TOUGNENING MECHANISMS IN A NATURAL COMPOSITE: A CROSSED-LAMELLAR STRUCTURE

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ABSTRACT

Living things in nature tend to evolve unique biological structures with special biological functions to survive and adapt to the surrounding environment [1]. The crossed-lamellar structure is the most widespread structure in mollusk shell, and more than 90% of the species in Mollusca contain this structure within their shells [2]. Another interesting phenomenon needs to be noted is that crossed-lamellar structure is a natural composite material containing ~99% $CaCO_3$ and only ~1% organic content [3]. The crossed-lamellar structure is a highly hierarchical structure, i.e., the macrolayer is stacked by the parallel 1st-order lamellae comprising the 2nd-order lamellae that consist further of the 3rd-order lamellae. Based on examinations on various species of shells, it was revealed that the crossed-lamellar structure can be further divided into to platelet-like and fiber-like structures with respected to the shapes of the basic building blocks [4], as shown in Figure 1. For the platelet-like crossed-lamellar structure, the 1st-order lamellae are roughly parallel to each other, but the 2nd-order lamellae inside a single 1st-order lamella show a mountain ridge-like feature. The orientation of platelets in the adjacent blocks is perpendicular to each other. For fiber-like crossed-lamellar structure, the 3rd-order lamellae are stacked parallel to each other inside each 2nd-order lath-like lamella, which is further arranged in row to form the sheet-like 1st-order lamellae. The fibers inside each 1st-order lamella are almost perpendicular to the ones contained in the neighboring 1st-order lamellae.

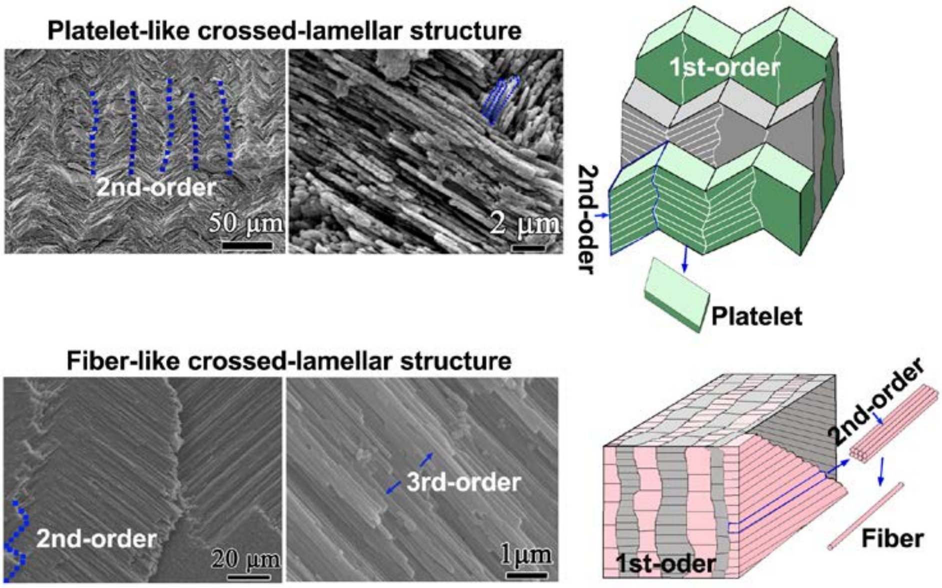

Figure 1: Two types of crossed-lamellar structures – platelet-like and fiber-like crossed-lamellar structures.

The complicated arrangement of the crossed-lamellar structures provides abundant interfaces, which can present several toughening mechanisms, as summarized in Figure 2. For example, in the indentation tests, there is a lot of microcracking and uncracked ligament bridging existing around the indentation. In the fiber-like crossed-lamellar structure, some fiber bridging along with the crack path can also be found. For shells with more than one crossed-lamellar layers, the interfaces between the macrolayers can effectively arrest the crack propagation. Furthermore, the crack deflection is another commonly-observed phenomenon, which can induce step-like cracking in the crossed-lamellar structure. In a stepwise compressive test, it was also found that the lamella between two channel cracks shows a convex morphology. All the mechanisms can effectively absorb the fracture energy, thus resulting in a higher fracture toughness. The identification of these key toughening mechanisms would serve as guidelines for the design of advanced bio-inspired composite materials for the high-performance structural applications due to a better understanding of the deformation behavior and toughening mechanisms of these attractive natural composites.

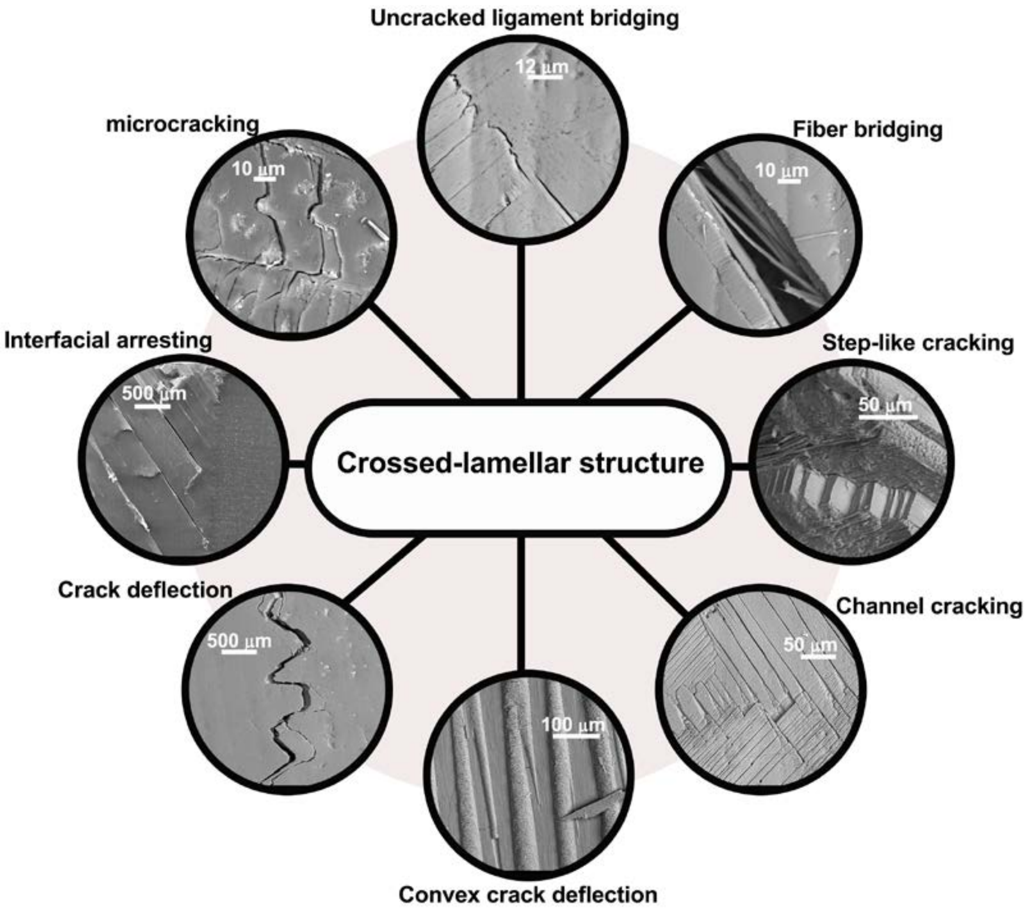

Figure 2: A variety of toughening mechanisms identified in the crossed-lamellar structures.

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