Chapter 6: Conclusions & Summary

This study aims to identify the mechanical properties of biopolymers in interfacial and near-surface regions of biomaterials, linking these mechanical properties to the mechanical function of biomaterials. The goal is to bring new conceptual insights into the structural-mechanical relationships of bio-mechanical materials systems.

In chapter 2, the fundamental characteristics of interfacial indentations in biomaterials were analysed and a framework to extract the (typically unmeasurable) interfacial elastic properties of the biomaterial using analytical scaling of its indentation modulus was introduced. This framework is insensitive to tip shape variations of the indentation testing, independent of the absolute dimensions of the biomaterial interface, and holds for the typical range of reinforcement-matrix modulus ratios of biological materials. This includes mineralized tissues like bony elements, mollusc shells, and sea sponges, as well as chitin-based tissues such as the different functional parts of arthropod cuticles, and cellulose-based tissues, for example the mid-lamella between adjacent cell walls within stems and leaves [1, 3, 4, 5, 34, 35].

In chapter 3, the interfacial dynamic (viscoelastic) modulus of biomaterials that dominates the structure-function relationships in various organisms is analyzed. These organisms include vertebrates (e.g., mammals, birds, and fish), invertebrates (e.g., insects, arachnids, and molluscs), and plants [2, 4, 13–16]. A compact analytical formulae is established that links the modulus magnitude and loss coefficient of the interfacial region within the biomaterial to those of its enclosing, large-scale, biomaterial segment. These formulae are then used to propose an analytical-experimental methodology that yields the interfacial characteristics of the biomaterial, via backcalculations. This is achieved from a feasible, far-field DMA analysis of the biomaterial itself. It is then demonstrated on zigzag-shaped sutural interfaces, which appear in various biological systems [REFS].

In chapter 4, the dynamic indentation modulus of viscoelastic films is analyzed. A theoretical modelling is introduced that leads to analytical relationships between the dynamic modulus of the pristine film, the film thickness, and the overall dynamic indentation modulus of the laminate. These relationships are further used to propose a methodological approach to backcalculating the film dynamic modulus from dynamic indentation measurements on the laminate. The modeling outcomes and its analytical relationships are insensitive to tip shape variations and independent of the absolute moduli magnitudes of the film and substrate. They are thus generally applicable to the broad dimensional range of laminates and their mechanical characteristics, i.e., from highly rigid to substantially compliant, and from nearly elastic to prominently viscous. The outcome of this study will resolve pending challenges in various synthetic and biological materials science disciplines and will serve as a keystone toward future designs of functional mechanical coatings in advanced materials [REFS].

In chapter 5, the possible functionality of a mechanically inferior bi-layer skin coating of the turtle shell is analyzed. In confining indentation effects to the near-surface region, the risk for potential damage in the hard-but-brittle bulk boney core is reduced. It is found that the turtle shell skin effectively functions as a bumper-buffer mechanism, which reduces localized stress intensification and promotes energy dissipation via plasticity. This, as yet unknown, soft-softer-hard design strategy of the turtle shell bio-shield significantly enhances its damage resilience capabilities upon surface indentations. This approach can possibly be adapted into synthetic materials to improve the resilience of engineering elements to surface damage effects.

The outcomes of this study pave the way to the identification of new interfacial and near-surface load-bearing mechanisms in various functional biological materials [2 add more refs!…]. As a result, it may be possible to promote the development of novel synthetic interfacial, and near surface, configurations, to enhance the mechanical functions of advanced engineering materials such as 1D–2D nanomaterials, nanocomposites, and additive manufactured materials [36-38].