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Research paper

Multi-scale hierarchy of Chelydra *serpentina*: Microstructure and mechanical properties of turtle shell

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ABSTRACT

Carapace, the protective shell of a freshwater snapping turtle, Chelydra *serpentina*, shields them from ferocious attacks of their predators while maintaining light-weight and agility for a swim. The microstructure and mechanical properties of the turtle shell are very appealing to materials scientists and engineers for bio-mimicking, to obtain a multi-functional surface. In this study, we have elucidated the complex microstructure of a dry Chelydra *serpentina's* shell which is very similar to a multi-layered composite structure. The microstructure of a turtle shell's carapace elicits a sandwich structure of waxy top surface with a harder sub-surface layer serving as a shielding structure, followed by a lamellar carbonaceous layer serving as shock absorber, and the inner porous matrix serves as a load-bearing scaffold while acting as reservoir of retaining water and nutrients. The mechanical properties (elastic modulus and hardness) of various layers obtained via nanoindentation corroborate well with the functionality of each layer. Elastic modulus ranged between 0.47 and 22.15 GPa whereas hardness varied between 53.7 and 522.2 MPa depending on the microstructure of the carapace layer. Consequently, the modulus of each layer was represented into object oriented finite element (OOF2) modeling towards extracting the overall effective modulus of elasticity (~4.75 GPa) of a turtle's carapace. Stress distribution of complex layered structure was elicited with an applied strain of 1% in order to understand the load sharing of various composite layers in the turtle's carapace.

1. Introduction

Turtles have existed dating 200 million years back. Chelydra *serpentina*, a freshwater turtle, evolves from the order Testudines and family Chelydridae commonly referred to as a snapping turtle. The upper shell dorsal carapace and the belly portion ventral plastron of a turtle are fused by the bridges (Gilbert et al., 2001). The shell includes portions of ribs and vertebrae, thus the turtle cannot crawl out of its shell. Hence, justifying its name, the turtles snap standing on all four feet when in danger, since it has a short shell not being able to retract the skull completely.

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