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Final report: Nacre-inspired interphase

Mechanical properties of fiber reinforced composites are greatly influenced by the fiber-matrix interphase. A strong interphase results in high strength, while a weak one enables debonding that leads to a high degree of energy absorption. Achieving both properties in one composite interphase is a great engineering challenge.
The biopolymer nacre exploits a combination of crack deflection and strain hardening and maximizes energy absorption, while simultaneously limiting delamination. The reason is its “brick-and-mortar” structure of brittle inorganic building blocks, which are “glued” together by a soft organic framework (Figure 1). In reference to this “brick-and-mortar” structure of natural nacre, a nanostructured coating was developed with high proportion (~ 90 wt%) of well aligned inorganic platelets embedded in a polymer matrix, but uniformly scaled down by more than 1 order of magnitude (Figure 2). [1] - [4]

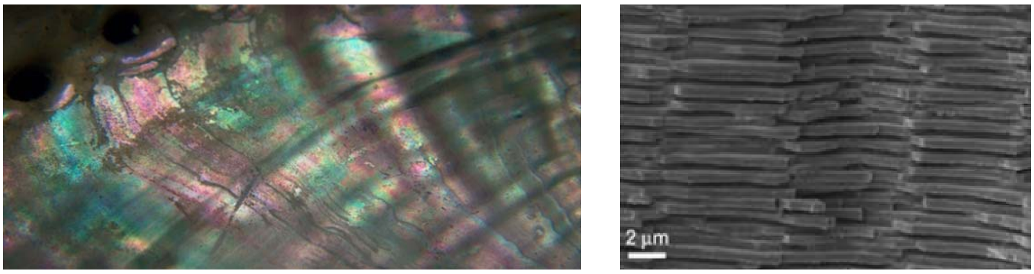

Figure 1. Natural nacre (left) and “brick and mortar” structure of nacre (right) [5], [6]

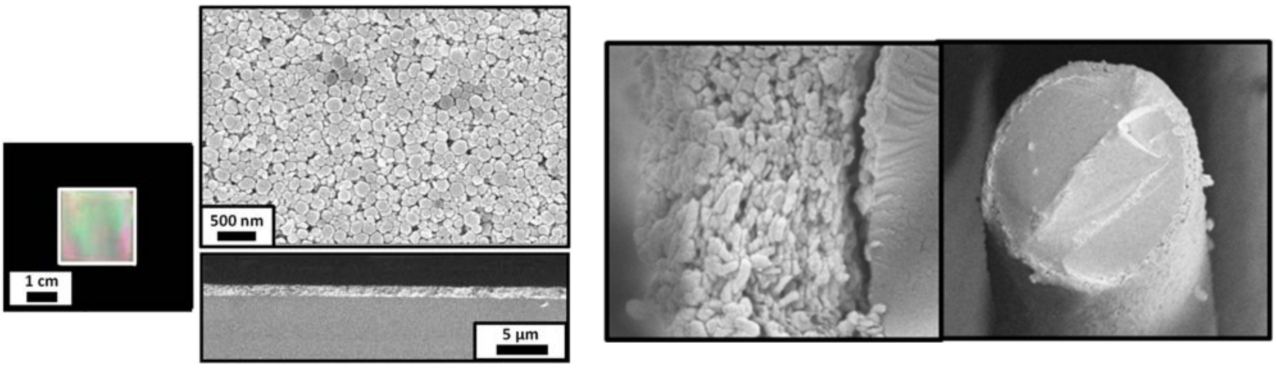

Figure 2. Nanostructured coatings deposited on a flat substrate (left) and a fiber (right).

A Layer-by-Layer (LbL) assembly resulted in coatings with ordered and dense layered nanostructure with a platelet misalignment as low as 8°. Assessment of the coating properties showed the known toughening mechanisms of nacre, such as platelet sliding and interlocking, as well as three-dimensional crack deflection. A similar elastic modulus and hardness close to nacre could be achieved, additional to larger plastic deformation in the material upon loading. [1]
Optimization enabled the transfer of the architecture of the coating to the curved surface of fibers, which showed an improvement of up to 30% upon loading in shear. Bundles of fibers could be coated

homogenously via LbL and a scale-up to coat continuous fibers by adding additional baths to the traditionally used sizing line should be easily feasible. The nanostructure coated fibers showed reduced local stress concentrations arising from fiber breaks and increased extend of fiber slippage compared to untreated ones. The results were in good agreement with the results on flat substrates. A balance of simultaneously strength and toughness could be achieved on a small scale and leads a promising way for future large-scale composite tests. [3][4]

References

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[3] De Luca F, Clancy A J, Sernicola G, Shaffer M S P and Bismarck A, 2017, Nanostructured Brick-and-Mortar Interphase Inspired by Nacre to Improve Carbon Fibre Composite Performance, *21st International Conference on Composite Materials (ICCM21)*, Xi'an, China. Paper ID: 4335

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[6] Barthelat, F., et al. "On the Mechanics of Mother-of-Pearl: A Key Feature in the Material Hierarchical Structure". J. Mech. & Phys. Sol. 55, 2, 306-337, 2007