of nacre are not perfectly flat and display a waviness which is sufficient to generate progressive locking and the transmission of tablet sliding over large volumes. Tensile tests parallel to the aragonite tablets yield relatively large inelastic deformations, generated by viscoplastic energy dissipation at the biopolymer between tablets due to their sliding on one another (and nano-asperities), and by the progressive “dovetail-type” locking made possible by their waviness as a toughness-generating obstacle [2-4].

Early toughness-generating concepts in composites, somewhat evocative of the wavy geometry of nacre tablets, include (i) intermittent interfacial bonding, proposed by Atkins in the 1970s [5, 6], and (ii) bone-shaped fibers, by Zhu and Beyerlein in 2002 [7]. In intermittent bonding, long fibers have alternate sections of high and low shear strength, obtained by intervallic surface treatments, resulting in a significant improvement in toughness and only little degradation in strength. In bone-shaped fibers, the presence of enlarged ends of short fibers results in increased strength and fracture toughness [7]. Both configurations share the concept of fiber anchoring that enhances the composite strength, combined with regions of relatively lower interfacial strength that absorb fracture energy by fiber pullout and crack bifurcation leading to high composite toughness. These configurations have served as the inspirational departure point for the research detailed in the present lecture.

We have investigated new forms of intermittent topological obstacles intended to generate toughness and strength in (micro and nano) fiber composites. Interfaces comprising obstacles in the form of beads spread along single fibers were designed, as a blend of the two concepts described earlier, bone-shaped short fibers and intermittent interfacial bonding, refer to Fig. 1.

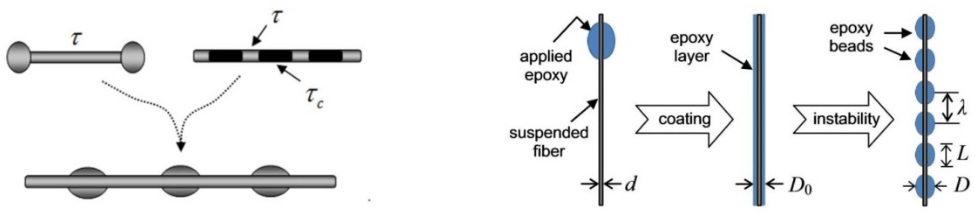

Figure 1 – (Left) Intermittent beading along a fiber, viewed as a blend of two earlier concepts: bone-shaped short fibers (top left) and intermittent interfacial bonding (top right). τ designates the fiber-matrix interfacial strength, and τ_c is the interfacial strength of the coated sections. (Right) Array of polymer beads formed along a fiber by the Plateau-Rayleigh instability [8, 9].

Using a model glass-epoxy fiber-reinforced composite, we modified the regular cylindrical fiber-matrix interface by applying intermittent epoxy beads along the fiber, taking advantage of the Plateau-Rayleigh liquid instability phenomenon [8,9]. Under load, the beads serve as fiber anchors in the matrix, thus exploiting the fiber strength to its maximum. During fracture, the pullout of beads through the matrix appears to dissipate more plastic deformation energy compared to the pullout of regular fibers. Fragmentation tests of beaded fibers in epoxy matrix demonstrate these failure mechanisms; single-bead fiber pullout tests with different bead sizes and surface treatments provide strength and toughness data that substantiate this approach. We also address the issue of how the critical length and structural strength and toughness are affected in a composite reinforced by beaded fibers. In particular, we question whether the classical concept of critical length still has a meaning similar to that for beadless fibers, and whether it can still be used as an indication of the quality of interfacial adhesion. The concept of intermittent beading has ample possibilities for optimization. It is also scalable and therefore practical.

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