Analysis of Failure Mechanisms and Mechanical Properties of Hierarchical Bio-inspired Composites

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by

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Abstract

Nacre, bone, spider silk, and antlers are some examples of biological composites which exhibit a great combination of mechanical properties such as high strength, stiffness, and toughness when compared to that of their constituents using which they made up of. This has inspired many researchers to investigate bio-inspired composites to explore the possibilities of making synthetic composites with superior mechanical properties using relatively weaker constituents. There are many reasons behind the achievement of a biological composite's superior mechanical properties, which range from the selection of constituents to its final arrangement. The basic structure of above mentioned biological composites is a kind of brick-and-mortar structure in which platelets with a defined configuration are dispersed in a pool of matrix. Here, the parameters that significantly influence the final mechanical properties are Young's moduli ratio of platelet to the matrix, the platelet aspect ratio, and the arrangement of platelets, especially the hierarchy.

In this thesis, we investigate the mechanical properties of hierarchical bio-inspired composites in which the two mostly observed staggering types found in nature: regular and stairwise staggerings are used. A preliminary failure study is conducted for one-hierarchical composites with regular and stairwise staggered configurations to get a clear idea of the failure sequence of different regions inside the composite such as the platelets and platelet-matrix interfaces. The influence of the failure sequence on the mechanical properties of the bio-inspired composite with a single hierarchy is also studied in detail. It is found that the inclusion of the first failure in the computation of the composite's toughness has a significant contribution, and we were able to quantify the same through our study. To obtain a more realistic approach, we conduct a case study using some material-set combinations used in the industries and recent research works. The results from the case study also reported the major contribution of the inclusion of the first failure towards the toughness of both regular and stairwise staggered composites.

Analytical models for predicting the properties of two hierarchical composites with different configurations at different levels of hierarchy (non-self-similar) are formulated and compared with the finite element analysis results. The results show a good agreement with the proposed model. We also generalize the two hierarchical analytical model to predict its mechanical properties. The optimized model of a generalized two hierarchical

composite enables the user to get the relevant design elements, like the platelet aspect ratio and number of platelets in a period, for a given input of material properties and strength, stiffness, and toughness requirements. This study could greatly help to simplify the design procedure in a hierarchical composite and to get an initial estimation of the mechanical properties of the final hierarchical composites before fabricating a full-scale model.