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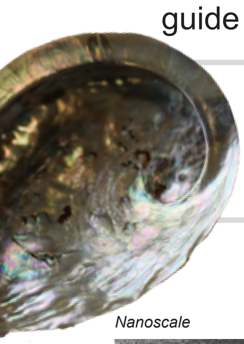
Processing and Fracture Mechanics of Multiscale Nacre-like Composites

Structural composites are a key material in the production of lightweight and fuel efficient vehicles. However, current high performance composites tend to fail catastrophically and without warning. As a result, composite parts must be over-engineer parts to ensure safety in use. To make lighter, less bulky parts, we need composites with improved fracture toughness. Improving the fracture toughness of a composite material without compromising its stiffness is a major challenge in materials science.

Biomineralized composites, like shell, tooth and bone, demonstrate that it is possible to produce high modulus composites with structures that become ductile when damaged, averting catastrophic failure! We're interested in developing a quantitative understanding of the fracture toughening structure property relationships in Nacre, also known as mother of pearl, a tough biomineralized composite that lines the inside of mollusc shells. By building a biomimetic composite, we have been able to extract some of the quantitiave structural design principles that govern nacre's fracture toughness. These design principles are independent of material composition and can be used to guide the design of more fracture tough composites in the future.



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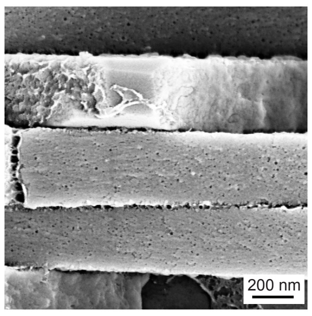
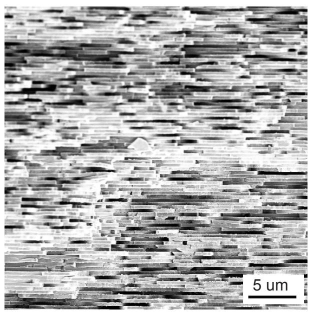
Nacre has multiscale hierarchical structure...

Nanoscale



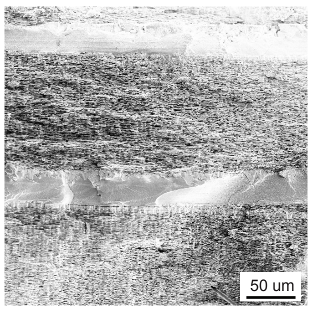
mineral bridges connect platelet interfaces

Microscale



brick and mortar microstrucure

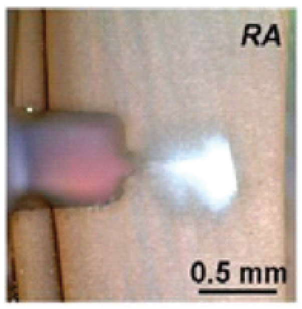
Sub-millimeter scale



growth bands separate structure into lamella

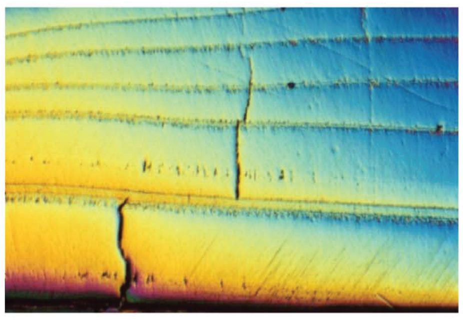
...which enable hieararchical toughening mechanisms

Nano- / micro-scale



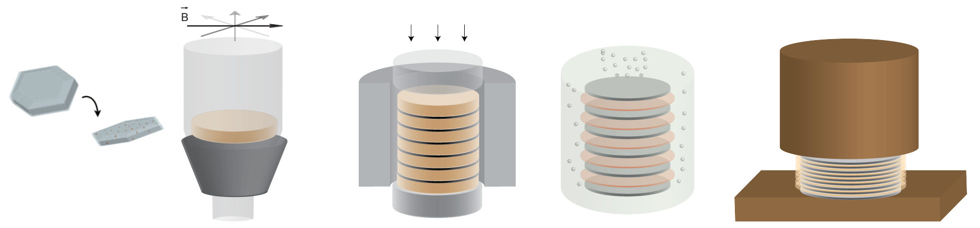
platelet pull-out dissipates fracture energy and forms process zones of local ductility [1]

Sub-millimeter scale



growth bands arrest and difflect cracks, preventing catastrophic faiure [2]

We built our own nacre-like multiscale composite...

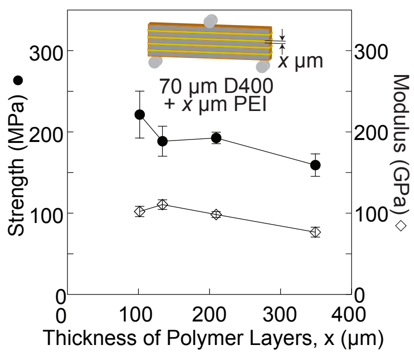


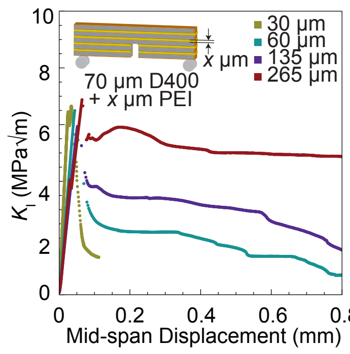
commercial titania-coated alumina platelets are magnetised and formed into mineral scaffolds using a vacuum assisted magnetic alignment process [3]

scaffolds are sintered under pressure to form titania mineral bridges between alumina platelets

sintered scaffolds are porous, so they are infiltrated with a low viscosity epoxy and laminated with a tough PEI film before curring

the resulting laminate has mineral-like stiffness and strength, but is able to bear high loads in extension!





Multiscale hierarchy is a viable approach fordesigning composites that are stiff, strong and fracture tough

Laminate stiffness and strength is determined by the mineral composite layers

Composite strength is determined by the strength of the reinforcements and the strength of the connectivity between them

Interfaces fail and platelets pull-out

$$\sigma_c \approx \gamma \tau S V_p$$

Platelets fracture before interfaces

$$\sigma_{c,\max} = \frac{1}{2} \sigma_p V_p$$

σ_c = composite strength

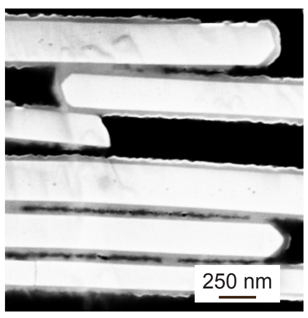
V_p = volume fraction of platelets

τ = interfacial strength between alumina and titania

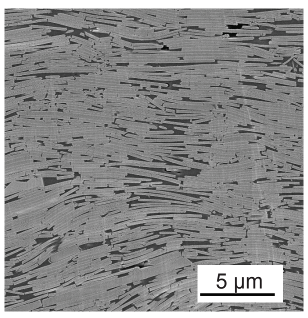
S = platelet aspect ratio

σ_p = platelet strength

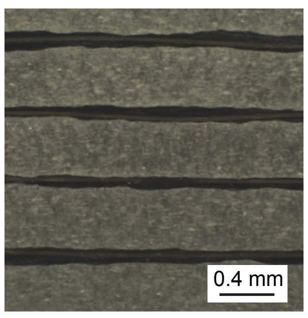
Nanoscale



Microscale



Sub-millimeter scale

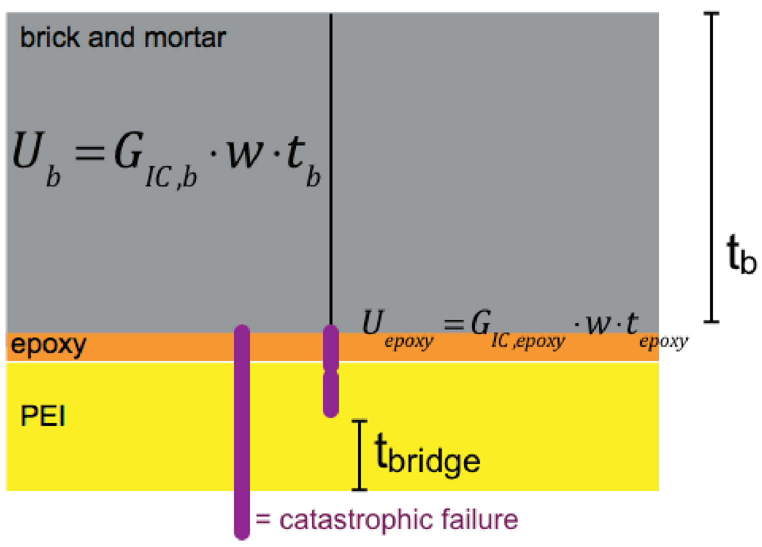


Polymer interlayers determine laminate ductility after damage

Composite toughness in extension is determined by the interlayer's capacity to absorb the elastic energy released with the stiff layer fails, and continue to to bear load

$$U_b \leq U_{epoxy} + U_{PEI}$$

Nacre and nacre-like composites are different from commercial composites because they incorporate a mecahnism for dissipating the elastic energy released when very stiff and strong reinforce-ments fail. This can be as simple as incorporating a sacrafical poly-mer protect the most ductile phase.



Producing new composites with mulitscale heirarchical toughening mechanisms, like the ones in displayed in nacre, could allow us to design thinner lighter parts with confidence. Vehicles with lighter components have the potential to be more fuel efficient

Partners:

BIO-INSPIRED MATERIALS
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2. Lin, A.; Meyers, M. A., Materials Science and Engineering A, 2005
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