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Overcoming brittleness through bioinspiration and microarchitecture

Barthelat, Francois, francois.barthelat@mcgill.ca; Mirkhalaf, Mohammad; Dastjerdi, Ahmad,
McGill University, Canada

ABSTRACT

The fracture of highly mineralized natural materials such as bone, teeth, or seashells is largely controlled by the interfaces they contain. These interfaces, relatively weak, deflect and guide cracks into configurations which eventually impede their propagation. As a result, weaker interfaces turn brittle minerals into tough materials which can deform and absorb energy from impacts. To explore these concepts in synthetic materials, we used a 3D laser-engraver to carve arrays of microcracks with well-defined geometries and toughness within the bulk of borosilicate glass slides. The microcracks, positioned along specific surfaces within the material, coalesce upon application of an external load and guide large cracks following the concept of “stamp holes”. Using this approach, we engraved curved interfaces with re-entrant features ahead of an incident crack in glass, defining jigsaw-like building blocks. After initial crack propagation along the weak interface, the jigsaw features produced a tremendous amount of toughness by pull out and interlocking, dissipating energy by friction. This powerful nonlinear failure mechanism, inspired by natural nacre, amplified the toughness of glass 100x. Infiltration of the interfaces with polyurethane generatedadditional toughening mechanisms by ligament bridging, similar to the mechanism of proteins in hard biological materials. This additional step led to a material made of ~95% of glass but 200x tougher, as stiff as plain glass but displaying nonlinear deformations and failing at strains in excess of 3%. This bioinspired glass not only shows how the powerful toughening mechanisms observed in nature can be harnessed in synthetic materials, but also showcase a new approach to making bioinspired composite materials by “fabricating” weak interfaces within stiff materials rather than assembling stiff building blocks within soft matrices.